Rajinder Peshin
Ashok K. Dhawan
Editors

Integrated Pest Management:
Dissemination and Impact

Volume 2

Springer

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Farmer field school for vegetable IPM in Sibayak Valley, North Sumatra, Indonesia (Courtesy: Photo by Mike Hammig, Clemson University, Clemson, South Carolina, USA).

Onion beds where virus-infected *Spodoptera exigua* are used by farmers as spray in biological control program. Onion beds where virus was applied (right) compared to heavily damaged control where no virus was applied. Ciladug, West Java, Indonesia. (Courtesy: Photo by Merle Shepard, Clemson University, USA).

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For
Devansh, Udit, Sahil and Salil

Preface

Integrated Pest Management – Dissemination and Impact, Volume 2 is a sequel to Integrated Pest Management – Innovation-Development Process, Volume 1. The book focuses on the IPM systems in the developed countries of North America, Europe and Australia, and the developing countries of Asia, Latin America and Africa. One of the major impediments in the dissemination and adoption of the IPM innovation is the complexity of the technology and reaching the vast population of farmers especially in the developing countries. The IPM-innovation development process is incomplete without the diffusion and adoption of IPM methods by the end users, and through its consequences. In spite of all the efforts in the developed and developing countries, the adoption of IPM is still low with few exceptions.

The book covers the underlying concepts and methodologies of the diffusion of innovation theory and the program evaluation; and reviews the progress and impact of IPM programs implemented in the industrialized, the green revolution and the subsistence agricultural systems of the world. Forty-four experts from entomology, plant pathology, environmental science, agronomy, anthropology, economics and extension education from Africa, Asia, Australia, Europe, North America and South America have discussed impact of IPM with an interdisciplinary perspective. Each one of the experts is an authority in his or her field of expertise. The researchers, farmers' education, supporting policies of the governments and market forces are the elements of the IPM innovation system to achieve wider adoption of IPM strategy in agriculture.

The diffusion theory and adoption of the IPM innovation is discussed in the first chapter to provide theoretical foundation to biological scientists for developing farmers' compatible IPM systems. Protocols for evaluation to measure socio-economic impact of the IPM programs are provided in Chapters 2 to 4. Identifying the farmers' needs, attitudes and skills for developing location specific IPM technology is detailed in Chapter 5. Implementation of IPM programs, farmers' education in the context of developed, and developing countries are documented in Chapters 6 and 7. The focus of Chapter 8 is on the impact of extension in disseminating IPM technology to smallholder farmers. The implementation, impact and the impediments of IPM programs in the green revolution lands of Asia and Latin America, and subsistence agriculture of sub-Saharan Africa is the focus of Chapters 9 to 13. The insight into the IPM programs in Europe and the initiatives of the European Union in popularising integrated protection in its member states, the IPM programs in Russia and the Commonwealth of Independent States, tracking down the history of IPM in erstwhile USSR are covered in Chapters 14 and 15. Dissemination and impact of IPM technology in the US agriculture is discussed in the subsequent Chapter 16. To explore the advances in IPM with respect to introduction of transgenic in Chinese and Australian agriculture and the controversy surrounding the trangenics and its compatibility with IPM, Chapters 17 to 19 have been included. The world food shortage because of conversion of agriculture crops like corn and soybean for production of bio-fuels in the USA is one of the hotly contested issues. The concluding chapter on IPM, bio-fuels and a new green revolution provides an insight to the changes in the patterns of agriculture in the USA. Renewed efforts are needed to develop the IPM innovation system for the wider adoption of IPM.

We are indebted to the contributing authors whose thought provoking insight, cooperation and guidance made it possible to realise the dream of updating IPM literature from an interdisciplinary and global perspective. We owe a great deal to Prof. A. K. Tiku for his insight in bringing out these two volumes. The book provides an invaluable resource material to the scientists, professionals, students, program planners, farmers and market forces.

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Chapter 1
Diffusion of Innovation Theory and Integrated Pest Management

Rajinder Peshin, J. Vasanthakumar and Rajinder Kalra

Abstract The Diffusion of Innovation Theory dominated the theory and practice of agricultural extension system all over the world for almost half a century. It came under criticism too during the period. The theory was not considered adequate to manage the process of dissemination of IPM technology. The inadequacies may be due to the attributes of IPM innovation as well as due to the sophisticated demands of IPM technology that was not amenable to the limited version of the theory. The diffusion and adoption of agricultural innovation has been a focal measure of agriculture development. IPM is a combination of different technologies that has not diffused as other simple one of technologies. Diffusion of IPM requires educating the farmers for its adoption and it must deal with farmers' needs, perceptions, constraints, objectives and its complexity demands. IPM is location specific and it requires several years of experiments, trials, repetitions and validations in a given area. It requires a clear understanding about the IPM tactics. The IPM tactics may vary from crop to crop and area to area. It needs a planned strategy of imparting knowledge and skill and active learning and active adoption by the farmers. The diffusion of innovation research has to give up the "ex-post-facto" design, which has been a prisoner of socio-economic factors influencing the adoption of innovation and in correlating the effects to these factors. The diffusion researchers should employ "action research" design to study the IPM implementation and feed the result to develop farmer-acceptable IPM system. The coordination of all the stakeholders of agricultural innovation system need to emphasise the outcomes of technology and knowledge generation and adoption of IPM practices rather than merely strengthening of research and extension systems.

Keywords Integrated Pest Management · innovation · technology cluster · diffusion of innovations · adopter categories · decision making · innovation system

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1.1 Introduction

Rogers' "diffusion of innovation theory" has played central role in extension theory and practice (Roling, 1988). Diffusion of innovation theory deals with "innovation – development process" which deals with six stages of need or problem, through research (basic and applied), development, commercialization (recommendation) of innovation through dissemination and adoption of the innovation by the end users to its consequences (functional or dysfunctional) (Rogers, 2003). Diffusion research studies have dominated the extension education research in 1950s and 1960s in the United States of America (USA) and Europe, and in 1960s and 1970s in developing countries (Valente and Rogers, 1995). The diffusion research provided feedback to agricultural researchers about the fate of their recommendations. *Diffusion theory provides a basis for creating coherent body of generalisations, without which, the huge body of completed research might be "a mile wide and an inch deep"* (Rogers, 1995).

Gabriel Tarde (1903) was the first to show that adoption of new idea within a social system follows an S-shaped growth curve. Anthropologists were the first to deal with diffusion studies. Most of the diffusion studies dealt with spread of agriculture innovations among the farmers and most of the diffusion researches have been produced by the rural sociologists. A classical study which received the greatest attention among social scientists was conducted by Bruce Ryan and Neal Gross (1943) on the diffusion of hybrid seed corn in two Iowa communities. The findings of the study showed that the adoption of innovation by farmers involved a combination of several processes. The processes of individual decision-making by a farmer to adopt or reject a practice, and diffusion of an innovation over time through a social system are closely interrelated. Diffusion studies, however, are not confined to the field of rural sociology alone. Diffusion research publications took off after the diffusion paradigm by Ryan and Gross (1943) and the number of publications had reached 3810 in 1995 (Rogers, 1995). This chapter aims to provide the theoretical background of diffusion of innovation theory and the adoption of Integrated Pest Management (IPM) innovation by the farmers. IPM is a cluster of innovations and a decision making innovation for providing economically viable and ecologically sound methods of pest management.

1.2 Diffusion of Innovation Theory

There are many theories that deal with generation of innovations, their diffusion and adoption or non-adoption by ultimate users. Such theories include actor network theory, knowledge systems and network theory, strategic niche management theory and adoption and diffusion of innovations theory (Rogers and Shoemaker, 1971; Rogers, 1983, 1993, 2003). Among the theories, the diffusion of innovation theory dominated the theory and practice of agricultural extension systems all over the world for more than half a century. The classical study of 1940s provided the initiative to target innovative farmers to adopt innovations so that other farmers would follow in course of time (Ryan and Gross, 1943). The Diffusion Theory provides an adequate explanation of the relationship between the technological innovations and the social relations. Nevertheless, with its research perspective and deterministic outcomes emphasising the information exchange, it is an ideal lower level framework for analyzing the processes of technology dissemination and the features of an innovation (Gartshore, 2004).

The literature on diffusion theory during 1970–1990 revealed two distinct categories of practitioners who either supported or criticized the diffusion theory. Some portions of the theory are sound while the remaining portions revealed the weakness to address the diffusion of innovations. The literature on the characteristics of innovations, the stages of adoption process and the effect of interaction of farmers on adoption are considered sound. The theory's focus on innovators and the resulting undesirable consequences of the extension approach that used the theory were the weak spots and attracted criticism (Stephenson, 2003).

Diffusion is the process by which an innovation is communicated through certain channels over time among the members of a social system (Rogers, 1962, 1983, 1995, 2003). It is a special type of communication in which the messages are about the new idea. The process by which an innovation spreads within a social system is called diffusion. An innovation diffuses within a social system through its adoption by individuals and groups.

Diffusion is a kind of social change. It is defined as the process by which alteration occurs in the structure and function of a social system. Diffusion of an innovation thus leads to social change. The diffusion of agricultural technologies through mechanization, improved seeds, and better plant protection measures resulted in increased productivity. This ultimately led to improved standard of living among farming community. The impact of the green revolution on farmers cannot be denied. In case of IPM which is a complex set of decision making process, there are a number of researchable questions. Whether the diffusion of innovation theory answers the questions related to four elements of this theory: IPM innovation and its attributes, communication channels for diffusion of IPM, time dimension and rate of adoption of IPM, and the social system affecting the adoption of IPM?

1.2.1 Elements of Diffusion of Innovation Theory

The four main elements of diffusion of innovation as identified by Rogers (1962) are:

i) An innovation
ii) Communication channels
iii) Time, and
iv) Social system

Thus, we can say that diffusion of innovation will take place only if a new idea or practice exists which is accepted by an individual or a group of people over a period of time. The rate of diffusion depends upon the availability of communication channels and structure of the social system.

1.2.1.1 Innovation

An idea, practice, or object that is perceived as new by an individual or an improvement over the existing one by the members of a social system could be termed an innovation. The perceived newness of the idea for the individual determines his or her reaction to it. The idea constitutes central element of an innovation, which has material or behavioural form. In diffusion literature, "innovation" and "technology" are used synonymously. Most agricultural innovations are in material form such as improved implements, high yielding variety seeds, chemical fertilizers and plant protection chemicals, while improved cultural practices are in behavioral forms. An innovation (technology) has two or either of the two components, hardware (material form) consisting of physical objects and software (behavioral form) consisting of knowledge base. IPM practices are mostly in complex behavioural form, except for resistant varieties. Some innovations or technologies take less time to spread in a social system while others may take longer time. Technologies consisting of knowledge base take longer time to spread. We can say that the time taken by an innovation is dependent upon different factors. The characteristics of innovation as generalized by Rogers (1962) are:

(i) Relative advantage: It is a ratio of the expected benefits and the costs of adoption of an innovation. Its sub-dimensions are economic profitability, low initial cost, a decrease in discomfort, social prestige, a saving of time and effort, and immediate reward.
(ii) Compatibility: It is the degree to which an innovation is consistent with past experiences and needs of farmers.
(iii) Complexity: It is the degree to which an innovation is difficult to comprehend and use.
(iv) Trialability: It is the degree to which an innovation can be experimented with either on limited basis or in installments.
(v) Observability: It is the degree to which the results of an innovation are visible to others. Higher the observability and communicability of results, higher would be the rate of adoption.

The characteristics of IPM practices influencing its adoption are discussed in Section 1.4.2.1.

1.2.1.2 Communication Channels

Diffusion is a particular type of communication in which the message content that is exchanged is concerned with a new idea. Communication is a process by which two or more people share or create information in order to reach a mutual understanding. A communication channel is the means by which message about an innovation or technology is shared among two or more individuals. The two important types of communication channels that would help the communicator in diffusion of innovations are interpersonal and mass media channels.

(a) Interpersonal channels are those channels, which are used for face-to-face communication between two or more individuals. Interpersonal channels are the means for persuading an adopting unit to accept a new idea. The interpersonal channels may include opinion leaders, subject matter specialist, extension worker, neighbours, friends, etc. Interpersonal channels help an individual to take decision about adoption of innovation by making subjective judgment about it.
(b) Mass media channels such as radio, television, and newspaper enable the message to reach a larger, diverse audience simultaneously in a relatively shorter time. Mass media channels are more effective to make an audience aware of the existence of innovations.

The communication channels may also be categorized either as localite channels or as cosmopolite channels, depending on the place of origin. Localite channels originate within the social system of the receiver such as neighbours, friends, relatives, leaders, etc. Cosmopolite channels have their origins outside the immediate social system e.g., extension workers. For the diffusion of IPM practices, all communication channels are useful. Mass media channels like radio, television, hoardings, web, etc should be used to create awareness about the negative externalities of pesticides and IPM philosophy, and to compete with the vast network and advertisement onslaught of pesticide companies. For changing the farmers' behavior (cognition, skills and attitudes), labor intensive communication strategy like meetings, demonstrations, workshops are advisable (Lagnaoui et al., 2004) and for providing experiential learning in the farmers' fields for comprehension and acquiring skills to take decision for implementation and adoption of IPM practices.

1.2.1.3 Time

Time is a third element in the diffusion process. Time does not exist independently of events but is an important variable of any communication process. The time dimension is involved in three aspects of diffusion process.

(a) Innovation-decision process: It is the process through which an individual passes from getting information about an innovation to its final adoption or rejection.
(b) Innovativeness of an individual or other unit of adoption, that is the relative earliness or lateness of an individual with which an innovation is adopted compared to other members of a social system. The classification of members of a social system on the basis of innovativeness includes innovators, early adopters, early majority, late majority and laggards.

(c) Rate of adoption: The rate of adoption is the relative speed with which the members of a social system adopt an innovation. Most of the innovations have an S-shaped rate of adoption. However, there is variation in the slope of the "S" from innovation to innovation as some new ideas diffuse rapidly while some other innovations take time to diffuse. The rate of adoption is measured by the length of time taken by a certain percentage of the members of a social system to adopt a new idea. There are differences in the rate of adoption for the same innovation in different social systems. Rate of adoption of IPM practices like sampling for determining economic threshold level for taking pest management decision has been slow. The pattern of adoption of IPM practices has followed S-shaped curve only when the farmers have been provided hands on experience in dealing with complex behavioral phenomena.

1.2.1.4 Social System

The social system, the fourth element, constitutes a boundary for the diffusion of innovations. A social system is a set of individuals, informal groups or organizations that are engaged in solving a common problem or in accomplishing a common goal.

The diffusion of an innovation gets affected by the social system. A social system is defined as a set of interrelated units that are engaged in a joint problem to accomplish a common goal. The members of a social system may be individuals, informal groups, organizations, and/or sub-systems. Diffusion occurs within a social system. Diffusion of agricultural innovations at the village level depends upon the structural characteristics of the village or social system, which may be homogenous or heterogeneous. The homogenous village may have population similar in social or demographic characteristics like caste, religion, culture, etc. whereas heterogeneous village may have population varied in the characteristics. The innovative ideas may flow smoothly in homogeneous village rather than in heterogeneous village. For example, a village with Bengali population will readily accept fish-rearing practices. The importance of the structure of a social system was well emphasized by Katz (1961), "It is as unthinkable to study diffusion without some knowledge of the social structures in which potential adopters are located as it is to study blood circulation without adequate knowledge of the veins and arteries."

Another important component of social system is its communication structure. The communication structure in a village is constituted by informal interpersonal links. The existence of these informal interpersonal linkages results in communication networks. These networks follow a set pattern of information flow. The well developed communication structures in a social system can facilitate the diffusion of innovations. A village having well integrated social structure is favorably oriented towards change. It influences its members who may be farmers to improve their farming situations by adopting innovative practices. In a village, there are few who act as leaders by influencing opinions of majority of people and they are called opinion leaders. The effective opinion leaders provide orientation to community members towards change and development by persuading them to participate in development activities.

Academics complement agricultural researchers who respond to complex realities by planning their activities within the context of an “Innovation System”. An innovation system is a group of organizations or individuals involved in the generation, diffusion, adaptation, and use of knowledge of socio-economic significance, and the institutional context that governs the way these interactions and processes take place (Hall et al., 2003; Hall, 2007). They recognize that the innovation is a social process involving interactive learning. The social side of innovation requires the process of networking, forming alliances, and partnerships, negotiating priorities and approaches that are central to IPM diffusion. Similarly, efforts of Participatory Technology Development and Transfer also delivered useful insights and lessons for diffusion of innovations (Arulraj and Vasanthakumar, 1996). The social system for popularising IPM consists of researchers, extension workers, farmers, policy makers and market forces. The innovation system approach for coordination of these social forces will speed up the rate of adoption of IPM practices.

1.3 Diffusion and Adoption Process

Diffusion and adoption are closely interrelated even though they are conceptually different. An innovation diffuses within a social system through its adoption by the members of the social system. It takes time for an innovation to diffuse throughout the social system. Not all farmers within a community adopt an innovation immediately after the introduction of a new idea. The same innovation may take different lengths of time for adoption by different people. Some are early in adopting an innovation while some take longer time. The members who are early in adopting an innovation influence other members of the social system to adopt the innovation, and they in turn influence others and it goes on.

Diffusion of innovation follows a definite pattern. Different people in a social system take different time to adopt an innovation. If the cumulative number of adopters of an innovation over time with in a social system is plotted, the result is an S-shaped curve (Fig. 1.1). This is called the diffusion curve. The S-shaped curve rises at first when there are few adopters in a time period, accelerates to maximum when almost half of the individuals in the system have adopted and then increases at a gradually slower rate as few remaining individuals finally adopt. Although all diffusion curves tend to be S-shaped but there is a variation in the slope of the S from innovation to innovation. Some innovations diffuse rapidly while some innovations take time to diffuse. “S” curve is quite steep when an innovation diffuses relatively rapidly and “S” curve is more gradual when innovations have slower rate of adoption. The rate of diffusion of an innovation and the diffusion curve are affected by the characteristics of an innovation and characteristic features of a social system.

There are few first individuals to adopt the technologies called innovators (the speed of diffusion process increases when other people in a social system observe the results and take decisions to adopt it. When other people in a social system interact with innovators, the rate of diffusion is more rapid). Few more farmers after

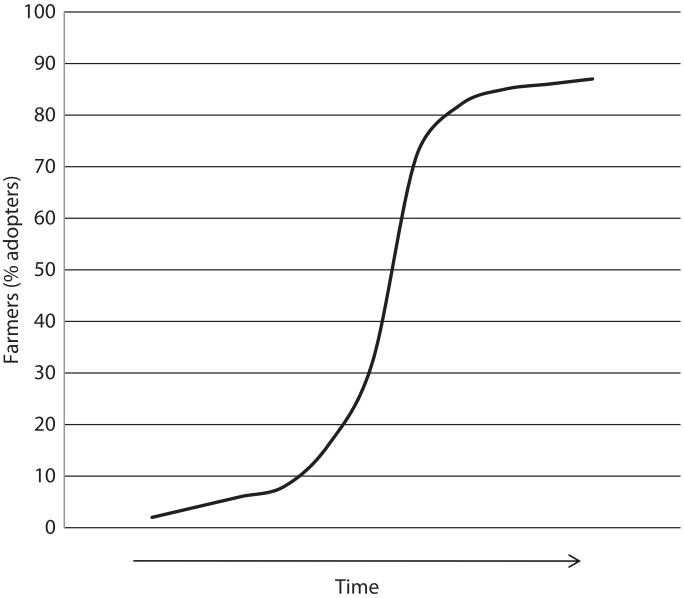

Fig. 1.1 S-shaped cumulative curve of rate of adoption

observation of results and interaction with innovators adopt the technology. Over a period, large number of farmers through interaction and watching the results of early adopters adopt the technologies. At this stage, the rate of diffusion slows down and comes to an end. The rate of diffusion may vary with the type of innovation and the type of social system in which it is diffused, communication networks/channels and leadership pattern. S-shaped diffusion curve is applicable only to successful innovations, which are accepted by all potential adopters. But in the cases of innovations which were accepted at the initial stage and may be rejected after some period, the S-shaped curve may take a dive. The adoption of complex IPM practices like sampling of pests following S-shaped curve has been reported by Grieshop et al. (1988) in California, USA. Where the communication channels used to disseminate these practices were the package of practices and other modes of transfer of technology as were used for diffusion of the green revolution technologies, the farmers were not even possessing awareness-knowledge of the thresholds of insect pests (Peshin et al. 2007a).

1.3.1 Concept of Adoption

Adoption is a decision to make full use of an innovation as the best course of action available. Lionberger (1970) defined adoption as the integration of an innovation into a farmer's ongoing operation through repeated and continuous use. Rogers and Shoemaker (1971) defined adoption as the use of a new idea continuously on a full scale. The “full scale” means one hundred percent utilization of an innovation. The decision to adopt an innovation involves a process. The adoption process is thus decision-making process involving a period of time during which an individual passes through mental stages before making a final decision to adopt an innovation.

1.3.1.1 Adoption Process

Ryan and Gross (1943) in their work of diffusion of hybrid corn seed into two communities in the United States first mentioned the sequence of stages in the process of adoption by farmers as:

i) awareness of the existence of an innovation
ii) conviction of its usefulness
iii) acceptance in the sense of willingness to try the innovation and
iv) complete adoption

According to Wilkening (1953), adoption process involved four stages

i) initial knowledge of a practice
ii) mental acceptance
iii) use on a trial basis and
iv) finally its full adoption

Adoption process is conceptualized to include different stages. There is no consensus among researchers regarding the number and sequences of adoption stages. The widely used five stage-model of the adoption process includes the following stages (Rogers, 1962):

I. **Awareness stage**: At awareness stage, the individual becomes aware of some new idea but does not have any detailed information or knowledge about it. The awareness of an innovation occurs either involuntarily or because of purposive action on the part of an individual seeking solution to a perceived need or problem. At this stage, it is important to create the right atmosphere for introducing the innovation. Mass media are widely used information sources to raise the awareness level.
II. **Interest stage**: At this stage, an individual develops enough interest about an innovation and gets motivated to seek more information and knowledge about it. He wants to know about innovation in terms of its nature, function, operation and usefulness. At this stage, the individual deliberately seeks out sources for more information about an innovation. At interest stage, individuals obtain information about an innovation from mass media.
III. **Evaluation stage**: At this stage, the individual proceeds to make a mental trial of a new idea by determining the applicability of the innovation to his personal circumstances and farming situation. The individual tries to visualize the expected outcome if he adopts the innovation. It is during this stage that

an individual decides whether to try out an innovation on a small scale or not. A favourable evaluation leads to mental acceptance of the innovation although the final decision to adopt an innovation may not be taken until the innovation after its trial on a limited scale shows better results or proves beneficial for the farmers. At the evaluation stage, neighbors and friends are the most preferred ones to seek decisions regarding adoption of an innovation.

IV. **Trial stage**: This stager is characterized by the small-scale experimental use. The trial provides an individual with the opportunity to evaluate the applicability of the innovation to his personal situation in concrete and tangible forms. A successful trial gives a feeling of security before deciding to adopt where as the innovations that are not successful, trials will have a higher rate of rejection by the individuals. An individual ranks neighbors and friends as the first in the information sources.

V. **The adoption stage**: The final stager in this mental process is the adoption stage. This stager is characterized by large-scale continued use of the idea and most of all satisfaction with the idea. However, an individual who has accepted an idea need not necessarily use it continuously. It means that there may be a chance of either continued adoption or discontinuance of adoption of an innovation. The discontinuance may be due to dissatisfaction with the innovation or due to availability of better alternatives (replacement). In the adoption stager, neighbours and friends are the preferred information sources.

The mass media channels of communication should be used to create awareness about IPM. The Punjab Agricultural University, Ludhiana used “street plays” to create awareness among the farmers in the villages covered under insecticide resistance management based IPM program in cotton, about the dysfunctional consequences of insecticides and IPM (Peshin et al. 2007a). In case of IPM, it is desired that result demonstrations and specific practical training should be provided to create interest in the farmers about IPM practices and for making evaluation whether to adopt the IPM innovation.

1.3.1.2 Innovation-Decision Process

An individual decision to adopt an innovation is not taken instantaneously but this process consists of series of actions and choices made by him or her over time. It is the process, which consists of sequential stages in the adoption decision made by individuals or other units of adoption. The innovation decision process is the process through which an individual or other decision making unit passes from first knowledge of an innovation to forming an attitude towards the innovation to a decision to adopt or reject an innovation to implementation of the new idea and to confirmation of this decision. Thus, the innovation decision process consists of five stages (Rogers, 1983). These are:

(i) **Knowledge stage**: An individual is exposed to an innovation’s existence and gains an understanding about it at this stage. An individual after gaining awareness about an innovation through communication channels develops predisposition towards it. Example, farmers through mass media or change agent, become aware of zero-tillage-seed drill. In order to know more about it they may visit an institute. Mostly people have a tendency to expose themselves to those communication messages that are in accordance with their needs and interests. This is called selective exposure. The individual's perceived need for an innovation may force him to seek knowledge about an innovation and develop the need to know more about it. Communication channels or change agents can create motivation among individuals to adopt it. In order to reduce uncertainty about innovation, an individual is motivated to seek information about its advantages and disadvantages for decision-making. Three types of knowledge possessed by an individual influence the innovation decision process.

- Awareness knowledge motivates an individual to seek "how to" knowledge and "principles" knowledge. This type of information seeking is concentrated at the knowledge stage of innovation-decision process but it may also occur at persuasion and decision stages. Here individual develops basic knowledge about an innovation.
- How to knowledge consists of information necessary to use an innovation properly. The adopter must understand what quantity of an innovation to secure, how to use it correctly and so on. The amount of how to knowledge needed depends upon complexity of an innovation, for more complex innovations amount of knowledge needed is relatively more compared to less complex innovation. There may be rejection or discontinuance of an innovation if adequate level of how to knowledge is not obtained by an individual prior to trial and adoption of innovation.
- Principles knowledge consists of information dealing with the functioning principles underlying how the innovation works. It is possible to adopt an innovation without principles knowledge but there are greater chances of misusing the new idea leading to discontinuance of the innovation. The individual's competence to judge whether to adopt an innovation is facilitated by principles knowledge.

(ii) Persuasion stage: At this stage, an individual forms a favourable or unfavourable attitude towards the innovation. The mental activity at the knowledge stage is cognitive whereas at persuasion stage it is affective. The individual becomes psychologically involved with the innovation and engages himself or herself actively in seeking the information about an innovation. The type of information received and how it is interpreted will determine individual's behavior at the persuasion stage. This is the stage at which an individual wishes to reduce uncertainty about the innovation by seeking information from his or her peers, change agent, etc about the expected consequences. Individual's attitude towards an innovation is developed by developing knowledge about the perceived attributes of innovation such as relative advantage, compatibility, etc. The formation of favourable or unfavourable attitude towards an innovation will subsequently lead to change in overt behavior. Consistent or positive attitude may result in adoption whereas negative attitude may lead to rejection. However, in some cases discrepancy in attitude and behavior may be there. A farmer may develop positive attitude towards high yielding variety but still use traditional varieties due to high input cost of chemical fertilizers. Attitude and behavior are not always consistent. There are other closely related factors that inhibit the use of innovation. Example, the farmer may wish to use improved seed variety but if there is no agency in his area to supply the improved seed variety, he will not be able to use improved seeds.

(iii) **Decision stage**: An individual at this stage decides whether to adopt or reject the innovation. Adoption is a decision to make full use of an innovation whereas rejection is a decision not to adopt an innovation. Most of the individuals partially try an innovation on small-scale prior to adoption. This small-scale trial is often a part of the decision to adopt it. The partial trial process amenable for an innovation facilitates the adoption of the innovation rather than innovation that cannot be tried on a small scale. For instance, zero tillage seed drill needs huge investment and cannot be tried on small-scale. Trial conducted by other agencies or individuals in the form of demonstrations are quite effective in speeding up the process of adoption. There may be a rejection decision by farmer that is not to adopt an innovation. There are two different types of rejection decisions:

- **Active rejection**: It consists of adoption of an innovation and then deciding not to adopt it.
- **Passive rejection**: It is also called non-adoption which consists of never really considering the use of an innovation.

(iv) **Implementation stage**: It is the stage when an individual puts an innovation into use. Implementation stage involves change in the overt behavior of the individual as he or she actually puts an innovation into use. The individual at an implementation stage may face problems in how to use it. A certain degree of uncertainty about the expected consequences of the innovation still exists for the individual. There are many doubts in his mind regarding its functions, use and expected consequences of an innovation. It is the active information-seeking period and the role of change agent is very significant at this stage. Change agent can provide technical assistance and can clear many of his doubts. It may be a terminating stage for some individuals. However, in other cases confirmation may occur. In case the adopters are organizations rather than individual, problems of implementation are more serious in nature. Mostly the organizations differ in size, organizational structure, type of individuals and organizational setting that affect the adoption of innovation. During the process of implementation, an innovation may be modified or changed.

(v) **Confirmation stage**: It is the stage when an individual seeks reinforcement whether to continue the use of an innovation or reject the innovation if he receives conflicting information. The confirmation stage continues after an initial decision to adopt or reject an innovation. At this stage, the individual seeks to avoid dissonance state or to reduce it if it occurs. Here the change agent plays a special role. The change agents provide supporting messages or information to the individuals who have earlier adopted an innovation. There are chances of discontinuance of innovation. Discontinuance is a decision to reject an innovation after having previously adopted it. Two types of discontinuance are:

a) Replacement discontinuance: It is a decision to reject an idea because better alternatives are available.
b) Disenchantment discontinuance: It is a decision to reject an idea because of dissatisfaction from its performance.

1.4 Dissemination and Adoption of IPM

Diffusion is a broader term, which encompasses unplanned as well as planned and directed spread of an innovation. In this chapter, emphasis is on planned and directed diffusion (dissemination)[1] of integrated pest management (IPM). IPM is a knowledge and skill intensive innovation. IPM, "is the careful integration of a number of available pest control techniques that discourage pest population development and keep pesticide and other interventions to levels that are economically justified and safe for human health and the environment" (FAO, 1994). Many technology transfer approaches were tried for dissemination of IPM methods. While Training & Visit (T&V) system failed, Farmer Field School (FFS) approach (For details see Chapters 8, 9 and 10) of educating farmers followed by community IPM activities and Farmer to Farmer approach registered success in IPM implementation in developing countries (Matteson, 2000). In developed countries like the United States of America, the Cooperative Extension Service has the primary responsibility for dissemination of IPM technology. A number of extension methodologies are used to disseminate IPM to the farmers. These include training about pest and natural enemies and field scouting, on-farm result demonstrations, field days, use of electronic and print media regarding information on the periodic/current status of pest and natural enemies, economic thresholds, computerised pest forecasting, newsletters, etc (For details see Chapter 16). In some European countries like Denmark, Netherlands, Norway, Sweden and Switzerland "IPM innovation system" approach is the corner stone for high adoption of IPM practices by the growers. The European Parliament is for developing regulatory frame work for taxes on pesticides. Taxes on pesticides are levied in Norway, Sweden and Denmark. Different strategies are adopted for implementation of IPM e.g., pest warning system, legislation, providing information about IPM to growers, employment of pest control advisors by large farmers and growers associations for plant protection, providing incentives for low pesticide IPM and support of market in encouraging sale of low pesticide use products (For details see Chapters 7 and 14).

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[1] Diffusion and dissemination is used interchangeably in this chapter.

1.4.1 Measuring Adoption of IPM

There is no agreement as to what constitutes adoption of IPM. There have been attempts by Economic Research Service (ERS) in the United States of America (Vandeman et al., 1994), van de Fliert (1993) in case of farmer field school IPM program in Indonesia, and Kogan and Bajwa (1999) in developing IPM continuum based on levels of IPM complexity (Fig. 1.2) to measure the level of IPM adoption. ERS in the United States (Vandeman et al., 1994) divided integrated pest (insect pests, plant diseases, weeds) management into integrated insect pest management, integrated disease management and integrated weed management, and identified 7–9 practices "indicatives of an IPM adoption". The level of adoption of IPM was categorized into the following (Benbrook and Groth, 1996):

I. low level of IPM adoption based on scouting (S) and pesticides application based on economic threshold(ETL) for one pest,

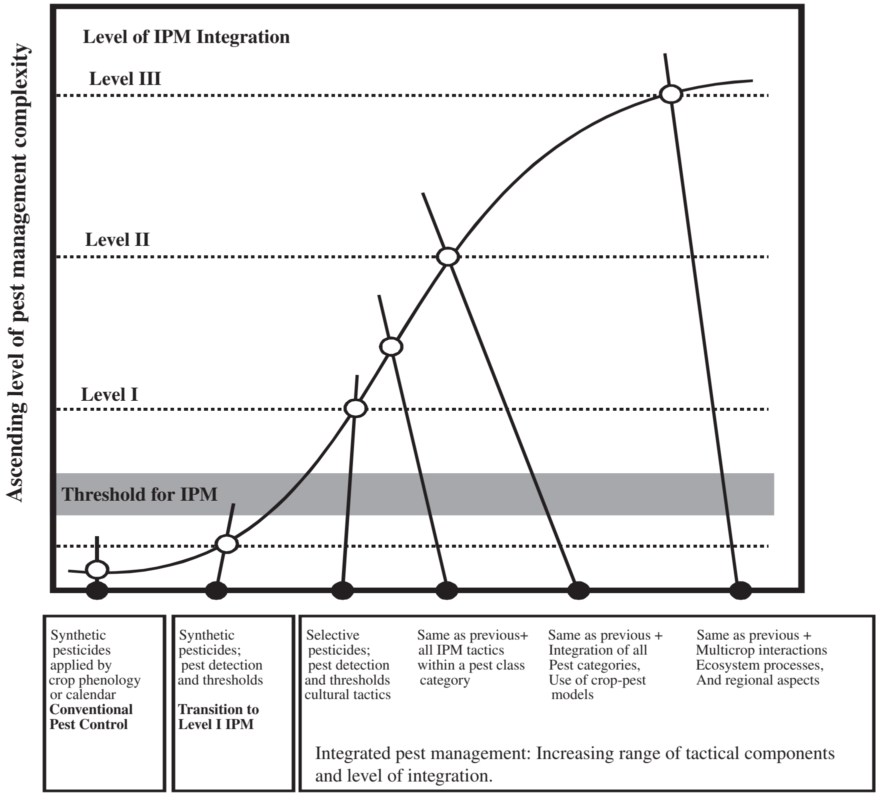

Fig. 1.2 Diagram depicting the IPM continuum, and showing the relative complexity of different levels of integration
Source: (Kogan and Bajwa, 1999) With permission from: *An Soc Entomol Brasil* (Anais da Sociedade Entomológica do Brasil).

II. medium level of IPM adoption based on low level adoption practices (S+ETL), plus 1–2 additional practices identified as indicative of an IPM approach, and
III. high level of IPM adoption, which requires adoption of low level adoption practices (S + ETL) plus 3 or more additional IPM tactics.

Kogan and Bajwa (1999) developed a six point continuum. It has at one end conventional pest control, and at the other end all IPM tactics which include selective pesticide based on threshold, cultural control, pest detection, ecosystem process, etc, depicting level of IPM adoption based on complexity of different levels of integration (Fig. 1.2).The continuum can be used to study the level of adoption of IPM.

I. The conventional pest management: use of synthetic pesticides based on crop phenology or calendar based.
II. Transition to level 1 IPM: synthetic pesticides based on pest detection and economic thresholds.
III. Graduation to level 1 IPM: use of selective pesticides based on pest detection and threshold, and crop manipulations techniques (cultural practices).
IV. At continuum 4 he placed integration of level 1 (use of selective pesticides based on pest detection and threshold, and crop manipulations techniques) with decisions based on pest categories.
V. The level 2 includes: use of selective pesticides based on pest detection and threshold, and crop manipulations techniques, decisions based on pest categories and use of crop-pest models.
VI. The level 3 integration at continuum 6 is selective pesticide use, pest detection, economic thresholds tactics, for different class of pest and pest categories based on important crop-pest models and addition of multicrop interaction, ecosystem processes and regional aspects.

Hence what constitutes the adoption of IPM, and what constitutes the well defined IPM approach at farmer level is far from clear. The IPM tactics may vary from crop to crop, from area to area, and the importance of a practice also varies. IPM practices cannot be proposed as a blanket recommendation (Dilts and Hate, 1996) and cannot be developed in the USA and disseminated in India- as was the case with pesticide. IPM is location specific and it requires several years of experiments, trials, repetitions and validations in a given area (Lagnaoui et al., 2004). Cultural practices of pest management combined with pest detection (agro- ecosystem analysis) and use of selective pesticides based on threshold is basic requirement to consider it for adoption of IPM.

1.4.2 Adoption of IPM

Worldwide the rate of adoption of IPM has been slow compared to adoption of pesticide use (Kogan and Bajwa, 1999). In the USA, the extent of adoption of the IPM practices in different crops has reached 71 percent from 40 percent in 1994 (GAO, 2001). In Europe the IPM policies, programs and coordination with private sector has resulted in promoting IPM and that has resulted in increased number of farms adopting IPM practices (Also see Chapter 1, Vol. 1 for details). The slow rate of adoption of IPM by farmers causes greater concern among policy makers and extension workers. The factors that make the farmer selective in adoption of IPM technology are numerous (Ridgley and Brush, 1992; Leeuwis, 2004). The complexity of IPM technology was cited as one of the possible reasons for low adoption (Rogers, 1995; Kogan, 1998). IPM is a diffused technology (cluster of technologies) (Kogan and Bajwa, 1999) and IPM practices like agro-ecosystem analysis, economic threshold levels of pests are software component innovations which are not highly observable as is the case with pesticides (Rogers, 1995). However, there is a growing recognition that there is some serious problem with the transfer technology (Wearing, 1988), as IPM becomes concrete only with farmer's direct hands-on experience with IPM (Rogers, 1995).

IPM innovation is knowledge intensive, in case of knowledge and skill intensive IPM practices, like economic thresholds, its rate of adoption among trained farmers has been slow, and its diffusion among untrained farmers has almost been negligible (Peshin, 2005). The transfer of technology problem may be rooted in the diffusion of innovation theory that provides the basis for the extension services. It needs different strategy through a process of knowledge and skill diffusion and active learning and active adoption by the farmers. It has to be a planned process of imparting knowledge and skills, and organized learning by the end users. The different IPM practices can be classified on the complexity- simplicity continuum. The Complexity associated with agro-ecosystem analysis, and determining threshold of insect pest are the deterrents in the adoption of these practices. (Wearing, 1988; Greishop et al., 1990; van de Fliert, 1998; Peshin and Kalra, 2000; Norris et al., 2003). According to Wearing (1988), IPM practices must deal with farmers' needs, perceptions, resources, constraints and objectives, and its complexity demands considerable resources are devoted to IPM dissemination.

Although diffusion research has contributed to our understanding of how technological innovations in agriculture spread in farming community in case of one off technologies like fertilizers, seeds, pesticides, etc, and recently in case of Bt cotton (Peshin et al., 2007b) but its application to knowledge- intensive-complex technologies is debated by the scientific community. IPM, which is a combination of different technologies (practices/methods) introduced in agriculture system in 1970s has not diffused like the green revolution technologies. Many practices of IPM emphasize change in farmers' decision making behavior, and therefore not appropriate to call these practices as innovations (Anonymous, 1996). IPM is both semi-continuous and discontinuous innovation. Semi-continuous because it presents difficulties both at communication and adoption level and farmers must partially change their behavior (Lagnaoui et al., 2004) regarding manipulation of agronomic practices specifically done to reduce pest build up. Discontinuous innovation as it is a departure from the calendar based pest management to threshold based pest management which requires cognition (new knowledge and comprehension) and analytical skills. Whether the adoption theory is applicable to IPM implementation, which emphasises learning process and not technological innovation (van de Fliert,

1993) is a researchable problem. IPM is complex and knowledge intensive mix of innovations namely, cultural practices (again a mix of different innovations), mechanical, biological, and chemical practices based on threshold theory. Almost all diffusion researches and studies on rate of adoption have concentrated on single innovation/practice and not a mix of practices. Thus, it is important to decide as to what can be termed as adoption of IPM and how it can be measured. The generalisation of diffusion of IPM innovation based on diffusion of innovation theory is not possible. Few studies have demonstrated or studied the rate of adoption of IPM forming S-shaped curve, IPM traversing innovation-decision process stages and farmer-to-farmer diffusion. Dissemination and adoption of IPM should be studied in the context of IPM attributes, incentives provided to farmers, quality of educating farmers about IPM practices, and the existing IPM innovation system of a country or region.

1.4.2.1 Innovation Attributes Influencing Adoption of IPM

The adoption of IPM largely depends on technological attributes more than socio-personal attributes. Age, education, farm size, computer ownership and other socio-personal attributes have no significant relationship with attitude towards IPM and decision making process of farmers (Grieshop et al., 1988, Zimmer, 1990) but land ownership, type of crop and previous experience with IPM program do influence farmers' decision making about IPM (Zimmer, 1990; Peshin, 2005). The attributes of innovation identified and generalized by Rogers (1983) are: relatively advantages, compatibility, complexity, trialability and observability. Fliegel, et al. way back in 1968 identified 15 attributes that had a relationship with rate of adoption. Those are: initial cost, continuing cost, rate of recovery, payoff, social approval, saving time, saving discomfort, regularity of reward, divisibility for trial, complexity, clarity of results, compatibility, association with dairying, mechanical attraction and pervasiveness. Not all these attributes may be relevant to determine the adoptability of IPM practices. Nevertheless, the attributes like relative advantage, compatibility, complexity, observability, risk/uncertainty and communicability of different IPM tactics determine the rate of adoption and adoptability of IPM. Complexity is the most important attribute that has delayed its adoption (Norton, 1982a, Zimmer, 1990). The attributes, which retard and accelerate the adoption of IPM, are listed in Table 1.1.

If we divide the IPM practices into crop plant manipulation practices, host plants resistant cultivators, use of sampling to determine economic threshold level of pests, conservation and augmentation of natural enemies, the effect of attributes which retards and accelerates the rate of adoption will vary. In case of crop manipulation practices, which are done specifically to control pests like sowing time, plant geometry, fertilization seed dressing etc. and are normally adopted by the growers but without paying attention to the role of these practices in reducing the pest build up (Peshin, 2005). The information about these practices can be disseminated through different channels of communication. In case of adjusting the sowing time to allow the crop to create asynchrony with the pest, the IPM

Table 1.1 IPM attributes which influence the rate of adoption

Attribute	Relationship with rate of adoption/adoptability	References
Complexity Knowledge, skill intensive and requiring comprehension	Negative	Lambur et al. (1985), Grieshop et al. (1988), Grieshop et al. (1990), Zimmer (1990), van de Fliert (1993), Peshin and Kalra (1998), Peshin (2005), Sivapragasam (2001)
Compatibility With farmers' needs, resources, constraints and objectives	Positive	Wearing (1988), Peshin (2005)
Less observability In case of software IPM practices and benefits of IPM	Negative	Grieshop et al. (1990), van de Fliert (1993), Peshin (2005)
Perceived risk In terms of reducing pesticide use/increase in pest, reduced yield and quality of produce	Negative	Stoner et al. (1986), Antle (1988), Grieshop et al. (1990), Sivapragasam (2001)
Relative advantage In reducing pesticide use and expenditure, higher/stable yields	Positive	Peshin (2005)
Time consuming and laborious	Negative	Grieshop et al. (1988), Peshin and Kalra (2000), Peshin (2005), Sivapragasam (2001)
Non-communicability Communication/dissemination of complex practices which require considerable resources	Negative	Wearing (1988)

programs need to demonstrate the effect of such practices to growers to highlight its relative advantages. These practices need adjustment in crop growing calendar of farmers, and must be made compatible with their farming. There is no complexity associated with these practices. The attributes at work for these practices are relative advantage-(economic and pest management), compatibility, but lack big bang and immediate observability in terms of pest reduction relative to pesticide use (Dent, 1995). These practices are disseminated for long in term of raising productivity of crops, but under IPM programs these practices need to be made adaptable to fit the farmers and they need to be educated about the benefits of these practices in suppression of pest population. Host plants resistance is compatible with all pest management practices and has distinct relative advantage in terms of less pest infestation. The scope of this tactics is immense in IPM programs provided it meets the yield and quality attributes compatible with needs of adopters. The adoptability and rate of adoption of transgenic like Bt-cotton which provides resistance against Lepidopteron insect pests has been very high (Peshin et al., 2007b), in both the developed and developing countries. The attributes that are responsible for its higher rate of adoption of resistant cultivars especially transgenic crop varieties are: relative advantage, compatibility, observability and, lack of complexity and risk (Peshin et al., 2007b). Adoption of cultural practices and resistant crop varieties will result in farmers growing a healthy crop, and healthy and vigorous crop is one of the best forms of pest management (Norris et al., 2003). The researchers should develop such cultural practices that have dual purpose of increasing productivity and reducing pest infestation. The technology developed at research stations should be field tested at growers' fields for technological attributes and adoptability.

1.4.2.2 Relative Advantage

Relative advantage of IPM practices over pesticide intensive pest management and observability of the relative advantages are important factors for its adoption. The relative advantages in term of reduction of pesticides expenditure and increased productivity has been reported from around the world. Relative advantage of different IPM methods like economic threshold level for taking pesticides use decisions, are not having high degree of observability and farmers perceive it risky (Grieshop et al., 1990; Peshin and Kalra, 1998; Wearing, 1988).

Let us take the example of IPM technology being disseminated in Asia through Farmer Field Schools (FFSs) in rice crop and the sub-dimensions of relative advantage of IPM practices. In case of economic profitability/benefits over pesticide based pest management, IPM programs resulted in saving on pesticide expenditure, which were small and not visible (observable) to farmers (van de Fliert, 1993) unlike economic advantages of the green revolution technologies (high yielding varieties, fertilisers, pesticides) and recently Bt cotton. Thus, the slow rate of adoption of IPM practices even among the trained farmers, and no diffusion to untrained farmers.

The sub-dimension of relative advantage- low initial cost does not have any relationship with IPM practices as it is a decision making process, but the other two sub-dimensions namely, saving of time and effort, immediate reward are having a bearing on adoption of sampling techniques. Sampling techniques are time consuming and laborious (Grieshop et al., 1988; Zimmer, 1990; van de Fliert, 1993; Peshin and Kalra, 2000; Peshin, 2005; Sivapragasam, 2001), and do not have immediate observable reward in reducing pest infestation. Therefore, these sub-dimensions of relative advantage negatively affect the adoptability and rate of adoption. Diffusion of an innovation being an uncertainty reduction process (Rogers, 2003), the agencies disseminating IPM must ensure to reduce uncertainty about the relative advantages of such IPM practices which are in direct conflict with conventional calendar based application of pesticides.

1.4.2.3 Observability

Higher the observability and communicability of results, the higher is the rate of adoption. IPM mostly is a software innovation and a decision making process. The software components of the technology have less observability (Rogers, 1995), thus slower rate of adoption. The observability of the benefit of sampling techniques, crop plant manipulation is distinctly far less than pesticides use to control pest. The low level of observability has reduced the adoption of critical IPM practices.

1.4.2.4 Complexity

Diffusion and adoption of innovations, which are complex to communicate and apply, like knowledge and skill intensive IPM practices (agro- ecosystem analysis, sampling) are slow. Although, use of plant protection chemicals diffused within the farming community at a faster rate but the use of pesticides according to good agricultural practices (right timing, right chemical against a particular pest, right dosage, right method of spray and right dilution) did not. For example in Punjab, agriculturally the most advanced state of India, the adoption of pesticides according to good agricultural practices is low (Peshin, 2005). Complex technologies- complex information do not diffuse in the same manner as do the simple and one of technologies. Dissemination of complex IPM practices require different menu for its adoption by the farmers. These practices cannot be diffused through "package of practices" published by the agricultural universities in India or through web based dissemination of IPM technology in the developed world. The economic threshold for insect pests of cotton were recommended and disseminated through its farm literature and other extension programs by one of the premier agricultural universities of India, Punjab Agricultural University, in the year 1979 for sucking insect pest (jassid *Amrasca biguttula*) and in 1992 for bollworm complex (*Helicoverpa armigera, Earias vittella*) and whitefly (*Bemisia tabaci*). However, the awareness- knowledge about these sampling procedures was zero where no IPM programs were conducted and mere three percent where IPM training was imparted, and its adoption was zero up to 2004–2005 (Peshin et al., 2007a). The farmers perceive economic threshold as it is knowledge, skill, labor intensive and time-consuming practice (Peshin and Kalra, 2000 and Peshin, 2005). The IPM programs implemented in northern India has mostly resulted in gain of knowledge about insect pests and natural enemies, but these programs did not impart skills to the farmers in pest management based on threshold theory. The conservation of natural enemies in the crop ecosystem can be achieved by applying economic threshold of pest for taking pesticide use decision. It is observed that IPM programs have achieved little success in case of complex practices.

The difficulty and complexity of determining ETLs could be overcome if adequate training is provided to farmers and if professional services are used, just like in the developed countries. The use of simplified action thresholds based on level of pest damage may be an alternative to actual pest counts and is worth considering (Walker et al., 2003). Research and development in pest management does not always lead to practical improvements. The issues generally fall into two categories, namely, (1) design, whereby R&D is aimed at the wrong questions or at developing inappropriate practices and (2) delivery, whereby despite the product being well targeted, the results are not getting through to be implemented by the pest managers and their advisers (Norton, 1982b). Simplifying ETLs, considering pests complex for calculating ETLs and the experiential delivery mode of complex IPM practices can help to increase the adoption. Supply-Push strategy (e.g., pesticide residues and health related issues) through legislation, enforcement or simply political will or the Demand-Pull strategy whereby the inherent advantages of adopting the IPM program (financial, risks reduction, etc) are perceived by the farmer as desirable towards meeting their farming objectives (Sivapragasam, 2001).

The combined efforts of the researchers at the research stations – the researchers and extension staff working at the farmers' fields, and inclusion of both biological and social scientist on development, adaptation, evaluation and education for bringing in complex IPM innovation into use by farmers (Wearing, 1988; Zalom et al., 1990). By adopting this model for dissemination of complex IPM practices, the rate of adoption resembled "S" shaped curve (Grieshop et al., 1988).

1.4.2.5 Compatibility

Compatibility in terms of past experience and need of the farmers is positively related to rate of adoption. An innovation that is consistent with the existing practices, past experiences and needs of potential adopters are more likely to be adopted. In addition to complexity of knowledge and skill intensive IPM practices, compatibility of these practices have been questioned by many especially in case of small farmers in developing countries (Bentley and Andrews, 1996; van de Fliert, 1998; Zadoks, 1989) and on accounts of cost involved for scouting in developed countries (Norris et al., 2003). In the USA and other developed countries, where farmers have large landholdings compared to developing countries of the world, farmers hire the services of scouts for monitoring their crops and finding threshold levels but its fiscal sustainability remains a big question as to who will bear the cost of sampling (Norris et al., 2003).

1.4.2.6 Non-Communicability

Communicability is the ease with which, know how and usefulness of an innovation can be communicated. Not all the IPM practices have the communicability. The crop plant manipulation practices done specifically to create asynchrony between destructive stage of pest and the crop are communicable, like adjusting sowing time of rice to avoid stem borer infestation, or planting cotton crop early to avoid late season American bollworm (*Helicoverpa armigera*) infestation. The communicability of resistant varieties is also easy if the variety has observable relative advantage over the variety it is replacing. The communicability of Bt cotton in Indian Punjab is an appropriate example. Even before the release of Bt cotton in Punjab, the farmers did possess awareness- knowledge about its benefits, and had purchased seed from far off states like Gujarat (India) where it was released earlier (Peshin et al., 2007b). The non-communicability of knowledge and skills to identify pest and their natural enemies and economic threshold levels is one of the attributes of IPM. Despite the relative advantages of IPM, it is very difficult to diffuse (Rogers, 1995), as it lacks communicability, and farmers are wondering whether they should believe the extension people who were propagating the benefits of calendar based pesticide use.

1.5 Predictive Model of IPM Adoption

The diffusion researcher should move beyond the Rogers (1983) model of diffusion of innovation, as has been suggested by Rogers (1995, 2003) himself. The diffusion of innovation research has to give up the "ex-post-facto" type research studies, which have been prisoners of socio-economic factors influencing the adoption of innovation and in correlating the effects to these factors. The diffusion researchers should employ "action research" design to study the IPM implementation and feed the result to develop farmers' acceptable IPM system.

The innovation attributes of IPM practice need to be studied with the farmers to evaluate innovation in terms of adoptability and adaptability. The qualitative and quantitative data be collected and fed into research system for making innovation fit the farmer. Adoptability indices of critical IPM practices for particular locations, crop etc. will help to predict the adoption or non-adoption of the innovation (Peshin, 2005). The biological scientists should involve social scientist from the field of extension education to find out the adoptability of their innovation to provide them the feedback, as to how the farmers will receive the technology and what needs to be done to make technology less complex and compatible to farmer. The extension education scientist should use an objective scale to elicit the responses of the farmers at whose field the technology is tested to work out the adoptability indices based on innovation attributes identified for a particular innovation namely relative advantage, compatibility, complexity, observability, risk and communicability. Adoptability indices can be worked out by the following formulae I and II (Peshin, 2005):

$$\text{Index of an attribute} = \frac{\text{Maximum score obtained by a group of farmers}}{\text{Maximum score obtainable}} \tag{I}$$

It can range from 0 to 1

Adoptability index is worked out by summing up the indices of positively related attributes e.g., relative advantage, compatibility, etc, and from it subtracting the sum of the indices of negatively related attributes like complexity, risk, etc as given by formula II.

$$\text{Adoptability index} = \frac{\sum \begin{array}{c}\text{Indices of positively related}\\ \text{attributes of an innovation}\end{array} - \sum \begin{array}{c}\text{Indices of negatively related}\\ \text{attributes of an innovation}\end{array}}{\text{Number of attributes}} \tag{II}$$

It can range from -1 to $+1$.

The adoptability index of a particular innovation can range from 0 to 1. Adoptability indices of IPM practices in cotton were worked out by Peshin (2005) using the above listed formulae I and II. Based on the adoptability indices it was concluded that adoptability of resistant cultivators (Bt-cotton) was high along with manipulation sowing time of cotton to reduce insect pest losses, but the adoptability of seed dressing, sampling for insect pests to determine economic threshold level was low. The entomologists can utilize the result of such studies to make use of ETL farmer friendly. Such innovations do not diffuse in the social system like the one off technologies of the green revolution (input intensive technologies) and recently Bt cotton (Peshin et al., 2007b).

The adoption process can be captured accurately if an innovation is followed over time as it traverses (courses) through the farming system (Structure of Social System). According to Rogers (1995) "Conceptual and Analytical Strength is gained by incorporating time as an essential element in analysis of human behavior". Alternative research approach to "after the fact data gathering (ex-post-facto)" about how IPM innovation has disseminated and adopted, the model given by Singh (2004) makes it possible to investigate the diffusion of innovation when the dissemination of technology has just begun (Fig. 1.3). Adoption decision process to determine dynamics of innovation adoption is based on the following three factors that can affect the adoption decision process (Singh, 2004):

i. Innovation attributes
ii. IPM program and policy efforts
iii. Other characteristics (socio-economic)

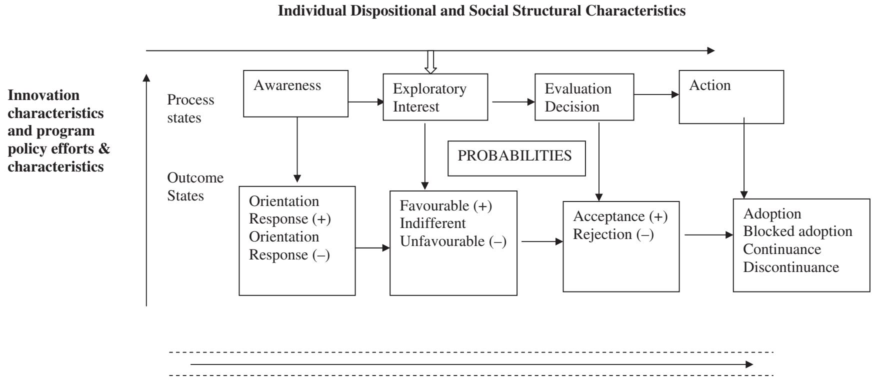

Fig. 1.3 Dynamics of innovation-adoption decision process
Source: Singh Raghbir (2004).

The process stages can be knowledge – awareness, exploratory interest, evaluation decision and action and the probabilities identified for outcome by Singh (2004) with these stages are:

I. Awareness: Orientation response can be positive or negative
II. Exploratory Interest:
    a. Favourable (+ve)
    b. Indifferent
    c. Unfavourable (−ve)
III. Evaluation Decision: Based on testing of innovation with farmers it can be:
    a. Acceptance (+ve)
    b. Rejection (−ve)
IV. Action:
    a. Adoption,
    b. Blocked adoption (Adopted, due to other reasons could not adopt)
    c. Continuance
    d. Discontinuance

This model is based on Marco chain model of probabilities. The model can be used to determine the IPM adoption process once the IPM intervention is introduced into the farming system, and can be used by researchers to fit the IPM methods to farming system, modelling of training or other IPM dissemination efforts to increase the adoption, and policy efforts required for IPM dissemination and adoption. In case of IPM the researchers should study the initial policy decision to disseminate IPM, what aspects of IPM need more emphasis. Field experiments in which pre- intervention, during intervention and post-intervention measurements can be obtained to study the adoptability of IPM tactics and modify these to be compatible with particular farming system to increase its rate of adoption.

1.6 IPM Innovation System

It is increasingly recognized that traditional agricultural science and technology investments such as research and extension, although necessary, are not sufficient to enable agricultural innovation (World Bank, 2007). Research and technology development contribute only part of innovation process (Rajalahti et al., 2008). An innovation system comprises the organisations, enterprises and individuals that demand and supply knowledge and technologies, and the policies, rules and mechanisms which affect the way different agents interact to share, access, exchange, and use knowledge (World Bank, 2007).

IPM has not been the creation of innovation per se, but the adaptation of the existing pest management practices, like cultural practices, physical practices, cultivation of resistant varieties and threshold based pest management. IPM program and policy (Singh, 2004) related to potential public and private sectors, which include policy decisions, coordinating all the stakeholders involved in IPM innovation system. In case of IPM, coordination of multi-stakeholder partnership is required, and it requires active coordination of the researchers, extension workers, farmers, policy makers and market forces for adoption of IPM. IPM innovation system offers alternatives for reforming the extension system involved with dissemination of IPM technology. Its attraction is that it recognises that innovation is not a research-driven process that relies simply on technology transfer. Instead, IPM innovation is a process of generating, accessing and putting knowledge into use. Central to the process are the interactions of different people and their ideas; the institutions (the attitudes, habits, practices and ways of working) that shape how individuals and organisations interact; and learning as a means of evolving new arrangements specific to local contexts (Sulaiman, 2008). IPM innovation system requires potential public and private sectors be involved in the creation (like research, development and marketing of bio-pesticides, bio-gents), diffusion, adaptation and use of all types of knowledge relevant to IPM. When all these stakeholders combine as is the case in Switzerland, where policy makers, researchers, farmers, extension services and market forces have joined to promote low pesticide integrated production protocols. In case of IPM, researcher/research institution, company, and farmer/farmer association enter into a risk- and benefit-sharing arrangement in the form of contracts, joint shareholding, or revenue sharing, which guarantees that one partner alone does not share benefits-risks (World Bank, 2007).

Overtime, the innovation system concept has gained wide support among the member countries of the Organisation for Economic Cooperation and Development (OECD). The concept has been applied in European Union and a number of developing countries as a frame work of policy analysis (OECD, 1997; 1999; Wong, 1999; Cassiolato et al., 2003).

1.7 Conclusion

The major constraints limiting the adoption of IPM practices are risk and complexity perceived by the farmers (Antle, 1988; Grieshop et al., 1990; Peshin, 2005). Though the farmers are aware about the toxic hazards of pesticides (Peshin, 2005), perceived risk factors in terms of more crops losses by reducing pesticides use, which in turn may reduce the productivity and profit is one of the major limiting factor in adoption of IPM. The involvement of farmers/farm organisations in development and diffusion of IPM practices in coordination with researchers, extension workers, and market forces for adoption of IPM will reduce the risk perception associated with IPM. The lack of vast trained personnel in sampling techniques for educating and providing direct hands on experience to farmers is hindering the effective dissemination and adoption of the technology. The IPM program needs to be designed with the farmers, which will take care of their needs, perception, resource constraints and objectives (Lambur et al., 1985; Rogers, 1995; Grieshop et al., 1990). “Good fit” between IPM practices and the farms is one of the key principles of IPM implementation (Wearing, 1988) and its examples are green house crops IPM in Europe, apple IPM in south Tyrol, cotton IPM in Texas, almonds IPM in California, apple IPM in Pennsylvania (Wearing, 1988).

To do this, considerable resources need to be devoted to IPM dissemination. The trainers have to move from imparting awareness-knowledge to higher levels of cognitive domain-comprehension, application and evaluation of IPM methods related to role of natural enemies, economic threshold, biological control (conservation and augmentation) as it exists in crop ecosystem, and how all IPM tactics intervened with each other (Grieshop et al., 1990). The diffusion researchers have to move beyond innovation bias and individual blame, they need to study technological constraints in terms of technological attributes, the quality of trainers and training, and other factors that limit the adoption of IPM practices. The trainers need to target those practices which are critical for transition of farmers to IPM practitioners. Most of the evaluation of IPM has been in term of its advantages and focused on economic attribute of IPM (Rajotte et al., 1986), though a significant factor in decision making (Grieshop et al., 1988) but non-economic attributes of the IPM innovation such as complexity, compatibility and ease of use are important to its adoption (Lambur et al., 1985). The Diffusion of Innovation Theory seldom investigated the effects of adopting such a package approach (Rogers, 2003). The effects of individual components were investigated and documented. However, effects of all the innovations, plus the synergistic effects were not investigated. Obviously, such thinking did not emerge for IPM technology too as IPM could be better considered as a technology cluster. Such a silence in Diffusion of Innovations Theory sounds louder alert on some of the unexplained stories of IPM impact.

The financial resource and work force available with pesticide companies to propagate the adoption of pesticide with immediate observable effects in terms of knockdown of pests is a challenge for IPM implementation agencies. Therefore IPM innovation system approach is required to involve all the actors namely researcher/research institution, company, and farmer/farmer association to enter into a risk- and benefit-sharing arrangement in the form of contracts, joint shareholding, or revenue sharing, which guarantees that benefits-risks are not shared by one partner alone.

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Chapter 2
Evaluation Research: Methodologies for Evaluation of IPM Programs

Rajinder Peshin, K. S. U. Jayaratne and Gurdeep Singh

Abstract Evaluation is a systematic approach by which the program process and results are compared with set goals and objectives to make value judgments about the program. In this regard, the evaluation of integrated pest management programs (IPM) is vital for making proper programmatic decisions. Formative and summative evaluations are the two major types of evaluation. Formative evaluation is used to assess the program process for its improvement. Summative evaluation is used to assess the program results for accountability. Institutions around the world are giving greater attention to the evaluation of extension programs. However, the evaluation of IPM programs is generally not up to the level it should be in terms of quality and rigger of evaluation research. The purpose of this chapter is to provide basic knowledge to the personnel involved in the evaluation about concept and purpose of evaluation, and appropriate research methods for conducting IPM evaluation studies. The theory based evaluation is helpful in designing the meaningful and rigorous studies. There are evaluation standards to guide the evaluators in this process. Before conducting IPM evaluation studies, it is important to review the practical considerations to ensure the quality and the usefulness of the study. Currently the evaluation of IPM programs lack consensus in selection of the indicators, research designs and adoption of appropriate methodologies. The social, economic and environmental indicators are taken into account while carrying out the IPM evaluation. The quality of an IPM evaluation can be improved by proper planning and selection of appropriate research design. Planning is helpful for achieving the evaluation objectives cost effectively. When the IPM evaluation studies are planned, it is important to consider the social, economic and environmental context of the farming community for achieving the practicality and the usefulness of the evaluation study. The IPM program evaluation is meaningful only if the results are communicated and utilized to achieve the evaluation objectives.

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2.1 Introduction

There is no uniformly accepted definition of what constitutes evaluation research (Kosloski, 2000). The concept of evaluation research has been an issue of debate among academicians. The academicians consider that evaluation research differs from both basic research as well as applied research. Some consider evaluation as research and applied science. Evaluation research is a form of applied social science which intends to assist in improving the quality of human services (Posavac and Carey, 1989). According to Douglah (1996) "*Research and evaluation both are mode of inquiry*." Alkin and Christie (2004) have discussed theories of evaluation in their paper "An evaluation theory tree." They explained that evaluation has grown on three pillars of orientation i.e. research orientation, decision making orientation and assessing worth. (i) Tyler (1942), Campbell and Stanley (1966) and many other prominent scientists emphasized well designed experimental and quasi-experimental designs for doing evaluation. They had more methodological orientation. (ii) Theorists having decision making orientation emphasized that evaluation is done to improve the program thus the major role of evaluation is to give feedback to program stakeholders to make better decisions. But it is not its only function. Program evaluation provides useful, objective, and timely information about the extent to which desired program results are being achieved. Stufflebeam's (2003) CIPP (Context, Input, Process and Product evaluation) model is one of the famous models for its decision making orientation. The model has been employed in many countries in short-term and long-term investigations. (iii) According to the third orientation, assessing worth or value is the main role of evaluation and the role of an evaluator is to give value to evaluation findings. Shadish et al. (1991) deems Scriven as "the first and only major evaluation theorist to have an explicit and general theory of valuing". After, that many other theorists emphasized value orientation of evaluation.

The field of evaluation research can be defined as "the use of scientific methods to measure the implementation and outcome of programs for decision-making purposes" (Rutman, 1984). A broader and more widely accepted definition is "the systematic application of social research procedures for assessing the conceptualization, design, implementation, and utilization of social intervention programs" (Rossi and Freeman, 1993). A much broader definition was offered by Scriven (1991) who defined evaluation as "the process of determining the merit, worth and value of things". It does not limit to a social program or specific type of intervention but encompasses everything. The object can be a program, a project, a product, a policy, or a one-off event. According to Scriven (1999) the discipline of evaluation has some more than 20 recognized fields including program evaluation, personnel evaluation, performance evaluation, product evaluation, training evaluation etc. Evaluation as such should start with a close examination of the purpose of the evaluation, and clear understanding of the Program and target clientele. It is not until the purpose and main evaluation questions have been agreed upon that the selection of appropriate methods should be considered (Petheram, 1998).

Integrated pest management (IPM) programs have been, and are being implemented throughout the world since the last four decades and the primary purpose of these programs is to reduce the use of pesticide by adopting alternate pest management practices. The purpose of IPM program evaluation is to seek the information needed for program improvement and weighing the results and consequences. In this chapter, the theory of evaluation research and its application to IPM program evaluation is discussed.

2.2 Historical View of Evaluation

Around 1960, the government of the United States of America (USA), invested large sums of money in programs in education, income maintenance, housing and health, and it increased the demand for evaluation (Bell, 1983). The US federal government took an interventionist role on social policy during the 1960s which resulted in the increasing interest in evaluation research as an academic pursuit (Shadish et al., 1995). Evaluation became particularly relevant in the United States of America during the period of the Great Society social programs associated with the Robert Kennedy and Johnson administrations. In 1965, Elementary and Secondary Education Act (ESEA) was passed and this prompted the US Senator Robert Kennedy to insist that each federal grant recipient conduct an evaluation for federally sponsored programs. It was with this particular act "program evaluation had been born overnight" (Worthen et al., 1997). By the late 1960s in the USA and internationally, evaluation research had become a growth industry (*Wall Street Journal*, cited by Rossi et al., 1979). It further expanded during the 1970s (Shadish et al., 1991; Petheram, 1998).The theory and practices of program evaluation emerged during this time. Theory of program evaluation had its roots in earlier work done by Ralph Tyler in the period between 1930 and 1945 in education (Tyler, 1967), Lewin (1948) in social psychology and Lazarsfeld and Rosenburg (1955) in sociology.

The systemization, standardizations and efficiency in the field of program evaluation in education were observed during the early part of the twentieth century (Petheram, 1998). The term "educational evaluation" was coined by Tyler. Tyler had enormous effects upon the field of evaluation and his approach called for the measurement of behaviorally defined objectives; it concentrates on learning outcome instead of organizational and teaching input (Madaus et al., 1991). As evaluation strategies and methods matured, evaluation theory developed towards one focusing on methodology, but in a broad context (Shadish et al., 1991). Around 1973, program evaluation began to emerge as a semi-professional discipline (Petheram, 1998). Around late 1970s and early 1980s, evaluators realized that the techniques of evaluation must:

i. serve the need of the clients,
ii. address the central value issues,

iii. deal with situational realities, and
iv. meet the requirements of probity, and satisfy the needs for veracity (Madaus et al., 1991).

Most of the program evaluation has been in the field of education followed by health- related programs. During 1960s "Great Society Program in the US," large sums of money were invested towards programs in education, income maintenance, housing and health. The massive spending on these programs increased the demand for evaluation. During the presidency of Ronald Reagan in the USA, program evaluation was given impetus in the 1980s, due to failure of the "Great Society Programs." One hundred third Congress of the United States of America in 1993 passed an Act "Government Performance and Results Act of 1993[1]." The act provides for the establishment of strategic planning and performance measurement in the federal government, and for other purposes to avoid waste and inefficiency in federal programs to avoid undermining the confidence of the American people in the government and reduce the federal government's ability to address adequately vital public needs. With this program evaluation gained momentum. Although evaluation developed in the USA, later it began to gain ground in Australia and Europe in 1960s. In India, program evaluation has not caught the attention of policy makers.

2.3 Theoretical/Conceptual Foundation of Evaluation

Evaluation theory comprises the many possible decisions about the shape, conduct and effect of evaluation, and is therefore, far from focusing on methods only (van de Fliert, 1993). The discussion on methodology includes the philosophy of science, public policy, validity, and utilization and the emphasis must be on making the methodology fit the needs of the society, its institution and its citizens, rather than the reverse (Kalpan, 1994). It is possible to conduct evaluation without paying any attention to theory and forms of evaluation, but such evaluative studies lack internal validity because these are not based on the rigorous evaluation research methodologies. The main emphasis should be on the purpose of evaluation which helps in identifying the key evaluation questions on the basis of which appropriate form of evaluation, appropriate model of evaluation and design of research can be selected.

Huey Chen has played the most important role in developing the concept and practice of theory-driven evaluation (Alkin and Christie, 2004). Theory-driven evaluation is gaining importance and is considered as the future approach to program evaluation. Theory-driven evaluation has been a movement of critical importance in the last two decades, in that sense it is a broader perspective of evaluation that has been conceptualized in the past (Chen, 1994). It is a process for evaluating programs in which a program theory, or logic model of program functioning is developed.

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[1] http://www.whitehouse.gov/omb/mgmt-gpra/gplaw2m.html

Then program theory is tested to discern its working and its intended and accidental impacts. Science demands that results should be reliable as well as valid both internally as well as externally. Experiments and quasi-experiments are dominant research designs and widely used. But if these designs are blended with program theory, these will yield efficient, effective results with information about how these results were obtained (Chen and Rossi, 1983). This approach to evaluation focuses on knowledge of social sciences and classical research designs.

A common element of all theory-driven evaluation applications is the development of a program theory, or "plausible and sensible model" *of the program* (Bickman, 1987) is constructed to achieve the desired outcomes. Program theory describes how the goals of the program are likely to be achieved by the program stakeholders. Program theory is the diagrammatic representation of actions, results and intervening factors, i.e. the relationship between cause and effect. *Program theory, similar to a logic model, is a graphical representation of program functioning as conceptualized by the program stakeholders* (Rogers et al., 2000). Chen (1990) defined program theory as "a specification of what must be done to achieve the desired goals, what other impacts may also be anticipated and how these goals and impacts would be generated." Donaldson (2001) names four sources of program theory: *prior theory and research, implicit theories of those close to the program, observations of the program, and exploratory research to test critical assumptions.*

Theory-driven evaluation is an approach in which the evaluator "makes explicit the underlying assumptions about how program are expected to work- the program theory- and then using this theory to guide the evaluation" (Rogers et al., 2000). They note that "program theory is known by many different names". Program philosophy, outcome hierarchies, theory of action, program logic, theory driven evaluation, and theory based evaluation, are other terminologies used synonymously. There are some skeptics of this theory but as Davidson (2006) (http://evaluation.wmich.edu/jmde/*)* says, "Program theory and its use in evaluation seems to be an argument that just would not go away depending on which part of the world one is in. But some of the best innovations are coming from those who understand program theory's potential and limitations." Russ-Eft and Preskill (2001) refer to four evaluation models that have characteristics of theory-driven evaluation: logic models, the Input-Process-Output model, Holton's HRD Evaluation Research and Measurement Model, and Brinkerhoff's Six Stage Model. There are certain shortcomings of this approach. Identifying assumptions and theories can be complex further measurement will be a problem (Weiss, 1998). In this section of the chapter we discuss the purpose of evaluation, evaluation standards, different forms of program evaluation and the models of evaluation to provide a theoretical background of program evaluation.

2.3.1 Purpose of Evaluation

Evaluation is the systematic assessment of the benefits of the programs in terms of the systematic acquisition of information based on empirical data to provide feedback about the program. The evaluation results can be used to influence decision making and policy formulation. The evaluation results influence decision making or policy formulation on the basis of empirically driven feedback. Need for accountability and control call for evaluation of programs. *Primarily evaluation is done in response to social inquiry* (Alkin and Christie, 2004). Evaluation is done to improve a program, to see its effect or impact on people, to check the performance of personnel or organization and to do cost benefit analysis. According to Powell et al. (1996) the *fundamental purpose of evaluation is to create greater understanding*. Purpose of the evaluation may be improvement of the program or knowing immediate effect or impact of the program. Chelimsky (1997) identified three purposes of evaluation research as evaluation for accountability, evaluation for development and evaluation for knowledge. Evaluation for accountability is for the funding agencies to incorporate accountability. Agricultural development programs that include IPM programs have a specific description of what is to be done, how it is to be done and what the intended outcome is. The accountability evaluation is to identify cause and effect, and research methodology should employ quasi-experimental research design. The accountability evaluation is summative in nature (Kosloski, 2000) and is referred to as summative evaluation (Scriven, 1991). A second purpose of evaluation is for development, which is conducted to improve the programs. It addresses questions: what are the appropriate indicators of programs success and what are the appropriate goals (Kosloski, 2000)? Evaluation for development or improvement of programs is process evaluation which is formative in nature and reports back to programs for its improvement. In the case of IPM programs, it is concerned with implementation of programs rather than its outcome. It asks questions like: is the IPM program implemented as designed and if so, what is the shortcoming of the designed implementation. The common research paradigm is action research, and the research design is quasi-experimental or case studies. The data collected are both qualitative and quantitative in nature. The relationship between treatment (IPM intervention) and outcome (behavioral change and adoption of IPM practices to reduce pesticide use, and income of farmers etc.) are empirically verified. In this case formative evaluation is followed by summative evaluation. A third purpose of evaluation is for adding to an already existing body of knowledge and for theory building. Evaluation for knowledge is for academic pursuit of researchers, program designers and for evaluators (Kosloski, 2000). It is diagnostic in nature to determine the etiology of causes and the questions are researchable cause and effect. In case of IPM programs, it can lead to finding the answers of questions – why does not IPM technology diffuse in social system like input intensive technologies or why does not the rate of adoption of IPM practices follow the “S” shaped curve? It is important to decide in advance the intention of evaluation. (Powell et al., 1996) *It is important to define the purpose of evaluation at early stage, otherwise it will lack direction and resulting information will not be useful*. In the case of IPM programs evaluation results based on scientific quasi-experimental models, the most dominant evaluation strategy, is based on objectivity and internal and external validity of the information generated.

2.3.2 Program Evaluation Standards

Joint committee for standards for educational evaluation has laid down certain standards for program evaluation. These include utility standards, feasibility standards, propriety standards and accuracy standards (Joint committee for standards for educational evaluation, 1994). ***Utility standards*** call for identification of stakeholders, credibility and value identification. It demands report clarity and timeliness so that intended users could get required information. ***Feasibility standards*** are to ensure uninterrupted evaluation process and that it should be practical or realistic, politically viable and cost effective. ***Propriety standards*** are to protect the rights of human welfare. They are intended to ensure that evaluation is responsible both ethically as well as legally. ***Accuracy standards*** are to ensure technical reliability and validity of the evaluation, and for that both qualitative and quantitative analysis need to be done. Accuracy standards also emphasize meta-evaluation. Appreciation for evaluation research, in terms of understanding of why a specific process needs to be followed is also important. It involves awareness of the ethical issues related to gathering information from program participants, knowledge of the basics of program evaluation, and understanding of incorporating evaluation as part of program planning (Bailey and Deen, 2002).

2.3.3 Types of Program Evaluation

The overall purpose of program evaluation is to provide feedback to stakeholders but specific sub-purposes always need to be defined for specific evaluation studies (van de Fliert, 1993). Commonly two main types of evaluations are distinguished, called *formative* and *summative* evaluation (Scriven, 1967; Neuman, 2000). This classification of evaluation studies is based on the purpose of evaluation.

2.3.3.1 Formative and Summative Evaluation

Formative and summative evaluation were first described by Scriven (1967), and these terms are broadly accepted. "Formative evaluation attempts to identify and remedy shortcomings during the development state of a program. Summative evaluation assesses the worth of the final version when it is offered as an alternative to other program" (Taylor, 1976). Formative evaluation is not only concerned with the definition given by Taylor (1976), it is conducted when the program is being implemented to provide program staff feedback on program weaknesses, which are useful in improving the program. Patton (1997) outlined their sequential nature: first, formative data are collected and used to prepare for the summative evaluation; then, a summative evaluation is conducted to provide data for external accountability. These terms have become almost universally accepted in the field of evaluation. "Formative evaluation" is conducted to provide program staff judgment useful in improving the program. "Summative evaluation" is generally conducted after completion of the program (or when the program has stabilized and for the benefit of an external audience or decision-maker). Formative evaluation is a type of process evaluation during the program implementation phase to assess whether the inputs (in terms of resources for IPM program) result in desired outputs (in terms of program objectives of IPM program) by employing certain processes (in terms of program implementation, activities, and interventions for dissemination of IPM practices). The information provided by formative evaluation during program implementation can be used to modify or reorient the subsequent stages of a program that is why formative evaluation is referred to "action research" where the results of formative evaluation of IPM program can be incorporated in the program for improvement. While summative evaluation provides the information whether the program should be continued, expanded or terminated, formative evaluation provides the feedback (report) to the program and summative evaluation reports about the program in terms of the achievement of the program objectives. Up to 1970s the emphasis was on summative evaluation, which is generally conducted after the completion of the program, but for the last two decades such emphasis is on formative evaluation. It involves the collection of relevant data while the program is being implemented to generate information for feedback. This feedback is utilized to identify the intended and unintended outcomes, and is helpful in improving the program to meet the needs of the situation. Summative evaluation, on the other hand, assesses the overall effectiveness of the program (sum total) in achieving the objectives of the program. Patton (1997) and others emphasize that evaluation should be an integral part of the program development process and, therefore, place equal or greater weight on the first phase, formative evaluation. According to Patton (1997), a formative evaluation should provide feedback on the original program and improve program implementation, while a summative evaluation should determine if the desired outcomes are achieved and can be attributed to the revised program. Chambers (1994) argues that it is not the timing, but the use of evaluation data that distinguishes formative from summative evaluation. He emphasizes that formative evaluation provides data with which to modify the initial intervention and its delivery so that the final intervention is more effective as revealed by the summative evaluation. Scheirer (1994) recommends using formative evaluation in a pilot situation to collect information on the feasibility of activities and their acceptance by recipients, suggesting qualitative methods such as interviews, focus groups, and observations to gather these data. In sum, these researchers suggest that formative evaluation should examine the effect of the program, the process of delivery, and the reactions of participants in the program.

2.3.4 Models of Program Evaluation

People use models to better explain the program theory in evaluation. Program theory means the underlying concept that explains how the program resources transform into training activities and program results. For example, in IPM programming, resources are used to develop educational materials and extension activities. As a result of these activities, farmers will gain new knowledge and follow IPM practices. As a result of practicing IPM, farmers will save money on pesticides and improve the quality of environment. There are different models used in evaluation. The most appropriate models for planning IPM evaluation studies are the logic model and Bennett's model. These two models are extensively used in planning extension evaluations studies.

2.3.4.1 The Logic Model

There are several pieces of a logic model. Program resources such as funds are called inputs. Training materials and activities are called program outputs. Program results are called outcomes. Depending on the time taken to manifest, outcomes can be categorized into immediate outcomes, intermediate outcomes and end results. The end results are called impacts.

The logic model rationally links proceeding with the antecedent explained in the program theory. The logic model relates proceeding rationally with the antecedent by using "if" and "then" linking words. The normal sequence of the logic model is inputs, outputs, outcomes and impacts. It also explains the programming context and explains the need for IPM programming and program priorities.

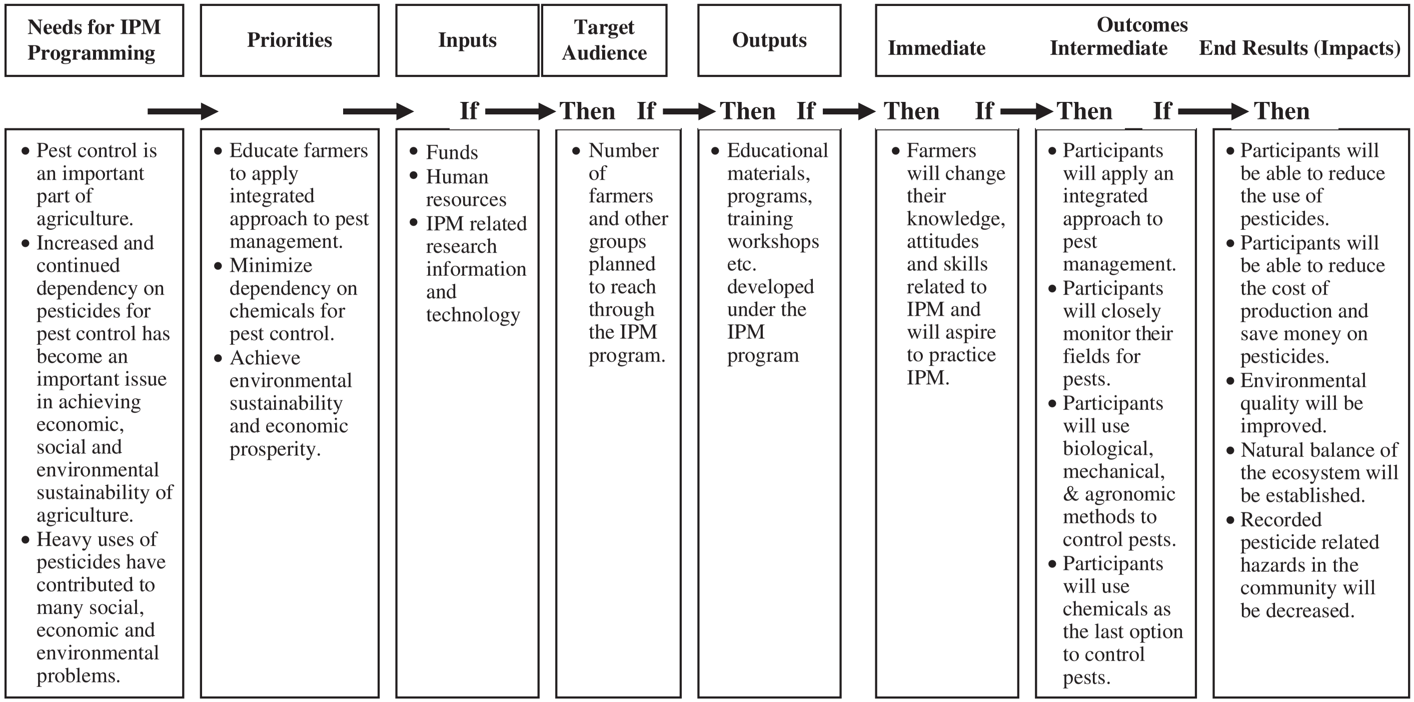
The logic model is very helpful to explain the IPM programming process. It elaborates how inputs transforms into potential results and shows the exact data collecting points and impact indicators. Therefore, the logic model is used for planning evaluations. Figure 2.1 demonstrates the logic model for IPM programming.

2.3.4.2 Bennett's Model

Claude Bennett (1975) developed this evaluation model for extension program evaluation. This model (Fig. 2.2) is known as Bennett's hierarchy of evidence in program evaluation.

Bennett's model displays the chain of events taking place from inputs to the end results. It starts with mobilizing inputs for the IPM programming. With inputs such as resources, extension can develop IPM educational programs and activities. When IPM extension activities are presented, farmers will participate. Their participation will lead to the next level of evidence-participants' reactions to the IPM program. If the program is effective, then participants will be able to change their knowledge, attitudes, skills and aspirations (KASA) toward IPM. That is the 4th level of evidence. If the program participants were able to change their KASA, then they will be able to change their pest management practices. Adoption of IPM practices will lead to the end results. This includes social, economic, and environmental impact of the IPM program.

Like the logic model, Bennett's model is helpful in understanding the chain of events in extension programming. It tells what types of data to collect at different levels of the hierarchy. Therefore, this model is useful in planning evaluations.



Needs for IPM Programming	Priorities	Inputs	Target Audience	Outputs	Outcomes: Immediate	Outcomes: Intermediate	Outcomes: End Results (Impacts)
• Pest control is an important part of agriculture. • Increased and continued dependency on pesticides for pest control has become an important issue in achieving economic, social and environmental sustainability of agriculture. • Heavy uses of pesticides have contributed to many social, economic and environmental problems.	• Educate farmers to apply integrated approach to pest management. • Minimize dependency on chemicals for pest control. • Achieve environmental sustainability and economic prosperity.	• Funds • Human resources • IPM related research information and technology	• Number of farmers and other groups planned to reach through the IPM program.	• Educational materials, programs, training workshops etc. developed under the IPM program	• Farmers will change their knowledge, attitudes and skills related to IPM and will aspire to practice IPM.	• Participants will apply an integrated approach to pest management. • Participants will closely monitor their fields for pests. • Participants will use biological, mechanical, & agronomic methods to control pests. • Participants will use chemicals as the last option to control pests.	• Participants will be able to reduce the use of pesticides. • Participants will be able to reduce the cost of production and save money on pesticides. • Environmental quality will be improved. • Natural balance of the ecosystem will be established. • Recorded pesticide related hazards in the community will be decreased.

Fig. 2.1 Logic model for IPM programming

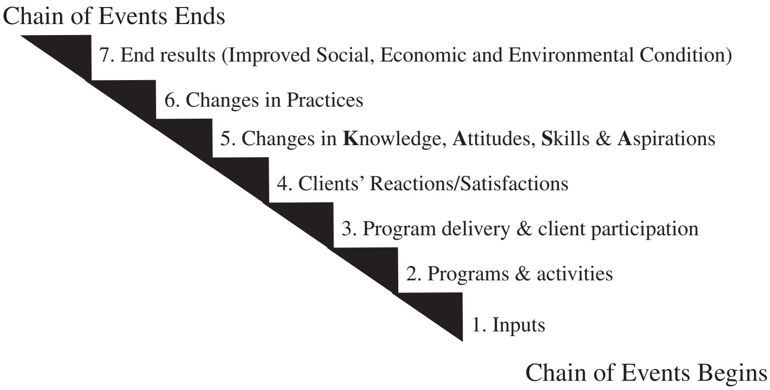


Fig. 2.2 Bennett's hierarchy – chain of events in extension programming

2.4 Current Situation of IPM Program Evaluation

Impact evaluation of developmental programs is expensive in terms of money and efforts. Perhaps because of this reason, evaluations are rarely conducted in professional manner in the developing countries. In the case of the green revolution technologies, viz. fertilizer use and pesticide use resulted in desired and undesired consequences going side by side but the studies measuring the undesired consequences received no attention especially in the developing countries. However, there have been studies to measure the undesirable consequences in the United Kingdom (Pretty et al., 2000) and the US (Pimentel, 2005, see Chapter 3 Vol. 1). IPM is the environmentally-favored plant protection strategy since the 1970s in both the developed and the developing world. The primary purpose of IPM programs is to adopt the different available pest management tactics namely cultural, physical, biological and chemical in a compatible manner to keep the pest population below those causing economic losses, there by reducing pesticide use. The evaluation of IPM programs has mainly focused on reduction of pesticide use, pesticide expenditure, increased yields and higher profits. IPM tries to achieve multiple goals, in that sense the impact of IPM programs cannot be measured only in terms of increase in income of the farmers or reduction in use of pesticides, but the impact of IPM is beyond that and perhaps more complex. There is no straightforward methodology to measure the impact of IPM programs. Research scientists support IPM and large numbers of organizations are funding IPM programs but evaluation of such programs is lacking. There is also little consensus on monitoring and assessment standards for its economic, social and environmental impacts, including the assessment of farmer IPM training. *Up to now, there are no agreed universal standards or indicators to quantify IPM impacts* (van den Berg, 2004; van den Berg and Jiggins, 2007). The indicators used in different studies for evaluating IPM programs are given in Table 2.1. Farmer field school (FFS) model of extension is widely used in developing countries for providing season long IPM training to farmers (For detailed discussion on FFS, see Chapters 6 to 10) The indicators used for evaluating IPM

Table 2.1 Evaluation indicators of IPM program

Country/Region	Design	Indicator(s)	Reference
India (Andhra Pradesh)	Before–after with control farmers and control villages	Change in agronomic practices, input use and farmer's attitude towards pest management, knowledge, decision making, labor use, reduction in use of pesticide.	Mancini et al. (2008)
Indonesia	Spatial econometric approach (Graduate, exposed and control farmers)	Increased yields, pesticide cost, performance of farmers	Yamazaki and Resosudarmo (2007)
India	With/Without	Natural capital, human capital, social capital, financial capital, physical capital	Mancini et al. (2006)
Asia	Before and after	Pesticide reduction, pesticide risk, predator pest ratio, species diversity	Echols and Soomro (2005)
Pakistan	Village case study	Poverty reduction	Khan and Ahmad (2005)
Pakistan	Single difference comparison (between trained and untrained) and difference in difference model (FFS farmers, exposed and unexposed farmers)	Decision making skills, field experiments, observed biodiversity, attitude, environment, social recognition, input use, field management, pesticide use in number and dose per season, cotton yields, revenue and gross margin.	Khan et al. (2005)
Asia	Cost benefit analysis	Enhanced farmer knowledge, skills and practices, increased farmer income, reduced use of pesticides, improved farmer health, enhanced agro-biodiversity, reduced rural poverty	Praneetvatakul et al. (2005)
India	Ex-post facto study, with/without	Knowledge about IPM, adoption of IPM practices, reduction in pesticide use and expenditure, higher yields	Peshin and Kalra (1998)

Table 2.1 (continued)

Country/Region	Design	Indicator(s)	Reference
India	Quasi-experimental; before/after, with/without	Knowledge gain and analytical skills, adoption, adoptability, reduction in pesticide use, pesticide expenditure and number of sprays, increase in output/input ratio	Peshin (2005)
India	Before and after, with and without double data design	Knowledge of cotton diseases, pests, natural enemies, ecosystem, pest management, other management practices and knowledge of other crops management practices, change in skill, confidence level in management of pest	Reddy and Suryamani (2005)
China	Econometric (Difference in difference model)	Yield, pesticide cost and gross margin	Wu et al. (2005)
Indonesia	Difference in difference model (two period data)	Yield and pesticide use, knowledge diffusion.	Feder et al. (2004)
Different countries viz: Indonesia, Bangladesh etc.	Case studies of 25 countries (Different designs)	Skill improvement, pesticide use (volume, spray frequency, chemical compounds), yield, input costs and profit, variation in yield or profit, quality of produce, marketability, ground water contamination, pesticide-related health symptoms, agricultural biodiversity, agricultural sustainability, policy change, gender roles, farmer-to-farmer diffusion, education and empowerment indicators	van den Berg (2004)
Indonesia	Sustainable livelihood analysis and participatory research process	Organizational indicators: participation, cohesiveness, common goal, time management, plan to follow, gender sensitive, leadership, technical knowledge, transparency, diversified activities, FFS funds, network, linkages	Jiggins (2002)
Asia	Cost benefit analysis at farm level and at program level	Farmers' awareness, knowledge, efficient farm input use, increase in yield, lower pesticide use and net profit of farmers	Feder and Quizon (1998)

Table 2.1 (continued)

Country/Region	Design	Indicator(s)	Reference
Indonesia	Case study, with/without and before/after	Reaction of FFS participants, knowledge gain, reduction in pesticide use, increased yield	van de Fliert (1993)
USA	Cost-benefit analysis with and without IPM splitting the field for treatment and control.	Reduced number of pesticide applications per growing season, value of pesticide cost savings per hectare, yield and quality of produce.	Sikora et al. (2001)
Peru	Case study, with/without	Enhanced farmer knowledge, adoption rate, information sources, perceived changes in pest damage, advantages and disadvantages of pest control practices.	Ortiz (1997)
Peru	Case study, with/without	Enhanced farmer knowledge, pest damage, yield, gross margin, internal rate of return, net present value	Ortiz et al. (1996)
Peru	Econometric, with/without	Enhanced farmer knowledge, productivity, input-output ratios	Godtland et al. 2004
Dominican Republic	Case study, with/without	Enhanced farmer knowledge, pest damage, yield, gross margin, internal rate of return, net present value	Alvarez et al. (1996)
Cuba	Case study, with/without	Enhanced farmer knowledge, pest damage, yield, gross margin, internal rate of return, net present value	Maza et al. (2000)
Peru	Participatory assessment, with/without	Perceived changes in knowledge, practices and organization	Buck (2002)
Peru	Case study, with/without, before/after	Enhanced farmer knowledge, strengthened organization, farmer perceptions, enhanced data about technology performance for researchers	Ortiz et al. (2004)

programs are mainly: reaction of farmer field school participants, knowledge gain, change in agronomic practices by adoption of IPM practices, reduction in pesticide use (volume, spray frequency, chemical compounds), increased yield, reduction in input use and variation in yield or profit. IPM program evaluation results based on scientific quasi-experimental designs, the most dominant evaluation strategy, can be used to improve the delivery of IPM programs. The informal evaluations being conducted by the stakeholders of IPM programs are unsystematic, the criteria and evidence used in making judgments are implicit. The trustworthiness – internal as well as external validity and reliability of results can therefore be biased. For example, the project reports of different IPM programs implanted in Indian Punjab reflected significant reduction of pesticide consumption, pesticide expenditure and increased yields in cotton crop, but the evaluative study based on evaluation methodology reflected many shortcomings of the informal evaluations conducted by stakeholders and variances of the results. The impact of IPM practices, like reduction in pesticide use and expenditure is a consequence of adoption of IPM practices, but seldom have these informal evaluations reflected the practices adopted by trained farmers as a result of IPM programs. At present evaluation of IPM programs having methodological foundations is generally missing and limited to isolated studies. The contribution of IPM programs in reducing the environmental pollution and health hazards needs to be studied and measured. The relative advantage of IPM in terms of net economic benefits- reduced pesticide expenditure, increased yields and increased output-input ratio may not be significant but the environmental impacts may be tangible. But these impacts cannot be measured in terms economic value due to methodological problems. Existing measures of economic evaluation of these impacts are not satisfactory (Waibel et al., 1998).

2.5 Practical Aspects of Evaluating IPM Programs

Before conducting IPM evaluation studies, it is important to review the practical considerations to ensure the quality and the usefulness of the study. These practical considerations include the following activities.

- Determining the appropriate evaluation approach for the study
- Planning and conducting the study
- Communication of evaluation results
- Utilization of evaluation results

When these key aspects of evaluation study are formulated, it is important to consider the social, economic and environmental context of the farming community for achieving the practicality and the usefulness of the evaluation study.

2.5.1 Determining the Evaluation Approach for the Study

The evaluation approach refers to the philosophical framework of conducting an evaluation study. There are different approaches to evaluation. Some of these evaluation approaches are expert oriented while other approaches are heavily participant oriented. The empowerment evaluation and participatory evaluation are examples for participant oriented evaluation approaches. The nature of IPM programs dictates the types of desirable approaches for their evaluations.

IPM is a multi faceted holistic approach to pest management. The success of IPM training programs primarily depends on the ability of training programs to empower farmers in making informed decisions to apply IPM practices. Empowerment of farmers will be achieved through educational programs. The extent to which farmers are empowered to make informed decisions in pest management contributes to sustain the IPM. Therefore, it is important to help farmers understand the outcomes and value of IPM programs. This implies the need for conducting the evaluation with farmers enabling them to understand the evaluation process and the results of the IPM program. This can be achieved only if farmers are given an opportunity to actively engage in the program evaluation process. If the IPM participants engage in program evaluation, they will be able to understand the evaluation process and the value of IPM. Farmers' understanding of the value of IPM is an important prerequisite for achieving the sustainability of IPM programs. The review of this information indicates that the participant centered evaluation approaches such as empowerment evaluation and participatory evaluation are suitable approaches for IPM program evaluation.

2.5.1.1 Empowerment Evaluation Approach

As the name indicates, an empowerment evaluation approach is based on empowering the target beneficiaries of the program to actively engage in program evaluation. Fetterman (2001, p. 3) described empowerment evaluation as an evaluation approach to foster "improvement" and "self-determination" of the target audience. The purpose of empowerment evaluation is to help the program beneficiaries evaluate their programs through "self-evaluation" and "reflection." An empowerment evaluation approach expects the evaluator to actively engage with the target audience to build their confidence and ability in planning, conducting and utilizing evaluation. The empowerment evaluation approach is compatible with the philosophy of IPM programming. Both IPM program and empowerment evaluation rely heavily on building the confidence and ability of the target audience to actively engage in the program. The evaluator's role in empowerment evaluation is more of a capacity builder. The external evaluator will act as a coach and a facilitator to build participants' confidence and capacity to actively engage in the evaluation process. This way the program recipients will become owners of the program and partners of the evaluation. As a result of this, planning, conducting, and utilizing evaluation will become a part of their responsibility. This way IPM program evaluation will become a joint responsibility of the evaluator and the farmers. Therefore, the empowerment evaluation approach is more practical than the expert oriented approach in conducting IPM evaluations. The main disadvantage of empowerment evaluation is that it takes time to build the confidence and competence of the target audience.

2.5.1.2 Participatory Evaluation Approach

A participatory evaluation approach is somewhat similar to the empowerment evaluation approach. However, a participatory evaluation approach does not focus heavily on building participants' confidence and ability to take part in evaluation process. Instead, the participatory evaluation approach considers the program participants as partners in the program evaluation process and works with them. This way, the evaluation process will become a collaboration between the evaluator and the IPM participants. The evaluator will act as a member of the IPM farmers and work with them in planning, conducting and utilizing evaluation. The evaluator's role in participatory evaluation is more of a collaborator than of a capacity builder. To the extent the evaluator is able to collaborate with the IPM farmers, their active participation in the evaluation process will be assured. International development aid groups extensively use this evaluation approach to evaluate their projects. Since the evaluator is not focusing on building confidence and capacity, the participatory evaluation approach is relatively less time consuming. It is also effective in building community linkages and trust in collecting data. Therefore, the participatory evaluation approach is appropriate for IPM program evaluation.

2.5.1.3 Guidelines to Determine Evaluation Approach

If the evaluator has adequate time and resources, it is appropriate to use the empowerment approach to IPM evaluation because that will lead to sustain the evaluation practice within the community. If the farming community is empowered to conduct their IPM program evaluation, they will be able to continuously evaluate their programs and make needed changes even after completing the IPM training. If the time and resources are limiting, participatory approach is the best option to IPM evaluation because it does not demand much time and resources.

2.5.2 Planning and Conducting the Study

The quality of an IPM evaluation study depends on proper planning and implementation of the study. Planning is helpful for achieving evaluation objectives cost effectively. Planning evaluation can be described as the organizing steps to systematically answer the following questions.

- Who wants to evaluate the IPM program?
- What are their information needs?
- How much resources are available for conducting the evaluation?
- What is the best design for collecting and processing this information within the limits of available resources?

The following steps can be used to find answers to above questions and plan to conduct the evaluation study.

1. Identification of key stakeholders and their information needs
2. Conducting an evaluability assessment
3. Setting evaluation objectives
4. Defining evaluation indicators
5. Selecting appropriate design for the study
6. Development of necessary tools for collecting data
7. Collecting data
8. Analyzing and preparing reports
9. Communication of results

2.5.2.1 Identification of Key Stakeholders and Their Information Needs

Identification of stakeholders of the IPM program is the first step of planning an evaluation study. The most common stakeholders of an IPM evaluation are policy makers, extension administrators, agricultural researchers, extension personnel, community leaders and farmers. Information needs of each of these stakeholders depend on the social, economic, and environmental situation of the program location. For example, farmers may want to know whether the IPM program is economically beneficial. Agricultural researchers may want to know whether the IPM program is economically and environmentally sound. Extension personnel may want to know how to improve the program. The review of these information needs of key stakeholders can be categorized into the following two major groups:

- Evaluation of program outcomes to determine the economic, social, and environmental benefits of the IPM program.
- Evaluation of the IPM programming process to improve the cost effectiveness of IPM programs.

The evaluation of program outcomes is called outcome or impact evaluation. The main purpose of this evaluation is to document the program results for accountability of the programming. The impact evaluation helps the extension staff to determine whether the program results justify the resources spent in the program. This information is essential in communicating the value of IPM programs to program managers and funding agencies. The outcome evaluation is called summative evaluation.

The program process evaluation is important for extension staff and program managers to identify strengths, weaknesses and alternatives in implementing IPM programs in a given social and environmental condition. In addition, process evaluation is helpful for monitoring IPM extension programs in the field. For example, by assessing the process against the set implementation targets extension can monitor the progress of IPM programs. The program process evaluation is called formative evaluation.

The planning and conducting of an IPM program evaluation should focus on summative as well as formative parts.

2.5.2.2 Conducting an Evaluability Assessment

Before conducting the full-scale evaluation, it is a good idea to conduct a preliminary assessment to determine whether the program situation warrants a meaningful evaluation. This type of preliminary assessment is called an evaluability assessment and it critically analyzes the following aspects of the program:

- Is IPM program well planned, meaningful and realistic in terms of the adoptability within the farming system? Is the IPM program adoptable to fit a particular farming system?
- Do the key stakeholders agree to provide the necessary support for the IPM program evaluation?
- Do key stakeholders agree to make programmatic changes based on the evaluation findings?
- Is the program evaluation feasible within the given social, economic, and environmental situation of the location?
- Can the IPM program evaluation data be collected within the allocated limits of available resources and time?

The first step of this preliminary evaluation is reviewing the IPM program for its quality and practicality within the context of social, economic, and environmental conditions of the geographic location where it is being implemented. It is a prerequisite that the IPM program should be well designed to meet the needs of the local farmers. That means the IPM practices should fit with the farming system of the geographic location. It should be practical in terms of delivering within the capacity of extension service. If these conditions are not being met, then it is necessary to revise the program to meet this condition for achieving desired results and conducting a meaningful program evaluation.

Verification of the stakeholder support for program evaluation is the second step of evaluability assessment. This step is important to determine whether the stakeholders agree to provide the necessary support and resources to conduct the evaluation. The support from extension administration, field staff, and farmers is essential to evaluate IPM programs. If this precondition is not met, it will be impossible to conduct an evaluation.

The IPM evaluation is meaningful only if the stakeholders agree to use the evaluation information for making necessary changes to improve their programs. At this step of the evaluability assessment, the evaluator should analyze the field information to assess whether the stakeholders are willing to make any programmatic changes based on evaluation results. If not, it is important to convince stakeholders to utilize evaluation results for program improvement before resuming the full-scale evaluation.

If the necessary data cannot be obtained from the participants, it will be very difficult to conduct any evaluation. Therefore, at the beginning it is very important to critically analyze whether the field situation of the targeted location is favorable for collecting evaluation data. For example, sometimes, it may not be possible to collect data due to some social issues such as miss trust between farmers and government agencies. If there is such an issue, it is important to address it before implementing the full-scale evaluation.

The available resources should be assessed to determine the feasibility of the evaluation study. If the resources are inadequate, then it is necessary to ask for additional resources or modify the design to match the available resources before beginning the full-scale evaluation study.

2.5.2.3 Setting Evaluation Objectives

Evaluation objectives specify the information needs of stakeholders and guide the rest of the evaluation process. Evaluation objectives are clear statements about the type of information planned to collect for meeting the information needs of stakeholders. IPM program evaluation can be conducted in different levels depending on the availability of resources. For example, if the available resources are not adequate for conducting a long-term impact evaluation of IPM programs, evaluation of immediate learning outcomes such as participants' changes in knowledge (cognition), attitudes, skills, and aspirations may be the best practical option. Depending on the availability of resources and stakeholder needs, it is important to focus on the levels of outcome evaluation and set evaluation objectives.

Examples for evaluation objectives:

- To document the short-term and intermediate outcomes of IPM programs
- To document the impacts of IPM programs
- To identify the factors needed to improve the IPM program
- To collect the information needed to monitor the progress of IPM programming.
- To conduct cost-benefit analysis of IPM programs for policy decisions.

2.5.2.4 Defining Evaluation Indicators

An indicator can be defined as a variable (Indicators for the Evaluation of the EU's Rural Development Programs, 2005). The process of defining what constitutes success for a project/program is an important step in developing evaluations. Defining the success indicators for IPM program is necessary to conduct evaluations. The success indicators allow project or program sponsors to evaluate whether they accomplished what they set out to do and what the direct or indirect impact of their project has been. According to Powell et al. (1996), "Indicators are observable evidence of accomplishments, changes made or progress achieved." These indicators are measured to quantify the changes made, inputs utilized or outcomes achieved.

Measurement of indicators helps in knowing changes brought by the program/ project.

Evaluation indicators can be considered as the reasonable and meaningful measures of the assessing step of the IPM program. Evaluation indicators can be categorized into the following four groups:

a) Indicators for measuring program inputs
b) Indicators for measuring program outputs

c) Indicators for measuring farmer participation
d) Impact indicators for measuring the program outcomes and impacts

Indicators for measuring program inputs. Program input means the resources utilized to develop and implement the IPM program. This includes money, personnel, and time. Input indicators are used to measure how much resources are utilized for the program, for example, the amount of money spent for the program. The input level indicators are used to determine whether the planned resources are mobilized into the program. If there is a budget shortfall at the beginning of the program, it is reasonable to expect that there will be some limitations to achieving the planned outcomes.

Indicators for measuring program outputs. Program output includes the educational materials, workshops and curricula developed and training programs, and educational activities delivered. Output indicators are used to assess whether the IPM program implementation is progressing as planned in developing and delivering targeted outputs.

Indicators for measuring farmer participation and their reactions. Farmers are the target audience of IPM programs. Their participation in the program is used as an indicator to assess whether the program is reaching the targeted number of farmers. The number of farmers reached and their levels of satisfaction with the IPM program are used as indicators for measuring the target audience's participation and reactions.

Indicators for measuring program outcomes and impacts. Outcome is described as the extent to which farmers changed or benefited as a result of their participation in the IPM program. The outcomes of IPM programs can be categorized into immediate outcomes, intermediate outcomes, and end results or impacts.

Immediate outcomes are the changes in participants' knowledge, attitudes, skills and aspirations. These changes take place during the training programs and can be recorded at the end of the training session. Intermediate outcomes are adoption of IPM practices and these changes take place sometime after the training. The end results of IPM programs are social, economic, and environmental improvements due to the adoption of IPM practices by farmers. These end results include money saved on pest control, reduced amount of chemical applications, water quality improvements, ecosystem improvements, reduced incidence of hazardous chemical exposures, etc.

The indicators used to evaluate outcomes are referred to as impact indicators. An impact indicator can be described as a reasonable and meaningful measure of intended client outcomes. For example, percentage of the participants who gained IPM knowledge is an impact indicator for measuring immediate training outcomes. Depending on the level of outcome evaluation, it is necessary to define impact indicators. The summary of possible evaluation indicators for an IPM program is displayed in Table 2.2.

Table 2.2 Evaluation indicators for IPM program evaluation

Type of evaluation indicator	Focus	Examples for impact indicators
Input	Input evaluation	• Amount of money spent • Number of staff assigned • Time spent for the program.
Output	Output evaluation	• Number of IPM educational materials developed • Number of IPM training sessions delivered
Farmers' Participation and Reactions	Farmers' participation evaluation	• Number of farmers trained.
	Farmers' levels of satisfaction with the program	• Number of farmers who said the program is useful.
Outcome	Immediate Outcome Evaluation	• Number of participants who improved their IPM knowledge. • Number of participants who developed positive attitudes toward IPM. • Number of participants who developed IPM skills. • Number of participants aspiring to practice IPM knowledge.
	Intermediate Outcome Evaluation	• Number of participants practicing IPM.
	End Result (Impact) Evaluation	• Reduced amount of pesticide usage. • Money saved on pesticide reduction. • Number of beneficial insects recorded in the field. • Reduced levels of pesticide residues in water-ways. • Reduced number of hazardous incidences of pesticide misuse.

2.5.2.5 Selecting an Appropriate Design for the Evaluation Study

Understanding the progression of the impacts of IPM program is helpful for selecting an appropriate design for the study. Figure 2.3 illustrates the possible progression of the outcomes of an IPM program.

The possible outcomes of an IPM program begin to unfold with the farmers' participation in training programs. If the training program is effective, participants will gain new knowledge about IPM and develop positive attitudes toward IPM. They also develop new skills such as identification of beneficial insects and application of alternative pest control methods like sampling for economic threshold level. If the farmers are convinced about the usefulness of the IPM program, they will aspire to practice IPM. These are the immediate learning outcomes of a successful IPM training program. If the participants left the training with an intention to practice IPM, then it is reasonable to expect they will adopt IPM practices for pest control

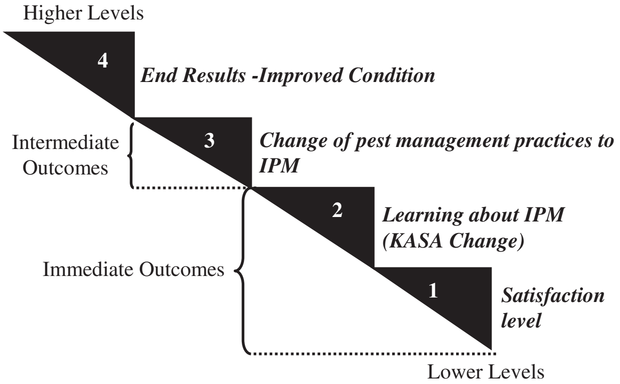


Fig. 2.3 Impact hierarchy of IPM programs
Source: Jayaratne (2007a).

on their farms. This practice change can be observed at some point after the training. Various social, economical, technological and environmental factors can contribute to farmers' decision to adopt IPM practices.

Practicing IPM on their farms is the intermediate outcome of the IPM program. This includes the use of biological, mechanical and chemical methods to control pests. Chemical methods will be used as the last option to control pests.

If farmers adopted the IPM practices, they will then be able to reap the long-term benefits individually and collectively. As individuals, farmers will experience reduced cost of production by the reduced application of pesticides. Collectively, farmers will be able to live in a cleaner and healthier environment. Water quality will likely to be improved. The ecosystem will be more balanced between harmful and beneficial insects. Fewer pest outbreaks can be the long-term results of IPM programs. The evaluation study should be designed to document these program outcomes. The evaluation of long-term outcomes of IPM programs takes more time and resources than the evaluation of immediate and intermediate outcomes.

There are two factors to consider when selecting an appropriate design for the evaluation study. First, the design should be practical within the limits of budgetary provisions and other resources. Second, the design should be adequately accurate to rely on evaluation results. Randomized experimental designs are more accurate than quasi-experimental designs. However, randomized experimental designs are not practical in many extension settings due to various factors such as randomization difficulties, ethical issues and budget limitations. Campbell and Stanley (1963) called the experimental studies that are not randomized, quasi-experimental studies. When accuracy and practicality are considered, quasi-experimental design is the most appropriate design for conducting IPM evaluation studies.

Quasi-Experimental Designs

Quasi-experimental designs use existing conditions for studying the treatment effect (Impacts of IPM program) instead of randomly assigning treatments (IPM programs). There are different quasi-experimental designs. The following quasi-experimental designs can be considered as the most practical designs for conducting an IPM evaluation study.

- Ex post facto design
- One-group before and after comparison design
- One-group time-series design
- Nonequivalent control-group design

(*a*) *Ex post Facto Design*: Instead of actual manipulation of the treatment, ex post facto experimental design uses a pre-existing condition as the treatment. Therefore, this design is appropriate for studying the impacts of an already conducted IPM program. The pre-existing condition is the implemented IPM program. Observations for studying variables will be made from the IPM implemented site. These observations should be compared with the similar observations made from a comparable site where there was not any IPM programming. An ex post facto study uses a comparable site as the control to find the program effects. The main criticism of this design is that there are potential sources of biases due to situational variations of two sites other than just the IPM program.

The following designs are appropriate if the evaluation study is planning with the IPM program implementation stage.

(*b*) *One-group before and after comparison design*: As the name indicates, this evaluation is conducted with one group. The data related to IPM impact indicators will be collected before conducting the program (pre-test) with the selected group. This includes collecting data related to farmers' knowledge about pest control, current pest control practices, their attitudes toward pests and chemical control, current cost of production, pesticide related environmental problems, and reported incidences of pesticide hazards. Then the IPM program will be conducted with the selected farmer group. Conducting the IPM program is considered as the "treatment" of this experiment. After conducting the IPM program, the data related to impact indicators will be collected (post-test).

Pre- and post-test data will be analyzed and compared to assess the impact of the program. The changes in farmers' knowledge, attitudes, skills, aspirations, and practices and social, economic and environmental improvements are considered as the impacts of the program. One-group before and after comparison design is widely used in extension program evaluation due to its simplicity and practicality. The main criticism of this design is that there are potential sources of bias to the results. Campbell and Stanley (1963) termed these potential sources of bias as threats to the internal validity of results and described eight different sources of threats to the internal validity. The most significant sources of threats affecting the validity of one-group before and after comparison design of IPM evaluation studies are history, seasonality, attrition and testing.

History. When any other event than the IPM program is taking place between the pre- and post-tests and contributes to the results of the study, then it will be considered as an internal threat to the validity due to history. For example, if some farmers in the IPM program have watched a documentary movie in a television program, and learned about possible harmful effects of pesticides and decided to reduce the application of pesticides, then reduced levels of pesticides may not be solely due to the IPM program.

Seasonality. In farming, seasonality is a very important variable. If the difference between pre-and post-tests are due to some of the seasonal variations, then it will be considered as an internal threat to the validity of the results. For example, if the pre-test data were collected after a favorable season for pests and post-test data were collected after an unfavorable season for pests, then the reduced levels of pesticide applications may be due to seasonal variability as well.

Attrition. Attrition means IPM participants leaving the study before it is completed. If some of the program participants drop out from the IPM evaluation study during the pre- and post-tests systematically, then attrition error can take place. For example, if the backward farmers dropped out from the IPM program, then post-test results might be artificially elevated toward high impacts because of the concentration of innovative farmers. The error due to attrition can affect the validity of the results of the evaluation studies.

Testing. Some farmers are smart to learn from the pre-test and may correctly answer at the post-test mainly due to what they learned from the pre-test. If this happened, then the results are not only due to the IPM program but also due to the pre-test. When this type of situation happens it is called an internal threat to the validity.

It is important to use an evaluation design that prevents these threats to the internal validity of results.

(*c*) *One-group time-series design*: In this design, the evaluator records observations for a few seasons before and after implementing the IPM program. That means 2–3 pre-tests and post-tests will be conducted during the study. Conducting multiple tests before and after the program will be helpful to partial out the seasonal effects on the results of the IPM program. For example, data from multiple testing points can be analyzed to see whether there is any change in the pattern of pesticides used by the participants due to seasonal changes other than the IPM program. However, testing, attrition and history will remain as threats to the internal validity of this design. This method is time consuming and will be difficult to implement due to multiple data collection points.

(*d*) *Nonequivalent control-group design*: In this design, two comparable sites will be selected for the evaluation study. One site will be used as the IPM programming (treatment) site. The other site will be used as the control site for comparison. To the extent these two sites are comparable, above described threats to the internal validity can be controlled. These two sites should be similar in terms of farming, agro-ecology, and socio-economic background of the farmers. However, two sites should be adequately distant from each other to prevent any cross contamination of information from the IPM (treatment) site to the control site.

After selecting the two comparable sites, a pre-test will be conducted separately in both locations at the same time to establish the bench mark of the field situations with regard to the measuring of impact indicators. Then, the IPM program will be conducted at the "treatment" site. The farmers at the control site will follow their regular farming practices without any IPM program. Then the post-test will be conducted at the same time at both sites to collect data related to the IPM impact indicators.

By comparing the pre and post-test differences between two sites, impacts of the IPM program can be evaluated. The control site will be helpful for neutralizing internal threats from history, seasonality, and the test effects as long as the sites are relatively similar. The advantage of nonequivalent control-group design is that it provides more reliable results than the one-group pre and post design does. This is the most practically feasible accurate design for IPM program evaluation. The main criticism of this method is the comparability of the two sites.

2.5.2.6 Collecting Data

After designing the evaluation study the next important step of planning an IPM evaluation study is the selection of an appropriate data collection method. The data collection methods are categorized into two major groups, namely qualitative methods and quantitative methods. As the name indicates quantitative methods collect numerical data and qualitative methods collect descriptive data or information. Quantitative data are considered as strong evidences of impacts and used for accountability of IPM programming. However, quantitative methods are lacking in exploring ability. For example, if the IPM program is not showing promising results in one location, then quantitative methods will be unable to track the reasons for that situation. In contrast, qualitative methods have the capacity to explore the situation and find reasons.

Quantitative Methods

As the name indicates, quantitative methods collect-numerical data. Numerical data are appropriate for documenting program impacts and accountability purposes. Therefore, quantitative methods are widely used in summative evaluation. However, quantitative methods are not appropriate for explaining reasons for certain situations. A survey is the most appropriate quantitative data collection method for IPM program evaluation studies. Surveys are conducted using questionnaires. There are three different approaches to conduct surveys.

a) *Personal interviews*: In this method, surveys are conducted face-to-face with the respondents using a questionnaire for collecting evaluation data. Since low literacy audiences cannot respond to a written survey, this approach is appropriate for collecting data from them. The main disadvantage of this approach is that it is labor intensive and demands more time and money than other methods. The field assistants who are employed to collect data should be trained to establish the uniformity of conducting interviews. It is important to select field assistants who are familiar with the linguistic, social and cultural environment of the farmers to prevent communication gaps and to facilitate the data collection process.

b) *Mail surveys*: This approach uses the mail service to collect data from the study sample. The survey questionnaire will be printed and mailed with a cover letter to the target audience for collecting data. It is important to explain the purpose of the survey in the cover letter and include a return address written envelope with a stamp to maximize the response rate. Normally, two to three weeks will be given for farmers to respond to the survey. Then, a reminder letter will be mailed to non-respondents. If there is not an adequate response rate, it is a good idea to send a second reminder letter to non-respondents. The main advantage of mail surveys is they are less expensive and efficient than face-to-face interviews. However, receiving a satisfactory response rate for a mail survey with farmers is a challenge. Use of an incentive such as a prize drawing for respondents may be a strategy for achieving a high response rate.

c) *Online surveys*: Data collection can be achieved by using on-line surveys. This approach is practical only if the target audience has access to the Internet and has the ability to use the web. This method is not practical in most of the developing countries. However, this may be an option for collecting data in developed countries. The survey will be developed as an online questionnaire and the web link will be e-mailed to the target audience. Like mail surveys, respondents will be given about two weeks to respond to the survey. A reminding e-mail will be sent to the non-respondents after two weeks. If the response rate is not adequate, then a second reminder will be e-mailed to non-respondents. The main advantage of an online survey is that it is easy to conduct. This approach of data collection saves time and money. The major limitation is that an online survey is not feasible in some rural parts of developed countries due to lack of Internet service.

Qualitative Methods

Qualitative methods collect descriptive information. These methods are important to identify reasons for certain conditions. Therefore, qualitative methods are very useful in formative evaluation. The main purpose of formative evaluation is to identify necessary information for the IPM program's improvement. Qualitative methods explore the situation to find answers for questions such as why certain conditions exist; how to improve the program; and what are the problems and alternatives. The most practical qualitative methods that can be used for IPM program evaluation are focus group interviews, observations, and case studies.

(*a*) *Focus group interviews*: A focus group interview is a guided discussion with about 8–10 farmers to gather necessary data and information about the studying situation. A facilitator using a preplanned questionnaire conducts the focus group interview and the discussion will be recorded. During the focus group, the moderator/facilitator asks open-ended questions related to the information needed and the group will be facilitated to express their views and answers to the question. The facilitator should encourage everyone to provide inputs and control the discussion without letting a few to dominate. It is important to use exploratory type questions and avoid "yes" and "no" answers type questions. After the interview, recorded information will be transcribed and analyzed to identify major points. Normally, it is important to conduct at least 2–3 focus group interviews with different farmers in the area to identify the general situation of pest management.

Focus group interviews can be conducted before, during and after implementing the IPM program to collect necessary information. Interviews before and after implementing the IPM program are helpful to understand the field situation with regard to the pest management practices of farmers and related social, economic and environmental conditions. The interview before the IPM program can be used to set the bench marks of the field situation. For example, if you identify that most farmers heavily rely on chemicals for pest control it will be a strong evidence for the need of IPM program. This information can be compared with the information gathered from the interview after implementing the IPM program to assess the changes in pest control approaches and improved social, economic and environmental conditions. Focus group interviews conducted during the IPM program implementation will be useful in identifying problems, issues, challenges and alternatives. The major advantage of focus group interview is that it is easy and quick.

(*b*) *Observations*: Observation is a practical method of collecting qualitative data. Observation can be used for collecting data when the phenomena being studied are observable through human sensors. This includes changes that one can see, hear, smell or feel. For example, if the IPM program is effective in reducing the use of pesticides, then the observer should be able to see an increased number of beneficial insects in IPM fields compared to the situation prior to the IPM program implementation. When observation is used as a method of collecting data, it should be organized systematically. The following steps are helpful in conducting systematic observations.

- Determine the observable indicators for the evaluating phenomena.
- Develop a rating scale for recording the observing indicators
- Train the observers to make systematic observations
- Collect data.

Determine the observable indicators for the evaluating phenomena. In IPM program evaluation, it is important to identify the possible changes that one can easily observe if the program is effective. Some of the possible indicators that one can observe are the number of farmers spraying pesticides in the field, levels of agrochemical smell in the field, number of beneficial insects observed in a specific area of the field, number of farmers using insect pest and disease resistant crop varieties, number of farmers using other pest control methods such as traps and mechanical methods.

Develop a rating scale for recording the observable indicators. After determining the observable indicators for the IPM program, it is necessary to develop a rating scale for recording the prevalence level of the indicators. The observer rating scales can be developed as ordinal scales for IPM program evaluation. This scale is helpful for transforming observations into quantifiable data. An ordinal scale is helpful in comparing situations before and after implementing the IPM program. For example, if the recording indicator is number of beneficial insects observed in a specific area of the field, then that information can be recorded as an ordinal scale. In an ordinal scale, the recording data are categorized into a few layers of hierarchical order. For example, level 1 = no beneficial insects in the area, level 2 = 1–3 beneficial insects in the area, 3 = 4–6 beneficial insects in the area, 4 = more than 6 beneficial insects in the area. Other observing indicators such as the level of chemical smell in the area also can be recorded in an ordinal scale. For example, 1 = pesticide smell is heavy in the field, 2 = pesticide smell is mild in the field, and 3 = there is no pesticide smell in the field. This will enhance the evaluation study's reliability.

Train the observers to make systematic observations. The observers used for collecting field data should be trained to streamline the data collection process and minimize the variability between the observers. All observing team members should understand the rating scales and practiced before gathering actual data. It is important to use the same observers before and after the IPM program for minimizing observer variability.

Collect data. Observations will be conducted before implementing the program in a specific time of the cropping season. The field observations will be recorded on the scales. The same observers and same time period of the cropping season will be used to record the field situation after implementing the program. The comparison of these two data sets can be used to identify program impacts.

(*c*) *Case Studies*: Case study is a qualitative method useful in investigating a situation thoroughly. In a case study, the investigator uses all sources of information available in the field to understand the situation. These sources of information include farmers, traders, community leaders, government agencies and observations. During the case study, the investigator should be able to immerse himself/herself as a member into the IPM farming community and study their ways of controlling pests. The success of a case study depends on the investigator's ability to understand the language and culture of the people in the area. The investigator has to spend an adequate amount of time studying in the field and meeting farmers to collect necessary data and information. Case studies are time consuming. However, they are helpful in understanding the field situation realistically and explore reasons for certain field situations.

2.5.2.7 Development of Necessary Tools for Collecting Data

An evaluation tool is a survey questionnaire designed to collect necessary data for process and results evaluation of IPM programs. Development of necessary survey tools for data collection is a challenging task for those who do not have necessary knowledge and experience in survey research. It is important to understand the nature of IPM programming in order to design appropriate data collecting tools. The IPM programming involves multi-session educational programs targeting to change farmers' pest control practices. These multi-session educational programs are focusing on changing the target farmers' knowledge and attitude and building their skills to apply IPM. Therefore, two sets of data collection tools can be developed to get necessary data. One set is for the assessment of the outcomes of individual training sessions. The other set is for the assessment of the overall program impact. The following two sets of tool templates can be used to collect necessary data. These tool templates can be modified for needed local situations.

Tool Template for Training Session Evaluation (Jayaratne, 2007a)

The main purpose of the training session evaluation tool is to collect data related to participants' knowledge, attitudes, skills and aspirations. These data can be recorded before and after the training session. The same scales will be used for pre and post-tests. On the post-test, participants' readiness to apply learned practices will be recorded as their levels of aspirations. Aspiration is a good indicator to evaluate the participants' potential practice changes. Levels of aspirations will not necessarily turn into practices after training. There are many other variables associated with the actual adoption of learned IPM practices in the field.

a) *Testing Knowledge*: Participants' knowledge about IPM can be tested using "true" and "false" type questions as organized in Table 2.3. The true or false questions should be developed from the subject content of the training session. The answer choice "don't know" is used to minimize the guessing error of the participants. The same questions will be asked before and after the training session. Pre- and post-test results for each participant will be compared to assess the change of participants' knowledge. The advantage of this format is it is easy to comprehend and respond. Multiple choice questions and open-ended questions also can be used to test participants' knowledge. Compared to true and false format these two methods demand more time for response as well as grading and analysis. This is the main disadvantage of these two methods.
b) *Testing Attitudes*: Attitude can play an important role in changing someone's behavior. However, changing and measuring attitudes are challenging tasks. The scale template in Table 2.4 can be used to record participants' attitudes toward IPM. It is important to include positive and negative statements in an attitudinal scale to maintain the neutrality of the scale. In the sample scale, there are positive and negative statements related to IPM and a 5-point Likert type scale. This

Table 2.3 Testing participants' IPM knowledge

Please circle your answer to each of the following statements	True	False	Don't Know
1. Use of other insects to control pests is a biological pest control method.	True	False	Don't Know
2. Integrated pest control method uses multi methods to control pests.	True	False	Don't Know
3. Use of resistant varieties are helpful to reduce the cost of pest control	True	False	Don't Know
4. Traps are mechanical methods of pest control.	True	False	Don't Know
5. There are some insects harmful to pests.	True	False	Don't Know
6. Pesticides are selective in killing insects.	True	False	Don't Know
7. There are unintended impacts of pesticide application.	True	False	Don't Know
8. Crop rotation is helpful in controlling some pests.	True	False	Don't Know
9. Timely cultivation is helpful to minimize pest problems.	True	False	Don't Know
10. Pesticide application decision should be made after assessing the economic threshold levels of pests in the field.	True	False	Don't Know

Table 2.4 Testing participants' attitudes

Please circle the number that best describes your *level of agreement* with the following statements:	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
1. Use of pesticides is the only method to control pests.	1	2	3	4	5
2. All the insects in fields are damaging to crops.	1	2	3	4	5
3. There are different methods to control pests.	1	2	3	4	5
4. Cultivation of resistant varieties is one of the best methods of controlling pests.	1	2	3	4	5
5. IPM helps you save you money.	1	2	3	4	5
6. IPM is not practical.	1	2	3	4	5

tool can be used to record participants' attitudes before and after the training. Recorded responses will be aggregated to get the overall value for the attitude. Before aggregating, response data for the negatively stated items should be reversed to get the overall value for the attitude on this scale. Pre and post-test results of each participant will be compared for assessing the change of attitudes.

c) *Recording Skill Changes*: Building participants' pest management skills is needed in practicing IPM. For example, participants should be able to scout their fields for pests and make management decisions. This can be done only if they learn how to assess pest damages and compare with economic threshold levels. Building participants' skills can be assessed by using the sample tool template in Table 2.5. In this template, participants' skills will be assessed indirectly by recording their confidence to apply learned IPM practices. By comparing pre- and post-test data one can compare the change in participants' skills related to IPM.

d) *Recording Potential Practice Changes (Aspirations)*: Participants' readiness to apply what they learned during the IPM training is a good indicator to assess the immediate training outcome. This intended practice change can be assessed by using the sample tool in Table 2.6. It is important to list the major practices

Table 2.5 Recording participants' skills

How confident are you in your ability to:	Not confident	A little confident	Somewhat confident	Confident	Very confident
1. Identify beneficial insects?	1	2	3	4	5
2. Identify insect pests?	1	2	3	4	5
3. Estimate pest damages?	1	2	3	4	5
4. Select pest resistant varieties?	1	2	3	4	5
5. Use mechanical pest control methods?	1	2	3	4	5
6. Estimate the threshold level of insect pests?	1	2	3	4	5

Table 2.6 Recording participants' aspirations

As a result of this program, do you intend to:	No	Maybe	Yes	Already doing this
1. Cultivate resistant varieties.	1	2	3	4
2. Use traps to control pests.	1	2	3	4
3. Use economic threshold levels for making decisions to apply pesticides	1	2	3	4
4. Scout fields regularly to monitor pests populations.	1	2	3	4
5. Use pesticides as the last option to control pests.	1	2	3	4

introduced by the training session. This scale can be included in the post-test survey instrument.

e) *Collecting Necessary Data for Training Improvement*: It is important to collect the process evaluation data useful for the trainer to improve the training session. These questions can be included in the post-test survey for collecting training session improvement data.

Sample questions for collecting training improvement data:

- Would you recommend this training workshop to other farmers?

  1. Yes
  2. No

- If not, why:____
- What did you like the most about this training workshop?
- What did you like the least about this training workshop?
- How could this training be further improved?

Tool Template for Overall Program Evaluation

The overall impact of the IPM program can be evaluated by conducting two comprehensive surveys before and after one year of the IPM program. It is important to conduct a bench mark survey before implementing the IPM program in the selected area to identify the existing field situation. This survey should collect the necessary data from the farmers in the selected evaluation sites to evaluate the overall impact of the program. These data include:

a. Current agronomic practices

  - Types and varieties of crops grown
  - Type of land preparation
  - Time of planting
  - Methods of weed control

b. Major pests

  - Insect pests
  - Diseases
  - Weeds

c. Current pest control methods

- Chemical
- Biological
- Mechanical
- Agronomical

d. Amount of agrochemical usage

- Herbicides
- Insecticides
- Fungicides

e. Farmers' attitudes and values toward

- Pest control
- Alternative pest control methods
- Agro-chemicals
- Environment
- Water quality

f. Farm Production

- Crop yields/hectare

g. Cost of production

- Cost of pest control
- Cost of production
- Profit

h. Community information

- Reported pesticide hazardous incidences in the community
- Pesticide related environmental issues reported

By collecting these data, one can evaluate the overall impact of the IPM program. For example, if the IPM program is successful, then by comparing the amount of pesticides used before and after the IPM program one can evaluate the levels of reduced pesticide usage. Collecting yield data is important to convince farmers that IPM is helpful to maintain crop yields even with reduced levels of pesticide applications. Costs of production and reduced levels of pesticide application data are essential to estimate the economic impact of the IPM program.

2.5.2.8 Analyzing Data

Descriptive and correlation statistics are appropriate for analyzing IPM program evaluation data. By comparing pre- and post- training workshop evaluations, one can document the following outcomes:

i. Participants' changes in knowledge, attitudes and skills
ii. Participants' potential practice changes (Aspirations)
iii. Ways to improve the training

By comparing the bench mark survey data and the follow-up survey, one can document the impacts of the IPM program. This includes practice changes and social, economic and environmental impacts of the IPM program.

2.5.3 Communication of Evaluation Results

The IPM program evaluation is meaningful only if the results are communicated with the key stakeholders to achieve evaluation objectives. There are different methods to communicate the evaluation results with key stakeholders.

i. Evaluation reports
j. Presentations
k. Newsletters
l. Newspapers
m. Radio programs
n. TV programs

The communication method should be selected based on the type of stakeholders. For example, an evaluation report can be considered as the best method to communicate evaluation results with funding agencies and administrators. Evaluation reports should be written in lay language to help the key stakeholders understand results. It is important to include an executive summary to highlight the key findings of the evaluation study. If the report is relatively long it is necessary to include a content page to guide the reader. Presentations are very effective method of communicating evaluation results with funding agencies, administrators and farmers. If the farmers are illiterate, presentation of results with pictures is the best option to communicate results with them. A presentation followed by a report will contribute to enhance the effectiveness of communicating evaluation results. Newsletters and newspapers are useful to communicate evaluation results with general public and policy makers. The only disadvantage of written medium is that illiterate groups will not have access to this information. Radio and TV are very effective in communicating evaluation results with the general public.

2.5.4 Utilization of Evaluation Results

Evaluation is only of value to the extent the results are utilized to achieve the evaluation objectives. Normally evaluation results can be used to:

o. Establish program accountability
p. Make programmatic decisions

q. Monitor programs
r. Improve programs
s. Market the IPM
t. Achieve program sustainability

Continued funding for IPM programs depends on the economic viability of those programs. Therefore, impact evaluation results should be used to justify the costs of IPM programming. Cost benefit data can be used to make programmatic decisions. For example, if the program impacts exceed the costs, then the management will be able to use those results to expand the IPM program. The process evaluation data can be used for program monitoring and improvement. For example, if someone planed to reach 100 farmers and was able to reach only 70 farmers, then the process evaluation information can be used to identify the reasons for the achievement gap and fix those problems.

Impact evaluation results can be used to market the IPM program to potential funders as well as potential farmers. The communication of program impacts with potential funders and farmers is the best strategy to convince them about the benefits of IPM programming. Testimonials of the farmers who have positive experiences with the program are very powerful messages in marketing IPM programs to potential users. Extension brochures can be developed with farmers' testimonials to effectively market IPM extension programs.

2.5.5 Meta-Evaluation for Evaluation Practice Improvement

Meta-evaluation means the critical review of an evaluation study. Evaluation is a systematic process. Critical review of this process is essential for someone to improve his/her evaluation practice. After completing the IPM evaluation, the evaluator should critically review the process to identify the evaluation related issues, problems, challenges and alternatives to improve the evaluation next time.

2.6 Sample Studies

Process and outcome evaluation of IPM base insecticide resistant management (IRM) program conducted in Punjab employed with and without, before and after quasi-experimental research design. The evaluation indicators were: participation of farmers in training program, reactions of participating farmers towards different aspects of training, gain in knowledge and analytical skills, application of gain in knowledge and skills for adoption of IPM practices, adoptability of IPM practices by working out adoptability indices, reduces pesticide applications and pesticide use (technical grade material), economic benefits in terms of reduction in pesticide expenditure, increase in yields and higher input/output ratio of cotton cultivation. The purpose of the evaluation study was to understand how the program is being implemented, whether the IRM intervention in terms of training of farmers resulted in expected outcomes through expected processes, and to provide feedback to stakeholders of the program for its improvement. Quasi – experimental cum survey design was adopted for the formative/process evaluation of the IRM program. A sample of 210 farmers – 150 IRM farmers (experimental group) and 60 non-IRM farmers (control group) were selected by purposive cum random sampling technique from 21 villages (15 villages with IRM intervention and 6 villages without IRM intervention). The IPM practices disseminated under the IRM program were selected for the study. The data were collected with the help of three research schedules, (i) Knowledge/analytical skill test (ii) questionnaire (iii) scale to measure adoptability of IPM practices. In addition to these, participant observations were recorded. Pre- and post- training design was adopted to find out the knowledge gain and with and without, and before and after design was employed for studying adoption and economic benefit of IRM program. The IRM farmers reported the knowledge gain as the first reward of the IRM program, which was significant (Table 2.7). There was not much difference in the adoption of cultural practices by the trained and untrained, but IRM farmers had used significantly lesser number of insecticides mixtures, insecticide applications, and also lesser quantity of insecticides (technical grade material) per ha, than non-IRM framers, and had thereby significantly reduced insecticide expenditure (Table 2.8). There was not any significant difference in yield between IRM and non-IRM farmers. Adoptability index and adoption of timely sowing was high, but the adoptability indices of sampling to determine economic threshold level to justify use of pesticides, seed treatment and Punjab Agricultural University recommended non-Bt cotton resistant varieties were low. The adoptability of Bt-cotton was high. The adoptability index of the use of insecticides according to good agricultural practices was medium. Adoptability indices can be used for predicting the rate of adoption of an innovation at farm level and to avoid pro innovation bias. Participatory evaluation of IRM program by the farmers showed encouraging results in terms of participa-

Table 2.7 Evaluation of knowledge gain and analytical skills[b] of farmers participating in IRM program

Evaluation indicator	Before IPM	After IPM	Paired difference
Knowledge level[a] (% farmers)			
Low (0–19.31)	50	4	−46
Medium (19.31–33.37)	48	31	−17
High (33.37–52)	2	65	+63
Mean knowledge score	20.17	34.70	14.53*
SD	6.76	7.46	5.66

* The paired difference was significant at $p < 0.01$ at df 149.

[a] Singh (1975) cube root method of categorization.

[b] The knowledge gain and analytical skills indicators included: Knowledge about proper insecticide use, insecticide resistance, problem of resurgence of insect pests, spray technology, conservation of natural enemies of pests, knowledge and skills for determining economic threshold levels of insect pests, agro ecosystem analysis and identification of insect pests and natural enemies of cotton ecosystem.

Source: After Peshin (2005).

Table 2.8 Evaluation of benefits of IRM program

Evaluation indicators	Before IRM program			After IRM program		
	IRM villages	Non-IRM villages	Difference	IRM villages	Non-IRM villages	Difference
Average number of insecticide applications	15.34	14.93	0.41^{NS}	13.07	15.43	2.36^{*}
Technical grade insecticide use (kg/ha)	NA	NA	–	5.602	8.032	2.430^{*}
Tank mixtures of insecticide (No.)	NA	NA	–	3.1	5.1	2.0^{*}
Insecticide expenditure ($ US/ha)[a]	229.00	247.67	18.67^{NS}	128.73	152.78	24.05^{**}
Insecticide expenditure to total cost of cultivation (%)	39.70	42.73	3.03	30.26	34.76	4.50
Average seed cotton yield (kg/ha)	1749	1704	045^{NS}	2300	2209	091^{NS}
Average net income ($ US)[a]	414.00	406.44	7.56	431.10	388.00	43.11
Output/input ratio	NA	NA	–	1.86	1.77	5.08
Adoption of sampling for ETL(% farmers)[b]	0	0	–	34	0	34

NS = Non significant, *Significant at $p < 0.05$, **Significant at $p < 0.01$. Two sample t test applied for testing the level of significance, NA = Data not available.

[a] At 2005 rates 1US $ = 45 Indian rupees.

[b] Adoptability[2] of sampling for ETL is low in Punjab.

Source: After Peshin (2005).

tion of farmers, but the program was not implemented with active participation of the farmers for experiential learning of complex technologies like sampling etc. Farmers suggested that lecturing and street plays alone are not enough to make farmers adopt complex IPM practices. To make farmers go beyond the lower level of cognitive domain, i.e. knowledge to higher levels, mainly comprehension and application of the IPM technology, experiential learning of farmers is required to make them confident for the adoption of IPM system at farm level (Peshin, 2005).

van de Fliert (1993) applied a case study method for evaluating IPM famer field school in rice crop in Indonesia. The case study covered only four IPM and four comparison villages and it did not allow for generalization of the evaluation results across the national IPM program implemented in Indonesia. The indicators of evaluation were: implementation of IPM program as per the extension methodology of facilitation of farmers, improved knowledge on pest and natural enemy identification, changed perception of farmers with respect to pest occurrence, rice ecosystem

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[2] Adoptability is the likely adoption of IPM practices based on innovation attributes.

Table 2.9 Summary of evaluation results of IPM and non IPM farmers in two villages in Central Java, Indonesia

Indicator	Before training		During training		After one season		After two seasons	
	IPMF	NIPMF	IPMF	NIPMF	IPMF	NIPMF	IPMF	NIPMF
No. of pesticide applications/ season	1.4	1.5	0.7	1.5	0.8	1.3	0.3	0.8
No. of granular applications/ season	0.4	0.3	0.7	0.9	0.7	0.8	0.6	0.7
Farmers not using pesticides (%)	2.6	31	41	19	46	24	50	43
Average insect control cost(US \$/ha at 1996 rates, 1\$ = Rp 1000)	16.0	11.0	9.0	15.5	9.0	10.5	4.5	9.5
Average yield (tons/ha)	5.38	5.11	5.77	4.64	3.70	3.11	6.38	5.68
N	44	134	48	129	46	120	42	115

IPMF = IPM farmers (farmers participating in season long farmer field school training program), NIPMF = non-IPM farmers, Rp = Indonesian currency.
Source: After van de Fliert (1993)

management by farmers, improved skills in field monitoring, yields, lower expenditure on pest management, net returns on rice cultivation, diffusion of IPM practices from trained farmers to other farmers. The IPM-FFS program resulted in gain in knowledge of farmers, reduced frequency of pesticide applications and insect pest control costs and higher yield (Table 2.9).

2.7 Future of IPM Evaluation Research

Social scientists or extension scientists have a moral and sensible obligation to evaluate extension programs (Russ-Eft and Preskill, 2001). How IPM programs work to improve or change behavior of clients has not been practically shown by social scientists. Theory-driven evaluation has been suggested as an alternative which stresses the role of social scientists in evaluation as well in planning and designing of IPM programs. (Hilbert et al., 1997; Russ-Eft and Preskill, 2001).

The input-process (outputs)-outcome-impact (IPOI model) based logic model should be used to design and conduct (Table 2.10) formative and summative evaluations of IPM programs. The input in terms of the resources (available time quality

Table 2.10 Theory based logic model for IPM program evaluation

System Approach for evaluation of IPM programs based on logic model				
	INPUTS →	**ACTIVITIES OR PROCESS** →	**OUTCOME** →	**IMPACT**
Method of evaluation	Input Evaluation	Process Evaluation	Outcome Evaluation	Impact Evaluation
Type of evaluation	Formative	Formative	Summative	Summative
Research design	Non-experimental research design based on IPM theory and participatory evaluation model	Quasi-experimental research and non-experimental research designs, in-depth observation and interviewing	Quasi-experimental and non-experimental survey design (Critical multiplism model)	Quasi-experimental design for evaluating immediate impact and ex-post facto design (longitudinal studies) for evaluating long-term impact
Time dimension	With IPM T1 Before the IPM program	With/Without,Before/During IPM T2 During the implementation of IPM program	With/Without,Before/After IPM T3 At the end of IPM program	With/Without,Before/After IPM T4 Over a period after IPM program
Evaluation indicators	1. Evaluation of IPM technology • To find out whether IPM practices fit the farmer by conducting pilot studies • Adoptability of IPM practices in terms of technological attributes • Adaptability of IPM practices 2. Evaluation of implementation (extension) methodology 3. Input evaluation in terms of human resources, available budget, etc.	Implementation of IPM program • Active participation of farmers and their reactions regarding IPM program • Experiential learning of farmers, e.g. agro-ecosystem analysis, sampling for ETL • Demonstration of IPM technology validated during input evaluation • Whether IPM intervention yields desirable changes? • Causal relationship	Outcome of IPM program • Gain in cognition and analytical skills • Change in attitude • Adoption of IPM practices which have been identified at input evaluation stage	Impact of IPM program • Continued adoption of IPM practices • Reduction in number of pesticide application and use (technical grade material) • Reduction in pesticide expenditure • Increased population of natural enemies and reduction in population of insect pests • Reduction in insecticide resistance in insect pests • Higher input/output ratio • Multiplier effect (farmer to farmer diffusion)

of trainers and adoptability[3]/adaptability[4] of IPM practices), processes or outputs (training intervention, implementation of IPM program, development and delivery of educational materials, whether farmers are involved actively in experimentation to develop adaptable practices, whether the farmers are provided experimental training in agro-ecosystem analysis, use of sampling methods for determining economic threshold level of pests for taking pest management decision). Process evaluation during program implementation is generally formative in nature but can also be summative, e.g. if the stakeholders need to know about the actual delivery of the program and its application by the farmers (Peshin, 2005) for justification of program spending. Both quantitative[5] and qualitative[6] methods for data collection should be used. The outcomes in terms of immediate effects at farmers' level should be measured in terms of cognition of IPM practices, acquiring analytical skills and developing favorable attitudes towards IPM, reduction in pesticide use by adoption of IPM practices and use of pesticides based on (economic threshold level) ETL. Impacts in terms of long-term effects are continued adoption of IPM practices, reduction in pesticide use, reduction in pesticide expenditure, increased population of natural enemies and reduction in population of insect pests, reduction in insecticide resistance in insect pests, higher input/output ratio, multiplier effect (farmer to farmer diffusion).affecting a wider population including the non-beneficiaries. Measuring the impact of a program is complex and clear causal relationships are often difficult to establish. Indicators for measuring impact of IPM program can be increasing biodiversity, reduction in cancer deaths or other health hazards etc. Impact evaluation is summative in nature (Table 2.11).

The report of Working Group II regarding phases and indicators for evaluations of impact concluded that evaluating the impact of agricultural technology is a challenge, and evaluating the impact of an information-knowledge intensive technology such as IPM is even more challenging (Ortiz, 2001). The impact in terms of increased population of natural enemies and reduction in insect pest population, and insecticide resistance in insect pests should be studied and for that the evaluation studies have to incorporate an interdisciplinary approach to evaluation. The summary of the "First Workshop on Evaluation of IPM Programs" held at Hannover in 1998 concluded that the impact evaluation requires several coordinated steps. "Different groups of IPM community, e.g. cost benefit analysis experts, plant protection people, and others using different sets of methodologies to measure impact....., The first step is to clarify methodological issues within the disciplinary groups" (Waibel et al., 1998, p. 60). The three working groups also identified the

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[3] Adoptability is the likely adoption of IPM practices based on innovation attributes. For details about the methodology for working the adoptability refer Peshin (2009).

[4] Adaptability is whether the technology fits the farmer and can be modified for best fit.

[5] Quantitative data collection usually refers to hypotheses testing in quasi-experimental designs. Quantitative research deals with standardization, objectivity and reliability of measurement.

[6] Qualitative evaluation refers to first hand information (observation) as how IPM program is implemented, the pattern of interactions between farmers and trainers. It is rich description of processes rather than outcome of IPM programs.

Table 2.11 Phases and indicators for impact assessment

Phase	Needs and opportunity assessment	Technological options	Learning model for, and integration, adaptation of options	Implementation of protocols (pilot scale)
Type of assessment	• PRA • Baseline • GIS • Modeling	• Technology evaluation • Modeling	• Technology evaluation • Process evaluation • Impact evaluation • Modeling	• Process evaluation • Impact evaluation • GIS • Modeling
Indicators				
Natural	• Yield • Pest levels • NE activity • Pesticide load • Soil health	• Yield • Pest levels • NE activity • Indicators of performance	• Yield • Pest levels • NE activity	• Yield • Pests level • NE activity • Pesticide load • Soil health
Human	• Participation • IPM knowledge • IPM skills • IPM practice • Health • Gender • Poverty	• Participation • Farmer perception	• Participation • IPM knowledge • IPM skills • IPM practice	• Participation • IPM knowledge • IPM skills • IPM practice (adaptation, adoption, rejection) • Health • Gender • Poverty
Social	• Collectivity • Awareness • Regulatory • Framework	• Collectivity	• Collectivity • Dissemination • Awareness	• Collectivity • Dissemination • Awareness • Regulatory framework
Financial/physical	• Farm economic analysis • Supporting infrastructure	• Farm economic analysis	• Farm economic analysis	• Farm economic analysis • Supporting infrastructure • Cost-benefits analysis

PRA: Participatory Rural Appraisal, GIS: Geographical Information System, NE: Natural Enemies.
Source: Ortiz (2001).

Table 2.12 Indicators for household, village and national level impact of IPM program

Impact Level	Indicators	
Impact on regional, national and global institutions and policies	Changes in policy formulation and implementation, network of influence, level of interaction with policy decision makers, IPM initiative: is it institutionalized?, change in the mission statements of institutions, changes of role and responsibilities of institutions, educational curricula, existence of policies to support biological or IPM techniques versus policies for pesticides, elimination of pesticide subsidies (set of indicators), effectiveness of pesticide legislation, structural change between institutions, responsiveness to farmers, changes in institutions (incentive structure), farmer social movements, evidence of acceptable good science, capacities for change in extension approach, proportion of research budget for IPM, price premiums, evidence of independent policy analysis, incorporation of economic instruments in crop protection policy, and existence of policy workshop (who and how)	Working group III
Village level impact	IPM and social diversity knowledge creation and sharing, durable institutional capacity, advocacy, scale effects, and extension community interactions	Working group II
Farm household level	Improved economic well being, adoption of new technologies and adaptation of technologies to local conditions, improved knowledge and analytical capacity, diffusion of knowledge farmer to farmer, decreased health risk, and healthier ecosystem	Working group I

After: Waibel et al. (1998).

indicators of impact evaluation of IPM programs at country level, village level and farm level (Table 2.12). The social scientists from the field of extension education, sociology, anthropology and economics, and biological scientists from entomology, plant pathology and agronomy must fine tune their evaluation methods to provide internally and externally valid results for measuring the impact of IPM programs. They need to employ both quantitative and qualitative outcome measures as discussed in this chapter. Quantitative methods are required to generalize and describe causal relationships (Cook, 1997) whereas qualitative methods are suited for describing program processes (Kosloski, 2000). The internal and external validity of the evaluation results can be resolved by evaluation syntheses representing meta-analytical techniques. In meta-analytical techniques research results from different independent IPM studies will be converted to a common metric like pesticide use, pesticide expenditure, yield increase, knowledge gain, output/input ratio etc, and then will be aggregated using different statistical techniques (Kosloski, 2000). However, there is one drawback with a meta-analysis technique – the methodological limitations in the original IPM evaluation studies on which the syntheses are based (Figueredo, 1993). The meta-analysis of 25 impact evaluation studies carried out by van den Berg (2004) for global IPM facility has the limitation since many studies are based on non-experimental designs and some suffer from internal validity issues. Toovercome the underlying problem of external and internal validity based on experimental and non-experimental evaluation, respectively, studies to measure outcome and impact of the IPM programs should employ “critical multiplism” evaluation technique (Shadish, 1993). The term “critical” refers to identifying biases in the evaluation approach chosen by the researcher and to overcome it; the results of different evaluation studies on IPM (that are not homogenous) are synthesized by avoiding constant bias. Research syntheses of different evaluation studies, provided biases are identified in different approaches of evaluation, will allow generalizing the results by increasing external validity without reducing internal validity. A theory-driven approach to quasi-experimentation is futile unless it is demonstrated beyond doubt that the IPM program was in fact implemented as intended at process evaluation stage. Quasi-experimentation at output evaluation stage cannot be accomplished without doing process evaluation.

In response to social inquiry, evaluation should provide sound and accurate results and in the interest of researchers, it should provide sufficient information so that the evaluation discipline continues to develop. Now evaluators have sound methodologies to critically analyze the evaluations. This process is called meta-evaluation. “Meta-evaluation is the process of delineating, obtaining, and applying descriptive information and judgmental information about an evaluation’s utility, feasibility, propriety, and accuracy and its systematic nature, competence, integrity/honesty, respectfulness, and social responsibility to guide the evaluation and publicly report its strengths and weaknesses” (Stufflebeam, 2001). According to Scriven (1999) meta-evaluation is the backbone of evaluation and it is the evaluation of evaluations themselves and should be done periodically. It has helped to resolve the controversy over the priority about internal versus external validity. According to Shadish (1998) meta-evaluation can be done at any stage of an evaluation, e.g., from planning to the evaluation of completed evaluation reports. The application of a critical multiplism model which is based on syntheses of quasi-experimental and non- experimental will allow the identification of biases in the evaluation approach chosen by researcher. It will allow for synthesizing the results of different evaluation studies on IPM, that are not homogeneous but are heterogeneous with respect to source of bias and to avoid constant biases, and for generalizability of evaluation findings (Kosloski, 2000). Research synthesis of quasi-experimental and non experimental studies increases both internal and external validity of results.

2.8 Conclusion

Evaluation is an integral part of any development program and it should be planned at the program designing stage to ensure that the evaluation will be useful for program management, improvement and accountability. This scientific feedback needs to be utilized for further improvement of programs and for decision making by stakeholders and policy makers. The desired as well as undesired consequence of new technologies needs to be measured as was not done during the green revolution period that resulted in un-sustainability and over exploitation of natural resources. The worth of IPM technologies can not only be measured in terms of adoption of IPM practices, reduction in pesticide use and increase in yields but it should consider all aspects related to socio-economic development, health, sustainability, environment conservation etc. that will represent the true worth of IPM programs. Evaluation should be action oriented- that seeks solutions to problems of IPM dissemination at implantation stage. The feedback needs to be made available to policy makers for further strengthening research as well as the extension of IPM programs and tapping government and non-governmental support in implementing IPM technologies at farmers' field for achieving the long-term sustainability of agro-eco systems.

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Chapter 3
Protocol for Economic Impact Evaluation of IPM Programs

George W. Norton and Scott M. Swinton

Abstract The purpose of this chapter is to describe steps that can be followed to assess economic impacts of IPM. These steps are well established for evaluating user and society level profitability. The protocol is less agreed upon for evaluating the economic value of health and environmental impacts, but this chapter highlights steps in applying a non-market valuation technique for that purpose. Economic impacts of IPM are felt by IPM users, members of their households, and society at large. IPM programs are undertaken to provide information to users, scientists, funding agencies, and the general public. Prior to any economic impact assessment, it is necessary to define the principal audience(s) and the types of impact of interest. Once that is accomplished, a protocol can be followed for economic assessment of IPM impacts that includes five components: (1) defining IPM measures, (2) measuring IPM adoption, (3) assessing user-level economic effects, (4) assessing market effects, and (5) estimating health and environmental (non-market) impacts. We described these components and then indicate briefly a process for assessing impacts of IPM on poverty. A sample budget form, baseline survey questionnaire, and a spreadsheet for calculating economic surplus are provided. A model is described for assessing the extent of IPM adoption.

Keywords Economic impact evaluation · IPM · baseline survey

3.1 Introduction

The purpose of this chapter is to describe a basic protocol or set of steps that can be used to assess economic impacts of IPM. Several book chapters and other sources are available that summarize methods for evaluating economic impacts of integrated pest management (IPM) (Fernandez-Cornejo, 1998; Norton and Mullen, 1994; Norton et al., 2005; Swinton and Norton, 2009). However, few sources

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provide information on the steps involved, including a sample survey form, spreadsheet, and budget form. Steps are well established for evaluating user and society level profitability. For evaluating the economic value of health and environmental impacts, methods employed have been diverse, and this chapter highlights steps in a specific non-market valuation approach.

Economic impacts of IPM are felt by IPM users, members of their households, and society at large. IPM programs are implemented to meet economic, health, and environmental objectives, and impact evaluations of IPM programs are undertaken to provide information to users, scientists, funding agencies, and the general public. Prior to an economic impact assessment, it is necessary to define the principal audience(s) and the types of impact of interest. For purposes of this chapter, we assume the primary audience includes IPM scientists and administrators of funding agencies, and that economic impacts on users and society in general are of interest. Our protocol for economic assessment of IPM impacts includes five tasks: (1) defining IPM measures, (2) measuring IPM adoption, (3) assessing user-level economic effects, (4) assessing market effects, and (5) estimating health and environmental (non-market) impacts. We also highlight a process for assessing impacts of IPM on poverty.

3.2 Define IPM Measures

IPM involves individual pest management practices as well as strategies that include combinations of practices or tactics. Virtually all IPM practices are aimed at managing pests and improving economic efficiency for their users, since few IPM tactics are subsidized and thus must be profitable if they are to be adopted. However, some tactics are more directly aimed at achieving health or environmental goals than are others. This multiplicity of IPM tactics and their uneven contributions to goals, creates a need to clearly define the measures of IPM to be evaluated.

Defining IPM measures means identifying the individual IPM tactics and then grouping them into levels of IPM adoption (e.g., Rajotte et al., 1985; Vandeman et al., 1994; Benbrook, 1996), or assigning points to individual practices to derive a continue scale of IPM adoption (e.g., Hollingsworth et al., 1992). Scientists and others can provide information to help group or score tactics so that higher levels represent progress in achieving IPM goals.

The definition of IPM levels varies across program, but an impact assessment begins by defining the boundaries in time and space where the program is fairly homogeneous. Scientists, extension workers, and others can help identify the tactics and levels. The more data that is supplied by scientists with respect to the effects of these tactics on production or pesticide use, the easier it is to group or score them. Even with accurate data, groupings will differ depending on implicit weights attached to economic efficiency (income) versus environmental goals. It makes little difference if IPM tactics are grouped or scaled, but the make-up of the stakeholders who do the grouping or scaling can influence results because of differing weights applied to the two primary IPM goals.

3.2.1 Measure IPM Adoption

Once specific IPM tactics and their time and space boundaries have been defined, IPM adoption can be measured, or in some cases, projected. While expert opinion can also be used for this purpose, it is best to conduct a survey of users or potential users. Optimally, a baseline survey is conducted at the start of a program and again at the time of evaluation. This comparison over time facilitates attribution of IPM adoption to an IPM program. If a baseline does not exist, it is still possible to conduct a survey and compare adopters with non-adopters using data from one point in time in a statistical regression analysis.

An example of a baseline survey that was applied in a tomato IPM program evaluation in Mali is included in Appendix. Although a baseline survey needs to be adapted to each program, the types of questions included in Appendix are illustrative. Questions are included in the survey for different purposes. Questions related to user and farm characteristics prove helpful in analyzing factors that affect IPM adoption. Often an adoption analysis is needed not only to attribute IPM adoption to a particular program, but to predict future adoption of IPM practices as well.

A typical adoption model might be as follows: IPM Adoption = f (age, education, land tenure, income, distance to market, member of farm organization, IPM training). The IPM adoption measure may be a single practice, group of practices, or another measure of the degree of IPM adoption. If a variable such as IPM training is included, it is usually necessary to estimate a second regression to control for the fact that participation in the training program may not be random. Unless the fact that those who participate may be different from those who do not, the results of the IPM adoption regression may be biased. The second regression might be as follows: IPM training participation = f (producer characteristics, location).

The results of this second regression are used to generate a predicted IPM training participation variable which is used in the first adoption regression in place of the simple IPM training variable (Feder et al., 2004). An example of this type of analysis is found in Mauceri et al. (2007). The model can be estimated using an instrumental variables technique. The participation regression can be estimated as a probit or logit model due to binary or grouped nature of the dependent variable.

Not only might this type of adoption model explain the impact of IPM participation, but it can be used to predict the adoption of a new IPM technique if it is similar to a previous IPM technique. An example is found in Moyo et al. (2007) who predict adoption of a disease resistant variety by income level of farmers based on estimated adoption of a previous variety.

3.2.2 Assess User Level Effects

Costs and returns per unit area and per enterprise change with IPM adoption. Budgets are commonly used to assess those changes. Data are required on inputs, outputs, and prices. Budgets for pest management alternatives can be compared using

Table 3.1 Budget per unit of area (hectare)

		Price or cost		Value or cost
	Units	per unit	Quantity	
Receipts				
__________________	______	______	______	______
__________________	______	______	______	______
Variable costs				
__________________	______	______	______	______
__________________	______	______	______	______
Income above variable costs				
Fixed costs				
__________________	______	______	______	______
__________________	______	______	______	______
Total costs	______	______	______	______
Income above total costs				

data from replicated on-farm experiments or from user surveys. When using experimental data, budgets may incorporate only those costs that differ across treatments, and results are subjected to analysis of variance to test for significant differences in mean profitability by treatment (Swinton et al., 2002). By developing a budget for each level of adoption, changes in net returns can be linked to levels of IPM adoption. An example of a form that can be used to construct an enterprise budget for each level of IPM adoption is presented in Table 3.1.

Results of budgeting analysis can be used by scientists and others to judge the profitability of practices they are developing or recommending to farmers, or of practices already adopted. A second major use of budget information is as an input into a market or societal level assessment of the economic benefits and costs of an IPM program.

3.2.3 Assess Market Level Effects

When many individuals adopt an IPM practice or program for a particular commodity, the resulting increase in production can affect the price of the commodity at the market level. Therefore assessing aggregate economic impacts of IPM, requires a market model that considers changes in costs, yields, prices, and the extent of IPM adoption. In addition, because the research and the adoption can occur over several years, and impacts that occur sooner are valued more than those that occur farther in the future, impact analysis must also account for the timing of benefits and costs and discount them appropriately.

Two primary methods are used to account for these price and timing effects. The first method involves calculating changes in economic surplus, and the second method involves incorporating those economic surplus changes in a benefit cost analysis. These methods are described in detail in Alston et al. (1995), and are summarized in Norton et al. (2005) and Swinton and Norton (2009) as follows: In Fig. 3.1, S_0 represents the supply curve before adoption of an IPM strategy,

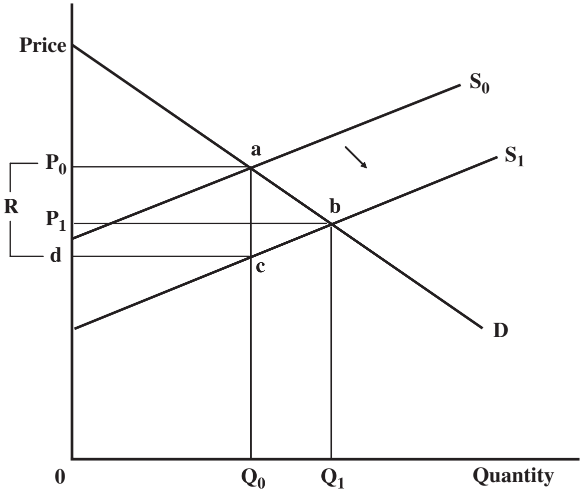

Fig. 3.1 IPM benefits measured as changes in economic surplus; Source: Norton et al. (2005)

and D represents the demand curve. The initial price and quantity are P_0 and Q_0. Suppose IPM leads to savings of R in the cost of production, reflected in a shift down in the supply curve to S_1. This shift leads to an increase in production and consumption of Q_1 (by $\Delta Q = Q_1 - Q_0$) and the market price falls to P_1 (by $\Delta P = P_0 - P_1$). Consumers are better off because they can consume more of the commodity at a lower price. Consumers benefit from the lower price by an amount equal to their cost saving on the original quantity ($Q_0 \times \Delta P$) plus their net benefits from the gain in quantity consumed. Their total benefit is represented by the area P_0abP_1.

Although they may receive a lower price per unit, producers may be better off too, because their costs have fallen by R per unit, an amount greater than the fall in price. Producers gain the increase in profits on the original quantity ($Q_0 \times (R - \Delta P)$) plus the profits earned on the additional output, for a total producer gain of P_1bcd. Total benefits are obtained as the sum of producer and consumer benefits.

The distribution of benefits between producers and consumers depends on the size of the fall in price (ΔP) relative to the fall in costs (R) and on the nature of the supply shift. For example, if a commodity is traded and production in the area producing the commodity has little effect on price, most of the benefits would accrue to producers. If the supply curve shifts in more of a pivotal fashion as opposed to a parallel fashion as illustrated in Fig. 3.1, the benefits to producers would be reduced. Examples of IPM evaluation using the economic surplus approach are found in Napit et al. (1988).

Formulas for calculating consumer and producer gains for a variety of market situations are found in Alston et al. (1995). For the closed economy market (no trade) in Fig. 3.1, the formula to measure the total economic benefits to producers and consumers, is $KP_0Q_0(1 + 0.5Zn)$, where: $K =$ the proportionate cost change, $P_0 =$ initial price, $Q_0 =$ initial quantity, $Z = Ke/(e + n)$, $e =$ the supply elasticity, and $n =$ the absolute value of the demand elasticity. Other formulas would be appropriate for other market situations. For the small open economy model (trade, but no effect on world price), the measure of total economic benefits to producers and consumers is $KP_0Q_0(1 + 0.5Ke)$.

These formulas can be placed in spreadsheets for the calculations. An example of a spreadsheet for the closed economy case is shown in Table 3.2. Benefits are calculated year by year. The first column lists the year the benefits and costs occur. Columns 2 and 3 list the elasticities of supply (e) and demand (n). Column 4 gives the maximum proportionate yield change (%ΔY) when the technology is fully adopted. Column 5 divides the %ΔY by the elasticity of supply to convert it to a proportionate change in cost per tonne. Column 6 gives the proportionate change in input cost per hectare and column 7 divides that cost change by 1 + %ΔY to convert the input cost change per hectare to an input cost change per tonne. Column 8 subtracts the per tonne cost change from the per tonne yield change to give a net per unit cost change. Column 9 is used in cases where the research is not yet complete and it represents the probability of success with the research. Column 10 is the adoption rate by year. Column 11 is the multiplication of the previous four columns to give the per-unit cost reduction once the yield, cost, probability of success and adoption rates by year are taken into account. It is the proportionate shift down in the supply curve. Column 12 is the price of the commodity and column 13 the quantity. Column 14 is the change in economic surplus per year. Column 15 is the research costs per year and column 17 is the net of benefits minus costs.

In summary, the spreadsheet simply breaks down the formula to calculate change in economic surplus into parts and then combines them. The most difficult aspect of an economic surplus analysis is the calculation or prediction of the proportionate shift in supply following IPM adoption. Cost differences as well as adoption rates must be calculated. The producer surveys, information on cost and yield changes in field trials, and other methods discussed above can be used to obtain the information required to estimate the supply shifts.

Once changes in economic surplus are calculated or projected over time, benefit/cost analysis can be completed in which net present values (NPV), internal rates of return (IRR), or benefit cost ratios (BCR) are calculated. The benefits are the change in total economic surplus calculated for each year, and the costs are the public expenditures on the IPM program. The primary purpose of the benefit/cost analysis is to take into account the fact benefits and costs need to be discounted, as the sooner they occur the more they are worth. The net present value (NPV) of discounted benefits and costs can be calculated as follows:

$$\mathrm{NPV} = \sum_{t=1}^{T} \frac{B_t - C_t}{(1+i)^t}$$

where:

B_t = the benefit in year t (change in economic surplus)
C_t = the cost in year t (the IPM program costs)
i = the discount rate

Table 3.2 Nigeria cassava – CMD resistant variety (closed economy assumption)

Year	e	n	Propor. Yield Change	Gross Propor. Cost Change	Propor. I. Cost Change Per Ha.	Propor. I. Cost Change Per Ton	Net Change	Probability of Success	Adoption Rate	K	Z	Price $/mt	Quantity 000mt	CTS 000$	Cost 000$	Net Benefit 000$
2002	1.00	0.20	0.50	0.50	0.05	0.033	0.467	0.90	0.00	0.000	0.000	60.00	40000	0.00	100	−100
2003	1.00	0.20	0.50	0.50	0.05	0.033	0.467	0.90	0.00	0.000	0.000	60.00	40000	0.00	100	−100
2004	1.00	0.20	0.50	0.50	0.05	0.033	0.467	0.90	0.00	0.000	0.000	60.00	40000	0.00	100	−100
2005	1.00	0.20	0.50	0.50	0.05	0.033	0.467	0.90	0.00	0.000	0.000	60.00	40000	0.00	100	−100
2006	1.00	0.20	0.50	0.50	0.05	0.033	0.467	0.90	0.00	0.000	0.000	60.00	40000	0.00	100	−100
2007	1.00	0.20	0.50	0.50	0.05	0.033	0.467	0.90	0.00	0.000	0.000	60.00	40000	0.00	100	−100
2008	1.00	0.20	0.50	0.50	0.05	0.033	0.467	0.90	0.00	0.000	0.000	60.00	40000	0.00	100	−100
2009	1.00	0.20	0.50	0.50	0.05	0.033	0.467	0.90	0.02	0.008	0.007	60.00	40000	20174	50	20124
2010	1.00	0.20	0.50	0.50	0.05	0.033	0.467	0.90	0.05	0.021	0.018	60.00	40000	50488	50	50438
2011	1.00	0.20	0.50	0.50	0.05	0.033	0.467	0.90	0.10	0.042	0.035	60.00	40000	101152	50	101102
2012	1.00	0.20	0.50	0.50	0.05	0.033	0.467	0.90	0.20	0.084	0.070	60.00	40000	203011	50	202961
2013	1.00	0.20	0.50	0.50	0.05	0.033	0.467	0.90	0.30	0.126	0.105	60.00	40000	305575	50	305525
2014	1.00	0.20	0.50	0.50	0.05	0.033	0.467	0.90	0.40	0.168	0.140	60.00	40000	408844		408844
2015	1.00	0.20	0.50	0.50	0.05	0.033	0.467	0.90	0.40	0.168	0.140	60.00	40000	408844		408844
2016	1.00	0.20	0.50	0.50	0.05	0.033	0.467	0.90	0.40	0.168	0.140	60.00	40000	408844		408844
2017	1.00	0.20	0.50	0.50	0.05	0.033	0.467	0.90	0.40	0.168	0.140	60.00	40000	408844		408844
2018	1.00	0.20	0.50	0.50	0.05	0.033	0.467	0.90	0.30	0.126	0.105	60.00	40000	305575		305575
2019	1.00	0.20	0.50	0.50	0.05	0.033	0.467	0.90	0.20	0.084	0.070	60.00	40000	203011		203011
2020	1.00	0.20	0.50	0.50	0.05	0.033	0.467	0.90	0.10	0.042	0.035	60.00	40000	101152		101152
2021	1.00	0.20	0.50	0.50	0.05	0.033	0.467	0.90	0.05	0.021	0.018	60.00	40000	50488		50488

The same spreadsheet that is illustrated in Table 3.2 can be used to calculate the NPV or IRR as these formulas are imbedded in the spreadsheet programs.

Aggregate or market level economic effects can be distributed in a variety of ways and have other social and economic effects across and within households. For example the formula $ZP_0Q_0(1 + 0.5Zn)$ can be used to calculate consumer benefits, and producer benefits are simply total benefits minus consumer benefits.

3.2.4 Value Non-Market Effects

IPM practices may have health and environmental impacts that are not valued in the market. Reporting on changes in use of pesticide active ingredients associated with changes in pest management practices or in the number of pesticide applications have often been used to assess these types of impacts. However, specific pesticides and how, when, and where they are applied affect health and the environment, thus requiring a more refined approach.

Assessing physical and biological effects of pesticide use that occur under different levels of IPM is difficult. In addition, pesticides have many distinct acute and long-term effects on sub-components of health and the environment such as mammals, birds, aquatic life, and beneficial organisms. And, because the economic value associated with these effects is generally not priced in the market, it is difficult to know how heavily to weight the various health and environmental effects compared to one another and compared to income impacts.

Some impact assessments have used location-specific models that require detailed field information such as soil type, irrigation system, slope, and weather, and produce information on the fate of chemicals applied (Teague et al., 1995). But many assessments of health and environmental effects have used non-location specific models that require information only on the pesticides applied and the method of application, and produce indicators of risks by health and environmental category as well as weighted total risk for the pesticide applications. Examples are the environmental impact quotient (EIQ) developed by Kovach et al. (1992), the Pesticide Index (PI) of Penrose et al. (1994), and a multi-attribute toxicity index developed Benbrook et al. (2002).

Each indexing method involves subjective weighting of risks across environmental categories. These methods perform two tasks (Swinton and Norton, 2008): the first is to identify the risks of pesticides to the individual categories of health and the environment, such as groundwater, birds, beneficial insects, and humans, and the second is to aggregate and weight those impacts across categories.

“The EIQ uses a discrete ranking scale in each of ten categories to identify a single rating for each pesticide active ingredient (a.i.). The categories include acute toxicity to non-target species (birds, fish, and bees), acute dermal toxicity, long term health effects, residue half-life (soil and plant surface), toxicity to beneficial organisms, and groundwater/runoff potential. The EIQ groups the ten categories into three broad areas of pesticide action: farm worker risk, consumer exposure potential, and ecological risk. The EIQ is then calculated as the average impact of a pesticide

AI over these three broad areas, and is reported as a single number" (Swinton and Norton).

"The EIQ is defined for specific pesticide active ingredients. In order to assess the actual damage from pesticide use on a specific field, the EIQ can be converted into a "field use rating." If only one pesticide is a applied, this rating is obtained by multiplying the pesticide's EIQ by its percent a.i. and by the rate at which the pesticide was applied.

Benbrook et al. (2002) developed an indexing method to monitor progress in reducing the use of high risk pesticides. For pesticides used in Wisconsin potato production, multi-attribute toxicity factors were calculated that reflect each pesticide's acute and chronic toxicity to mammals, birds, fish and small aquatic organisms, and compatibility with bio-intensive integrated pest management. These factors were multiplied by the pounds of active ingredients of the pesticides applied to estimate pesticide-specific toxicity units. These units can be tracked over time or related to use of IPM" (Swinton and Norton, 2009)

One mechanism that can be used to reduce the subjectivity on the weights used in multi-attribute indexing methods is to elicit information on individuals' willingness to pay for risk reduction for the various health and environmental categories. Because there is usually no market price for reduced health and environmental risk, alternative monetary valuation techniques are needed such as contingent valuation (CV), and experimental auctions, and hedonic pricing (Freeman, 2003; Champ et al., 2003).

Contingent valuation uses a survey to collect data on people's stated willingness to pay (WTP) to receive a benefit or their willingness to accept compensation for a loss. In the context of pest management, respondents might be asked how much they would be willing to pay to reduce the risk of pesticides to various categories of health and environment. The WTP data could then be linked to pesticide use data to arrive at a value for a change in pesticide use (Higley and Wintersteen, 1992; Mullen et al., 1997; Swinton et al., 1999; and Cuyno et al., 2001).

From the Cuyno et al. study on onion IPM in the Philippines, assessing changes in pesticide risks involved several steps. First, the environment was classified into impact categories. Second, risks posed by individual pesticide active ingredients were assessed for each category. Third, the degree of IPM adoption was defined. Fourth, the effects of IPM adoption on pesticide use were estimated. Fifth, willingness to pay for risk reduction was obtained from a survey of residents in six villages. Sixth, information on risk reduction information and on willingness to pay was combined.

Environmental categories used by Cuyno et al. included the types of non-target organisms affected – humans (chronic and acute health effects), other mammals, birds, aquatic species, and beneficial insects. Risks posed by specific pesticides applied to onions in the region were assessed by assigning one risk level for each active ingredient for each environmental category using a rating scheme partially summarized in Table 3.3.

Hazard ratings from previous studies were used as well as toxicity databases such as EXTOXNET. Both toxicity and exposure potential were considered in arriving at

Table 3.3 Pesticide impact scoring system

Impacts	Indicators	High Risk = 5	Moderate Risk = 3	Low Risk = 1
Human Health				
Toxicity				
Acute Toxicity	Pesticide Class (WHO Criteria)	Ia; Ib	II	III
	Signal Word (EPA Criteria)	Danger/Poison	Warning	Caution
Chronic Toxicity	Weight of Evidence of Chronic Effects	$>$ 1 Positive Conclusive Evidence	Data Gap Possible Probable	Negative Inconclusive Evidence
Exposure				
Leaching Potential	Groundwater Ubiquity Score	GUS $>$ 2.8	.8 $>$ GUS $>$ 2.8	GUS $<$ 1.8
	Leaching Potential Score	High	Moderate	Low
Runoff Potential	No. of Red Flags Exceeded for the ffg:	$>$ 2 red flags	1 red flag	0 red flag
	Soil Adsorption (Koc) $>$ 300			
	Soil 1/2-life $>$ 21 days			
	Water Solubility $>$ 30 ppm			
	Surface Loss Potential	High	Moderate	Low
Air Contamination	Henry's Law Constant			
	Place of Application	Aerial	Crop/Soil Surface	Soil
Food Residues	Systemicity		Systemic	Non-systemic
	Time of Application		Post-emergent	Pre-emergent
	Plant Surface Residue Half-life	$>$ 4 weeks	2–4 weeks	1–2 weeks
Aquatic Species				
Toxicity	95 hr LC50 (fish) mg/L			
	Fish/Other Aquatic Species Toxicity	$>$ 10 ppm	1–10 ppm	$<$ 1 ppm
Exposure	Runoff Potential Score	High	Moderate	Low

Table 3.3 (continued)

Impacts	Indicators	High Risk = 5	Moderate Risk = 3	Low Risk = 1
Beneficial Insects				
Toxicity	Beneficial Effects Score (BENE)	BENE > 50	25 < BENE < 50	BENE < 25
	Insect Toxicity Ratings	Extreme/High	Moderate	LOW (1)
Exposure	Plant Surface Residue Half-life (same as human health)	> 4 weeks	2–4 weeks	1–2 weeks
Mammalian Animals				
Birds				
Toxicity	Bird toxicity ratings	High/Extreme	Moderate	Low
	8 day LC50	1–100 ppm	100–1000 ppm	> 1000 ppm
Exposure	Soil Half-life	> 100 days	30–100 days	< 30 days
	Plant Surface Half-life	> 4 weeks	2–4 weeks	1–2 weeks

(Source: Cuyno et al., 2001).

the assigned risks for each of 44 pesticides. An overall eco-rating score was then calculated with IPM adoption and without IPM adoption. The difference represents the amount of risk avoided due to the program. The formula for the eco-rating was: $ES_{ij} = (IS_j) \times (\%AI_i) \times (Rate_i)$, where ES_{ij} is the pesticide risk score for active ingredient i and environmental category j, IS_j is the risk score for environmental category j, %AI is the percent active ingredient in the formulation, and $Rate_i$ is the application rate per hectare.

Expected reduction in pesticide use as a result of adopting the IPM technologies was based on experiments conducted in farmers' fields. Willingness to pay for environmental benefits of the onion IPM program were obtained through a CV survey of 176 randomly selected farmers in the region. Farmers were asked to provide willingness-to-pay values for different formulations of their most commonly used pesticides. Five formulations were offered, with one that avoids risk to each of the five environmental categories. For example, farmers were asked whether they would purchase their most commonly used pesticide, reformulated to avoid risk to human health, at a series of prices (in 50 peso increments) higher than its existing price. The estimates of willingness to pay to avoid pesticide hazards to the various environmental categories were then adjusted downward by 30% to reflect the fact that the pesticides in the local area were applied 70% on onions during the dry season, and 30% on other crops, principally rice and other vegetables.

Reductions in pesticide hazards due to implementation of five IPM practices were calculated by multiplying the risk score for each pesticide by the percent active ingredient, and then multiplying this result by the application rates per hectare, with and without the IPM practices. The percent reduction in this eco-rating hazard was multiplied by the willingness-to-pay value for each category to arrive at an economic benefit per person. Aggregate benefits were obtained by multiplying the per person value by the number of people in the region.

3.2.5 Assess Poverty Impacts

In developing countries, the question that is often posed is not how much does an IPM program affect income, but how much does it affect poverty. IPM adoption can lower per-unit costs of production and out put price, increase the supply of food products, and may or may not raise incomes of adopting producers. The poor can gain disproportionately as consumers from lower food prices, as they spend a high proportion of their income on food.

Economic surplus analysis can be combined with household-level data analysis to construct assess changes in poverty resulting from adopting IPM. The surplus analysis provides estimates of changes in prices and economic surplus. The household-level analysis uses information about changes in production costs associated with IPM adoption and consumption patterns to infer household-specific changes in income following adoption. Economic surplus can be assigned to individual producers and consumers. With appropriate survey weights, household income changes can be used to estimate changes in aggregate poverty. This method is described in a paper by Moyo et al. (2007).

Analyses of predicted changes in poverty resulting from adoption of IPM involve three main steps: (i) computing the household-level value of the welfare measure (income or consumption per capita) and comparing it to the poverty line; (ii) determining which households did or are most likely to adopt the new IPM technology and estimating how household welfare will change following adoption; and (iii) adding up the change in the number of poor people or households resulting from adoption. The household analysis of income changes among adopting households can be used to create an estimate of market-level surplus changes (corresponding to the total change in income for all participants in the market) and of changes in poverty in the population. Details of the procedures for this type of poverty analysis are described in Moyo et al. (2007) and are not repeated here.

3.3 Overview of Selected IPM Impacts from Previous Studies

The primary purpose of this chapter is to present a protocol for IPM impact assessment, not to summarize impact results. Nevertheless, it may be helpful to briefly highlight just a few results from previous studies. Most of the ex post impact assessments of IPM have occurred in the United States, although increasingly such assessments are being completed in other countries as well as IPM spreads globally. Impacts of IPM on yields, pesticide use, and net returns estimated in published studies were summarized in a presentation by Fernandez-Cornejo at the 5th National IPM Symposium in the United States in 2006 (Table 3.4).

In the 67 studies cited, pesticide use decreased in all but 11 cases, and net returns per hectare increased in nearly all of them. Several studies also have estimated market level returns (e.g., Napit et al., 1988; Beddow, 2000; Debass, 2001; Moyo et al. 2007). Napit for example found an internal rate of return on public investment in IPM in the United States of more than 100%. Beddow found a $7 million net present value for the Pennsylvania sweet corn IPM program. Debass found a $14–29 million benefit for soil amendments as part of an IPM program in Bangladesh. Moyo found a $35–58 million return for Peanut IPM in Uganda. The list of such studies around the world continues to grow. Fewer studies have estimated environmental benefits, but that list as well continues to grow. Mullen et al. (1997) found annual environmental benefits of the peanut IPM program in Virginia of more than $800000. Cuyno et al. (2001) found annual environmental benefits of $150000 in six villages in the Philippines due to an onion IPM program. Beddow found $8 million in environmental benefits to the sweet corn IPM program mentioned above. One study, Moyo et al., also found poverty rates to decline by more than 1% in a peanut growing area of Uganda due to IPM.

3.4 Conclusions

IPM programs are implemented to meet economic, health, and environmental objectives, and impact evaluations of IPM programs are undertaken to provide information to users, scientists, funding agencies, and the general public. A protocol is

Table 3.4 Impacts of IPM on pesticide use, yields, and net returns

Commodity	Country	IPM techniques	Pesticide Use		Yield per hectare	Net returns per hectare	Number of studies
			Most common effect	Range (%)			
Cotton	U.S	Scouting only	Increase	−64 to +92	Increase	Increase	10
Cotton	U.S	Scouting and others	Decrease	−98 to +34	Increase	Increase	11
Soybeans	U.S	Scouting only	Decrease	−21 to +83	Increase	Increase	5
Soybeans	U.S	Scouting and others	Decrease	−100 to −85	na	Increase	2
Corn	U.S	Scouting Only	Increase	+15 to +47	Increase	Increase	1
Corn	U.S	Scouting and others	Decrease	−15 to +67	Increase	na	2
Peanuts	U.S	Scouting and others	Decrease	−81 to +177	Increase	Increase	6
Fruits/Nuts	U.S	Scouting only	Decrease	−43 to +24	Increase	Increase	7
Fruits/Nuts	U.S	Scouting and others	Decrease	−41 to +37	Same or increase	Same or increase	8
Vegetables	U.S	Scouting and others	Decrease	−67 to +13	Same	Increase	9
Rice	China	Scouting and Host plant resistance	Decrease		Same	Increase	2
Rice	India	Multiple	Decrease		Increase	Increase	1
Rice	Sri Lanka	Multiple	Decrease		Increase	Increase	1
Fruits/Nuts	New Zealand	Scouting and others	Decrease		na	Increase	1
Vegetables	Philippines	Multiple	Decrease		na	Increase	1

Source: Presentation by J. Fernandez-Cornejo at the 5th National IPM Symposium, St Louis, Missouri, April 4, 2006.

described in this chapter for economic assessment of IPM programs. It includes four steps for assessing economic impacts: (1) defining IPM measures, (2) measuring IPM adoption, (3) assessing user-level economic effects, and (4) assessing market effects. It also provides information on methods for estimating health and environmental (non-market) impacts and poverty impacts.

Acknowledgments The chapter draws on previous work with Jeff Mullen, Leah Cuyno, Jason Beddow, Sibusio Moyo, and Jeff Alwang among others.

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Appendix: Tomato IPM Farmer Baseline Survey from Mali

Respondent ____________ **Date of Interview** ____________

Code number ____________

Gender (circle) M or F Interviewer ____________

Community ____________ **Village** ____________

I. **Socio-demographic profile**

1. What is your age? ____________ years
2. What is the highest grade/year in school you have completed? ____________
3. How many working persons are there in your family? ____________
4. What farmers' organizations are you a member of? ____________
5. How far is your field from the nearest market (km)? ____________

6. How far is your village from the nearest major road (km)? ______________

7. How far is your house from the nearest extension agent (km)? ______________

8. What month(s) did you plant tomato in the field?

   Dry season month ______________
   Rainy season month ______________

9. List crops you grew last year and the number of hectares (total for both seasons)? Also list the number of hectares of tomato and other vegetables produced by other household members

Crop	1. Millet/ Sorghum	2. Maize	3. Rice	4. Tomato	5	6	7	8
Farmer								
Other members								

10. How much of the land (hectares) that you use for tomato do you own, rent, share crop, common field or control by other means?

	Tomato for Farmer	Tomato for other members
a. Own		
b. Rent		
c. Share crop		
d. Other (specify)		

11. How many years have you cultivated tomatoes? ______________

II. Factors affecting pest management decision-making

12. Who buys the pesticides in your household (check all that apply)?

______________a) Farmer
______________b) Spouse
______________c) Both husband and wife
______________d) Other members of the household

13. How much did you spend on pesticides (insecticides, fungicides, herbicides) last season for: (a) tomatoes? ______________ (b) Cotton? ______________ (c) Other crops? ______________

14. What proportion of vegetable do you consume in your household? __________%

15. How many baskets of tomato did you produce last year?

   Dry season ______________ Basket size ______________kg
   Rainy season ______________ Basket size ______________kg

16. At the time of selling most of your tomatoes, what was the most common price? *(Please, give the units)* __________

17. To whom (where) did you sell your tomato? (Check all that apply)
    (a) __________ Field
        i __________ Male trader
        ii __________ Female trader
    (b) __________ Local market
    (c) __________ Others *(Please specify)* __________

18. What proportion of your total annual income comes from tomato? __________

19. What percentage of your total annual income is from farm income? __________

20. Which of the following factors were important in your choice of pesticides (insecticides, fungicides, herbicides, etc)?

	Important
a. Pesticide cost	__________
b. Extension agents	__________
c. Pesticide dealer advice	__________
d. Relatives' advice	__________
e. Fellow farmers' advice	__________
f. Safety	__________
g. Local media (radio)	__________
h. Efficacy	__________
i. Availability of cotton pesticides	__________
h. Others (specify)__________	__________

21. Did you borrow to finance your crop production?
Yes__________. No__________
(if no, go to question 25)

22. What proportion of your borrowing came from each of the following sources?

a. Local micro finances __________
b. Rural projects __________
c. Friends, relatives, neighbors __________
d. Local traders __________
e. Others *(specify)* __________

23. What proportion of the amount borrowed was spent on pesticides? __________

24. What proportion of the amount borrowed was delivered in kind as pesticides?
____

25. Have you, or any member of your family, ever participated in Farmer Field School (FFS) Training for IPM?_______Yes_______No

26. If yes, for which crop(s) (a) ____________ (b) ____________

27. when did you participate in FFS?____2001____2002____2003____2004____2005

28. Have you ever been visited by an agricultural extension agent, who discussed non-pesticide means of controlling crop pests? (a) Yes________ (b) No________

29. What is your source of tomato seeds?
_____ a) Private dealers
_____ b) Extension service
_____ c) Self
_____ d) Neighbor/Friend
_____ e) Others (specify) ____________

30. What type of water source do you use for tomatoes?
_____a) Irrigation system
_____b) With cans
_____c) Rainfed
_____d) Others (specify) ____________

III. Perceptions of the effect of pesticides on human health and the environment

31. Using pesticides to control pests can harm water quality on the farm.
____________ Agree
____________ Disagree
____________ Don't know

32. If agree, do you think your farm's water supply has been negatively affected by pesticide use?
____________ Yes
____________ No
____________ Don't know

33. Do you attribute any health problems that you or any of your family may have experienced to pesticides?
____________ Yes
____________ No
____________ Don't know

IV. Knowledge of Tomato Insect Pests and their Natural Enemies

A. Knowledge of Tomato Pests (insects, diseases, viruses)

34. What are the pests of tomato that you know?

a) White fly ____________
b) Aphids ____________
c) Worms (Describe) ____________
d) Bacterial wilt ____________
e) Early blight ____________
f) Viruses ____________
g) Nematodes (root galls) ____________
h) Weeds ____________
i) Damping off (Seed nursery) ____________
j) Others (Specify) ________________________

35. In what way(s) do these pests cause damage in tomato?
(a) Reduce yield ____________ (b) Reduce quality____________

36. How severe do you believe these pests are in terms of effects on yield and/or quality of your tomato crop?

	Some effects	Large effect
a) White fly		
b) Aphids		
c) Worms		
d) Bacterial wilt		
e) Early blight		
f) Viruses		
g) Nematodes		
h) Weeds		
i) Others		

37. What proportion of the tomato production do you believe you lose to all types of pests? ________%

38. What proportion of this loss was due to viruses?________%

B. Knowledge of Natural Enemies of Tomato Pests

39. Are there insects that do not cause damage to your tomato crop?
_____ a) Yes
_____ b) No
_____ c) I don't know

40. If YES, what are they? Name as many as you can.

____

41. What do these insects do in your field? ________________

42. What do you think happens to these insects when chemicals are applied on your tomato crop?

V. Pest Management Practices for Tomatoes

43. What do you do to control your tomato pests?

_____ a) Use of resistant variety
_____ b) Plant extracts
_____ c) Other (specify) ____________
_____ d) Host free period
_____ e) Time of planting
_____ f) Crop rotation
_____ g) Nets for seedlings in nursery
_____ h) Others (specify) ____________

____

44. How do you control your **tomato virus** problems? (Please check all that apply)

_____ a) Pesticide application
_____ b) Use of tolerant variety
_____ c) Host free period
_____ d) Time of planting
_____ e) Crop rotation
_____ f) Nets for seedlings in nursery
_____ g) Others (specify) ____________

45. If you use any pesticide on tomato, where did you learn about it (them)?

_____ a) Private dealers
_____ b) Farmer field school
_____ c) Extension
_____ d) Neighbor/Friend
_____ e) NGO
_____ f) Others (specify) ____________

46. If you used any non-pesticide control method for tomato pests, where did you learn about that method? (Check all that apply)

_____ a) Private dealers
_____ b) Farmer field school
_____ c) Extension
_____ d) Neighbor/Friend
_____ e) NGO
_____ f) Others (specify) ____________

47. With how many farmers did you share information about pest management practices? ____________

48. What tomato varieties did you plant last year and why?

Variety
1.
2.
3.

49. Why did you use these varieties?

Variety	High yield	Good quality	Tolerant to diseases	Tolerant to viruses	Tolerant to insects	Market price	Seed availability	Others (specify)
1.								
2.								
3.								

50. Did you apply pesticides in your tomato fields last season?

_____ a) Yes
_____ b) No (Go to Q.61)

51–54. IF YES, please tell me which pesticides you applied last season on tomato and for which pests?

Pesticides applied	Target pest	Number of applications	Quantity applied per application
51.	52.	53.	54.
1. _____	_____	_____	_____
2. _____	_____	_____	_____
3. _____	_____	_____	_____
4. _____	_____	_____	_____

55. Do you apply these pesticides before you see the damage or afterwards?

_____ a) Before
_____ b) After
_____ c) Both

56. How effective were these chemicals?

_____ a) Effective
_____ b) Not effective
_____ c) Don’t know

57. Who applied the pesticide on your tomato?

_____ a) Husband
_____ b) Wife
_____ c) Son
_____ d) Daughter
_____ e) Others

58. What protection measures do you use when preparing or applying pesticides?

_____ a) Clothing
_____ b) Mask
_____ c) Gloves
_____ d) boots
_____ e) Other
_____ f) Nothing

59. What do you do with empty pesticide containers?

_____ a) Re-use
_____ b) Sell
_____ c) Disposal (Specify how) ____________
_____ d) Others

60. Where do you store your pesticides?

_____ a) In the field
_____ b) In the granary
_____ c) In the house
_____ d) Others (Specify)____________
_____ e) Do not store pesticide

61. What share (percent) of your total variable costs in tomato production is devoted to each of the following inputs?

Input	**Percent of total variable costs**
Plowing	
Hired Labor	
Seeds	
Pesticides	
Fertilizer	
Organic manure	
Other (specify)	

Chapter 4
Economic Evaluation of Integrated Pest Management Programs

Kamal Vatta, A.K. Dhawan and Rajinder Peshin

Abstract This paper makes an attempt to highlight important methods of economic evaluation of Integrated Pest Management (IPM) Programs. The farm level decision making process in pest management can be evaluated by using the economic threshold model, the marginal analysis model, the decision theory model and the behavioral decision model. Economic evaluation of the IPM programs, at the farm level/aggregate levels, can be carried out using cost-benefit approach, economic surplus model and econometric model. The paper further makes an attempt for micro level investigation of the impact of IPM program for cotton in Indian Punjab by using the data pertaining to 210 cotton farmers comprising 150 IPM farmers and 60 non-IPM farmers spread over 21 villages in three districts. The difference of difference technique was used to measure the impact of adoption of IPM program on extent of pesticide use and productivity of cotton.

Keywords Economic evaluation · Integrated Pest Management

4.1 Introduction

The Malthusian theory of population and food production was set false by the technological developments and their adoption by the farmers throughout the world. It resulted into relatively larger per capita increase in the food production as compared to the increase in population. This was made possible by the introduction of high yielding varieties (HYVs) of wheat during the mid 1960s and that of rice during early 1970s especially in the developing countries like India and China. The introduction of HYVs brought more and more area under cultivation and encouraged intensive use of external inputs. Pesticides have been one such input being used intensively to ensure higher production and productivity by reducing the crop losses caused by the pests. By any measure whether it be volume used, hectares

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treated, or market value, the use of global pesticide is large and still rising. During 2004, the world pesticide use reached 2.0 kg/hectare as compared to 0.5 kg/ha during 1965. In addition, the world pesticide exports also reached at the level of US$ 15.9 billion (http://www.envirostats.com). The developing countries, including China, account for approximately 31 per cent of total pesticide use in the world (http://oregonstate.edu). The pest outbreaks worldwide have resulted into a treadmill like situation with the share of pesticides in the total cost of cultivation rising in some regions from 2.1 per cent to more than 20 per cent, over time (Peshin et al., 2007).

Despite all that, there has been no significant additional return to the pesticide use. Rather the over-use and misuse of pesticides has led to many negative impacts throughout the world (Khan and Iqbal, 2005; Feenstra et al., 2000; Orphal, 2001; Ahad et al., 2001). The impact has not only been restricted to agriculture in the form of reduction in productivity via increased resistance in the insect pests but was extended to many aspects such as human health in the form of pesticide residues in the produce, exposure to the chemicals by the workers and the environmental impacts as well. Increased pesticide use led to a change in the pest scenario in many regions (Peshin et al., 2007). Very high use of pesticides has even resulted into a decline in the area under some crops due to sharp rise in the cost of cultivation.

To overcome this downward slide in productivity of cotton crop many integrated pest management (IPM) programs were initiated such as Regional Program on Cotton IPM by Commonwealth Agricultural Bureau International (CABI) in 1993, Food and Agricultural Organization (FAO)-European Union IPM program for cotton in 2000, National Agricultural Technology Project (NATP) for IPM in 2000 and Insecticide Resistance Management Program in 2002 (Peshin et al., 2007). The focus of these IPM programs was to reduce and rationalize the pesticide use by encouraging the farmers to adopt other pest management practices like cultural and manual-mechanical practices in absence of any effective bio-agents. The utility of such programs emanated out of the fact that knowledge being the fourth important factor of production, influences the decision making of farmers and hence their productivity as well as profitability.

IPM programs have been termed as highly successful in reducing the pesticide use and promoting some other benefits. With increasing trend of investment/ expenditure on IPM programs, the questions are being raised on such investments vis-à-vis the resulting benefits from such investments, which usually flow over time and are expected to be of comparatively larger extent.

The success of these programs can be justified only if they could significantly reduce the pesticide use along with the other perceived ill-effects of pesticide use in comparison to the costs incurred on these programs. It is pertinent to undertake economic evaluation of all such programs with a view to identify/compare the stream of benefits and expenditure arising over the period of implementation of such programs. This paper makes an attempt to outline the methodology used in economic evaluation of such IPM programs. It further provides an evaluation of the IPM program being implemented in Punjab, an important food basket of India.

4.2 A Review of the Decision Making Process in Pest Management

Decision making process in all economic problems is largely governed by scarcity of the resources. Pest management is one such problem. Mumford and Norton (1984) have emphasized that both the normative and positive aspects of economics can be useful in assessing the performance of pest management activities. There are four important economic models of decision making at the farm as well as aggregate level: (i) the economic threshold model, (ii) the marginal analysis model or optimization model, (iii) the decision theory model, and (iv) the behavioral decision model. A brief description of all these models has been given below.

4.2.1 The Economic Threshold Model

The concept of economic threshold in pest management has been developed through the contributions of both the entomologists and the economists. Economic threshold may be defined as that level of pest population density at which the pesticide use is justified (Stern et al., 1959). Below this level of pest population, no significant economic harm is caused to the crop and hence incurring cost on the pesticide use is not justified. Above the threshold, economic losses from pests exceed the costs to be incurred to control the pest. The model requires the information on three important parameters; (i) unit price of the crop output (P), (ii) crop yield before (Y_o) and after the intervention (Y_i), and (iii) cost of pesticide application (C). The economic loss due to pest attack may thus be expressed as below, where the left side and right side represent costs and benefits of the pest control, respectively.

$$C = (Y_i - Y_o)^* P$$

The economic losses start accruing when the costs exceed right side of the above expression. This expression may be outlined in the following form to identify the threshold level of pest attack on a particular crop. The pest population only above T justifies the pest control application.

$$\mathrm{PLRT} = C$$

Where P = Unit price of the crop output, L = Loss of crop yield per unit of pest population, R = Reduction in pest attack achieved by the pest control, and T = Level of the pest attack.

The threshold level, thus is given by

$$T = C/\mathrm{PLR}.$$

However, non availability of required information may pose problems for estimation of this model. Further, when more than one options exist for the pest control, the model may fail to single out the optimum strategy.

4.2.2 The Marginal Analysis or Optimization Model

While the entomologists are interested in working out the pest population levels beyond which the crop losses exceed the cost of control, the economists tend to determine the most profitable level of pest control for a given level of pest population. Marginal analysis model is, thus, based on the economic principle of reducing the pest population up to that level, where the marginal returns just exceed the marginal costs of pest control. The marginal analysis is based on three important assumptions; (i) profit maximizing behavior of the firm, (ii) perfect knowledge of the production function, and (iii) prevalence of the law of diminishing marginal returns.

Hillebrandt (1960) was the first to apply the concept of marginality to pest control. Using hypothetical example, she derived a dosage response curve highlighting the crop yields corresponding to different doses of pesticide use. Diminishing returns were successfully demonstrated with successive doses of pesticides. Economic threshold was thus defined as the level to which the pest population should be reduced, where marginal returns just exceed marginal costs. This concept, however, tended to create confusion amongst the entomologists and the economists. While, the former were interested in identifying the pest population levels for undertaking the pest control, the latter were interested in determining optimum levels of pest control for a given pest population. To avoid such confusion, Mumford and Norton (1984) recommended the use of economic threshold in the sense of break-even decision as given by Stern (1973).

4.2.3 The Decision Theory Model

The previous two models make an assumption of certainty, which is rarely the case in the pest management decisions. Nothing seems to be known with certainty while managing the pest problem in the fields. Often, pesticides are applied even before actual appearance of the pest and thus application is based not on the basis of perfect knowledge but on the basis of farmer's perception about the pest attack and the expected losses. Risk and uncertainty arises due to the involvement of numerous biological, technical and economic factors in the pest management. In addition, the farmer (the decision maker) also lacks perfect knowledge on all these factors. Unlike economic threshold model, the decision theory model incorporates uncertainty.

The model is based on the fact that the severity of pest attack may differ under different conditions on a particular farm. The decision maker is not perfectly aware of the severity of pest attack in advance owing to uncertainty. However, he is aware of the probability distribution of severity of pest attack i.e. pest attack can be classified into different severity levels along with the probability of such attacks to occur in future, based on the previous experience of the decision maker. As there are different pest management strategies based on the severity of pest attack, the decision maker

Table 4.1 A hypothetical payoff matrix for decision making

Action	Severity of pest attack				Expected outcome
	Level 1 (p1)	Level 2 (p2)	–	Level i (p_i)	
Action 1	R_{11}	R_{21}	–	R_{i1}	O_1
Action 2	R_{12}	R_{22}	–	R_{i2}	O_2
–	–	–	–	–	–
Action j	R_{1j}	R_{2j}	–	R_{ij}	O_j

is aware of the returns associated with each such strategy corresponding to different severity levels. All this information can be easily summarized into payoff matrix (Table 4.1). The matrix represents i-levels of severity of pest attack and j-levels of actions for pest control.

The expected outcome of jth action is actually the probability-weighted outcome for a particular action and can be expressed in the following manner.

$$O_j = \sum pi^* R_{ij}$$

Where, O_j = Expected outcome of jth action; p_i = Probability of ith level of pest severity; R_{ij} = Net returns from jth action corresponding to ith level of pest severity.

The values of p_i can be assigned on the basis of subjective as well as objective assessment. While the former are based on expert judgments, the latter are derived on the basis of past experience or information already available. Valentine et al. (1976) used both the objective and subjective probabilities for decision making in the control of gypsy moth (*Lymantira dispar*) in New England forests. Carlson (1970) also used the subjective probabilities of different levels of losses from peach brown rot (*Monilinia fructicola*) for this model to predict the crop disease and its control. To derive the net returns, the cost of control and value of output can be obtained from farmer interviews.

As per the assumption of profit maximization, the decision maker will opt for that action which corresponds to the highest level of expected returns. However, this is true only for the risk-neutral farmers, who do not consider risk as a major concern during their decision making. However, all the actions may entail a different degree of risk. Risk-averse farmers try to opt for that action which reduces the variability of outcome. Driven by twin objectives of profit maximization and risk reduction, the farmer may opt for the action corresponding to less than maximum level of outcome. Most of the decision theory models have largely considered the above two objectives. However, Norton (1982) introduced another approach, called “satisficing approach”, where the farmer’s tendency is to reject those actions which yield more unsatisfactory results based on trial and error. The Decision Theory Model is highly applicable when the short-term occurrences can be reliably estimated.

4.2.4 The Behavioral Decision Model

This model is based on the assumption that a farmer's pest control decision may not be based on the actual situation but on his perception of the situation. It may result into a lot of variations in the pesticide use across the farmers even if the crops remain the same. This is due to the reason that different farmers in a particular region, growing the same crop, perceive the pest problem and the resulting losses to a varying extent. These perceptions vary in different degrees from the actual situation in the region and on the farms and hence the variations in pest-control actions and their extents. Such differences were duly demonstrated by Tait (1977). Daku, Norton, Pfeiffer, Luther, Pitts, Taylor, Tedeschini, and Uka (2000) also confirmed such differences among olive growers in Albania.

Norton and Mumford (1983) explained the pest-control behavior with the help of behavioral decision model. The model can be further classified into static and dynamic models. The static model studies the farmer's decision for a particular crop in isolation. The model assumes that a farmer has his own perceptions of the pest problem, which may vary from the real problem. Based on his perceptions, he makes the assessment of the pest problem and evaluates the possible options. The dynamic model considers the past pest management decisions of the farmer as well as his other farm management decisions i.e. it incorporates the past behavior of a farmer regarding pesticide use and other important decisions in crop cultivation. It implies that behavioral tendencies of the farmers in a region may result into a significant variation in the pesticide use on a given crop. Further, decisions such as the cultivation of a crop like maize for fodder or for grain may also affect the pesticide-use decision.

4.3 Methodology of Economic Evaluation of IPM Programs

In this section, an attempt has been made to outline important methods being used to evaluate the economic impacts of IPM programs. As the economic benefits of IPM programs accrue not only at the individual farm level but also at the aggregate levels of village, community or a region, it is important to look at the methodology at two different levels. Hence, this section discusses separately, the methodology of evaluation at the farm level as well as the aggregate level.

4.3.1 Evaluation at the Farm Level

Any farm level intervention is broadly aimed at improving the profitability or risk reduction of a particular farm operation or a group of operations, which fits well in the overall objectives of profit maximization and risk reduction from farming. Owing to this reason, most of the evaluation efforts in past have focused largely on assessing profits and risk on the farms concerning with IPM programs.

The impact on profits has largely been measured with the budgeting technique. Many studies have measured profit to be the difference between gross revenue and the cost of adopting an IPM intervention/program. However, there have been varied measures of profits used for such assessment, which have affected the comparability of the results of these studies. Napit et al. (1988) evaluated the economic benefits of extension integrated IPM programs by using the budgeting technique for different crops. They used net returns as a measure of profits and used t-tests for measuring any significant differences to management per unit of land and costs of pesticides occurring at the user level. Trumble et al. (1997) also used the budgeting technique for economic and environmental impact evaluation of IPM program in celery. Net profits for different treatments were estimated by using the partial budgets. The evaluation established that the IPM programs caused a significant reduction in the pest population and hence, a rise in average yields and net profits. A rise in the net profits by more than US$ 410 per ha was achieved by the program with 40 per cent less use of conventional pesticides. Headley and Hoy (1987), while conducting a benefit-cost analysis of an Integrated Mite Management Program for almonds, also used the cost saving approach to estimate the impact at the farm level. A grower was expected to save US$ 60–110 per ha with the adoption of such program. Apart from improved profits, economic benefits of an IPM program may also entail a reduction in the risk. Such benefit may easily be estimated by assessing the yield variability. The coefficient of variation is an appropriate measure for judging the yield variability.

Another approach to estimate the farm level impact of an IPM program on a farm producing/using multiple outputs/inputs has been provided by Feder and Quizon (1999). The objective of a farm household is maximization of profits. The households tend to achieve this objective for a given level of input/output prices under the constraint of fixed factors of production such as land, knowledge about pest management and other factors, etc. A household's profit function can be expressed as follows

$$\Pi = \pi(\overline{P}_x, \overline{P}_y, L, K, Z)$$

Where, P is household's profit, $\bar{P}x$ is the vector of input prices, $\bar{P}y$ is the vector of output prices and $L,\ K$ and Z are the land, knowledge of the pest management and other socio-economic factors (age, family characteristics, etc.), respectively. The output and input are themselves the functions of the above variables. In the above equation, it is the variable K (knowledge about pest management practices) which is of interest in estimating the farm level impacts of IPM. This variable impacts the input use of a farmer through improved knowledge on pest management and the supply function by improvement in production through better input use. The impact of improved knowledge on input use as well as on output can be calculated by deriving the partial derivatives of input use function and supply function with respect to the variable K. Feder and Quizon (1999) have further highlighted the limitations of before-and-after and with-and-without methods of estimating the farm level impacts as they may ignore the spillover effects, simultaneous effect of

IPM dissemination efforts and long run outcomes of the program, and have established the superiority of two-stage and simultaneous equation procedures in such estimation.

4.3.2 Evaluation at the Aggregate Level

There are two broad approaches for economic impact evaluation of agricultural research programs. These approaches are economic surplus approach and econometric approach and both of these estimate the production functions concerning agricultural research or knowledge. Both these approaches have been briefly discussed in this part.

4.3.2.1 Economic Surplus Approach

This approach is widely used in both ex-ante and ex-post evaluation of economic benefits. The supply seems to shift up as a result of the adoption of an IPM program producing surplus for both the producer as well consumer. The approach tends to measure such surplus resulting from the adoption. Economic surplus further tends to measure the welfare impact of a research program/intervention. However, two important methods used under this approach are cost-benefit analysis and economic surplus model. These two methods are discussed below in detail.

Cost-benefit analysis: It is a simple method of comparing the costs and benefits emerging out or expected to emerge out of a particular project over a period of time. The purpose for such analysis is to ascertain whether investments in a project or an intervention are economically viable or not. If benefits (expected) exceed the costs, the project is termed as economically viable, otherwise not. Generally two measures are used for estimating this surplus of benefits over the costs. One, the difference between the benefits and the costs is calculated; two, ratio of benefits to costs is calculated. Positive difference between the benefits and costs in first case and ratio of more than one in the other indicate economic viability. Larger difference or ratio indicates larger surplus and hence stronger viability.

The benefit cost analysis, generally consists of three steps such as (i) Identifying the time period for which the project/intervention generates benefits since its start, (ii) identifying and estimating the stream of economic benefits and costs during this period, (iii) estimation of the economic surplus by finding differences between benefits and cost or by the ratio.

A major limitation of the method is that it assumes either (i) perfectly inelastic supply curve and perfectly elastic demand curve to estimate the value of surplus production or (ii) perfectly elastic supply curve and perfectly inelastic demand curve to estimate the value of inputs saved due to the intervention. The methodology has some other shortcomings as well as operative problems owing mainly to still unresolved difficulties with quantifying certain economic consequences of IPM practices such as benefits derived from sustained practices including human health and the environment (Feder and Quizon, 1999). Also, there are chances of omission or double counting of impacts of intervention.

Economic Surplus Model: The economic surplus approach permits the estimation of the economic benefits generated by adoption of technological innovations, compared to the situation before (without) the adoption, where only traditional technology was available. The model actually tends to assess the economic impact by evaluation of enhancement in supply as result of IPM intervention. The model tends to estimate how an increase in output and/or reduction in costs of inputs translate into shift in the supply function of the commodity under study. The shift in supply curve may alter the point of equilibrium which may change the quantum of benefits/costs associated with an intervention. The surplus arising out of the intervention may be further split into producer and consumer surplus. The model can be easily explained with the help of Fig. 4.1. Adoption of IPM technologies helps to restrict the movement of supply curve from S_1 to S_0. In the absence of adoption of IPM technology, the pests would have developed resistance to the pesticides restricting the supply. Consumer surplus is measured by the difference between what a consumer is willing to pay (rather than going without IPM technology in this case) and what he actually pays. The consumer surplus corresponding to the supply levels of S_0 and S_1 is given by FAP_0 and FBP_1, respectively and the surplus arising due to IPM intervention is given by the difference of the above two surpluses

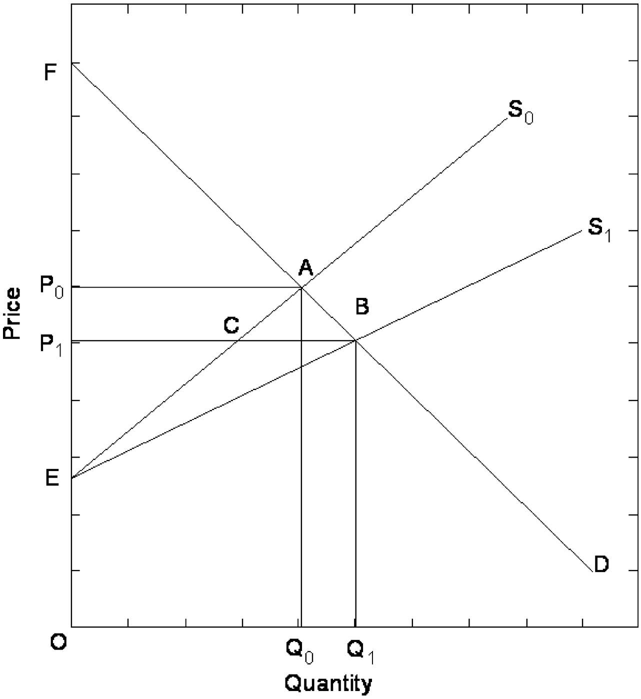

Fig. 4.1 Economic surplus from adoption of IPM technologies

and is represented by P_0ABP_1. Such a surplus arises as a result of decline in price of commodity for the producer due to shift in the supply curve from left to right. Despite fall in prices, the producer surplus arises as a result of increase in supply, which compensates the loss in profits due to fall in prices. The loss in producer's surplus due to fall in prices is given by P_0ABP_1 and gain in surplus due to increased supply of the commodity is given by ABE. Finally, the producer surplus resulting from such intervention is given by CBE (which equals the difference between ABE and P_0ABP_1). The impacts on producer depend on the elasticity of demand and supply curves. This model has an edge over the benefit cost analysis as it does not assume the perfect elasticity/inelasticity of the supply and demand curves and in fact takes into account the price response to the shifts in supply curve as a result of the intervention. The impact of IPM intervention with economic surplus model requires information on resulting productivity enhancement, equilibrium price of the product, costs, rate of adoption of the technology, time gap between research and adoption, and price elasticities of demand and supply.

Economic surplus model can be easily used in ex-ante and ex-post evaluation of an IPM program and can be effectively combined with other models for evaluation involving multiple objectives. In addition, the economic surplus model has the ability to include the effects of changes in the other variables such as economic growth and population changes, etc. on potential benefits and costs of an intervention.

4.3.2.2 Econometric Approach

These methods attempt to estimate direct relationship between the crop productivity and research intervention. This method is more appropriate for ex-post economic evaluation. While specifying the production function, yields or profits can be expressed as the dependent variables and the expenditure on the IPM program as one of the independent variables. The production functions have largely been estimated using the parametric methods of estimation. The production function can be expressed in the following manner:

$$Y_t = f(X_t)$$

Where, X is the vector of different independent variables. Once the production function is estimated, then the parameter estimates can be used to find out marginal returns of different inputs, including that of investment in an IPM program. However, the use of econometric method for impact evaluation of the IPM programs also has some limitations. First is the problem of multi-collinearity, indicating strong correlation between many of the independent variables, which affects the correct estimation of parameters. Second, some of the inputs are found jointly endogenous with the output and hence do not yield consistent estimates. In addition, many a time, omission of some explanatory variables from the production function may yield biased and inconsistent estimates as most of the effect of these omitted variables remains absorbed by the unexplained residual term of the model.

4.4 A Micro Level Evidence of Farm Level Impacts of IPM Program

In this section, we have presented the evaluation of farm level impacts of an IPM program in Indian Punjab. The state of Punjab spearheaded the green revolution in the country as a result of introduction of high yielding varieties (HYVs) of wheat during mid-sixties and that of rice during early seventies. With the total cropped area, amounting to just three per cent of entire country, its share in the wheat and rice production of the country amounted to almost 22 per cent and 12 per cent, respectively. The production system in the state is the best example of an intensive cultivation system as almost 98 per cent of the cropped area is irrigated and cropping intensity has reached 189 per cent, one of the highest in the country. As a result of intensive cultivation, the input use is also at one of the highest levels. The share of insecticide cost in the total cost of cultivation of cotton in Punjab increased many folds from 2.1 per cent during 1974–1975 (Dhaliwal and Arora, 2001) to 21.2 per cent during 1998–1999 (Sen and Bhatia, 2004). In pesticide hotspots like Bhatinda district in Punjab, it was 50 per cent of the total cost of cultivation (Shetty, 2004). This was despite the fact that many IPM programs were implemented in Punjab from time to time.

4.4.1 Sampling Details

The study was conducted in the cotton growing areas of Indian Punjab. Cotton in Punjab accounts for 10 per cent production and 5 per cent area under cotton in the country and also achieved the highest average productivity since 2000–2001. The cotton growing districts in Punjab are Bathinda, Ferozepur, Mansa, Mukatsar, Faridkot, Sangrur and Moga with more than 70 per cent of cotton growing area falling in the first three districts. For conducting this study, the districts of Bathinda, Ferozepur and Mansa were purposively selected due to the highest levels of pesticide use. The study was based on a sub-sample of the Integrated Resistance Management (IRM) program, being implemented by Central Institute of Cotton Research, Nagpur, India since 2002 in 28 districts, distributed over 10 states in India, which account for more than 80 per cent insecticide use in cotton. For evaluation of the impact of IPM in cotton, a total of five villages in each district were selected randomly from ten villages being covered under the IRM program in 2004–2005. In addition, two control villages from each district were also selected for such evaluation. Thus, out of a total of 21 villages, the data were collected from 210 farmers (10 from each selected village) for the study (Peshin, 2005).

A semi-structured questionnaire, in the local language, was distributed amongst selected farmers before the start of the cotton-growing season in 2004–2005. This was done in order to avoid the problems/discrepancies associated with recall/recollection of information by the farmers after the growing season was over. The respondents were revisited after regular intervals (with a time gap of not more than three weeks) during the crop growing season, to ensure proper and correct recording of the required information and to dispel doubts emanating while recording the data. The questionnaire focused on the socio-economic characteristics of the respondents, extent and level of adoption, input use, cost of cultivation, production and returns.

4.4.2 Analytical Procedure

The study used difference of difference (DD) model to evaluate the impact of IPM program (Wu et al., 2005). The sample selection, not being random in such studies, may result in biased estimates for the important parameters. The advantage of DD model lies in the fact that it intends to assess the program impact by differencing out the time invariant unobservable household or village characteristics which may influence the participant selection or program placement and therefore tend to remove the bias in estimates. IPM projects aim at changing farm and crop management practices in cropping systems that have become overly dependent on chemical pesticide use. Some important effects of adoption of IPM may relate to more efficient use of pesticides, improving crop yield and reducing yield variability (Fleishcer et al., 1999). In addition, the IPM adoption may affect the other input use (including labor use) and may also reduce the incidence and extent of health hazards resulting due to increased pesticide use. However, the present study evaluates the impact concerning the pesticide use, yield and yield variability of the cotton crop.

4.4.3 Results of the Impact Assessment

In this section, an assessment has been made of the impacts of adoption of IPM program by the farmers in the study area. Table 4.2 highlights the extent and cost of pesticide use, area under cultivation and yield of the crop among IPM and non-IPM farmers before and after the adoption. There was a reduction in the number of sprays on both the IPM and non-IPM farms. However, the reduction was higher on the IPM farms. While the number of pesticide sprays declined by 5.31 on IPM farms, the corresponding reduction was 4.62 on the non-IPM farms. The respective reduction in the cost of pesticide spray was approximately US$ 112.83 and 106.80 per hectare. An increase in the area under cultivation and average yield of the cotton crop was also observed on both the categories of farms. While the yield increased by 649 and by 505 kg/ha on IPM and non-IPM farms, the area under cotton crop increased by 0.81 hectare and 3.30 hectare, respectively. In nutshell, the results reveal a larger reduction in the number of pesticide sprays, cost of pesticide use and better improvement in the average yield of cotton on IPM farms as compared to that on non-IPM farms. On the other hand, the increase in area under cotton was more in case of non-IPM farms.

Before concluding on the impact of IPM adoption, it is better to examine the statistical significance of such differences on both the categories of farms. The regression results showed no significant impact of IPM adoption in reducing the number of pesticide sprays and cost of pesticide use (Table 4.3). There was also no

Table 4.2 Pesticide use, area and yield of cotton crop amongst IPM and non-IPM farmers

Particular	IPM farmers			Non-IPM farmers		
	Before	After	Change	Before	After	Change
1. Area under cotton (ha)	5.38	6.19	0.81	2.65	5.95	3.3
2. No. of pesticide sprays*	15.34	10.05	−5.31	14.93	10.31	−4.62
3. Cost of pesticides (US$)[a]	257.63	144.83	−112.83	278.63	171.83	−106.80
4. Average yield (kg/ha)	1749	2300	649	1704	2209	505

*Tank mixtures of insecticides taken as one application.

[a] At present rates 1$ = 40 Indian rupees.

Data source: Peshin (2005).

Table 4.3 Impact of IPM adoption on pesticide use, area and yield of cotton crop

Dependent variable	Explanatory variable	Coefficient	Std. error	Probability
Increase in area under cotton $R^2 = 0.11$ $F = 26.0$	Constant	10.03	1.24	0.00
	IPM adoption dummy	−7.54	1.48	0.00
Reduction in the number of sprays $R^2 = 0.01$ $F = 0.19$	Constant	4.13	0.74	0.00
	IPM adoption dummy	0.38	0.88	067
Reduction in the cost of sprays $R^2 = 0.01$ $F = 0.19$	Constant	39.05	4.95	0.00
	IPM adoption dummy	2.57	5.89	0.66
Increase in yield $R^2 = 0.01$ $F = 1.84$	Constant	2.61	0.33	0.00
	IPM adoption dummy	−0.53	0.39	0.18

Data source: Peshin (2005).

significant impact on yield improvement as a result of IPM adoption. Contrary to the expectations, the increase in area under cotton was significantly higher in case of non-IPM farmers. This might be due to significantly lower area under cultivation during the year 2003. The non-IPM farmers might have acted fast to increase the area under cotton and catch up with other farmers in the region to appropriate the benefits of Bt-cotton which promised the revival of economic viability of this crop in the region after a long incidence of severe pest infestation, significantly harming its economic viability.

4.5 Conclusions

Intensive crop production systems have resulted into very high use of inputs including the use of pesticides. Intensive pesticide use has raised questions regarding their marginal benefits and also has led to many negative impacts. Pesticide scenario has also undergone significant change over time in many places. There have been huge investments in the Integrated Pest Management (IPM) programs, aimed at significantly reducing the pesticide use. There is need for economic evaluation of such programs as huge investments need to be justified through equivalent or higher marginal returns. The farm level decision making process in pest management can be evaluated by using the economic threshold model, the marginal analysis model, the decision theory model and the behavioral decision models. Economic evaluation of the IPM programs, at the farm level/aggregate levels, can be carried out using cost-benefit approach, economic surplus model and econometric models. A micro level investigation of the impact of IPM program in Indian Punjab reveals no significant impact. The non-IPM farmers shifted a larger area under cotton, perhaps in order to catch up with the IPM farmers to appropriate the benefits of Bt-cotton, which promised the revival of economic viability of this crop after a long incidence of severe pest infestation in the region.

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Chapter 5
Eliciting Farmer Knowledge, Attitudes, and Practices in the Development of Integrated Pest Management Programs for Rice in Asia

James A. Litsinger, Edgar M. Libetario and Bernard L. Canapi

Abstract Much IPM technology for rice has been developed at research stations in Asia but on the balance little of it has been adopted by farmers who find many of the recommendations inappropriate. The farmer field school training method has made valuable inroads in overcoming this problem in that it has found that farmers value group learning and conducting farmer-led research which provides both knowledge and gives the farmers tools to fine tune technologies. For more effective training programs, extension worker and researcher team members need to better understand farmers' knowledge, attitudes, and practices. Anthropologists have developed methods to elicit ethno-scientific cultural subjective norms and perceptions from farmers which are discussed and complemented by surveys as well as other methods developed by rural sociologists and IPM practitioners.

Keywords Farmers' pest knowledge · attitudes and practices · ethnoscience · insect pest · weeds · plant diseases · vertebrate pests · agricultural extension · participatory research · farmer survey methods

5.1 Introduction

Integrated Pest Management (IPM) is the farmers' best use of a mix of control tactics that are biologically, environmentally, economically, socially, and culturally acceptable (Kenmore et al. 1985). Decision makers will base their control decisions on their knowledge and perception of pests, ecological principles that govern populations, their relationships to yield, and the interactions and cost-benefit of the mixed tactics. The first modern rice varieties were developed in the Philippines at the International Rice Research Institute (IRRI) in 1963, at a time when insecticide trials on IRRI's experimental farm recorded losses (mainly from stemborers) of 30–40% (IRRI 1964, Pathak and Dyck 1973). But such losses were not typical of farmers' fields as the trials were performed on highly stemborer susceptible varieties. Such

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published high losses from insect pests, unfortunately, set the mindset of policy makers to believe insecticides were as necessary as fertilizer in order to attain the promised yield potential of the new semi-dwarfs. A dependency of insecticide usage emerged for insect pest control which began in the 1950s and peaked during the farmer adoption period of the new rices (Kenmore et al. 1987). Before the concept of IPM was developed (Stern et al. 1959), ecological principles of pest management were largely unknown thus insect pest control stresses the use of insecticides.

The Green Revolution, initially based on prophylactic insecticide applications, produced unforeseen economic and environmental costs (Kenmore et al. 1987). Outbreaks of insects that were formerly rarely encountered were facilitated by the newly constructed irrigation systems that prompted even more insecticide usage supported by government subsidies and loan schemes (Litsinger 1989). The brown planthopper *Nilaparvata lugens* became the prime target and chemical companies focused on new insecticides while breeders developed new resistant varieties (Heinrichs and Mochida 1984). Resurgence causing insecticides promoted new brown planthopper biotypes to be selected to overcome resistant rice genes (Gallagher et al. 1994). As a consequence rice IPM was initiated in 1978 in Asia by Ray Smith, the father of IPM, with a training course in the Philippines (Smith 1972, Philippine Bureau of Plant Industry 1978). The FAO Inter-Country Program for Integrated Pest Control in Rice in South and Southeast Asia followed on which extended IPM to farmers through Farmer Field School training programs (Matteson et al. 1994).

Ecological studies showed resurgence caused by insecticides destabilized the biodiversity of insect species such that it was impossible to predict their population dynamics (Heong 1998). As a consequence, food-web chain links were shortened from loss of general and specific predators, natural enemy populations were decimated and slow to recover, and secondary pest development occurred (Cohen et al. 1994).

IPM on rice initially began with the use of insect pest and disease resistant varieties (Khush 1989) supplemented with insecticide usage based on decision thresholds. Work on economic injury levels began at IRRI in 1972 (Dyck et al. 1981). On-farm yield loss trials began on rice as part of the Cropping Systems Program at IRRI in 1976 (Litsinger et al. 1987) which provided the basis for the setting of threshold levels (Litsinger et al. 2006a,b,c). Waibel (1986) and Smith et al. (1988) showed economic thresholds were economical. Although economically attractive, adoption of rice IPM has been relatively low. While research continues to build on an immense body of knowledge within agriculture, it has also become increasingly clear that much of the post-Green Revolution knowledge does not reach farmers' fields (Price 2001). When it does, the predicted impacts often do not occur. Farmers' misperceptions was one part of the problem as they tended to overestimate the losses of pests and feared pest outbreaks if they did not use insecticides.

Goodell (1984a), in her anthropological village studies conducted during IPM training courses, also concluded that pest control is the most difficult aspect of scientific agriculture for small-scale farmers living in developing countries to master. Bernsten (1977) had come to this same conclusion. Of the various components of modern agriculture, IPM presents by far the most difficult challenge as farmers make the transition to scientific farming. The demands of irrigation, chemical fertilizers, and even of standardized agricultural credit follow more or less understandably from the operations of traditional farming and permit a considerable degree of self instruction through experimentation. In contrast IPM requires the farmer to grasp a far more complex set of concepts, much of which is often anything from self-evident, standardized, or amenable to trial and error learning.

A conclusion of the IRRI Constraints Program in Indonesia was that greater skill was needed by farmers to spray liquid insecticide than broadcast granules, and that spray volumes were lower than recommended thus coverage was poor (Nataatmadja et al. 1979). It was concluded that insecticides are too complex a technology for farmers to efficiently utilize. Most are toxic only to specific pests, can be washed off by rain, require being placed on a specific part of the rice plant, and must be mixed correctly. From the farmers' perspective, IPM technology also is sometimes counter-intuitive (Goodell 1984a). Certain expensive insecticides turn out to be the cheapest when properly used, excessive insecticide use leads to resurgence, secondary pest outbreaks and pesticide resistance, and the proliferation of some arthropods which are beneficial turns out to benefit the crop. Farmers therefore need exceptional incentive and intensive training to gain command over even the rudiments of IPM.

The degree to which farmers adopt new pest control technology depends on their understanding of pests, their familiarity with the control techniques, and availability of resources for their purchase. Pest recognition is basic to efficient control (Litsinger et al. 1980). Kenmore et al. (1985) offered a range of constraints that limit adoption of IPM that are itemized as political, social, and perceptual aspects of IPM programs that impede technology being used or hinder benefits from technology from arriving after use.

Morse and Buhler (1997) offered a different prognosis. For them the common perception of IPM was that it was born out of a crisis brought on by the unrestricted use of pesticides. The crisis was most immediately felt by farmers, but rapidly impacted upon society as a whole and solutions were urgently needed. IPM became the answer for many. But they noted that the group which promoted IPM was not farmers or politicians but scientists. They also noted that its promotion has been extremely effective. Although IPM originated in developed, high-input agricultural systems in industrialized countries, it has been heavily recommended as the appropriate system in developing countries even in areas that historically have not had high levels of pesticide usage (Conelly 1987). This effort was meant to stop the process of the pesticide treadmill from ever developing but the reality was that pesticide usage in more traditional agriculture was prohibitively expensive for farmers (Jahn et al. 1997, Heong et al. 2002).

The most common reason given for the poor adoption is the pesticide industry and their so called pesticide lobby's influence on governments. But problems have been put down to extension and research as well. It has been suggested that researchers are too narrowly focused within disciplines and lack holistic thinking. In contrast IPM requires a team of biological scientists, socio-economists, and anthropologists who can bring their many skills to bear by capitalizing on interdisciplinary teams. However the skills to do this are not possessed by many natural scientists given the fact that most of their work and training has been very narrow.

Morse and Buhler (1997) believe the main constraint to adoption is a fundamental lack of appreciation of farmers' problems by IPM implementers. Taking farmers as the starting point in the development process goes under the rubric of *farmer first* which embodies a partnership with outsiders acting as catalysts or facilitators in the agricultural development process (Chambers et al. 1989). It is interesting that the starting point is often IPM and the choice for farmers thus is limited. One can question whether this is farmer first as an *a priori* decision. Farmers may not have been asked if this is the approach that they want. Seen through this viewpoint, the evolution of IPM with all of its contradictions, failures, and frustrations becomes a very natural progress and poor adoption by farmers is easily explained – after all if it is not really meant for farmers then why should they be expected to follow it.

As in most traditional systems, rice farmers did not consider insect pests to be important compared to the other constraints they were facing such as drought and flooding. In other cases farmers agreed that insects were important but could do nothing about them. They are willing to tolerate high losses given the high cost in cash and labor for control measures. Many farmers have alternative income from fishing, livestock, and other enterprises (Conelly 1987).

Traditional agricultural systems meet the test of sustainability but have not been able to respond production-wise to the rate of human population increase (Litsinger 2008a). Thus changes in traditional systems were necessary, but as Thurston (1990) argues, a thorough understanding of these systems is imperative as a first step before changes are initiated. Part of this understanding involves learning about farmers' knowledge, attitudes, and practices (KAP) (Tait and Banpot 1987). Farmers' decision-making process must be understood to understand the rationale of farmers' pest management practices (Rola and Pingali 1993). Farmers' pest control activities reflect their individual perceptions, not necessarily the actual situation. Most perception studies to date have not explained farmers' behavior because they do not differentiate between actual losses and farmers' perception of those losses. Few KAP studies have been carried out to date, but of those that have, the primary conclusions have been that farmers cannot differentiate between pests and natural enemies, they are unskilled at applying pesticides, overuse them, and apply at the wrong time (Heong et al. 1994, Price 2001). New understandings are forthcoming however (Heong et al. 2002). Eliciting of KAP typologies and paradigms falls in the realm of ethnoscience.

5.1.1 Ethno-Science

Modern agriculture is based on the scientific method. While farmers follow another method based on their own understanding of what they consider as significant factors and relationships in their environment and how these can be combined to form a workable whole (Brosius et al. 1986, Nazarea-Sandoval and Rhoades 1994). The output of science is publications while for farmers it is energy, food, and survival. Systematic approaches to applied ethno-science are scarce and remain primarily the work of anthropologists. Ethno-science focuses on probing culturally relevant domains of indigenous people to derive folk taxonomies, hierarchies, and paradigms. Farming is an activity of indigenous people based on their own understanding of what they consider as significant factors and relationships in their environment which is known as their ethno-science and how these can be combined to form a workable whole (Nazarea-Sandoval 1991, Nazarea-Sandoval and Rhoades 1994). This is a different reality than what researchers who follow the scientific method perceive. It is unclear whether farmers perceive pests as a threat to yield or as fellow creatures with a legitimate claim for their fair share (Brown and Marten 1986, Björnsen-Gurung 2003). Farmers' knowledge about their environment and their beliefs concerning it are termed the cognized model or a subjective norm. Nature is seen by farmers through a screen of beliefs, knowledge, and purpose and it is in terms of their images of nature, rather than on the actual structure of nature, that they act (Brosius et al. 1986). Yet it is upon nature itself that they do act and it is nature that acts on them, thus transactions between farmers and the environment are guided by images of nature as perceived by them. These images or conceptualizations are partly responsible for determining how farmers evaluate, decide, and behave given certain conditions and alternatives in their daily lives. The cognized model represents farmers' understanding about their world.

5.1.2 Why Study Farmers' KAP

Exploring farmers' perceptions and knowledge allows us to clarify definitions to use the proper language and farmers' logical framework (Björnsen-Gurung 2003). All these elements facilitate communication and thus are very important for IPM programs. Ethno-agronomy is the subset of the cognized model that takes into account the indigenous knowledge of farmers (Nazarea-Sandoval 1991). The cognized model is perpetually interacting with the operational reality in which farmers find themselves – absorbing, discarding and continuously being refined by experiences and perceptions. At the same time it guides choice and behavior by influencing discrimination and explorations. Farmers cannot act on agricultural options that are unrecognized or those that are so unfamiliar that they provoke feelings of incompetence or inadequacy. Neither can they incorporate strategies that are deemed to be essentially incompatible with the existing system of production and rhythm of life's activities. In order to design and promote agricultural development programs that have a better chance of passing thorough the farmers' filtering systems and being seriously considered, researchers need to understand the ethno-agronomy of the indigenous farmers.

Farmer knowledge can differ profoundly from scientific knowledge but both have strengths and weaknesses. Farmer knowledge was valid in the past but failed to adapt to the rapidly changing rice technologies that followed modern rices. Among the

Tharu of Nepal the majority of farmers still perceive their knowledge and practices as inferior to externally promoted technologies (Björnsen-Gurung 2003).

Farmer surveys should precede applied research to ensure it is not merely an academic exercise, but before we start our discussion we need to distinguish between two cultural types of farmers' systems, traditional and modern, and know their characteristics. Discovering orderly principles for commonly occurring fauna in farmers' fields is a prerequisite for understanding the selection of management practices in decision making.

5.2 Two Types of Farming Systems

The first are farmers who cultivate crops using traditional practices with very few purchased agro-inputs such as fertilizers and pesticides. For these groups of farmers it is important to study their current systems both to learn of potential new practices but also to understand the system's subcomponents. The development strategy for such a system is making small improvements rather than replace practices with high input agriculture. Unless dynamic changes such as opening a market nearby or accessible credit at low interest, farmers will persist to be risk adverse and will not adopt modern practices wholesale.

The second group represents those farmers who already have adopted modern practices with the objective to rationalize their use of pesticides and inject alternative, more sustainable practices. In this case studying KAP is crucial in being able to address their misconceptions in order to more effectively change them. It is still possible to learn of useful indigenous practices that they developed. Agricultural extension efforts focus more on this group of farmers.

5.2.1 Traditional Low Input Systems

Traditional agriculture usually is associated with primitive agricultural systems or pre-industrial peasant farming. Poverty and socio-economic insecurity characterize the lives of many rural people and are exacerbated among the vast number of small or traditional farmers who often have few resources beyond the labor of their families. However traditional farming usually is based on agriculture that has been practiced for many generations (Thurston 1998). The accumulated knowledge would be considerable as man began crop production 10,000 years ago. Some 60% of the world's cultivated land is still farmed by traditional and subsistence methods (Altieri 1984). Small farmers have developed complex farming systems that have allowed them to meet their subsistence needs for centuries even under adverse environmental conditions (marginal soils, in drought- or flood-prone areas and with scarce resources) without depending on mechanization or modern chemical inputs. Much of the information on indigenous and traditional agriculture is anecdotal rather than experimental, much to the chagrin of researchers.

Altieri (1984) pointed out that in Latin America, at the end of three projects, an evaluation team concluded that no significant new technological packages capable of yielding increased net returns could be offered to the peasants. More holistic approaches were needed that entailed a deeper understanding of: (i) present farming practices, (ii) why they were practiced, and (iii) what is required of a new technology if it is to be accepted. Researchers have failed to consider basic features of low input peasant agriculture such as ability to bear risk, labor constraints, symbiotic crop mixtures, and diet requirements that determine the decision criteria and resource use by farmers.

Among primitive and peasant societies, cultural values and attitudes, beliefs, and behavioral patterns often play an equal or greater role than economic considerations when deciding whether to accept or not new production practices (Thurston 1990). Kinship obligations, peer group pressure, fatalistic beliefs, negative social sanctions regarding accumulations or surplus, individuality, caste differences and constraints, and the perpetuations of common traditional values through family socialization all represent serious challenges to outside change agents. Researchers must appropriately address problems in the context of farmers' systems before efficient, proven techniques can be disseminated to other farmers. Understanding traditional agricultural systems and taking them as a basis for development, including the use of effective traditional methods is the starting point for IPM (Matteson et al. 1984). The problem is that entomologists too often discount small farmers' traditional pest control systems. But not all traditional practices are environmentally friendly as believed by some by definition. Cultural practices, for example, include such ecologically harmful activities as pouring kerosene and whale oil on the paddy water, use of nicotine and chili pepper sprays, arsenic laced chemicals, and the use of fire (Litsinger 1994).

The basic premise is that appropriate technology for farmers must emerge from agro-ecological studies that identify the conditions influencing traditional cropping systems. For example in Batangas, Philippines, farmers grow dryland rice by direct seeding in furrows and even perform inter-row cultivation for weed control with the same implement (*lithao*). The main weed is nutsedge *Cyperus rotundus* which cannot be controlled by normal cultivation and hand weeding is too expensive. Thus farmers run a spike-toothed, box harrow at 45° angles to the rice rows during the first month of rice growth, to uproot nutsedge but also ripping out some rice plants. This occurs repeatedly until canopy cover. Farmers overseed to compensate. The method works satisfactorily except in years of frequent rain during the first month after crop emergence making the soil too wet for the animal drawn implements to be pulled. Still until a better method to control nutsedge is found, farmers will continue with their traditional method. A similar remedy was developed in rainfed wetland rice in S. Asia called the *beusani* system for grassy weed control (Fujisaka 1991).

An analysis of small farm systems cannot be done from a conventional farm-management appraisal whereby labor scarcity, small farm size, lack of modern technology, or low land productivity are singled out as the main constraints (Altieri 1984). Although the productivity per unit of land may be low, the farmer may obtain a high level of productivity from other resources which are scarcer to him, or unknowingly enhance the energy efficiency of his cropping system by maximizing the ratio of food calories obtained to cultural energy investment. Thus meaningful analysis must incorporate the farmers' management standards and farmers' production criteria, especially with regard to risk. Risk avoidance is traditionally expressed through farm diversification, often by using products of one enterprise in the production of another. A common example is a crop-livestock system.

A first step towards the development of successful IPM strategies adapted to farmers' realities is an understanding of farmers' perceptions of pests, existing control methods, and costs and efficiency of control measures (Adesina et al. 1994). But there are strong arguments to build IPM strategies on the indigenous knowledge base of farmers. One should do so knowing there are likely to be gaps in their knowledge, especially on biology and ecology. Thus studies should focus on both aspects. Social and biological scientists should work closely together to understand farmers' perceptions in order to enhance their management skills.

5.2.2 High Input Farming Systems

Adoption rate of IPM technologies by farmers who have embraced modern varieties and agro-inputs is determined by the degree of relevant site-specific adaptive research that is performed to identify the best fit of modern and traditional agronomic and pest control practices (Reichelderfer and Bottrell 1985). As a part of the knowledge required to undertake this process, researchers' understanding of farmers' current practices and the basis for them is a key component which is efficiently carried out by a characterization of the stakeholders. Farmers often have not had adequate training and misapply inputs such as injudicious insecticide usage which affects the stability of the agricultural system (Heong et al. 2002).

5.3 Useful Purposes for Eliciting Information

There are many useful reasons for gathering information from farmers in their communities with regard to IPM. Part of the problem is that local knowledge is relatively unformulated and for this reason is difficult to access (Trutmann et al. 1993). It is also a farmer's problem. There is no forum, no institutionalization that could lead to the pooling, exchange, and local assessment of this knowledge. Consequently farmers are forced to be inquisitive and innovative, but beneficial ideas of one farmer are often not extended to other farms.

5.3.1 Discovering Indigenous Technologies

Reasons to study agricultural activities of traditional farmers are first that some traditional farming systems have excellent records of research management and conservation (Thurston 1990). Systems that have lasted for millennia justify serious study, although practices and systems developed by traditional farmers are not always successful. Second, as many traditional practices are labor-intensive; this aspect may be important and attractive in societies having an abundance of labor, chronic unemployment, and lack of jobs in urban areas to pull them away from farms. Capital and technical skill requirements of traditional technologies are generally low and adoptions often require little structuring of traditional societies.

Although considerable evidence shows that traditional farmers experiment and innovate, most useful traditional methods of agriculture probably were developed empirically through millennia of trial and error, natural selection, and keen observation (Thurston 1990). Traditional systems, especially in the tropics, frequently resemble natural ecosystems that, with their high level of diversity, appear to be stable, resilient, and efficient. Traditional farmers are not always interested in the highest yields but may be concerned more with attaining stable, reliable yields. They minimize risks and seldom take chances that may lead to hunger, loss of their land, and the need to seek work in low paying jobs in a crowded city.

Often traditional farming practices provide effective and sustainable means of disease control. Traditional practices and cultivars (land races) have had a profound effect on modern agriculture and most of our present practices and cultivars evolved from these ancient techniques and plant materials. The agricultural system of traditional farmers including their pest control practices are in danger of being lost as agriculture modernizes. Those practices should be studied carefully and conserved before they disappear.

5.3.2 Farmer-Led Research

Farmers, by the very act of farming, are carrying out adaptive research, a fact which is often ignored by planners and scientists (Fujisaka 1991). “Farmer as expert” is the credo of the farmer field school training method (Matteson et al. 1994). Farmers are professional specialists in survival, but their skills and knowledge have yet to be fully recognized. The origins of many farmers’ contributions to current agricultural practices and to the research agenda are not well documented (Thurston 1990). Many ideas which have their roots in farmers’ minds and fields and are observed by researchers, later become established as recommendations.

As Bentley (1992a) observed there is no way that scientists can develop all the technologies farmers need for the many different types of agricultural environments. Anthropologists can help the farmers undertake some of this adaptive research themselves. They can help by figuring out what the farmers know and what the scientists know and then teaching the farmers what they need to know in a way that is consistent with what they already know. This sounds easy and obvious but in actual fact can take years to perform. Farmer-led research encourages farmers to undertake their own experiments. Some farmers are scientists who need to be sought out and to take part in farmer training programs. For example one farmer in Honduras made an artificial diet based on tortilla dough to rear armyworms to identify their parasitoids. Farmer-led research, if properly designed, can fulfill the large gap of fine tuning technology to local environments.

Ooi (1996) found Indonesian farmers rely on knowledge developed by other farmers, reinvent ideas brought from the outside, and actively integrate them into complex farming decisions. Hence it is important to develop processes for farmers to learn how to answer their own questions. Experimentation is not alien to farmers as they are continuously doing this as part of the farmer's own agricultural performances. It is difficult for researchers to work with farmers but not the reverse (Bentley 1994). Farmers constantly experiment and some technologies spread spontaneously such as modern varieties but rarely IPM. Although styles are different – farmers generally try one thing at a time using the field as the experimental unit, whereas scientists divide the field into small plots. Farmer participatory research is not for beginners and requires a number of years for researchers to learn the process. Part of success in developing practical IPM systems in Zamorano, Honduras was filling in knowledge gaps of farmers and letting them develop the technologies.

In the past several decades, agricultural researchers have increasingly considered farmers' perspectives in asking and answering of problem solving questions (Fujisaka 1993). Farmer-oriented approaches have included building on indigenous technical knowledge and farmer participatory experiments. Such approaches incorporate farmers' knowledge in research formulation, involve farmers in testing of innovations, and complement research conducted in the developed world and international research centers.

But there often is a social distance between university educated researchers and undereducated farmers. The social distance mentioned in Bentley and Andrews (1991) was ameliorated in part in IRRI's on-farm research programs as researchers lived in the local town and work crews and staff were hired locally. Thus the staff were the offspring of the targeted farmers and bridged the gap between researchers and farmers. It is the farmers who adopt and integrate technologies into their systems. Farmers have both traditional- and outsider-derived knowledge as well as knowledge generated by their own experience. Many pest problems are new so there is little traditional knowledge. Farmers have to live by their creativity and skills. Farmers undertake experiments by trying new varieties in small plots but their basis for experimentation and invention is limited due to their scarce resources. Absence of microscopes and knowledge of basic science limits their capabilities to observe.

Critics of the technological package approach to agricultural development charge that past programs lacked understanding and appreciation of the ecological and socio-economic milieu they are operating in, exclusion of the small farmer as both collaborator and beneficiary, and inept promotion of inappropriate technology (Matteson et al. 1984). As a result the development and extension of improved agricultural technology for small farmers in the tropics is being re-examined.

Interaction of researchers and farmers can insure appropriateness of new technologies (Watson and Willis 1985). Inattention is more likely to lead to non-adoption. Farmers act in the present and researchers plan to prevent future problems. Better integration of these divergent approaches can help establish appropriate, sustainable, and socio-economically feasible agricultural techniques. Farmers' knowledge is good for noting years and seasons of high or low pest infestations (time and season) as well as for spatial distribution in an area and ecological zones.

5.3.3 Facilitate the Extension Process

Studies of farmers' knowledge should examine how pests are perceived as well as identify gaps in their knowledge and important areas where natural scientists and extension agents could provide critical input to assist farmers (Adesina et al. 1994). It is important for social and natural scientists to work closely together in order to understand farmers' pest perceptions, enhance their pest identification and management skills, and identify farm-level constraints to adoption.

The knowledge gap between what farmers know and what they should know is great thus research to integrate communication sciences and focus on the delivery end of the science-practice continuum is most needed (Heong 1998). There needs to be a synthesis and distillation of information such as heuristics which farmers can test. Understanding how farmers make decisions is vital to being able to interject changes as needed. IPM is often developed with little understanding of farmers' objectives, needs, and constraints.

Matteson et al. (1994) concluded many farmers are too indoctrinated to contemplate the possibility of not using insecticides. They excuse the insecticide's lack of visible effect on the crop based on the assumption that losses would have been worse without treatment. Developing countries' farmers have developed an ingrained, uncritical, and dependent attitude toward pesticides. That attitude exists because of ignorance, fear, and passivity. After four decades of demonstrations and commercial promotions, some farmers are overconfident of their mastery of pesticide application and its value. Misunderstanding of costs and benefits makes simple prescriptions for prophylactic pesticide applications appear attractive and undemanding compared to IPM. Much of the insecticide is applied in a preventative manner and is unnecessary. An understanding of the roots of these misperceptions forms a basis for extension programs.

5.3.4 Compare Farmers' Practice to National Recommendations

It is instructive to adaptive researchers that farmers have modified many recommended crop production practices including input usage (of seeding and agrochemical rates) and application frequencies. The current crop husbandry represents a synthesis of modern scientific farming (new semi-dwarf seeds and purchased chemicals) with traditional practices (Goodell 1984). The outcome shows how farmers have adapted the new farming methods into their production system over a span of less than two decades. Of twenty-one crop production and pest management practices evaluated, farmers and researchers agreed on only eight (Table 5.1). The

Table 5.1 Comparison of agronomic and pest management practices between farmers' methods and national recommendations based on a survey in an irrigated, double-rice crop site, Guimba, Nueva Ecija, Philippines, 1984–1985[a]

Agreement between national recommendation and farmers

1. Number of tillage operations in seedling nursery and field
2. Maintain flooded rice field until ripening stage
3. Split application of fertilizer to field
4. Choice of agrochemical products
5. Apply one herbicide application
6. Weed control combination of good land preparation, continuous flooding, herbicide usage, and spot weeding
7. Insect control combination of use of resistant cultivar, cultural practices, and chemical control
8. Disease control based on resistant cultivars

Farmers' practice differs

1. Use of non-approved rice cultivars
2. Interval between tillage operations in land preparation less than 1 week
3. Doubling or tripling seeding rate
4. Flood a level, wet seedling nursery 5 cm deep instead of dry bed method
5. Do not realize the importance of weed control in the seedling nursery resulting in transplanted weeds
6. Transplant seedlings 50% older
7. Plant hills randomly, not in straight rows
8. Apply 33–50% more N fertilizer
9. Fertilizers not applied basally
10. Apply insecticides prophylactically either tied to the timing of fertilizer or when neighbors sprayed
11. Underdose herbicides and insecticides by one-third or one-half
12. Spray volume for insecticides and herbicides less
13. Use insecticides to control fungal and bacterial diseases

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[a] 34 farmers interviewed.

differences can mostly be explained by the divergent approaches to technology development (Litsinger 1993).

Most of the recommended practices were developed in replicated experiments on research stations with the results tested in farmers' fields. This reductionist approach involved a series of experiments where only one or two variables were tested at a time while holding the other practices constant under stress-free conditions (optimal land preparation, water management, and fertilizer application were provided; pests were eliminated by frequent, high dosage pesticide applications). Farmers, on the other hand, evolved their practices in a holistic manner by trial and error under a background of dynamic stresses. The holistic approach to experimentation, varying one or several practices among those comprising a crop production system, allows expression of a multitude of interactions. The reductionist approach, on the other hand, is designed to prevent unwanted interactions. The scale of the trials also is vastly different leading to errors in extrapolation. Researchers lay out 50–100 m^2 plots while farmers test new ideas on a scale 10 to several hundred times larger. For example, it may be easy to evenly sow a dry bed nursery of 5 m^2 but if this were done on a scale of 500 m^2, the tedious work would result in less even seed distribution. Both researchers' (reductionist/scientific) and farmers' (holistic/-traditional) approaches have significant contributions to make, but the resultant best fit is highly location specific. In general, farmers need assistance in understanding scientific farming while researchers need feedback from farmers on the performance of new technologies under farm conditions.

5.3.5 Training Needs Assessments

Often learning what farmers do not know is as important as what they know (Bentley and Andrews 1991) as this will lead to what to focus on in training programs. Studies have shown that beneficiaries of training programs, no matter what training topic, become bored if the material is already known to them. On the other hand, it is obvious that more time is needed to explain information that is less well known by farmers. By prioritizing training efforts in terms of what is least known among the concepts that should be learned, the courses can become more focused and therefore more effective. KAP studies are instrumental in discovering what farmers do not know.

5.3.6 Undertaking Projects to Improve IPM

Most of the KAP studies were conducted either as part of regional projects to improve local production or from exercises to improve extension methods. In the former case a number of the studies were done in conjunction with farming systems research that was embraced by IRRI in Asia or Zamorano Agricultural School in Honduras.

In Asia the most cited in this chapter is the study in Central Luzon, Philippines that involved the input of anthropologists and other social scientists working hand in hand with biological scientists to test the farmers' interest and ability to adopt IPM and examine socio-economic and organizational constraints to IPM at the field level, understand farmers' KAP concerning pest control, evaluate IPM technology on-farm, and incorporate IPM technology in an extension course for farmers and to test the course's effectiveness as a method of technology transfer. The project later morphed into the Farmer Field School method.

The Zamarano project also used the services of an anthropologist and was a long term project to enhance IPM adoption among maize and bean subsistence farmers in Central America with many of the same objectives as in the Philippine project.

5.4 KAP Information Eliciting Methods

Elicitation of information from farmers by various methods should be confirmed by in-depth field observation of farmers' behavior (Matteson et al. 1984). Some methods are descriptive of existing cropping systems and the array of farmers' attitudes and practices. Others are directed to pest control that describe farmers' perceptions and objectives and the control measures available to them (what methods of control do they adopt, and when and at what level to use them). They must also assess which pests the farmer thinks attack crops, how often, what damage is thought to incur, what worst loss is thought likely to be, what control measures farmers are aware of, and how effective they are considered to be. Anthropologists and ethnoscientists approach data gathering in a different manner than biological scientists. Pest management personnel are most interested in learning of farmers' control methods and their recognition of the most important pest problems. Anthropologist are interested in learning of farmers' knowledge systems as a prerequisite for constructive collaboration between farmers, scientists, and extension services.

5.4.1 General Information Elicitation Pointers

Gathering good data requires considerable familiarity with the farmers in terms of project objectives. It is best if enumerators are hired from the location itself and who are familiar with local dialects and social conditions (Zandstra et al. 1981). Surveys to find the farmers achieving the highest yields and compare their practices to those with the lowest yields is a useful exercise when trying to improve farmers' IPM practices.

5.4.1.1 Stratification of Surveys

Surveys are normally stratified by location, farm size, rice culture, irrigation type, varietal class, subsistence vs. commercial, employment full or part time, ethnicity, or by ecological zones. Stratification allows for greater explanatory powers upon analysis.

5.4.1.2 Accuracy of Information

Farmer surveys of all kinds involve an investment in time and resources, thus one should strive to conduct the inquiries in as efficient manner as practical. Adequate replication will reduce sampling error. Within each stratification class at least 20 farmers should be interviewed. During the process of analysis if questions arise one can revisit the farmer for clarification or else follow-up surveys can be conducted.

In IRRI's Farming Systems Program in Iloilo, Philippines, farmers said their farm size was significantly lower than it really was. They in turn may not know the real farm size as when fields were measured by a tape it was found that farmers with small holdings overestimated and those with larger holdings underestimated farm size. Obtaining accurate yield data therefore is often difficult. In Thailand a constraints study noted farmers tended to underestimate yields when compared to crop cuts taken in the same fields (Adulavidhaya et al. 1979). Differences were as high as 28% but in one location they overestimated by 15%. In Chhattisgarh, a new state India, researchers at Indira Ghandi Agricultural University in Raipur who took yield cuts and also interviewed farmers found farmers were conservative and under-reported yield by some 10–15% on a regular basis. Their reason was to appear more poor in order to receive entitlements handed out by government. Other sources of error are the measuring units used by farmers. In Chhattisgarh farmers measure rice seed used in transplanting by a box, but the size of the box varied from 2 to 3 kg capacity depending on the location. Farmers also report yield in sacks and in the Philippines these are 50 kg and in Chhattisgarh are 70–80 kg. The capacity of the sacks can vary a great deal and even the farmers' memory of how many were harvested can also vary as few take written records. Often a share of the harvest is given to harvesters who provide labor and is not counted as yield. The most accurate method is to undertake a total yield cut of 25 m^2 in 5 stratified locations of 5 m^2 increments in the field at harvest. Determining pesticide dosage is also dependent on knowing the area of the field, the concentration of the pesticide, and the volume of material consumed.

Whatever method is used when asking farmers questions there is a need to focus on, a specific field, a specific crop, and a specific year for more accurate responses. For example, the question of "what insecticide do you use", farmers may think you mean "have ever used" vs. "what I used last crop". In such surveys one should ask the farmer to reflect on the last harvested crop. All questionnaires should be pretested with five or more farmers for accuracy of wording and utility of questions. Each question should be carefully thought out and wording should be in the farmer's language. Often farmers till several fields that may be widely separated thus it is important to have the farmer answer questions for one of these fields rather than all of them as the management may vary between them. Often fragmented fields are on different soil types and some may be irrigated while others rainfed.

Questionnaires should be preceded by informal surveys to learn terms farmers use and to develop ideas of the kinds of questions to ask. One should triangulate the answers by using other elicitation instruments on the same farmer population. Informal inquiries can be followed by more formal ones. Direct observation should be combined with surveys by questionnaire for verification.

The process of learning from farmers is iterative. Farmers' responses lead to new questions and thus more surveys. What matters more than how many farmers are interviewed is what questions are asked. The sample size at the end of the iterative process of multiple surveys may be in fact be large. In our opinion it is better to perform a number of successive surveys, each building from the last, than conduct a single large survey where lengthy questions become tedious for farmers, resulting in less useful information.

Goodell et al. (1982) noted that if the interviewer were an outsider and not known by the farmer then farmers may think the interview is a test. For example to the question of how many insecticide applications were given last season, farmers may want to please the interviewer and show they are a cooperating farmers with government programs. They believed therefore that a "good" farmer would apply pesticides more frequently. In fact we heard farmers state they sprayed weekly when in the presence of government agents when in fact they only sprayed a few times a crop. Farmers are suspicious of outsiders that represent the government and thus may underestimate yield and farm area. Therefore it is very important to instill trust. Once trust was established farmers were most vigorous in providing scientists with accurate interpretation. One way to ensure trust is to hire field staff from the farm community and to engage in long term contact. If these local people can be the interviewers accuracy of information will increase.

5.4.2 Elicitation Methods

Methods fall into two major groups – informal and formal. Informal methods refer to surveys undertaken without questionnaires.

5.4.2.1 Informal Survey Methods

During problem identification or when first working in an area, informal surveys are methods that can quickly gather broad descriptive data about farmers and local conditions. Informal interviews allow farmers and others to express their experiences without excessive structuring by the interviewer. This approach allows both the interviewer and interviewee to pursue topics of interest freely and in depth. When interviews are conducted in a relaxed and friendly manner, the researchers and farmers will have a chance to become better acquainted. This gives the researcher time to become acquainted with farmers' vocabulary, concepts, and ideas. This form of inquiry should lead to a much deeper understanding of the farmers, their farming systems and environment, how they reason, and their decision-making process. While informal methods have their disadvantages, they also have an important role to play. They aid the team in quickly learning about farmers and farmers' conditions and obtaining an early appraisal of researchable problems and opportunities.

Participant Observation

This obvious method takes many forms starting with the most simple approach of talking to a farmer either in his or her home or preferably in the field. Opportunities to verify farmers' knowledge of pests can be realized by asking questions about a pest problem that is in the field at the time of the encounter. This questioning will produce the greatest accuracy in terms of what pest damage really looks like. The drawback is that only a few pests are likely to be in the field at any one day. However this method is best practiced by members of research teams who live in the area and conduct on-farm research trials, thus they are in the field almost on a daily basis and will informally meet farmers throughout the crop cycle.

Weed scientists, Rao and Moody (1988), provided an example of participant observation in Guimba, Philippines where three farmers were observed daily by A. N. Rao who lived at the site for a cropping season. Each day he visited the fields of the collaborating farmers to observe their work and condition of the crop. While time consuming this did lead to a number of discoveries of hitherto unknown weed problems and the farmers' perception of those problems along with developing practices in dealing with them. Participant observation is useful for learning about practices that the interviewer is not aware of and thus will not ask such questions as he or she has never seen the situation before.

Photos of pests and their damage were used in early studies (Litsinger et al. 1980, Heong 1984) but it was found that farmers could not conceptualize many groups of pests by this method. Farmers recognized the larger insects such as mole cricket and rice bug but not smaller ones. Damage, small insects, or disease were least recognized from photos that were not life size. In Malaysia, farmers were able to recognize tungro from photos (Heong 1984), but other diseases are less recognizable. Nazarea-Sandoval (1991) underscored the problem with photographs as well as even specimens taken out of the field. In her typology of Laguna farmers she categorized arthropods on the basis of locomotion, sound, and smell over morphological ones. She added that farmers' inability to respond correctly to static or inanimate specimens could be easily misinterpreted to mean lack of knowledge when actually the informants were more attuned to discriminating among live ones that move, buzz, exude odors, and bite.

An improved method was employed to bring specimens of insects or damaged plants for farmers to identify (used by Litsinger et al. 1982 and Fajardo et al. 2000). Interviewing in the field is even a better method but is more time consuming (Fujisaka et al. 1989). In that way farmers can see the distribution of damage which is diagnostic for some pest groups (occurring in patches) that can be differentiated from soil problems (general uniformity) for example.

Participant observation, of course, is the method of choice of anthropologists. A deeper engagement in participant observation, involves actually living with a farm family over a season or more. Grace Goodell lived in three villages in C. Luzon, Philippines for 2.5 years and observed farmers' behavior firsthand regarding their farming practices including pest control. Other anthropologists such as Gretta Watson who lived among farmers in Kalimantan, Indonesia for more than a year produced insights on farmers' KAP that would not have been possible otherwise. Jeffery Bentley who worked in Honduras and Sam Fujisaka with IRRI spent weeks among farmers but did not actually live in project villages, however their staff did. Support staff were hired from the local villages themselves thus they had familiarity with the location and farmers. Often in sites several ethnic groups live in the area thus it is important to have field staff who are from each of the groups in order to communicate effectively.

Role of Anthropologists

High input systems such as irrigated rice have generally been left to economists but the attraction to indigenous knowledge has gone hand in hand with low-input systems (Price 2001). This is in part due to the unique abilities of anthropologists for language and behavioral analysis. Several variables may influence the way in which researchers perceive the knowledge of farmers: (i) the scientists' values, (ii) assumptions about the nature of scientific knowledge, (iii) dislike of simple technical alternatives, and (iv) unjustified assumptions about the farmers' constraints and opportunities (Moody 1994). Scientists have rarely investigated the reasons behind the practices that farmers mentioned. Thus the science underlying rational practices and myths behind "not-so-scientific" practices have not been understood. Consideration of the farmers' values instead of the superimposition of researchers' values on those of the farmer are valuable (Altieri 1984). Therefore the input of social sciences in multi-disciplinary research teams becomes imperative.

Anthropologists, archeologists, ethno-scientists, and geographers and to a lesser degree ecologists, economists, and sociologists have more disciplinary tools to better understand traditional agriculture than is the case for biological scientists (Thurston 1990). Those in the agricultural sciences seldom take courses in these disciplines or read much of their literature with the occasional exception of ecology and economics. Likewise professionals in non-agricultural disciplines often do not read agricultural literature or take courses in production sciences. Consequently each discipline develops a separate language that is often unintelligible to outsiders.

Recently anthropologists utilized free listing, pile sorting, and triad testing to measure ethno-entomological knowledge in the Philippines and Nepal (Price and Gurung 2006). Free listing is an exercise to elicit as many arthropod names as exist in the particular tribe being interviewed. Pile sorting is an exercise in validating the list and triad testing determines the classification system used. In triad tests, farmers were asked to observe three items and to isolate one on the basis of perceived difference and pair two on the basis of similarity. They were asked about the basis for their choice. Nazarea-Sandoval (1991) added another method which asked one farmer to describe an arthropod to another farmer without the latter seeing the arthropod by facing the other way. The exercise was performed as a contest or game to get the farmers more interested in cooperating.

Farmers and scientists share different knowledge bases and can learn much from each other (Bentley 1992a). Scientists are generally reductionists and miss many interactions as they do not farm or put the system together as farmers do. On the other hand, farmers lack knowledge on ecology and biology. It is a role of social scientists (particularly anthropologists) to bring the two together.

While it is highly useful to have anthropologists join a team of economists and biological scientists, often distances between disciplines and personalities get in the way of smooth working relationships. Each side must exercise patience. Below are some of the contributions and insights that an anthropologist provided when she joined a multi-disciplinary team; these were summarized in a workshop held at IRRI on the topic (Goodell et al. 1982):

1. The role as mediator between farmer and scientist could only be temporary and should not be used a crutch for either party in the process. Agricultural scientists are a part of the farmers' world and vice versa so they must learn to deal with one another,
2. Farmers are often reluctant to deal forthrightly with scientists and their staff,
3. Initially the farmers were suspicious of the motives of the anthropology team members. A strong peasant movement in C. Luzon in the late 1940s and 1950s

left no socio-political structures in tact and few active local leaders; indeed it made the rural population highly suspicious of outsiders, especially young organizers, and

4. The anthropologist sees technology as a process in any society's growth. When scientists are working in a highly competitive sector of a society with a long history of colonialism, they must be aware of farmers' timidity, obedience, and dependence. Scientists developing technology for farmers must bear in mind the infamous history of middlemen who buffer the elite from the farmers and vice versa. The role of the anthropologist was in forming lively farmers' organizations by helping farmers make scientists interact with them directly as partners in their own development. Because few scientists considered farmers' frank exchange as a requisite to technology development, the anthropologist's systematizing of farmers' feedback was a service to the scientists themselves. She proposed that farmers might make more lively partners if they interacted with scientists in groups (consolidated by mutual interests and the routine practice of some form of collective action) rather than as individuals in the long, formal, one on one standard interviews IRRI is famous for.

Use of Para-Anthropologists

An experiment was conducted in the Zamarano project of training agriculturalists in anthropological techniques, to become para-anthropologists (Goodell et al. 1990). Not explicitly identifying themselves with the project, the para-anthropologists followed open-ended inquiry techniques to corroborate, at the local level, information already obtained through national and regional surveys and reconnaissance surveys, such as rural health and education conditions, the role of women, farm families rhythm of work and expenditure, off-farm economic opportunities, and community politics. The para-anthropologists downplayed their knowledge of agriculture in order to encourage the farmers to teach them what they knew and were learning from the project. After an initial period in the field, these informal investigators chose key informants representing a range of farmers stratified according to wealth, education level, initiative in and receptivity to innovation in agriculture and the home economy and industriousness.

The following are insights from the para-agronomists regarding procedural advice on running a similar project:

1) Begin work in the collaborating communities several months before the research or extension team does,
2) Hold a meeting with as many villagers as possible to present some explanation for your presence in the community, so that they can give you an identity (though this need not be very detailed),
3) Expect your work to start slowly,
4) Dress simply; avoid using details of dress which villagers associate with extension agents (e.g., caps, boots, uniforms),
5) Do not use the same kind of motorcycle as technicians,

6) Cultivate the villagers' vocabulary,
7) Do not show your knowledge of agriculture, you will get the root of their understanding if they feel they must explain the basics to you,
8) Be willing to perform small favors for your informants, such thoughtful gestures help cement personal relationships,
9) If villagers see you frequently or for long periods of time with project staff they will be less inclined to give you accurate feedback,
10) Organize on a weekly basis the themes you want to investigate, the informants will seek you out, and the outstanding questions left over from previous visits which you still want to pursue, leaving yourself some leeway for investigating the unexpected,
11) It is usually more efficient to conduct informal research in the late afternoons or evening when farmers are not busy in their fields,
12) Keep a good sense of humor, don't be aggressive, and be pleasant,
13) Follow the villagers rhythm of life and participate in religious days and celebrations when possible,
14) Every aspect of the work becomes easier during the second year, you will feel less self conscious you will have friends in the village, and your teammates will respect your work, and
15) If you are to be replaced have a few weeks overlap.

Role of Psychological Methods

Entomologists, attempting to change farmers' behavior, have worked with behavioral scientists and have attempted to understand the farmers' psyche to delve into his attitudes and beliefs particularly in regard to insecticide misuse. The basic idea is to learn the current belief system in order to be able to change it. Bandong et al. (2002) undertook detailed interviews from farmers who recently applied insecticide to determine what motive did the farmer initially have in going to the field when the decision was made. Numerous studies have shown that farmers mostly react to seeing insect pests or their damage, although some apply in a prophylactic manner based on crop growth stage or react when they see a neighbor spray. Questions were posed that followed up on what observations the farmer made: did he make the decision from afar or did he enter the field to inspection plants, how often does he visit the field. What units of measurement were used in estimating pest density. What insect stage or damage symptom was measured. The researchers concluded that in the absence of both extension workers and farmers' organizations to provide guidance, farmers individually have evolved their own individual decision protocols.

Heong (1998) and Heong et al. (2002) have campaigned against overuse of insecticides by farmers and have embarked on mass media extension programs to overcome this behavior. They have measured farmers beliefs, attitudes and subjective norms through a series of statements posed to farmers and asked them to reply as to whether the statement as to how strongly they believed on a five point scale from "definitely not true", "in most cases not true", "may be true", "in most cases true", and "always true" using prompt cards. Some of the statements were "applying insecticides will increase yields", "killing all insects is important", "some insects are beneficial to rice yields" and "insecticides are harmful to health". They also elicited ways that they determine the harmfulness of insect pests and the role of peer pressure from government agents, chemical company representatives and people in the village.

Heong and Escalada (1997a) stress that to change farmers' misperceptions new elements must be introduced into the cognitive structure, e.g., different perception or information which introduces conflict to motivate change. They used psychological theories to this end. The manner by which new information fits into the cognitive structure will influence how it will be processed. New information which requires less change in cognitive structures would have more chance of being accepted. On the other hand information which challenges the cognitive structure is more difficult to integrate and is likely rejected, or distorted to fit, or lead to a change in the cognitive structure itself. When faced with uncertainty people often use decision rules or heuristics. Heuristics are learned through experience. Without having to retrieve all the information in stored memory these simple rules help humans organize and interpret new information. Cognitive dissonance is information that conflicts with existing attitudes, choices or behavior that can lead to a state of psychological dissonance. This usually leads to a re-evaluation of the two choices. If given a simple decision rule that is in conflict with prevailing perceptions is introduced would farmers be motivated to assess it in order to resolve their dissonance. The heuristic that was introduced was that early season defoliating rice insects do not cause significant losses thus farmers should not apply insecticides for the first 40 days of a crop. Heong (1998) found that simple experiments established in farmers' fields rapidly changed their perceptions and attitude leading to less insecticide usage.

5.4.2.2 Key Informants and Group Interviews

Multi-disciplinary team visits and informal discussions individually and with groups of farmers normally are carried out at the start of a project during the planning stages. This was used by Litsinger et al. (1980) in interviewing rainfed rice farmers in three sites in the Philippines as part of the Cropping Systems Program on-farm project at IRRI. Informal group interviews particularly were held. Fujisaka et al. (1989), with the same objectives, also engaged in open ended, informal interviews of individuals or groups of farmers. Such interviews served to elicit information on farmers' diagnoses of pest problems and traditional and current control practices.

Farmers are more comfortable in meeting as a group, but often only a few would talk. Keep in mind that most likely the group will be composed of village leaders and may not be representative of the average farmer. Group interviews are a good way to identify farmers who are the most innovative or to learn which ones normally obtain the highest yields. They then can be interviewed to learn of their successful methods. Collective memory can be invoked in obtaining more accurate dates of historical events such as pest outbreaks or to know how many markets are present or what sources of credit are available as well as other institutional services. A history of other such projects that occurred in the past can also be obtained.

5.4.2.3 Reconnaissance Surveys

The reconnaissance surveys are used most often by multi-disciplinary development projects targeting a particular location. They tend to be quick, informal, or exploratory in nature and are usually followed by formal methods. There are many variations with the rapid rural appraisal (RRA) being most known. These methods were developed to produce a report within a month as previously lengthy baseline surveys were carried out with the results seldom available within a year. RRA is a flexible, low-cost and time saving set of approaches and methods with appropriate check lists used by teams composing researchers, extension workers, NGOs, rural bank staff, agro-input dealers, and key farmers to collect and analyze information about and from the rural people and learn of the conditions existing in rural areas. RRAs also have a secondary objective of team building among the members. RRAs provide a thorough idea regarding problems, potentials, resources, and solutions to formulate realistic development programs feasible to achieve within a specific period of time in a given rural locality or to use the information and analysis by stakeholders to formulate need based research programs to solve the problems of rural people. The survey also relies on gathering of secondary data regarding soil surveys, rainfall and climate data, irrigation systems, population studies, etc., from databases as well as interviewing extension workers, bank officials, cooperatives, and other stakeholders if their members are not on the data collecting team.

Group members attempt to gain impressions of what enters into the farmers' decision-making with regard to their farming systems such as their knowledge and beliefs, their obligations, their goals, and their perceptions of risk. At this stage the team formulates hypotheses to explain present farming practices.

Reconnaissance surveys generally take 4–5 days once a region has been defined as the target for the project. The first morning may be spent eliciting information from all the team members about their opinion of why farmers in the area are not getting higher yields. Over the next several days the team members break up into small groups that fit in a vehicle and go to a specific village to interview farmers. At first the groups are told to ask individual farmers to describe their farming system in as much detail as possible including estimated yields and to prioritize farmers' constraints to higher production. Each team member will interview different farmers. In the afternoon the team members debrief and combine all of their findings in a synthesized form on whiteboards with all looking on and participating. Key farmers who also make up the team members can provide input and clarification. From this initial description there will be questions about certain practices which then become the topic for the following day's interviews. Team members go to different villages and continue the process. In the end a list of prioritized research topics is developed based on the findings which are then tested in on-farm trials. The more experienced the team members the better is the outcome of the initial workshop and list of priorities for research. Secondary data is collected after the fieldwork.

Diagnostic surveys are a variation of reconnaissance surveys used to identify farmers' problems and causes with a focus on prioritizing research needs.

Diagnostic methods for rice research combine complementary, but still rapid, qualitative and relevant quantitative methods, farmer interviews, field sampling, national and local level statistics and substantial inputs by other scientists after the field study is completed (Fujisaka 1990, Fujisaka et al. 1991). Participants in the diagnostic survey should include extension workers and researchers from various disciplines as well as some farmer leaders. Farmers are randomly sampled within villages and interviewed preferably in the fields where crops and problems can be observed. Villages are randomly or purposively selected to represent differences within region or environment.

Team members learn by doing and the first task is often to unlearn conventional ideas about farmers and their practices and about ways of interacting with farmers. The main technique is the informal, open-ended and interactive but structured interview. Rather than passively asking prepared questions and recording answers, interviewers are encouraged to think and interact by:

1. Understanding the broad issues being investigated,
2. Constructing questions that reflect accumulating knowledge, make sense to respondents, and result in useful responses, and
3. Thinking about responses and then further probing with follow-up queries until a holistic and internally coherent picture emerges.

Diagnostic surveys proceed from more general to more specific lines of inquiry as data and understanding are accumulated. Research seeks not only to describe farmer practices but also to understand the perceptions and technical knowledge underlying practices. It was assumed that understanding why farmers do what they do (e.g., not using inorganic fertilizer because of the perception that soils become compacted) provides a necessary (although not sufficient) basis for research leading to development and transfer of farmer-appropriate innovations.

Understanding of the whole farm system, which implies building on farmer practices and perceptions. Farmers have adapted management strategies tuned to interacting opportunities and constraints. Farmer perceptions and knowledge (technically correct or not) underlie practices and decisions. A diagram of a weed problem with its hypothesized causes is shown as an example of the output from a RRA (Fig. 5.1). This diagram serves as a framework for field research.

5.4.3 Formal Survey Methods

Informal survey methods have limitations because rigorous methodologies are not followed. Farmers interviewed may have been selected purposely and not randomly thus statistics cannot be used to summarize the data. Without a written questionnaire, interviewers may not ask questions in the same way for each respondent. Thus quantification, coding, computer analysis, and summarization become more difficult and the reliability of conclusions is more subject to question.

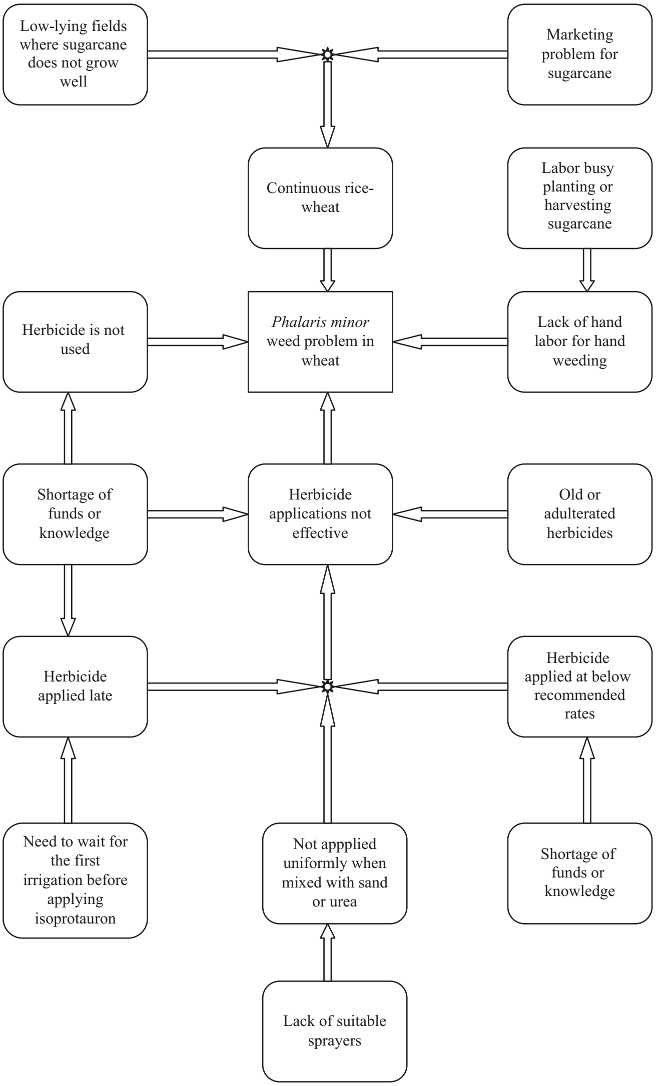

Fig. 5.1 Causes of the *Phalaris minor* weed problem in wheat in the rice-wheat rotation as determined by a rapid rural appraisal exercise. Tarai zone of India (Hobbs et al. 1991)

5.4.3.1 Participatory Rural Appraisal (PRA)

The PRA has much the same objectives as the RRA but the data are collected by the farmers themselves with the assistance of a few facilitators. A PRA consists of a series of data gathering exercises, each carried out for a different subject. The data is quantifiable as the sample of farmers often includes most of the villagers. A PRA is more likely to be carried out by NGOs or government field staff wanting the perspective of the farmers as the primary goal. The information is owned, analyzed, and used by local villagers. The focus of intervention is also more localized thus more detailed information is taken of each target village.

Examples of some PRA exercises are given from an exercise conducted in two villages (Chatoud in Arang block and Tarra in Dharsiva block) in Raipur district of Chhattisgarh, India (IGAU 1997). Farmers could recall, when undertaking an historical time analysis, that the villages began in the late 18th century and there were severe famines in 1900 and 1962 and severe droughts in 1953 and 1956. Modern rices were introduced in the mid 1970s. In 1975, 1977, and 1983 there were severe epidemics of gall midge which was resolved in 1984 by the introduction of a resistant rice variety. An epidemic of armyworm occurred in 1985 was followed by one from the brown planthopper in 1990. Farmers were then asked to determine when major insect pests and diseases attacked their major crops during the year. They graphed the time of each crop on a crop calendar and pinpointed the periods during each crop when the pests were present in the field noting when maximum attack occurred (Fig. 5.2).

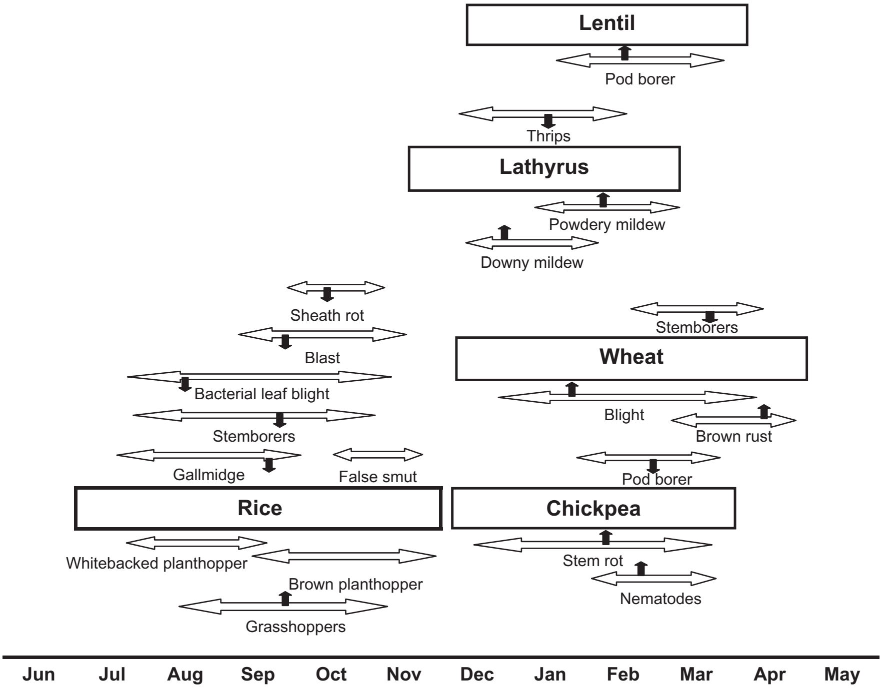

Fig. 5.2 Farmers' perception of major insect and disease pest occurrence in the various cropping patterns in a participatory rural appraisal in two villages (Chatoud in Arang block and Tarra in Dharsiva block) in Raipur district of Chhattisgarh, India, 1995. Dark arrows indicate periods of maximum abundance (IGAU 1997)

In the same PRA, matrix ranking exercises were carried out for the farmers to decide on what crops to grow and which varieties of each crop were the most suited in the area. In both exercises the farmers first decided on the criteria to rank each crop and variety. Often insect pests and diseases were of concern and farmers wanted to grow crops and varieties which had less pest incidence.In another exercise carried out by farmers and PRA facilitators (IGAU 1997), farmers were asked to note changes and trends in agriculture that were occurring over the past five years compared to earlier times. Farmers noted that there was an increase in use of purchased inputs such as fertilizers and pesticides and at the same time pest incidence was increasing which they attributed to the heavier usage of fertilizers. In the same exercise they noted that groundwater levels were declining which was causing alarm.

Chhattisgarhi farmers were requested to list locally developed agricultural practices or indigenous technical knowledge which resulted in a number of practices to protect stored seeds from insect pests. A receptacle was made from mud which was used to stored grain. Neem seeds and dried leaves were mixed with stored seeds in the mud sealed containers. Another method was to make a slurry of cow dung mixed with water into which seed was mixed in sufficient quantity to coat the seeds which then were allowed to dry before storing. Farmers had two local methods for weed control. The first is *beusani* or bushening which is a locally developed weed control practice based on tillage. Bushening is also a form of water conservation and is used in areas where irrigation or rainfall are unpredictable (Fujisaka 1991). In another exercise farmers were asked to list all of the agricultural implements they have which would include pesticide sprayers. Finally farmers are asked to rank the major constraints for their key crops and make a problem-cause diagram. In the diagram they made they pointed out the problem of pests and diseases as well as labor shortage for weeding.

After reviewing the data from numerous PRAs we concluded that RRAs are more appropriate for developing a research agenda whereas PRAs are best for extension or implementing self help programs. PRAs have become very popular but often the research teams that undertake them often think this is all they have to do to understand the practices and perceptions of farmers, but in reality the information gathered has barely scratched the surface of uncovering technical constraints.

5.4.3.2 Surveys Using Questionnaires

Aside from PRAs, surveys using questionnaires are also very popular. Questionnaires can be used for many purposes:

1. Documenting pesticide usage (kind, frequency, timing, dosage),
2. Determining reasons farmers spray,
3. Determining the most common target pests for sprays,
4. Farmers' knowledge and perceptions of pests, the damage they do, and control measures, and
5. Vocabulary used to name pests.

A select number of the surveys are described to give the reader a sampling of the kinds and purposes of the inquiries, most of which support ongoing research or training activities. A series of interviews of some 100 farmers has been carried out periodically since 1966 in C. Luzon by the Economics Department of IRRI (Cordova et al. 1981) called the "loop survey" as the towns where the survey was carried out followed a circular route beginning in Bulacan province and onto San Jose, Nueva Ecija before turning westward to Tarlac province and then heading south to Pampanga province and back to Laguna province. This survey is unique in that the same farmers were interviewed over time to recall their farm management practices over the previous season including all input usage.

IRRI's Constraints Program included socio-economic baseline surveys that posed questions on input usage such as agro-inputs (IRRI 1979). One of the earliest studies of rice farmers in Asia that focused on pests, Litsinger et al. (1980), formed a questionnaire to determine the capabilities of farmers to recognize pests and evaluate their importance. On-farm cropping systems studies were ongoing in the project sites and responses from the farmers could be matched against field data collected on pest species and population levels. The study also hoped to reveal new pest control techniques from farmers including new technology × technology or technology × environmental interactions to be discovered by researchers and fed back to experiment stations.

A later study with a questionnaire in an irrigated rice site in Guimba, C. Luzon, Philippines was undertaken by an interdisciplinary team and found that farmers had reasons for not following many researchers' crop production practices (Fajardo et al. 2000). The study concluded that future inquiries can evaluate more of those reasons and determine in what areas farmers were ignorant thus needing greater training, or whether farmers' actions had merit under prevailing conditions. A key to the survey was forming a multi-disciplinary team so that input from diverse disciplines could help guide the interpretation of farmers' answers. The survey produced both an agenda of verification trials and the need for more focused subsequent surveys.

Surveys in Thailand, Cambodia, Laos, and Nepal, in rainfed areas followed on RRAs as part of the rice-wheat research consortium between CIMMYT and IRRI and the rainfed wetland and dryland rice consortia of IRRI and national programs (Fujisaka 1990). van de Fliert and Matteson (1990) undertook a farmer survey to obtain demographic data from Sri Lankan irrigated and rainfed rice farmers as well as their KAP relating to rice pest control with a view toward training. Therefore the questionnaire specifically delved into their media habits, organizational and religious memberships, and the channels through which they get their information on new rice cultivation practices. The data were used to design and evaluate a multimedia campaign in support of rice IPM extension and to set farmer training priorities for the FAO IPM training program.

A series of surveys is important to being able to delve more deeply into farmers' reasons for undertaking their practices. Rubia et al. (1996) undertook a series of three surveys each with pre-tested questionnaires. The first was to learn the importance of white rice stemborer *Scirpophaga innotata* to farmers. A second survey was conducted to determine farmers' knowledge of white stemborer. A third survey to determine farmers' management practices.

Goodell et al. (1982) critiqued survey methods that called for the respondents to recall over an entire crop which she felt was not as accurate as more frequent ones. One study that followed this example was the study of farmers reasons to apply insecticides which was carried out by interviews every few weeks with farmers (Bandong et al. 2002). When a farmer revealed that he had applied an insecticide he was questioned in detail on the reasons leading up to making the decision including the target pest and on his method to assess its abundance, how he measured it, and the reason for going to the field when the decision was made. He was asked to recall his observations from the time he left his home.

5.4.3.3 Farm Record Keeping

The most rigorous data collection method is farm record keeping, an example of which was carried out in the Philippines in four irrigated rice locations by IRRI between 1981 and 1991 (Litsinger et al. 2005). A research base for on-farm trials was formed by renting a house in the rice community and hiring local staff from each area. The four sites spanned 23 crops in Zaragoza and 13 crops in Guimba, both towns in Nueva Ecija province in the heart of the Philippines largest rice bowl in C. Luzon, 17 crops in Calauan, Laguna 20 km from the IRRI campus, and 15 crops in Koronadal in South Cotabato, Mindanao. Farm sizes ranged from <1–4 ha with land preparation done by rotary tillers.

Each season some 20–40 farmers were selected per site to note their farm operations particularly in regard to agro-input usage. Each farmer was given a small notebook for him or her to record all farm operations and input usage. They were visited 3–4 times a season by local staff to check on the record keeping. In this way the team could note trends and relate the insecticide usage to pest densities sampled in the field as part of a research project to develop action thresholds for insecticide decisions. Additional surveys were done each season focusing on different related topics and information was built up in an iterative approach.

5.5 KAP of Arthropod Pests

Price (2001) found that Filipino farmers could name 26 different insects in rice fields. A number of farmers' classification systems were elicited by following the triad testing and arthropod description games. Tagalog farmers in Laguna province Philippines first divided arthropods into harmful and harmless categories. Harm included crop damage (Nazarea-Sandoval 1991). Harmful arthropods were divided into those harmful to plants and humans. For arthropods that were harmful to plants the farmers made the distinction among those plant feeders that caused yield loss and those that did not. This is a very important distinction which not all indigenous people make. Among the harmless category farmers recognized useful arthropods that were food items, pollinators, or toys, while useless arthropods were divided into those that made noise or emitted odor.The Tharu of Nepal recognized 80 arthropods and classified them among the *kiraa* or those living animals that are harmful either directly or indirectly and include reptiles and even tigers (Björnsen-Gurung 2003). Arthropod classification is further divided by agricultural aspects followed by physiological-behavioral, ecological, and human directed features rather than morphology as in Western science.

5.5.1 Species Recognition Through Language and Observation

A precondition to an effective partnership between farmers and researchers/extensionists is effective communication. Communication is partly based on using a common language. Language does not only consist of names and words, but also of concepts and frameworks. In the 1960s, cognitive anthropology and ethno-science evolved to gain a better understanding of how a culture perceives the universe through its language (Warren 1989). Language can define a people's physical, social, and intellectual environments and how these knowledge systems enable decision making process to function. For example, Indian rainfed rice farmers who have fragmented holdings do so on purpose having some in uplands and some in lowlands. They match the varieties with the topography and soil type and choose field locations from inheritances in as many of them as they can as a risk aversion strategy. Having many names in a local language for soil types shows importance that the soil resource has in the life of the Indian farmers; contrariwise a lack of a name denotes non-importance or lack of recognition (Hunn 1982). Interestingly Björnsen-Gurung (2003) found that Tharu farmers recognize more insects than they can name.

In Chhattisgarh India, among the Tharu of Nepal (Björnsen-Gurung 2003), and in the Philippines (Nazarea-Sandoval 1991) small scale farmers are hired as laborers by larger farmers and they, rather than the large scale farmers, better know the prevalent insect pests and can point out which ones that cause the damage. It is important for farmers to recognize the major rice pests. For example rice breeders have developed a number of varieties resistant to brown planthopper but not to its closely related whitebacked planthopper *Sogatella furcifera*. Filipino farmers do not distinguish between the two species (Litsinger et al. 1980), while Indian farmers do (*bhura maho* and *safed maho*). In addition confusion of two pests may lead to the wrong conclusions. Farmers in the Muda irrigation scheme in Malaysia confused symptoms of whitebacked planthopper with tungro virus disease (Heong 1984). Thus farmers who assess whitebacked planthopper damage as tungro will embark on a multi-spray regime designed to kill a disease vector whereas whitebacked planthopper, which transmits no disease, can normally be controlled with one application.

5.5.1.1 Grouping Many Species Under One Name

In Nicaragua one pest can have a number of local names in a single region and different pests may be called the same in different regions (Björnsen-Gurung 2003).

In the case of pests of stored grain, while scientists may list 25 distinct species, Honduran farmers have only one term *gorgojo* that translates into “weevil”. Bentley (1989) found farmers lack knowledge on insect pests and often lump many species under one name. Thus insects are categorized into grosser categories than is common for plants or other phenomena of the natural world. They tend to gloss over morphological and ecological differences. Bentley pointed out that the lack of discrete names for each species is not necessarily an indicator of a gap of knowledge because they know that stored grain is attacked by a different *gorgojo* but they use the same name for all. The same farmers, however, have an impressive knowledge of plant stages of common crops.

Filipino farmers were unable to identify some of the major pests at all and lumped them under general terms of “worms” or “hoppers”. Litsinger et al. (1980) found Filipino farmers term greenhorned caterpillar *Melanitis leda ismene*, armyworms *Mythimna* spp. and *Spodoptera* spp., and leaffolders *Cnaphalocrocis medinalis* and *Marasmia* spp. under the heading of “worms”. According to Waibel (1986) some Filipino ethnic groups use of the term “armyworm” is a proxy for all defoliators, but leaffolders were not mentioned. Leafhoppers are more prone to be recognized as they dwell in the upper half of the rice plant and jump from plant to plant when disturbed. They are all lumped under one name generally including green leafhopper that translates as “head of a horse” in Tagalog (Litsinger et al. 1980). Planthoppers, on the other hand, are more sedentary and dwell at the base of plants. But most Filipinos interviewed considered homopterans to be defoliators, only a few know they suck the sap. The category of “hoppers” includes not only planthoppers but four or so leafhopper species. Even though there have been outbreaks of planthoppers in Malaysia, when pointed out brown planthopper was not seen as particularly worrisome, perhaps it is too small and was a new pest (Heong 1984).

Dryland rice farmers in Claveria in N. Mindanao were shown samples of pest damage or specimens which they were asked to identify (Table 5.2). The answers were ranked into two categories. Recognition that an insect caused discolored grains was given partial credit but full credit was given if the farmers named rice bug as the cause. Some 90% of farmers could recognize rice bug but only 32% knew the damage it caused. Most farmers knew leaffolder damage was caused by an insect (58%) but only 37% could identify it. Both deadhearts and whiteheads can be caused by other phenomena than stemborers which must have confused the farmers as most did not name stemborers as the cause. Seedling maggots cause deadhearts and drought and blast disease can cause whiteheads. Scores may have been higher if the exam were done in the field. Only 37% of farmers knew root aphids were the cause of their characteristic damage. Whereas a total of 74% knew the damage was caused by an insect (37% + 37%) and one quarter of farmers did not recognize them. Some 90% of farmers knew the damage caused by seedling maggot was an insect but only 10% knew it was a fly. The brown planthopper and green leafhopper are present in dryland rice but none was recognized as they are of no economic importance. Whereas most wetland rice farmers in the Philippines can recognize these two common insect pests.

Table 5.2 Farmers' recognition of dryland rice pests based on actual specimens or damage. Claveria, Misamis Oriental, Philippines, 1986

Specimen	Level of recognition (% farmers responding)[a]	
	Full	Partial
Rice bug adult	90	8
Discolored grains (rice bug damage)	43	32
Leaffolder-damaged plant	37	58
Stem borer deadheart	37	52
Root aphid damage symptom	37	37
Stem borer white head	35	50
Defoliation from leaf feeder	30	63
Termite/white grub/cricket-damaged plant	18	78
Seedling maggot-damaged plant	10	80
Brown planthopper	0	28
Green leafhopper	0	30

[a] n = 60.

All stemborer species in the Philippines and India fall under the same name even though there are at least three species having distinctly different moth morphologies (Litsinger et al. 1980). In India stemborers are lumped under one name *tana chedak* which translates as stemborer.Farmers' perception of a pest is influenced by their observations, knowledge, and experience in the field as well as their interactions with extension workers, researchers, the mass media, their observations and experience, chemical sales agents, family, other farmers, and available control technology as a conceptual framework (Rubia et al. 1996)

Bentley (1992b) concluded that farmers' knowledge worldwide of pests is uneven but follows a similar pattern. He proposed that farmers' pest recognition could be characterized along two axes describing: (i) ease of observation of the pest phenomena and (ii) the importance according to the farmers' perception, not necessarily the scientists' perception. Thus farmers recognize species of arthropods more readily which were both important and easily observed. While arthropods that were unimportant and difficult to observe tended to be poorly understood. There are other criteria as well.

5.5.1.2 Criteria for Recognition

Many researchers have noticed that cultural importance and morphological attributes are key to folk classifications of arthropods. Bentley and Rodríguez (2000) constructed a folk classification in Honduras which was partly based on physical appearance of the different arthropod groups such as Linnaean orders and major families and partly based on cultural value. Species that were easy to observe were those that were large ("hard to ignore and therefore named"), social, colorful, abundant, noisy, and diurnal. Recognition based on utility was based on being a pest of crops or humans or livestock, dangerous or painful, used for games, toys, ornaments, rituals, or art.

5.5.1.3 Size

In many situations farmers are elderly and their eyesight is generally not good (Matteson et al. 1994). This faculty needs to be taken into consideration when training farmers to monitor smaller pests. Most farmers overlook insect pests due to their small size and inconspicuousness. Only 45% of farmers in the Ivory Coast were able to identify some rice insect pests representing both dryland and wetland environments (Adesina et al. 1994). There were terms for small flies used by those farmers but none was associated with gall midge that damages rice.

Interestingly a high proportion of Malaysian farmers (38%) could not name any rice insect pests (Heong 1984). Even though the main insect pest reported was stemborers, still some farmers believed that deadhearts were attributed to the "wrath of the moon". Other pests mentioned were large including *Leptocorisa* rice bug and black bugs *Scotinophara* spp., the latter are cryptic in nature. Farmers would encounter black bugs while weeding. Rice bug names translate as "bad odor" as well as "beetle". Some tended to associate any worm found in the field to be a stemborer. Farmers in C. Luzon, Philippines, in the past thought that a second crop of rice planted in the dry season would die from hot dry wind which in fact was stemborer damage (Cendaña and Calora 1967).

Most farmers recognize the larger pests. For example in Leyte, rice bug is considered as the most important insect as it is large and feeds on the grain (Heong et al. 1992). Most Leyte farmers have names for large insects such as greenhorned caterpillar, armyworms, and leaffolder but most translate into "worm". Greenhorned caterpillar was commonly found in the Chhattisgarh rice plain but only women hired for weeding and not the farmers could recognize it but still gave it no name. Leaffolder in Batangas *uod sa dahon* translates into leaf worm (Litsinger et al. 1980).

5.5.1.4 Mobility

The more mobile insects such as leafhoppers and moths are more recognizable to Filipino farmers. There are half a dozen leafhoppers that feed on rice and they feed on the leaves and thus are prone to flight when disturbed. One leafhopper *Nisia atrovenosa* that feeds on nutsedge *Cyperus rotundus* growing in rice bunds was thought to be a rice pest because people saw it jump onto rice plants while walking. Studies showed it does not feed on rice (dela Cruz and Litsinger 1986). Also there are a large number of moths in rice fields which are easily flushed out by people passing. Flying moths can be composed of up to four leaffolders, three stemborers, and vegetative stage defoliators such as caseworm *Nymphula depunctalis*, hairy caterpillar *Rivula atimeta*, and semi-looper *Naranga aenescens* plus the occasional cutworm or armyworm. Filipino farmers will make a decision to spray upon seeing moths flushed from the foliage (Bandong et al. 2002). To the trained eye all moth species can be distinguished by coloration, markings, and flight behavior. Only farmers who have been trained have developed these skills.

5.5.1.5 Abundance

In rainfed rice areas the rice whorl maggot fly *Hydrellia philippina* is less abundant and ignored (Litsinger et al. 1980). Commonness, therefore, does not guarantee that a pest will be recognized. Rice caseworm for example was equally abundant in two rainfed rice provinces and has a distinct name in Iloilo province *salabay* but not in Pangasinan, even though caseworm is more prevalent there. The farmers represent two distinct ethnic groups with distinct languages. Rice bug is not mentioned by farmers in Nueva Ecija because it is quite uncommon there due to a lack of aestivation sites, but in another area which has wooded areas, it is considered as the major insect pest (Pineda et al. 1984).

5.5.1.6 Importance in Terms of Damage Caused

Some pests are known more by the damage symptom than the insect itself. For example stemborers are more known for their damage particularly whiteheads. In a study of three provinces, each having a specific ethnic group, only in one (Batangas) was there a term for deadheart but there is a term for whiteheads in all three groups (Litsinger et al. 1980). Even though whiteheads can be caused by other factors such as drought and disease, Filipino farmers have seen the tunneling of the larvae at the base of the withered panicle. They will readily show you the larvae in the field as they have split open the stems to locate the larvae.

The least observable insects (whorl maggot, defoliators, and leaffolders) were monitored by noting damage (Matteson et al. 1994). Malaysian farmers could name leaffolders which they said do a characteristic damage (Heong 1984). Despite being highly abundant, surprisingly leaffolders are often overlooked. Farmers noticed the scarification damage at the tips of leaves after considerable damage is done and the larva had left. Showing leaffolder larvae in their webbed shelters surprised many Filipino farmers. Once in a while spiders will be found from such folded leaves as well.

In the Philippines, weekly IPM training sessions were held in the C. Luzon rice bowl which included a visit to the field to assess the pest situation. Goodell et al. (1982), a resident anthropologist, concluded that in some cases farmers appeared more observant than scientists. A rice leaf damage symptom called *aksep* in Tagalog was described in detail. It was the result of the feeding of a combination of up to four insect pests attacking up to the first five weeks in the field. Each species contributed to the variation in the larval feeding injury expression. The damage symptom was described in greater detail by the farmers than researchers and was an amalgam of damage from rice whorl maggot, rice caseworm, semi-looper, hairy caterpillar and even the occasional armyworm or cutworm. Symptoms included discolored (whitish) spots and streaks, holes in leaves, neatly cut tops of leaves as by scissors, scrapings leaving only the veins, chewed areas from the margins to brownish colorations. Damage symptoms accumulated over time and went through aging changes from whitish, pale green, yellowish to brownish. These symptoms would change from field to field reflecting the differing proportions of each species feeding.

In the beginning the scientists tried to assess the contribution of each species to the damage but in the end followed the farmers' method of lumping it all as one character.

In rainfed rice areas of the Philippines, the same pest complex also occurs but infestation is much less. Even so farmers do not recognize whorl maggot but they have a name for the damage just as with *aksep* although it is less richly described. In Pangasinan farmers refer to early season pest damage symptoms as *gutalo* which includes whorl maggot, caseworm, and defoliators (Litsinger et al. 1980). Interestingly Chhattisgarhi farmers in India have a word for the same complex *chitri banki* which includes a number of pests – caseworm, leaffolder, and surprisingly whitebacked planthopper. The complex of pest damage caused in the vegetative stage appears whitish.

In Koronadal, Mindanao irrigated rice farmers of Ilocano and Ilongo ethnic groups have names for rice planthoppers and leafhoppers which they term hoppers (*ulmog* or *waya-waya*) and state that they suck the leaves or base of the plants and cause hopperburn (*inulmag* or *malaya ang palay*). Stemborers were only given a distinct name in Ilongo (*tamasok*) but described the damage as causing deadhearts (*aglabbaga ti uggot* or *malaya ang ugbos*) or whiteheads (*agpuraw ti unga* or *magaputi ang bunga*) and that the worm bores the stem and eats the shoot of the plants.

Armyworm has a distinct name in Ilocano *arabas* which damage is most recognized as it cuts the panicle. Larvae also eat the leaves but panicle damage is most distinct and alarming to farmers. Whorl maggot was said to cause whitish leaves and is called a small fly *kusim* or *langaw na gagmay*. Mole cricket is readily recognized and called a*rarawan* or *mara-mara* and is said to cut, feed on, and scrape the roots. Greenhorned caterpillar is very large and distinct but is only described in Ilocano as "worm with a horn". Rice seed bugs were called *dangaw* or *tiyangaw* with Ilocanos stating that the bugs produce a bad odor (*nalapod nga dangaw*) and farmers stated that they cause empty grains, by sucking out the juice of the grains.

In a dryland area in Claveria Mindanao Philippines, untrained farmers gave accurate descriptions of common rice insect pests such as rice bug and stemborer (Fujisaka et al. 1989). "Ricebug sucks the milk substance in the grain from panicle initiation to the milk stage. Damaged grains are empty, black, half-filled, and bitter. Attacks are at night. Damage is up to 50%." "Stemborer attacks from the vegetative stage to panicle initiation. The larval stage is the most destructive because larvae bore the nodes near the plant base and eat the soft portion inside. Panicles become white with empty grains. Damage is 20–40%." On the other hand in the Ivory Coast farmers there cannot associate whitehead damage with stemborers (Adesina et al. 1994).

5.5.1.7 Metamorphosis

Insects have different morphologies in the various juvenile stages and even between male and female adults. Young planthoppers and leafhoppers are whitish and the five or so intermediate stages each take on various markings before reaching adulthood with the adults distinctly different in color. Egg stages are rarely noticed by farmers. Encounters with farmers in the field revealed that most Filipino farmers do not recognize the egg masses of stemborers. Metamorphosis was highly confusing to farmers in C. Luzon according to Goodell et al. (1982). She concluded that just being able to name a pest, however, does not mean that farmers will recognize all stages in the field. In Laguna butterflies were considered as sources of fascination due to their bright colors and graceful flight as well as children's toys. Not one informant recognized that the larva was an immature form of the butterfly (Nazarea-Sandoval 1991).

The Tharu of Nepal believe that caterpillars mate and lay eggs as they are seen together in one place and are not considered to be the immatures of butterflies. Small insects are generally considered to be the progeny of larger ones. In Chhattisgarh farmers believed that dung flies came from smaller flies and then grew to be the even larger ones they see.

Honduran farmers were ignorant of basic facts of insect biology in that many believed that insects sprang spontaneously from the soil or fertilizer (Bentley 1989). This idea of spontaneous generation was based on the correct fact that when fertilizer was used more pests appeared. Farmers also noticed that the number of some pests increased after insecticides were used but were ill-equipped to understand why. The concepts of insecticide resistance and insect resurgence are difficult for farmers to grasp as they run counter-intuitive to what they had learned about insecticides in the past.

Honduran farmers developed a conspiracy theory that the chemical companies put new pests in each bottle (Bentley 1989). This limits of farmers' knowledge means that they saw no alternatives to insecticides. It is interesting that a small percentage of farmers interviewed in C. Luzon, Philippines voiced similar beliefs of spontaneous generation (insect pests come from the water) as well as conspiracy theories (pests come from fertilizer bags).

Storage weevils were believed by Honduran farmers also to generate spontaneously from the grain (Bentley 1989). Farmers know little about insect reproduction and ecology, and spontaneous generation is by far the most common notion of insect genesis. Farmers point out that the stomach contents of the caterpillar is green just like the plant, thus must have come from the plant.

A number of Filipino farmers casually interviewed, however, understood the various stages of insect metamorphosis, but there are still a significant number that do not. Only a few can associate a caterpillar with the adult moth or know about the egg stage. Laguna farmers did not connect the immatures of mosquitoes with the blood feeding adults (Nazarea-Sandoval 1991). Mayans also did not link the butterflies with caterpillars and recognized many of the leaf feeding stages and generally disregarded the adult stage (Nazarea-Sandoval 1991). This is evidence that folk science is for the most part applied science and rarely truly theoretical.

5.5.1.8 Familiarity Due to Control Efforts

Handpicking insects used to be a more popular method of insect pest control before modern pesticides appeared (Litsinger 1994). In Japan and Korea, rice farmers regularly removed deadhearts along with the stemborer larva from rice fields to limit their spread. Special nets were made to collect caseworm larvae. Large lepidopterans were removed by hand from the foliage.

In other places mass campaigns were undertaken to hand remove insects during outbreaks such as occurred in the mid-1980s in Java when the white stemborer suddenly emerged as an epidemic pest. School children were trained to hand remove moths and egg masses from seedbeds. Consequently most farmers were able to readily identify moths (97%) and egg masses (96%) in a study conducted during the epidemic (Rubia et al. 1996). According to Rubia farmers generally are unaware of stemborer egg masses and if asked in the field to explain what they were had no idea.

5.5.1.9 Food Items or Insects as Toys

Some insect pests are more recognized and tolerated because they are collected for food such as the mole cricket in Ilocano areas of the Philippines. Special collecting baskets are made for this purpose where mole cricket is considered to be a delicacy. Grasshoppers and locusts are gathered from rice foliage for the same reason. White grub adults as well are delicacies in Batangas and in Mindanao and are shaken from trees, collected, and deep fat fried. Rats in NE Thailand are eaten but not in C. Thailand as in the latter they are considered as pests while in the former location they are not (Brown and Marten 1986).Strings are tied to the adults by children to swing around in the air giving the insect its common name of “toy beetle” (Litsinger et al. 1983).

5.5.1.10 Ranking by Importance

Questionnaires

In KAP questionnaires farmers were asked to name insect pests that occurred in each growth stage based on their observational experience in the area. Farmers were first asked to focus on the seedbed and recall all the insect pests they knew that fed on seedlings. Then the farmers were asked to shift to the vegetative stage in the field and finally in the maturing stage of rice to name pests from each. After the list was completed the pest names were read back and the farmer was asked to rank the top ten in terms of importance on a scale beginning with 10, for the most important, 9 for the next, etc. The average rating for each pest produced the “importance value” for all insect pests in the site (Litsinger et al. 1982). The frequency of mentioning each pest was also ascertained.

Waibel (1986) used a different system in his interviews and asked the farmers to rank their insect pests which rankings were averaged over five sites to produce the following list:

1. Stem borers
2. Defoliating armyworms
3. Brown planthopper
4. Leaffolders

Stemborers were regarded as the most important pest group in the wet season and brown planthopper in the dry season in Nueva Ecija but not the other sites. Scientists also agreed that stemborers cause the greatest yield loss among all insect pests of rice in the Philippines based on yield loss studies (Savary et al. 1994, Litsinger et al. 2006a). Defoliating armyworms, however, are much less important generally speaking. But this term may include other defoliating pests attacking in the vegetative stage that are termed *aksep*. It is surprising that rice bug was not considered more important. Farmers generally rate it higher, although scientists would agree with a low ranking as its importance is more psychological than real (Litsinger et al. 1998). Modern rices produce many more grains per area than traditional rices thus its impact is diminished. Also a number of fungal diseases cause spotting on the grains called "dirty panicle" that farmers confuse with those caused by rice bug increasing its perception of being more important than it is (Lee et al. 1986). Unpublished insecticide trials by us to specifically control the rice bug did not lead to a yield increase. The only time that losses were documented was on the IRRI experimental station under extremely heavy infestations of $>10/\mathrm{m}^2$ which occur very infrequently.

In questionnaires used in the Philippines, rainfed wetland farmers clearly assign greater importance to epidemic pests over chronic pests which is understandable (Litsinger et al. 1980). Chronic pests such as stemborers cause yield loss season after season whereas epidemics can cause harvest failures in one in ten years. In Iloilo and Pangasinan provinces on rainfed wetland rice, epidemic pests also were more greatly valued, "hoppers" in the former and tungro in the latter site. Whereas in a dryland rice site in Batangas province farmers were more concerned with termites and "hoppers". The "hopper" in this case was whitebacked planthopper that became moderately numerous but no significant yield loss occurred on traditional varieties (Litsinger et al. 1987). Their moderately high number was the result of the high rate of nitrogen farmers applied to dryland rice (110 kg/ha). Researchers dismissed termites as important but placed more emphasis on other soil pests such as white grubs and ants. White grub larvae consumed the roots and killed rice seedlings whereas ants removed seed to reduce the stand (Litsinger et al. 1980). Farmers have learned to compensate by overseeding.

Target Pests for Insecticide Applications

Another method of assessing the importance of insect pests is to quantify the percentage of insecticide applications directed at specific pest groups. This was done in two sites in the Philippines over 14 rice crops. Both sites have higher insect pest incidence than the national average. The first site Zaragoza in Nueva Ecija province is at the end of a large irrigation system and thus fields are planted asynchronously, whereas Koronadal in South Cotabato province is an area with artesian spring irrigation systems where farmers grow five crops in two years. Over a third of the applications (20.5% + 16.5%) were directed at defoliating pests, occurring at the vegetative stage as part of the *aksep* syndrome (Table 5.3). Leaffolders represented the next most important target pest group receiving 15% of applications were mainly in the flag leaf stage. The third most important group occurred during ripening with

Table 5.3 Summary of insect pest targets for insecticide applications in two irrigated rice sites, Zaragoza and Koronadal, Philippines, 1984–1991

Insect group	Responses (%)[b]
Defoliators	21
Worms	17
Leaffolders	15
Rice bug	8
Stemborers	7
Hoppers	6
Planthoppers	5
Whorl maggot	4
Caseworm	4
Leafhoppers	4
Moths	3
Armyworms/cutworms	2
None specified	2
Greenhorned caterpillar	1
Ladybeetles[a]	1
Total	100

[a] Insect predator misidentified as a pest.

[b] Zaragoza 6 crops and 245 farmers 1984–1987, 565 applications Koronadal 8 crops 271 farmers 1984–1991, 762 applications.

the rice bug (9% of applications). Leafhoppers and planthoppers totaled 16% of applications which is surprising because the varieties grown in the two areas are modern rices which are resistant to the green leafhopper *Nephotettix* spp. and brown planthopper. Other pests were less targeted. A few farmers sprayed when they saw ladybeetles, which are beneficial insects. An extensive list of targeted insect pests for insecticide application is presented in Bandong et al. (2002). Most of the targeted insect pests were chronic pests which are also discussed in detail in Litsinger et al. (2006a,b,c) for stemborers, whorl maggot and defoliators, and leaffolders from farm record keeping data from four sites in the Philippines. Farmers base decisions on seeing insects and select the more mobile and thus more readily seen planthoppers, leafhoppers, and moths. The least observable insects (whorl maggot, defoliators, and leaffolders) were monitored by noting their damage. Rapusas et al. (1997) and Heong et al. (2002) produced similar lists in Laos.

5.6 Estimates of Yield Loss

For yield loss perceptions, some researchers are hesitant to askfarmers as they doubt that farmers could estimate losses accurately, although percentages are proffered when asked. Conelly (1987) stated that even a researcher could not make accurate estimates so he did not report farmers' responses. But we feel that while it is true that farmers probably cannot estimate accurately, it is important to know farmers' perception of losses, as such understanding shapes attitudes and control decision making. Kenmore et al. (1985) and Heong and Escalada (1999) noted that farmers overestimation of losses attributed to insect pests is a common misperception leading overuse of insecticides.

Losses in Malaysia were estimated realistically by 44% of the farmers interviewed to be <0.6 t/ha with 56% stating higher levels and a small number of farmers (3%) even placing losses >3 t/ha (Heong 1984). Leaf feeding insects were believed to cause high yield loss by 86% of farmers, while 9% disagreed, and 6% had no opinion.

Farmers in the Ivory Coast astutely stated that a number of factors affect losses from insect pests such as soil type, soil fertility, presence of standing water, type of forest vegetation, presence of weeds, and presence of termite mounds (Adesina et al. 1994). Farmers' awareness becomes more profound in that they know termites become more abundant during drought when more mounds are formed which in turn exacerbates loss. Highest losses measured in yield loss studies in the Philippines on irrigated rice occurred with a combination of drought and stemborer attack (Litsinger et al. 2005). Ivory Coast farmers further stated that estimates of losses are highly variable, and a large number (63%) even said losses were not important and put greater credence on insect pest abundance during specific crop growth stages.

Palis (1998) reported that farmers in C. Luzon felt that, if they did not use insecticide, losses would be 20%. Waibel (1986) found farmers overestimated losses giving figures from 25–50%, which is very high, probably by remembering outbreaks more than average years. But crop loss assessment is difficult for farmers as the yield loss-pest density equation is highly dynamic: on the one hand modern rices have the capacity to compensate from high levels of damage but need optimal growing conditions to do so while multiple stresses exacerbate loss (Litsinger 2008b). Farmers expect high losses to occur if they do not use insecticides. Data from four irrigated sites in the Philippines using the insecticide check method determined losses were 13% or 0.62 t/ha as an average of 68 crops from 1981 to 1991 (Litsinger et al. 2005). This would be a high estimate if extrapolated for the Philippines as a whole, as two of the four sites, as mentioned, were above average in insect pest infestation.

Javanese farmers correctly believed that the greater the infestation level the greater the loss (Rubia et al. 1996). They, however, overestimated the loss. Most expected damage from the white stemborer to be 1 t/ha. But they are ignorant of the concept of crop compensation, and losses were considerably less based on field trials.

5.7 Knowledge of Pest Ecology

Farmers' understanding of pest ecology is mixed. In Kalimantan in a detailed study by an anthropologist, farmers showed insightful knowledge of pest ecology and said rice bug was more abundant when wet planting season is preceded by a long dry season (Watson and Willis 1985). Farmers knew that both nymphs and adults suck unripe grain. They said mole crickets live in moist but not flooded ground and they are less severe in years when onset of rainy season is abrupt. Despite the conclusion reached by Björnsen Gurung (2003) Nepalese farmers correctly concluded that rice bugs underwent a dormant period between rice crops in forested areas.

Most Javanese farmers interviewed believe white stemborer moths migrate to their fields from neighbors' fields (34%) or nearby villages (19%) or districts (23%) (Rubia et al. 1996). Other responses were in declining order: carried by wind/attracted to light, from infested plants, carryover from last season, due to weather, seasonal, and do not know (3%). They found that rice farmers did not know white stemborer passes the dry season in the stubble. In the Philippines, farmers in Iloilo encountered in the field were able to show us white stemborer larvae aestivating in the crowns of stubble in the dry season. They proudly split open the plants to show us the larvae.Some Filipino farmers know that because caseworm larvae float within rolled up leaves on water they enter with the irrigation water, but few farmers understand that most pests enter by aerial movement (Bandong et al. 2002).

5.7.1 Knowledge of Arthropod Natural Enemies

Rapusas et al. (1997) translated the term natural enemies into "arthropods in the field that did not damge rice" does not convey the idea of a natural enemy. There are many arthropods in rice fields which call the aquatic habitat their home but neither feed on rice nor kill pests. Still the idea was grasped and farmers responded with names like spiders, damselflies, dragonflies, preying mantis, ground beetles, frogs and wasps. Most farmers acknowledge that they have seen insect pests trapped in spider webs or know that dragonflies eat insects in flight. Some 69% of Sri Lankan farmers interviewed knew the concept and existence of natural enemies in rice (van de Fliert and Matteson 1990). Birds (73%) and dragonflies (23%) were most mentioned. Knowledge about predatory and parasitic arthropods, however, was slight. On the other hand, 22% of the same farmer population believed that all insects in the field are harmful, while just 55% disagree with this statement. In Java ducks are popular and are herded into rice fields to control pests (Brown and Marten 1986).

All farmers surveyed in Guimba (n = 30) could name a natural enemy of insect pests with spiders (80%) heading the list followed by frogs (70%), birds (40%), fish (6%), and ants (3%). The farmers believed that all groups except birds would be adversely affected by insecticide usage in the fields. In the rainfed wetland area of Solana in the Cagayan Valley, most farmers (93%) named a natural enemy, with spiders (87%) heading the short list followed by frogs (53%) and birds (18%) (Litsinger et al. 1982). In three rainfed rice sites, only 70% of farmers could name natural enemies listing birds, spiders, frogs and dragonflies (Litsinger et al. 1980). In Claveria 85% of dryland rice farmers could name 1–2 natural enemies with birds (72% of farmers), cats (22%), chickens (20%), reptiles (12%), spiders (8%), frogs (3%), and dogs (2%) mentioned. Some 60% said insecticides would poison them. Many Filipino farmers do not realize that insecticides will negatively affect friendly arthropods (Palis 1998).

Bentley's (1992a) experience with Honduran farmers was highly similar to that of studies in the Philippines and elsewhere in Asia. Farmers are generally unaware of the existence of most natural enemies except for the larger and more conspicuous types. A farmer said that stored grain "generates" weevils about the size of a pinhead and then they grow to their full size. But the insect the farmer identified was actually a beneficial parasitoid wasp. When asked to list beneficial animals, Honduran farmers responded by naming spiders and some vertebrates such as birds and toads. They have seen spiders trapping moths in their webs (Bentley 1989).In the Philippines, untrained farmers respond by naming birds, spiders, frogs, or dragonflies as larger predators (Litsinger et al. 1980). None knew of parasitoids or smaller predators (Nazarea-Sandoval 1991). A more recent study showed that 60% of C. Luzon farmers believed that all insects were harmful despite one-third of them acknowledging the presence of beneficials (Palis 1998). Tharu farmers in Nepal could not recognize or name any parasitoids or beneficial predators (Björnsen-Gurung 2003). Spiders were considered harmful due to their irritating urine. Praying mantis are said to attack children and tear out their eyes. Mud wasps that collect larvae for food for their young are believed to be abducting children that they will turn into their own kind. Insects that make noise are said to be crying for food or are expressing joy.

Farmers often spray when they see some insects in the field whether they are pests or not. Some spray when they see dragonflies and tear down spider webs (Matteson et al. 1994). Laotian farmers named spiders, dragonflies, beetles and wasps (Rapusas et al. 1997) while in Cambodia farmers sprayed when they saw these beneficials in their fields (Jahn et al. 1997). Many Chhattisgarhi farmers interviewed also thought spiders, dragonflies, and bees were pests. In Laguna Philippines, farmers believed that "rice spiders" at times spin cobwebs so thick that the leaves stick together and fold up and the plant causing yellowing of the leaves thus consider them as pests (Nazarea-Sandoval 1991). What the farmers described was the egg mass cocoon or shelter that spiders make. Farmers are generally less aware regarding natural enemies but most recognize some larger ones such as web building spiders and dragonflies. The Laguna farmers hardly had any recognition of certain arthropods as being beneficial in checking pests. Ladybeetles, spiders, and dragonflies were perceived as children's playthings.

Ladybeetles are normally considered as pests as farmers see the adults and larvae feeding on pollen (they do not know that rice self-fertilizes within the flower thus the external pollen is superfluous) (Bandong et al. 2002). But farmers observe them feeding on the grains and believe that seed set will decline. As most Filipino farmers grow vegetables they are also familiar with phytophagous ladybeetles such as *Epilachna philippinensis* thus it is easy to see why some think ladybeetles damage rice plants. Leyte farmers also targeted ladybeetles as a pest (Heong et al. 1992). In a survey by Heong et al. (1994) found that 5% of insecticide applications by Leyte farmers targeted ladybeetles. A similar result occurs in the Philippines (Table 5.3). In addition most farmers in Hunan, China believe ladybeetles are pests of rice (Shao et al. 1997).

In another study based on a questionnaire C. Luzon, Philippines farmers named spiders, dragonflies, and grasshoppers as friendly (Rola and Pingali 1993).

Grasshoppers were probably confused with katydids which is mistaken for a grasshopper. The large species *Conocephalus* feeds on insect pests conspicuously and can eat entire stemborer egg masses, hairy mat, and all (Rubia et al. 1990) but it is an omnivore and will eat developing rice grains (Barrion and Litsinger 1987).

Rola et al. (1988) concluded that Filipino farmers could not differentiate between pests and natural enemies and 31% of respondents thought all arthropods in a rice field were pests. An interesting response came from similar farmers in C. Luzon during a training activity which included collecting with a sweep net. The collection was placed in a large, clear plastic bag which boiled with buzzing insects. Upon seeing this the owner of the field wanted to go home to fetch his sprayer and treat his field immediately. Similarly the attitude of most Honduran farmers is all insects in a crop are harmful (Bentley 1989). This viewpoint is held by many farmers in surveys (Heong et al. 2002).

5.8 Evaluation of Control Practices

The results from a KAP study in Kenya from farmers tilling traditional rainfed cropping systems would parallel the effort of trying to improve rice culture in unfavorable environments (Conelly 1987). There, insect pests among all constraints that face the farmers, are far down the list in importance. Most traditional farmers do not consider insect pests to be important. Traditional systems are subsistence systems and do not generate much cash for the farmer to invest in inputs or hired labor thus there are few options against insect pests. Drought can also affect the crop so risks from investing in inputs are high. Genetic resistance which is common for irrigated rice varieties is focused on epidemic pests which will not be of much importance in single rice cropping except with long maturing varieties. But few farmers used insecticides and lacked knowledge on how to apply them. Many said chemicals were too expensive. Thus farmers are willing to tolerate losses. Botanical insecticides along with mechanical methods such as killing stemborer larvae by hand or uprooting heavily infested plants were more preferred. Many farmers have alternative income from fishing and livestock. Only when a market is available and a high price is offered would they be tempted.

It was recommended in Kenya for farmers to burn stalks as they harbor stemborer larvae but the straw is used as fodder in the dry season (75% of respondents) or fuel (48%) or for construction of granaries (56%) (Conelly 1987). Early planting was also recommended but many farmers (60%) perceived that pests become more abundant not less, especially birds. Erratic rains make early planting risky and it is too costly to replant. Many felt that insect damage is only serious during droughts. In addition heavy rains wash off insects. Farmers need early rain for land preparation. In such cases getting farmers to accept IPM will be difficult. Recommendations for cultural control of rice insect pests based on early plowing after harvest to kill stemborers and synchronous planting were criticized by an anthropologist as being unacceptable to farmers (Goodell et al. 1982).

5.8.1 Genetic Resistance

Filipino farmers along with a large majority of their Asian neighbors in favorable irrigated areas have overwhelmingly adopted modern rice varieties (IRRI 1985), even in regions with weak extension services. From the first modern rices developed at IRRI, insect pest resistance was bred into them as a pre-condition before release (Khush 1977, 1989). IR5 and IR8, the first modern rices, were moderately resistant to green leafhoppers (Heinrichs et al. 1985). IR36 came some years later and became the most popular rice variety ever developed in terms of area sown, and was rated resistant or moderately resistant to green leafhoppers (3 species), brown planthopper (3 biotypes), and stemborers (2 species). The large record keeping survey in four sites in the Philippines conducted by us from 1981 to 1991 in four sites found modern cultivars grown in 97% of all rice crops planted with only 3% being traditional tall types (Table 5.4). Farmers planted traditional varieties in flood prone areas or for specialty foods. The survey showed Philippine Seed Board approved varieties were sown by 81% of all farmers when averaged over all crops, followed by 16% unapproved cultivars with 9% being named and 7% numbered by farmers.

Over the decade surveyed, farmers planted 179 different rice cultivars of which only 19% were approved varieties, while 26% were non-approved named cultivars, 47% were numbered cultivars, and 3% traditional varieties. All of the approved varieties would have insect pest and disease resistance, while this would not necessarily be true for the others. The reason that so many non-approved cultivars were adopted by farmers was their desire to find rices that yielded even more than the approved ones. The government cannot regulate seed distribution and many enterprising locals contracted with farmers to grow cultivars pinched from variety trials hoping that these would be named. Those that were not were still sold to eagerly awaiting farmers. These businessmen capitalized on farmers' willing acceptance of new varieties and desire to continuously improve yields. Varieties with higher numbers were considered better. A decade earlier an unimproved numbered line "1561" became popular among C. Luzon farmers but was susceptible to green leafhoppers and was one reason put forward why a tungro epidemic emerged.

Resistant varieties when grown widely can have a significant population depressing effect on insect pests. In the 1990s brown planthopper once again became a rare insect in the major rice bowls of the Philippines with the widespread acceptance of IR64 and related varieties. In Chhattisgarh, India which during the 1980s was devastated by gall midge has over recent years been deprived of the pest in many areas thanks to the wide adoption of resistant varieties such as Mahamaya, released in 1994 by Indira Ghandi Agricultural University in Raipur (R.K. Sahu personal communication).

There were differences between Philippines survey sites in the prevalence of unapproved lines, as in Zaragoza, Calauan, and Guimba released cultivars represented 44, 49, and 60% of cultivars, respectively, while in Koronadal 70% were numbered non-approved cultivars. Over all sites, crops and seasons, IR64 was the most popular cultivar, averaging 20% of all fields sown followed by IR60 (12%) and IR42 (7%). The most popular cultivars differed within sites. IR36, IR42, IR52,

Table 5.4 Most popular cultivars planted in irrigated, double-cropped rice in four locations, Philippines 1981–1991. Cultivars are segretaged by rice culture and as those modern varieties approved by the Philippine Seed Board, unapproved modern rices, and traditional rices

Cultivar	Farmers sowing cultivar per crop (%)[a]																			
	Zaragoza					Guimba				Koronadal							Calauan			
	Wetbed		DSR		Site avg	TPR		DSR	Site avg	TPR		Dapog		DSR		Site avg	Dapog		Site avg	Grand avg
	WS	DS	WS	DS		WS	DS	DS		1st	2nd	1st	2nd	1st	2nd		WS	DS		
MODERN	**97**	**100**	**100**	**100**	**99**	**96**	**100**	**100**	**99**	**100**	**99**	**100**	**98**	**97**	**100**	**99**	**92**	**90**	**91**	**97**
Approved	**84**	**83**	**70**	**88**	**81**	**93**	**93**	**88**	**91**	**61**	**63**	**64**	**65**	**96**	**75**	**71**	84	76	**80**	**81**
IR26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	**1**	**0**
IR29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**1**	**0**
IR30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**0**	**0**
IR32	0	0	0	0	**0**	2	2	8	**4**	0	0	0	0	0	0	**0**	0	0	**0**	**1**
IR36	12	12	0	21	**11**	5	4	0	**3**	0	1	1	2	3	6	**2**	0	1	**1**	**4**
IR42	27	20	0	9	**14**	5	0	0	**2**	0	0	0	0	0	0	**0**	16	8	**12**	**7**
IR45	0	0	0	4	**1**	0	0	0	**0**	0	0	0	0	0	0	**0**	0	0	**0**	**0**
IR46	0	0	0	0	**0**	0	0	0	**0**	0	0	0	0	0	0	**0**	6	0	**3**	**1**
IR48	0	0	0	0	**0**	0	0	0	**0**	0	0	0	0	0	0	**0**	1	0	**1**	**0**
IR50	2	2	0	9	**3**	0	0	0	**0**	0	0	0	0	0	0	**0**	2	1	**1**	**1**
IR52	5	12	0	12	**7**	1	0	0	**0**	0	0	0	0	0	0	**0**	0	0	**0**	**2**
IR54	2	3	0	2	**2**	0	0	0	**0**	0	0	1	0	4	0	**1**	5	2	**4**	**2**
IR56	2	2	0	2	**2**	7	2	0	**3**	3	1	3	0	0	0	**1**	2	1	**1**	**2**
IR58	0	1	0	0	**0**	9	2	0	**3**	0	0	0	0	0	0	**0**	0	0	**0**	**1**
IR60	3	5	10	1	**5**	5	14	10	**10**	26	34	24	42	29	45	**33**	1	2	**1**	**12**
IR62	0	1	0	0	**0**	1	1	0	**1**	12	14	16	11	16	13	**13**	10	6	**8**	**6**
IR64	16	14	20	27	**19**	41	43	38	**40**	5	1	11	1	10	0	**5**	11	22	**17**	**20**
IR65	0	0	0	0	**0**	0	0	0	**0**	0	0	0	0	0	0	**0**	2	4	**3**	**1**
IR66	4	1	5	0	**3**	10	15	21	**15**	3	2	2	2	7	4	**3**	1	4	**2**	**6**

Table 5.4 (continued)

Cultivar	Farmers sowing cultivar per crop (%)[a]																			
	Zaragoza					Guimba				Koronadal							Calauan			
	Wetbed		DSR		Site avg	TPR		DSR	Site avg	TPR		Dapog		DSR		Site avg	Dapog		Site avg	Grand avg
	WS	DS	WS	DS		WS	DS	DS		1st	2nd	1st	2nd	1st	2nd		WS	DS		
IR68	3	0	0	0	**1**	0	1	0	**0**	3	1	2	0	9	0	**2**	0	0	**0**	**1**
IR70	0	0	0	0	**0**	0	0	0	**0**	0	0	0	0	10	0	**2**	5	0	**3**	**1**
IR72	1	0	0	0	**0**	4	2	7	**4**	5	5	1	5	9	7	**5**	0	0	**0**	**3**
IR74	0	0	10	0	**3**	0	0	0	**0**	4	2	1	1	0	0	**1**	0	0	**0**	**1**
IR76	2	0	10	0	**3**	0	0	0	**0**	0	0	0	0	0	0	**0**	0	0	**0**	**1**
Ri10	3	**4**	15	0	**5**	2	7	4	**5**	0	0	1	0	0	0	**0**	3	2	**3**	**3**
C4	0	0	0	0	**0**	0	0	0	**0**	0	0	0	0	0	0	**0**	1	2	**1**	**0**
C12	0	5	0	0	**1**	0	0	0	**0**	0	0	1	0	0	0	**0**	0	0	**0**	**0**
Unapproved	**12**	**16**	**30**	**12**	**18**	**3**	**6**	**13**	**7**	**39**	**36**	**36**	**32**	**2**	**25**	**28**	8	14	**11**	**16**
Named	**12**	**11**	**30**	**12**	**16**	**2**	**4**	**13**	**6**	**14**	**4**	**7**	**3**	**0**	**4**	**5**	4	11	**8**	**9**
"IR58"	3	7	0	9	**5**	0	0	0	**0**	0	0	0	0	0	0	**0**	0	0	**0**	**1**
"IR66"	0	0	0	0	**0**	0	0	0	**0**	0	0	0	0	0	0	**0**	0	1	**0**	**0**
C1	0	0	0	0	**0**	0	0	0	**0**	0	0	0	0	0	0	**0**	17	22	**19**	**5**
C2	0	0	0	0	**0**	0	2	0	**1**	0	0	0	0	0	0	**0**	0	0	**0**	**0**
C3	0	0	0	0	**0**	0	1	13	**4**	0	0	0	0	0	0	**0**	0	0	**0**	**1**
C1000	0	3	0	0	**1**	0	0	0	**0**	0	0	0	0	0	0	**0**	0	2	**1**	**0**
C13000	1	0	0	0	**0**	0	0	0	**0**	0	0	0	0	0	0	**0**	0	0	**0**	**0**
R45	0	0	0	1	**0**	0	0	0	**0**	0	0	0	0	0	0	**0**	0	0	**0**	**0**
V3	0	0	0	0	**0**	0	0	0	**0**	0	0	3	0	0	0	**0**	0	0	**0**	**0**
Agoo	3	0	30	0	**8**	0	0	0	**0**	0	0	0	0	0	0	**0**	0	0	**0**	**2**
Taiwan	0	0	0	1	**0**	0	0	0	**0**	0	0	0	0	0	0	**0**	0	0	**0**	**0**

Table 5.4 (continued)

Cultivar	Farmers sowing cultivar per crop (%)[a]																			
	Zaragoza					Guimba				Koronadal							Calauan			
	Wetbed		DSR		Site avg	TPR		DSR	Site avg	TPR		Dapog		DSR		Site avg	Dapog		Site avg	Grand avg
	WS	DS	WS	DS		WS	DS	DS		1st	2nd	1st	2nd	1st	2nd		WS	DS		
Index4	0	0	0	0	**0**	0	0	0	**0**	3	0	1	0	0	0	**1**	0	0	**0**	**0**
Bordagal	0	0	0	0	**0**	0	0	0	**0**	1	2	0	0	0	0	**0**	0	0	**0**	**0**
Bornec	0	0	0	0	**0**	0	0	0	**0**	0	0	1	0	0	0	**0**	0	0	**0**	**0**
Major	0	0	0	0	**0**	0	0	0	**0**	9	1	1	0	0	4	**2**	0	0	**0**	**1**
Korean	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	**1**	**0**
Numbered[b]	1	6	0	0	**2**	**1**	3	0	**1**	25	32	29	29	2	21	**23**	4	3	**3**	**7**
TRADITIONAL[c]	**3**	**0**	**0**	**0**	**1**	**4**	**0**	**0**	**1**	**0**	**1**	**0**	**2**	**3**	**0**	**1**	**8**	**10**	**9**	**3**
Total	100	100	100	100	**100**	100	100	100	**100**	100	100	100	100	100	100	**100**	100	100	**100**	**100**

[a] WS = wet season, DS = dry season, DSR = direct seeded rice, TPR = transplanted wetbed rice, dapog is transplanted seedlings 10–14 days old.
Only cultivars which averaged 1% usage in any one crop are listed. See text for details on numbers of farmers surveyed by site.

[b] Most popular were: 33, 40, 43, 56, 90, 95, 98, 206, 247, 1606, 1609, 1803, 1814, 1900, −12, −17, −36, −49, −90, 17–3.

[c] Most popular were Malagkit, Milagrosa, Wagwat, Sinan Digo, Sinan Pedro, Sinan Felix, S. Domeng.

IR64 and Agoo were the most popular cultivars in Zaragoza. Agoo and Ri10 were particularly popular for direct seeded rice in the wet season and IR36 in the dry season also for direct seeded culture. IR60, IR64, and IR66 were most popular in Guimba. C3, a variety developed by the University of the Philippines, was popular for direct seeding in the dry season. In Koronadal IR60, IR62, and "90" were the most popular cultivars. Many other numbered cultivars were popular in Koronadal as well. IR42 and "90" were more preferred in the second crop. In Calauan IR42, IR62, IR64, and C1 were the most popular cultivars. IR42 was more preferred in the wet season and IR64 in the dry season. Named and numbered cultivars were quite location specific. Malagkit was the most popularly grown traditional cultivar is glutinous and is used in making sweets for festive occasions.

The survey also showed there was a wide range between sites as to the percentage of farmers planting more than one rice cultivar in a given crop season. Highest percentage was in Calauan where 57 and 52% of farmers respectively planted an average of 2.1 cultivars (maximum of 5) per crop in the wet and dry seasons. In Koronadal farmers almost always planted only one rice cultivar per crop (average 1.0 cultivar/crop, range 1–2), while Guimba farmers averaged 1.3 (range 1–4), and Zaragoza farmers 1.6 (range 1–6). Planting more than one cultivar per season is seen as a risk avoidance mechanism, although some farmers will plant a better tasting variety for home consumption with another higher yielding cultivar for sale.

Genetic resistance is directed against epidemic-causing insect pests such as the brown planthopper and green leafhopper. Both of these insects transmit virus diseases thus are normally controlled by targeting the vector. In addition there is also some limited resistance against the omnipresent stemborers (Chaudhary et al. 1984). Breeders using pyramiding techniques can only incorporate so many resistant genes in a new cross while still maintaining high yield and other desirable qualities. Each gene generally only affects one pest. Genetic resistance in a single variety only has resistant genes to at most three insect pests and three to four diseases, that means placing some six or seven genes in a new cross. Breeding is much like juggling as the "juggler breeder" in this analogy can only keep so many objects in the air at any one time, upon adding another one in the air would fall out.

Host plant resistance has been performed by traditional agriculturalists for millennia through selection of seeds from the best performing plants. The world gene bank for rice has over 80,000 land races. In Solana in the Cagayan Valley, Filipino rainfed wetland farmers, planting predominantly traditional tall rices, stated that such varieties had "general insect pest resistance" (Litsinger et al. 1982). In another study, again with rainfed farmers in three locations, farmers also believed that traditional varieties were resistant to "all insect pests" (Litsinger et al. 1980). Despite such statements, most traditional varieties in greenhouse trials have been found susceptible to almost all insect pests and diseases. Their low yield and non response to inorganic fertilizers has led farmers and others the conclude that such varieties are "resistant". Their long maturity gives the crop ample time to compensate and produce stable but low yields despite insect abundance. Insect pests do poorly on these cultivars because of their low nutritive status (= low yield). Few farmers apply inorganic fertilizer to these varieties which is known to increase insect pest abundance (Litsinger 1994).

Traditional farmers have developed their own methods of minimizing pest damage using genetic resistance. Indonesian dryland farmers in Indramayu, Lampung province S. Sumatra, in a highly risky environment of uncertain rain and vulnerability to insect and vertebrate pests as well as diseases, will sow up to ten local varieties in a field. Through interviews, we learned farmers were able to explain the qualities of each cultivar. Varieties differed in maturity so that in a year of early rains, the early ones will mature, while in a good year the longer maturing varieties will give highest yield. Some have different rates of resistance to blast and by mixing them will temper the rate of attack in the same way as using multi-lines. Their goal is yield stability as farmers cannot endure a year with no harvest from a long drought.

Most farmers when asked to choose qualities of a rice variety opt for high yield with pest suppression qualities lower down in priority. Although the farmers know that resistant varieties reduce the need for insecticides, a survey in Sri Lanka found 50% of respondents were skeptical about the high yielding qualities of such varieties (van de Fliert and Matteson 1990). In C. Luzon Palis (1998) found that pest resistance was not a major factor in selecting a variety. In Claveria, a farmer survey of dryland farmers placed high yielding potential (72% of respondents) and good taste (58%) above "general pest resistance" (57%) as desired qualities in selecting rice varieties (Table 5.5). A further 3% of farmers valued specific resistance to blast disease. Thus pest resistance was a sought after characteristic for more than half of the farmers. The most popular dryland traditional varieties have resistance to blast disease in contrast to wetland environments where disease resistance is less important (Arraudeau and Harahap 1986).

The survey also showed general pest susceptibility (38%) topped the list for the main reason farmers gave for changing rice varieties (Table 5.6). Susceptibilities to blast and birds were lower in the list as specific pests. Some 8% of farmers mentioned that repeated planting of the same variety would cause it to lose resistance over time, although they gave no explanatory reason. But some 4% did not believe

Table 5.5 Farmers' stated preferences when choosing a dryland rice variety, Claveria, Misamis Oriental, 1986

Varietal attribute	Farmers responding (%)[a]
High yielding	72
Good eating quality	58
Pest resistance	57
Early maturity	25
Good tillering capacity	22
Good storage quality	12
Experimenting with new variety	10
Disease (blast) resistance	3
Lodging resistance	2
Vigorous growth	2

[a] n = 60, some farmers gave more than one answer. All farmers interviewed responded.

Table 5.6 Farmers' reasons for replacing a dryland rice Variety, Claveria, Misamis Oriental, 1986

Reason	Farmers responding (%)[a]
Susceptible to pests	38
Late maturing	27
Low yielding	22
No available seeds	13
Low tillering	10
Susceptible to lodging	10
Susceptible to bird damage	8
Susceptible to blast disease	5
Inferior eating quality	5
Poor performance in infertile soil	3
Poor storage quality	2

[a] n = 60, some farmers gave more than one answer. All farmers interviewed responded.

this was a reason. Still this concept is widespread among rice farmers worldwide and due to their seed selection methods they cannot maintain good quality seeds over time due to crop mixtures, uneven maturity, and off types thus must periodically seek a new and more pure source, either certified seed or from a neighbor that has an exceptional crop.

Many farmers believe long awned cultivars are resistant to rice bug. This was tested in greenhouse trials and found to be not true (Litsinger et al. 1998). One can see that perhaps anthropomorphically speaking that farmers would believe that long awns interfered with feeding. But rice bugs fed equally on varieties with and without awns. Watson and Willis (1985) found that Kalimantan, farmers select resistant rice varieties against rice bugs that have even maturation of panicles and a thick hull. The former quality would be very useful while the latter would not as rice bugs insert their mouthparts through natural openings in maturing grains and do not drill through the hull as is common with pentatomids.

Surveys of farmers in a number of Asian countries revealed that while most farmers understand the concept of host plant resistance, within a region, they are inconsistent in explaining what pests are affected by a particular variety. The record keeping survey team in the Philippines asked farmers in two irrigated rice sites to name rice varieties which they believed had resistant properties against rice pests and to name the pests. Most farmers (73–86%) named predominantly modern rices bred at IRRI. Most of the responses stated the generalized term "hoppers" to mean planthoppers and leafhoppers. While this is true, a better answer would have been brown planthopper and green leafhoppers as for other species, notably whitebacked planthopper, there is no resistance except in IR60. Both of the sites (Koronadal and Guimba) have had epidemics of hoppers and virus diseases such as tungro. Tungro was mentioned by some farmers but hoppers was the term most used. It is interesting that "pests in general" was so commonly mentioned for IR varieties which is not supported by field evidence. However this term was most used in Koronadal which is a site with the most unapproved cultivars so perhaps farmers were making this distinction as unapproved cultivars would have higher pest incidence. Also interesting is that other pests such as rice bug, worms, and moths were mentioned which also would be difficult to defend. A survey of farmers in Leyte said varieties were resistant to rice bug, armyworms, cutworms, and stemborers. In only the latter case would breeders and entomologists agree (Escalada and Heong 1993). For stemborers, most IR varieties have some modest level of resistance which generally is less discernable at the field level. Extension services at the time of the survey were weak thus farmers were not well trained in knowing what pests were resistant in the various varieties. On the other hand, there have been so many varieties released over the past two decades that only an expert would be expected to know the resistance spectra for each variety, thus the farmers' assessment is good.

Farmers were then asked what they believed the basis of the resistance was due to. The most common answer from informal meetings with irrigated rice farmers is that resistance is morphologically based. This was confirmed in the Claveria study where half the farmers in the survey had an opinion on a mechanism. The most common was that the stems were hard (25% of responses)(50% of farmers responded) as the basis for insect pest resistance therefore not be eaten or bored into. There is some credulity in the belief of hardness as silica is known to be actively accumulated by rice plants which acts particularly against stemborers. As rice grows it packs cells with silica molecules to give strength and pest resistance to tillers (Bandong and Litsinger 2005).

A few Claveria farmers in the study came up with astute replies of antifeedants (8% of responses) and tolerance (2%) as mechanisms. There is evidence of ovipositional deterrent chemicals in rice varieties against stemborers (Chaudhary et al. 1984) and tolerance is a well known coping mechanism of modern high tillering rices (Litsinger et al. 2006a). Some Chhattisgari farmers believed gall midge resistance was due to the slippery surface of the plants which did not allow eggs to adhere. This answer, although remarkable in the depth of the thinking, is not correct.

Marciano et al. (1981) and Heong et al. (1995a) concluded that because farmers did not understand what pests are negatively affected by resistant varieties they sowed, that they oversprayed. But when one looks at the insect pests that farmers target, most of them were not those that resistance checks (Table 5.3). Farmers in both Koronadal and Zaragoza targeted mostly (82%) chronic pests whereas resistant varieties are designed to prevent epidemics from brown planthopper and green leafhopper targeted by only 10% of applications. Our research using the insecticide check method (Litsinger et al. 2005) has shown that there is economical yield loss from these chronic pests but it is spread evenly over the three main growth stages: vegetative (5%), reproductive (5%), and ripening (3%) making it uneconomical to protect with insecticides. If all of the loss occurred in one growth stage then protection by insecticides may be more economical.But the farmers' low insecticide dosage does not provide the killing power necessary to recover such low loses from modern rice varieties.

On the other hand, modern high tillering varieties are highly tolerant if managed well agronomically, thus the farmer is better off spending his scarce resources on crop management practices other than insect control. The "farmers' practice" has led to economic returns in some situations such as when the crop is under stresses from other causes as well (Litsinger et al. 2005). The crop then compensates from not only the lowered pest injury but also from some of the other stresses. Still the farmer is better off tackling the other stresses such as weeds than to attempt to control insect pests with insecticides. The negative effects of insecticides including killing natural enemies and endangering the farmer and the environment normally override the slim potential benefits.

The Sri Lankan farmers who named brown planthopper resistant varieties were from the dry zone where there have been past outbreaks (van de Fliert and Matteson 1990). At the time of the survey there were three insect pest resistant varieties to brown planthopper or gall midge. One brown planthopper resistant variety was very long maturing and less useful. They concluded (and we support that conclusion) that most farmers need to become more aware of the importance of the relation between choice of variety and pest control. More knowledge about existing resistant varieties is required of farmers to be better managers and decision makers.

5.8.2 Physical or Mechanical Control

Physical and mechanical control methods are quite commonly practiced particularly within traditional systems (Litsinger 1994). Many of them were developed before the era of modern insecticides and are both labor intensive and practical. In some areas of Asia, field labor is still prevalent thus many of these methods can be economically used. In a survey in rainfed areas of the Philippines, 84% of farmers said they handpicked insect pests at least on one crop (Litsinger et al. 1980). Marciano et al. (1981) found 38% of Laguna farmers hand picked stemborer larvae and moths. In Kalimanatan farmers net rice bugs from rice fields (Watson and Willis 1985). In 35% of dryland rice farmers in Claveria stated that they handpicked insects as a control method when prompted by the interviewer (Table 5.7) whereas only 2% mentioned this practice when asked to list control methods only by recall (Table 5.8). Some 5% of farmers used light traps to capture rice bugs.

Grasshoppers and crickets are collected in community-wide hunts by hand and with nets in some rice growing villages of Cambodia. This method appears very effective (Jahn et al. 2007) with the benefit of using them as fried human food, fed to farm animals, or used in compost. Discussions with farmers in Thailand and Laos indicated that trapping provides adequate control of crabs, but Cambodian farmers report that trapping does not control crabs. Crabs are pests in that they tunnel into rice bunds causing loss of water, thus are considered serious threats.

In a PRA survey in Chhattisgarh India, farmers stated a common indigenous practice was to store rice seed in airtight clay containers (*kothi*) covered with a special mud from Pakistan (*multani miti*) that has water sealing properties (IGAU 1997). While this would physically prevent stored product insect pests from locating the grains it will not kill any that entered in the field thus the grains must be air dried periodically and exposed to the heat killing sun.

Table 5.7 Dryland rice insect pest cultural, traditional, and superstitious practices affirmed by farmers as prompted by an interviewer.[a] Claveria, Misamis Oriental, Philippines

Practice		Farmers responding (%)
Prayers (against all pests)		97
Early planting date observation[b] (all pests)		97
Field sanitation		95
rats	30	
worms	18	
rice bugs	5	
other insect pests	5	
Crop rotation		85
Plowing under stubbles (against all pests)		85
Smudging using grasses or rubber		77
rice bugs	15	
worms	5	
leaffolders	2	
planthoppers	2	
Synchronous planting		72
birds	37	
worms	7	
rice bugs	5	
chickens	3	
rats	2	
soil pests	2	
Moon phase observation (against all pests)		72
Use of plant parts		65
Bamboo (*Bambosa* sp.) branches	23	
Patulang (*Macaranga* sp.) branches	5	
Lemon grass (*Andropogon citratus*)	3	
Kilala (*Pandanus* sp.) branches	3	
Kamanian (Burseraceae) branches	3	
Handamay (*Trema* sp.) branches	2	
Rouging		58
aphids	7	
root aphids	2	
worms	2	
Rituals and magical practices		57
Trial plantings (evade bird damage)		53
Installing of cross		53
Talking to spirits (against selected pests)		52
Overseeding		40
Burning stubbles (against all pests)		38
Handpicking (all pests)		38
worms	8	
rice bugs	2	
Wider plant spacing		17
Scarecrow (against birds)		11

[a] n = 60, interviewer tape recorded the conversation and all farmers responded.

[b] April–June.

Table 5.8 Farmers' cultural, physical, mechanical, traditional, and superstitious practices mentioned by recall without prompting to control dryland rice pests, Claveria, Misamis Oriental., Philippines

Practice	Farmers practicing (%)[a]
Superstitious	53
Smudging[b]/(all pests)	22
Scarecrow (birds)	8
Use of *patulang* (*Trema* sp.) branches	5
Light trapping (rice bugs)	5
Use of dead animal as bait[c]/(rice bugs)	3
Rat poison baiting	3
Use of tobacco extract spray (stem borer)	2
Rouging (leaffolder damaged leaves)	2
Handpicking worms	2
Field sanitation (rats)	2
Burning of animal fats[d]/(repellent all pests)	2

[a] n = 60, 62% of farmers responded.

[b] Use of rubber tires, plastics.

[c] Dead dog, star fish.

[d] Goat meat.

5.8.3 Cultural Controls

Rice farmers are very good at developing cultural control measures which also form part of normal crop husbandry that have negative effects on insect pests and thus are dual purpose (Litsinger 1994). The most detailed listing of cultural control practices elicited from rice farmers comes from Guimba an irrigated site in the C. Luzon rice bowl. The 30 farmers interviewed came up with eight cultural control methods (Table 5.9). The most commonly used was rouging or removing of infested plants to reduce the spread of tungro (83%) although one farmer mentioned removing stemborer infested whiteheads which is a mechanical control measure. In Laguna, Marciano et al. (1981) reported that 94% of farmers rouge virus infected plants and whiteheads. The former is a recommended practice while the latter would have minimal effect. Some 60% of Guimba farmers mentioned planting synchronously with their neighbors for insect and vertebrate pest control which is a viable practice. 37% of the farmers correctly stated the beneficial effect of diluting the damage among the neighbors rather than killing the pest. Draining fields is a recommended control practice against brown planthopper and caseworm (Litsinger 1994). Plowing soon after harvest is recommended against weeds and stemborers and would have the added benefit of removing habitat from rats. Plowing under stubble is recommended more than burning as the added organic matter fertility benefits the crop. The survey showed that farmers were aware of and used many non-pesticide control measures. The interviewer was able to compile such a long list by coaxing out the responses.

In Claveria, few farmers mentioned cultural control practices by recall and without coaxing (Table 5.8). The only practices mentioned were roguing and sanitation.

Table 5.9 Cultural practices recalled by irrigated rice farmers, Guimba, Nueva Ecija, Philippines, 1986

Practice	Respondents (%)[a]	
Removal of infested plants	83	
Plants turned red, became stunted (tungro)		83
Stemborer whiteheads		3
Synchronous planting with neighbors	60	
Insects will scatter		37
Less rat damage		7
Less bird damage		3
Remove weeds in the field by hand	50	
Competes with rice for nutrients		40
Lessens tillering in rice		10
Acts as shelter for rats		7
Flooding the field	30	
Weed control		30
Rat control		3
Draining the field	30	
Caseworm control		23
Hopper control		7
Worm control		3
Plow under rice stubble	23	
To control weeds		20
To kill worms		7
Remove shelter for rats		3
Burn rice stubble	23	
To kill stemborer worms		17
To control tungro		3
Transplant old seedlings	10	
More resistant to pests		10

[a] 30 farmers surveyed in Bantung village, all responded.

However when a second attempt was undertaken that mentioned the practices one by one, nine methods were elicited from farmers (Table 5.7). The interviewer used a hidden tape recorder to document the responses of farmers with the view that farmers would be more forthcoming with answers. This probably had less benefit in a site such as Claveria where staff lived in the town and farmers knew them. When prompted, 97% of the farmers said that early planting escaped seedling maggot damage which was affirmed by field trials (Litsinger et al. 2003). Farmers did not always associate cultural control practices with pest control as these operations are common crop husbandry. Very high rates of farmer adoption of cultural control practices emerged upon coaxing including field sanitation, crop rotation, early plowing of stubble, synchronous planting, roguing, overseeding, burning stubble, and wider spacing.

The KAP survey in rainfed sites in the Philippines (Litsinger et al. 1980), noted 6% of farmers used at least one cultural control method. The most common were:

1. Increased seeding rate (58%)
2. Intercropping in dryland rice(46%)
3. Crop rotation (34%)
4. Time of planting (22%)

Marciano et al. (1981) in irrigated Laguna found 86% of farmers used water management to control diseases and insect pests, 70% said removal of weeds controlled some insects, 38% stated low fertilizer usage decreased insects and diseases. In rainfed rice countries water management is also used for pest control (Fujisaka 1990). Farmers flood fields to control rice seedling maggot. These are wetland fields that are provided with supplemental irrigation from reservoirs in the monsoon season. Sandy soils are normally without standing water in the early growth stages allowing the *Atherigona* flies to invade. For rice hispa *Dicladispa armigera*, farmers drain fields. It was also concluded, however, that many pests had no control methods. For mole cricket, Kalimantan farmers plant in wetter areas, place seedbeds isolated from the previous year's seedbed, and transplant in places that can be flooded (Watson and Willis 1985). These practices seem to be practical and effective.

Synchronized planting among neighbors as a cultural control practice was known by 93% of Sri Lankan farmers surveyed but they say they were forced to follow this planting schedule due to fact that water delivery occurs by turnout areas thus all farmers within one turnout are obliged to plant together. Fifty eight percent said they planted either early or late to avoid pests, but according to van de Fliert and Matteson (1990) this contradicts the synchronous planting need for planting at the same time. In fact this not true, synchronous planting works by diluting the pest infestation across all fields, whereas planting time is an escape mechanism where for various reasons pests are known to be in low numbers during a certain season. Early and synchronous planting would actually be two control practices that combined would give even a greater effect. Most farmers know the benefits of synchronous planting, for if they plant out of step, then insect pests, rats, and birds become serious problems (Litsinger et al. 1980).

Many Sri Lankan farmers astutely perceived healthier crops to be more tolerant (ie. resistant) to pests (van de Fliert and Matteson 1990). Rainfed farmers in Sri Lanka try to cut costs by reducing urea by 1/3 to $^1/_2$ which is a risk aversion strategy; at the same time such farmers should not waste their scarce resources on prophylactic insecticide applications and if they had funds should increase fertilizer rates to increase tolerance (Litsinger 1993). Cambodian farmers said they applied fertilizer to insect damaged areas (Jahn et al. 1997).

In Kalimantan, farmers burn weeds in surrounding non-cultivated areas to control rice bug and time plantings so crops do not mature during March (Watson and Willis 1985). Burning weeds is not a good practice because it is also a habitat for insect pest natural enemies. Their objective is to reduce rice bug habitat on wild grasses but bugs are known to disperse long distances so this method would have little effect. Avoiding planting in a certain month must be known from experience thus should be effective. More important for rice bug control is planting among neighbors such that all crops mature at the same time.

Notable cultural control methods have been developed by rice farmers by other crops in rice-based cropping systems. Legumes such as cowpea and mungbean were relay planted into rice a week before harvest. Harvesters step on the seeds pushing them into the moist soil and no inputs are needed to be able to harvest up to 1 t/ha. Research has shown that the standing rice stubble left after harvest protected the legume crop against a wide array of migratory insect pests such as aphids, leafhoppers, beanflies, and thrips (Litsinger and Ruhendi, 1984). IRRI has found that intercropping systems such as maize and legumes which encourage predators such as spiders which linger in a legume such as groundnuts at the base of maize plants (Litsinger and Moody 1976). However research has found that the controlling influence of the legume or wide spacing on maize borer was only effective in plots of 50 m^2 or smaller (Litsinger et al. 1991).

5.8.4 Biological Control

As stated earlier, genetic resistance can provide protection against at most 3–4 insect pests and for the rest IPM asks the farmer to rely on natural control and to bolster tolerance through adopting good agronomic practices. Only when other methods fail should insecticides be used as they disrupt beneficials which are Nature's gift to the farmer. There is ample scientific evidence to support the beneficial effect of natural enemies in insect pest suppression on rice (Ooi and Shepard 1994). Way and Heong (1994) concluded that wetland rice has natural stability mechanisms, more than other crops.

Rice farmers are need to be aware of a suite of interlinked concepts related to biological control to be able to efficiently manage their crop. After knowing the breadth of natural enemies they should know that their densities are sufficiently high that they can normally suppress most insect pest populations and that insecticides do them harm therefore precaution needs to be taken in making decisions whether to apply them or not. Misuse of insecticides can lead to secondary pest outbreaks and resurgence. Thus natural enemies need to be managed to foster their numbers as they are more effective than most insecticides. Bentley (1992a) found Honduran campesinos were generally unaware of the existence of most natural enemies except for spiders and some vertebrates such as birds and toads. This is the same result from the previously mentioned surveys mostly in Asia. Small scale farmers were thought to be unable to comprehend biological control because it was too esoteric (Glass and Thurston 1978). Many farmers perceive natural enemies as pests, even the presence of spiders would cause some farmers to spray. Thus IPM training programs place much effort in trying to correct this attitude. In farmer field school extension courses, farmers become highly captivated while learning of the existence of the wide variety of natural enemies present in ricefields and what pests they feed on (Ooi 1996). Farmers are encouraged to set up “insect zoos” where they hold natural enemies with rice pests in cages to see if pest numbers decline.

5.8.5 Traditional Practices

Traditional practices are those that farmers develop using local materials and differ from cultural controls in that the methods used are not normal crop husbandry practices. Thurston (1990) concluded that traditional knowledge can be overvalued or romanticized but it would be a mistake to despise or ignore it. Indigenous crop protection practices according to Watson and Willis (1985) are often highly site specific, and practices do not exist for all pests and in all locations. Farmers carry out pest management in an ecological context as they often consider interactions of crop varieties, soil, water, and socio-economic factors. Their farming environment differs by location and on a seasonal and longer term basis; farmers' responses are likewise variable and dynamic. Most farmers' techniques aim at reducing rather than eliminating crop pests, and attaining satisfactory yields. The small-scale approach of many farmers contrasts markedly with the regional emphasis and single crop or pest emphasis of researchers and institutes.

Many traditional insect pest control practices on rice are listed in Litsinger (1994). More traditional practices are followed by farmers cultivating in the marginal and risk prone environments than in favorable irrigated areas where modern rices and agro-chemical inputs dominate.

Watson and Willis (1985) found that Kalimantan farmers in swampy rice environments burned fires to smoke out rice bugs as well as broadcast leaves of some fragrant plants (lemon grass) as control measures. For mole crickets some farmers broadcast table salt. In Claveria 22% of dryland rice farmers also practice smudging by burning old rubber tires and plastics to repel rice bugs (Table 5.8). Fewer numbers used a botanical insecticide, a bait to attract rice bugs, a homemade tobacco extract spray, and burning animal fats as a general repellant. The rice bug bait based on rotting protein is widespread in Asia (Dresner 1958). Even in an irrigated area where farmers practice modern rice culture 19% of Laguna farmers said they used baits and smudging for rice bug control (Marciano et al. 1981). In Cambodia farmers used salt against pests in general, ashes against caseworm, and smoke and bait against rice bugs (Jahn et al. 1997).

The study in three rainfed areas of the Philippines predictably resulted in a number of traditional practices. Some 60% of farmers stated they practiced at least one traditional method (Litsinger et al. 1980). Ash from fire residues is placed as a barrier around migrating armyworm larvae or spread on the crop foliage against sucking insect pests. Smoke is burned for rice bug and other insect pests. Rock salt is placed in the soil to combat white grubs in dryland rice. Kerosene and soap are sprayed for other pests. 15% of Laguna farmers said they sprayed soap against hoppers (Marciano et al. 1981).

Use of plant parts was common with some 13 plant species mentioned (Litsinger et al. 1980). Some 72% of Pangasinan farmers using *Gliricidia* branches pushed into the paddy for caseworm and whorl maggot control. *Gliricidia sepium* is known to be resistant to termites and is used as a stand for orchids in people's yards. In Batangas, 28% of farmers used *Cordia* sp. branches (a known medicinal plant) within or beside fields either to ward off or to attract pests (trap crop). Eleven other plant species are described in detail. 65% of dryland rice farmers in Claveria utilized plants as botanical pesticides in some manner as determined by guided questions. Six plant species were recorded with bamboo being the most prevalent (Table 5.7). Laotian famers mentioned *Gliricidia* and neem as botanical pesticides (Rapusas 1997). In Laguna 44% of farmers said they used some kind of botanical insecticide for caseworm and other pests (Marciano et al. 1981). Ivory Coast farmers recalled a number of indigenous practices based on plants such as throwing either lemons into the field to repel insects or placing palm leaves on the ground (Adesina et al. 1994).Chhattisgarhi farmers who say insecticides are ineffective against *chitari banki* use botanical insecticides from local plants in the nearby forests. They told us they harvest branches of the *karra* tree full of leaves which they place in the affected parts of their field (15 kg of leaves for 0.2 hectare). The water turns black from the exudate from the immersed leaves. Another botanical is *bantulasa* medicinal plant. The dried flowers of the *mahuawa* tree can be used to soak up kerosene which is broadcast for *chitari banki*. Neem trees were also mentioned. Several botanicals were also used by Guimba farmers by directly placing the leaves in paddy water in areas affected by caseworm (Table 5.10). Again botanical insecticides such as neem have been popularized but these are extracts from the seed rather as the leaves themselves. Neem leaves are used by farmers to protect their stored grain in confined receptacles where their odor repels pests. Placing them in the field would greatly dilute their effect and we actually tested *Gliricidia* leaves against caseworm in the laboratory with no favorable result. Rock salt was used against tungro and caseworm with dubious effect. Cooking oil as a sticker and kerosene for caseworm control would produce the desired effect. Kerosene has been used throughout rice growing

Table 5.10 Traditional pest control practices recalled by irrigated rice farmers, Guimba Nueva Ecija, Philippines, 1986 [a]

Practice	Respondents (%)	
Detergent soap	50	
Sticker for insecticides		43
Caseworm control		3
Tungro control		3
Use of plants as botanical insecticides	40	
Gliricidia branches for caseworm		20
Cogon[b] leaves for moths		13
Rock salt	17	
Tungro		14
Caseworm		3
Bait for rat poison	10	
Broken rice with endrin insecticide		7
Broken rice with DDT insecticide		3
Cooking oil as an insecticide sticker	7	
Kerosene to control caseworm	3	

[a] 30 farmers surveyed in Bantung village.

[b] *Imperata cylindrica*.

Asia by applying it as a film in paddy water (Litsinger 1994) and would no doubt be lethal. It is also phytotoxic to rice so it needs to be drained after a few days.

One traditional practice of Ivory Coast rice farmers was hot water for termites (Adesina et al. 1994). For rice hispa, farmers drain fields and apply a botanical product (Fujisaka 1990). In Cambodia crabs are controlled by botanical repellants (Jahn et al. 2007). In C. Luzon in an irrigated rice bowl where insecticides are the usual insect pest control practice, a survey of farmers found a surprisingly large number of traditional practices known by local farmers in Guimba (Table 5.10). The most commonly known is the use of detergent (40% of respondents) as a sticker for insecticides or directly sprayed to ricefields for caseworm and tungro control. Goodell (1984) mentions that in Zaragoza, a nearby area, where some farmers spray a laundry detergent. Moore et al. (1979) tested a number of detergents in the US against garden pests and nowadays soap products are popular for home gardeners for aphid control.

5.8.6 Superstitious Practices

A fine line separates farmers' knowledge from their beliefs. Much of farmers' knowledge may appear to us as a belief or as a simple superstition. A credence embedded in local belief system is even more than knowledge due to the given supernatural sanction. What appears to be a silly story to the outsider is a reality to many farmers. This would be particularly true if pests for part of indigenous mythos of origin as with the Tharu tribe in Nepal where the rice bug was created by their god to damage rice thus requires control by means of a ritual (Björnsen-Gurung 2003).

Rituals play important roles in the adoption of farmers (such as the Bontok of N. Luzon Philippines) to ecological constraints they have faced for generations (Prill-Brett 1986). Rituals emphasize the relationship between the human social world, the material world, and the supernatural world. Rituals provide reassurance, giving indigenous people a feeling that they have some degree of control in their continuous encounters with unpredictable natural phenomena. Rituals also structure the way people act with their environment on a sustainable basis. Ritual sacrifices are carried out to ensure good harvest. The bile sacs of chickens are examined and if the prognosis is not good a rest day is declared. Bontocs believe rest days are critical to minimize pest damage to the rice crop. Because each step of the cultivation cycle is synchronized throughout the village, delays at harvest allow pests (rice bug) to concentrate on late harvests to cause great damage.

Superstition is defined as a belief, practice, or rite irrationally maintained by ignorance of the laws of nature or by having faith in magic or chance and usually involves the supernatural and is often associated with rituals. In Uttar Pradesh, India women plow their fields semi-naked to invoke rains. Such practices involve the power of certain actions, or avoidance of some actions, to diminish or deflect ill effects (of pests) and/or to promote the positive influence (pests go away). Farmers resort to such superstitious practices for pest control, often based in pagan religious observances that have lingered in people's memories since ancient times. These are methods of last resort when farmers feel they have no other options and feel helpless under a situation of threatening yield losses from pests, that they could not otherwise control, and could lead to extreme hardships for their families. Farmers become desperate and few options are left except practices based in superstition. They invoke the powers of spirits of ancient pagan religions even though they practice more mainstream religions at the same time. At times they seek the assistance of local shamen. In Claveria, the richest source of such practices we found in the Philippines, some 53% of farmers when prompted admitted to using superstitious practices. These practices are presented in a hierarchical manner beginning with methods that are similar to traditional practices to increasing degrees of irrationality ending in the occult (Table 5.7). Many of the practices enumerated by farmers involve their knowing of them, but how many are actually pursued on a regular basis is hard to know.

As is common in cultures worldwide, some rice farmers in the Philippines avoid planting during a full moon (Litsinger et al. 1980). Most (72%) say planting by the moon phase is followed. However there is no consistency in the practices which were said to lead to fewer pests and varied from planting during the third quarter (12%), full moon (10%), 3, 5 or 7 days after the full moon (2–7%), last to first quarter (9%), or except during a new moon (2%). Other methods employ luck. Farmers avoid unlucky planting dates with the number seven (Litsinger et al. 1980) or on death anniversaries of relatives (Altieri 1984). In Guimba 13% of farmers avoided unlucky planting days (Tuesdays and Fridays or Mondays in August). Some 24% of Laguna farmers believe in unlucky planting days that if a crop were planted would risk high pest incidence (Marciano et al. 1981).

The next set of practices are based on religious beliefs. The first are from Litsinger et al. (1980) where Catholic Filipino farmers have a priest bless seed for planting on Holy Saturday to ensure a good crop. Farmers recite prayers while circling the field to appeal to a higher power to spare their crop. In Laguna 21% of rice farmers recite prayers to seek avoidance of pest problems (Marciano et al. 1981). In Sri Lanka, a Buddhist country, religion only had a slight effect on farmers' pest control practices, where 15% of respondents were Buddhists say that for religious reason they do not like unnecessary killing of animals including pests (van de Fliert and Matteson 1990). A practical consequence is that 1% say they avoid spraying on religious holidays. In Bhutan, Buddhist farmers have stronger religious convictions toward insects and do not like the idea of killing any animals such as insect pests in a rice field. Foreigners using sweep nets were requested to leave the field on religious holidays (G. Arida, personal communication). The Tharu of Nepal are also Buddhists but they believe they can kill *kiraa* but not other kinds (Björnsen-Gurung 2003). In Claveria 97% of farmers said they prayed to spare their crops from pests.

Others use rituals such as placing a bamboo pole in each corner of the field, but this rite can only be done by one person. The effect is that insect pests will be repelled from the field (Litsinger et al. 1980). These can be quite varied. Catching a mating pair of insects and returning home without looking back. The insect pair is then released expecting them to lead other insect pests away. Riding a horse or carabao around a rice field at twilight to repel rice bugs or circle the field with a burning bamboo pole is another. In Nepal where farmers practice rice bug worship, two bugs are caught, painted red and black and carried around the community before releasing them outside the community to usher it away from their fields (Björnsen Gurung 2003). Offerings of food items and burning of incense accompany this ritual.

Others employ shamen or other local religious people to address the spirits. African farmers stated a number of indigenous practices such as consulting traditional herbalists (Adesina et al. 1994). Most farmers, however, carry this out directly. Others address spirits to control pests. In rainfed areas of the Philippines, 39% of farmers offer food (rice, eggs, chicken) to appease spirits to spare their crop from pests (Litsinger et al. 1980). We were told that the farmer should avoid becoming angry against pests otherwise spirits may become vengeful. Trial plantings also are carried out to appease spirits. Malaysian farmers have been used to planting and leaving the crop to the mercy of the "invisible diseases". Ignorance of damage by a casual agent is also widespread. This partly is due to the cultural element of superstition and partly to the low level of knowledge (Heong 1984).

In Claveria farmers collectively have a rich inventory of rituals and magical practices. There is much individuality in how each is performed as no two were explained in exactly the same way. 57% of farmers stated that they practiced at least one of such practices (Table 5.11). Rituals include making offerings, performing ceremonies that would have the effect of causing the pest to avoid or leave the field. Some involve using the blood of animals. Others involve burning certain plants and often local shamen perform the rites. These are mainly done against animal pests (insects and rats) with none done against plant diseases. Presumably this is because they do not have eyes thus cannot see the rituals' effects.

The last category of superstitious practices fall under the title of black magic or witchcraft which involve sacrifice of animals and voodoo like rituals to "scare" the pests away from rice fields. A number of these incorporate parts of each type so the division between magical and black magic is blurred. Black magic methods are used to scare the pests and include torture or ritualized killing or threats to kill. For example rice bugs are "threatened" or tortured with needles. Many of these methods have similarity to voodoo rituals practiced in Haiti and are done in secrecy. In Chhattisgarh several superstitious practices are known by farmers to control rice caseworm (*chitri banki*). The first is to take the leaves from a tree near to where a person committed suicide and place them in the field to control the pest. The second is for a person who was born legs first to eat puffed rice which makes a crunching sound while walking around the infested field while saying out loud that he was eating caseworms in order to scare them away.

Fujisaka et al. (1989) also recorded a number of similar superstitious practices from the same site in Claveria and asked if farmers would have the same or similar ones for other crops. The answer produced amusement among farmers who then explained that such crops are grown with fertilizer and pesticides while rice is a sacred crop. As the primary staple crop for many Asian countries rice is synonymous with life and many religious practices evolve around it (De Datta 1981). It is interesting in the case of the Philippines which is predominately Catholic that many farmers still believe in the ancient religions what were in place before the

Table 5.11 List of superstitious pest control practices that involve rituals, black magic, and prayers of dryland rice farmers in Claveria, Misamis Oriental, Philippines[a]

1) Kill white chicken in the field, let blood drain into the soil. Make offerings of prepared food from the chicken carcass and talk to the spirits. This is done every year.
2) Done in the afternoon. Prepare a fire at the center of the rice field to produce smudge using *kamanian* herbage. In front of the smoke, say some prayers. After finishing prayers, cross over the smoke to exit the field.
3) Kill chickens and prepare foods. The *Baylan* (local priest) will perform the *Panigal-i* to talk to the spirits in the fields. Prayers are said in old native language.
4) *Dalawit* ritual. Done at the start of planting season. Prepare lots of food, especially chickens, wine, cigarettes, lime, areca nuts and betel pepper leaves at the middle of the field. A local priest will murmur prayers to petition to the deities that the crops be spared from pests. Successful cropping would oblige the farmer to do similar food offerings as thanksgiving.
5) *Palihi* 1. Stick in a bamboo branch each in the 4 corners and one in the middle of the rice field. It is believed that like a bamboo branch, a rice stem would be as hard to resist damage by stemborers and other worms.
6) *Palihi* 2. When about to plant, place a comb, a needle and a handful of chicken dung on top of the seeds. the comb would prevent chickens scratching the sown seeds, the needle would make the seeds invisible to the chickens, and the chicken dung would filth the seeds that would discourage forage by chickens.
7) Place a cross (bamboo, lumber or small round sticks) at the middle of the field. Said to invite spirits to watch crop and ward off all pests. Sometimes associated with rituals. Some farmers would place a branch of bamboo at the side of a wooden or timber cross.
8) Scarecrow. Install a scarecrow at the middle of the field even well advance before panicle emergence. Some farmers would install it during the night, not letting anyone see him doing it. Said to frighten pests, including insect pests and birds, and never to touch the rice crop.
9) Sticking in of bamboo branches in random spots in a field to expel white grubs.
10) For rice bugs. Catch 7 rice bugs. Put rice bugs in the mouth and walk around the field. Spit bugs out at the end.
11) For rice bugs. Place a pin in the anus of 4 rice bugs and release. Shoo while telling them to go away and never to come back again.
12) For worms. Get 3 worms and wrap in a black cloth. Hang over the fireplace in the kitchen. Say begging words to the worms, asking them not to infest the crop anymore.
13) For worms. Look for a rice stemborer-infested plant. Cut off parts to expose worm. Talk to the worm ‘Go away’ then bite to kill the worm. After, walk across the field starting from east to west then north to south. Do not come back to the field for three days.
14) For worms. Get some deadhearts or whiteheads. Dissect and remove worms with the use of a sharp needle. To torture worm so that others would not follow suit.
15) For worms. Look for stemborer deadhearts or whiteheads. Dissect and collect worms using the sharp end of a stingray tail. Place worms in the mouth, walk around the field and blow (spit) them at the last corner, which was also the starting corner, of the field.
16) For worms. Walk alone and look for a stemborer deadheart in the rice field. Remove the worm using the teeth. With the worm in the mouth, close eyes and walk straight forward across to the other side of the field where worm is blown out. Do not allow anybody to enter the field for three days.
17) For worms. Save a sharp bone of a fish. Collect any lepidopteran larvae in the rice crop. Dissect and remove by piercing the worm using the sharp fish bone. Walk around the field with the pierced worm at hand. Throw the bone and the worm into the middle of the field when about to leave.
18) For worms. Get a larva of an infesting insect. Get a betel nut, a betel pepper and some lime. Sandwich the larva in the betel chew and let a child do the chewing.
19) For all pests. Look for a nest of a bird with eggs. Bury the nest with the eggs during the night with nobody else around to watch.

Table 5.11 (continued)

20) Feeding rats rice through a ritual performed as an act to bribe them not to damage the farmer's crop
21) Unlucky planting dates are odd dates in June that if planted then more pests in general would occur. June is one of the main planting months.
22) Planting by the moon with the 5th and 7th days after full moon auspicious days to avoid pest problems

[a] n = 60. As narrated by farmers.

arrival of the Spanish. In Yogyakarta, Indonesia in the baseline survey for IRRI's Constraints Program farmers were asked about their beliefs in the existence of a rice god and whether they made offerings to make it rain and ensure a good harvest (Widodo et al. 1979). Most farmers rejected the traditional beliefs and were in favor of modern inputs.

Ethnicity was noted by Litsinger et al. (1982) that also may explain differences in adoption of superstitious practices between locations. Tagalog farmers in the more developed C. Luzon and Batangas utilize fewer of these methods and are less superstitious than Ilocano or Ilongo farmers that reside in Northern Luzon, the Visayas, and Mindanao (Litsinger et al. 1980, Pineda et al. 1984, Fujisaka et al. 1989). Farmers in Zaragoza and Calauan were mainly Tagalog, while Guimba farmers were a mixture of Tagalog and Ilocano. Pangasinan has its own ethnic group while Ilongos dominate in Iloilo. Each of these cultures has maintained superstitious practices from the older farmers based on beliefs before modern rice culture and pesticides. However younger generations of farmers would be less likely to employ these methods. In Claveria which was only recently settled has a mixture of ethnicities: Cebuano (32%), Misamisnon (30%), Boholano (20%), Higaonon (7%) and Ilongo (7%).

Many of these methods showed fertile imaginations that are felt to be developed out of desperation. Of the methods described above, only planting by the phase of the moon would have any scientific basis as many rice insect pests use the moon to time dispersal periods (Perfect and Cook 1982). With the advent of pesticides, many of these practices are no longer used. But pesticides tend to be expensive and only those farmers in favorable areas where high yields would justify paying for their cost would farmers no longer have need for superstitious practices.

5.9 Chemical Control

Insecticide usage by rice farmers began in the 1950s with the development and marketing of organo-chlorine and organo-phosphate chemicals. By 1966 following 10 years of free insecticide treatments carried out by government technicians, Philippine rice farmers had adopted insecticides widely, then they became eligible for a loan package in the government production program Masagana 99 (Kenmore et al. 1987). Thus insecticide usage on rice pre-dates the Green Revolution, but the introduction of modern rices most certainly boosted usage particularly in the less risk-prone irrigated environments. Extension services campaigned for the adoption of insecticides as a means of ensuring the promised high yield potential in much the same vein as use of inorganic fertilizers. Usage was monitored in the Philippines by Kenmore et al. (1987) from a compilation of some 30 independent surveys carried out over the country from the 1950s to the mid 1980s. Usage followed a linear rise from <30% of farmer users in 1960 to >90% by 1980. Farmers adopting heavy usage of inorganic fertilizers were more prone to purchase insecticides.

5.9.1 Expected Benefits

Use of insecticides as well as modern rice varieties was a sign of a farmer being modern and progressive. Those who did not were considered lazy, old fashioned, or ignorant (Brunold 1981). In Quezon Province Philippines, for example, 91% of farmers surveyed adopted pesticides more readily than modern varieties (Kenmore et al. 1985). In Mindanao rice farmers used more insecticides and herbicides than fertilizers even though returns were greater from fertilizers (Kenmore et al. 1985).

Soon farmers perceived greater reasons to use insecticides (Litsinger 1989, Heong et al. 2002). In Sri Lanka, among the areas surveyed, the area with the highest number of insecticide applications occurred where brown planthopper and a vectored virus were prevalent (van de Fliert and Matteson 1990). Lowest insecticide usage was in an area of unsure irrigated water supply. Almost all farmers were aware of the health hazards of pesticides, but 53% believed that using more insecticide will mean greater profits. Almost none mentioned harm to the environment from pesticide usage.

Insecticides are used by traditional farmers in very small amounts, if at all, but their expectations for insecticides are often unrealistically high, and once they became affordable, farmers sought them if they had funds (Thurston 1990). Insecticides are looked upon favorably by farmers in developing countries, e.g., in Mbita, Kenya farmers stated insecticides are the most effective pest control method even though most had never used insecticides (Bentley and Andrews 1991).

In a survey in the Philippines most (98%) rainfed farmers believe insecticide use increases yield, with 51% expecting gains less than 25% (Litsinger et al. 1980). Field trials from the areas surveyed, showed that this estimate was correct in many cases but the practice was uneconomical due to the low yield levels. Yield was found to be independent of the number of insecticide applications in irrigated Laguna, Philippines (Marciano et al. 1981). Rice is a difficult crop to achieve good control with insecticides, principally because good coverage is essential and the low pressure knapsack sprayers and the farmers' penchant for low volumes means that this is not achieved (Litsinger et al. 2005). Motorized sprayers would overcome this deficiency but are much more expensive and breakdown frequently and thus not used.

In a survey in Iloilo, Philippines, some 90% of farmers believed that insecticides increased yield and 94% thought they will get a lower yield if they do not spray

(Brunold 1981). The farmers further estimated a 50% loss if rice were not sprayed. In a survey in Malaysia, 81% of farmers said insecticide application will increase yield, with 14% saying it will not, and 5% had no opinion (Heong 1984). In the Philippines farmers are highly convinced of the value of insecticides as barely no respondent perceived an insecticide as ineffective or as causing more pest problems (Warburton et al. 1995).

In Iloilo calendar based applications were mostly followed to avoid risk of missing an application as the farmers in the past had experienced a pest outbreak (Brunold 1981). Still most could not afford the prophylactic schedule therefore they spray only when pests were detected. Still most farmers believed yield suffered as a result of not following a calendar schedule despite field trials that showed low pest incidence and insignificant loss. Chemical company advertisements are effective in shaping farmers' attitudes (Kenmore et al. 1985). Waibel (1986) and Tjornhom et al. (1997) also felt propaganda from chemical companies and dealers tended to generalize pest outbreaks such that even people in areas that never experienced outbreaks feared them.

Farmers strongly believed that insecticides were effective against stemborers and that not using them would result in low yields (Heong and Escalada 1999). Farmers realized that insecticides would destroy natural enemies but placed moderate importance to this effect as well as the negative effect of insecticides on human health (Heong et al. 2002).

Spraying insecticide is considered a good practice and a social norm, thus IPM training will need to re-establish a new norm in society, for example that spraying for stemborers normally is not economical and therefore not beneficial (Heong and Escalada 1999). KAP studies showed farmers will spray when whiteheads are less than 1%. There is likely no yield loss from such an infestation that would be economically recoverable from insecticide sprays. Thus farmers perceptions of benefits from insecticide use tend to be overestimated.

5.9.2 Change in Attitude

Modern commercial insecticides have resulted in a dramatic change in attitudes among rice farmer adopters. An example from Java is presented from a KAP survey (Rubia et al. 1996) where overall, insects were seen as important but controllable, with the exception of a newly emerging pest, the white stemborer, which was seen as important but uncontrollable (85%). Farmers felt that the stemborer could not be controlled because they could not control it with insecticides. No other control practices were considered even though the Dutch had instituted delayed planting as an effective community wide practice (Litsinger 1994).

Farmers in Iloilo, Philippines found insecticides were readily available but were considered expensive (Brunold 1981). Thus farmers tended to purchase the cheapest broad-spectrum generics in 100 ml bottles, which are the most unsafe to use and cause the greatest instability in arthropod populations in ricefields (Cohen et al.

1994). Factors such as costs, side effects, and labor to spray are not seen as barriers. Iloilo farmers said that calendar-based insecticide treatments increased yields and missing one spray would endanger the whole season thus farmers said they would sleep better only if they followed a spray calendar (Brunold 1981). When asked about other strategies, 88% felt that spraying after seeing damage would be very risky and 55% thought that need based usage would result in lower yields. Farmers think if they wait for signs of damage before spraying, then the crop would be lost, thus calendar basis is considered best (Kenmore et al. 1985).

Central American farmers have energetically adopted insecticides and will spray when a beetle eats a whole in a leaf (Bentley 1989). Honduran farmers like to see a dramatic die-off after spraying as all insects are perceived to be their enemies. Belatedly farmers accepted the observation that there were more pests after they used insecticides than before. They could not understand the concepts of insecticide resistance, resurgence, and secondary pest outbreaks.

5.9.3 Insecticides Seen as Medicines

When encountering a pest problem, most Malaysian farmers in the Muda Irrigation scheme reacted by spraying their crops (Heong 1984). The KAP survey determined that insecticide application seemed to be the only tactic they were aware of. Quite often a pest infestation is thought to be analogous to human illness and insecticides are seen as drugs or "medicine" just as with Filipino farmers. In most languages the word "insecticide" translates as "medicine" and as in human health insecticides are perceived to cure a malady. Some farmers, however, apply insecticides for prevention (prophylactic applications), but most farmers would not take preventative medicines, thus the health analogy wrong in the strict sense (Bentley and Andrews 1991, Escalada and Heong 1992). But well known benefits of drugs combating human illnesses are equated to insecticides and "after becoming sick" is equated to "after seeing pests".

Another point was made that ease of use outweighs negative attributes as Filipino farmers in Leyte prefer easy-to-use pesticides to labor intensive cultural and traditional methods (Escalada and Heong 1992). Familiar, available, independent, reliable, time-saving, easy to use, and effective are preferred over not cheap and not safe.

5.9.4 Decision Making

One of the most complicated management decisions farmers face in rice culture is to know when to react to an insect pest infestation. Farmers often spay when they see pest damage and do not check to see if living insects are present. The insecticide can only kill living insects and cannot repair their damage. In Java, for example, farmers did not know that applying insecticide when stemborer whiteheads were evident was too late and a useless effort (Rubia et al. 1996). Leyte farmers, on the other hand, were motivated to prevent a worst case scenario in which they perceived a loss of $415/ha and thus were willing to spend $39/ha to prevent it (Heong and Escalada 1999). Clearly farmers misperception of the danger posed by insects was overvalued. Often there is little help to provide guidance to farmers who mostly make their own decisions as shown in this example in rainfed rice culture in the Philippines (Litsinger et al. 1980). Farmers receive guidance from:

1. Farmer himself (51% of respondents),
2. Extension worker (32%),
3. Neighbor (4%),
4. Advertisement (4%),
5. Pesticide dealer (1%), and
6. Radio 1%.

Some farmers are more likely to react to pests they can see more than less observable types. Filipino farmers in Pangasinan province were unwilling to treat mungbean sown among rice stubble for early season insect pests such as beanfly. These Pangasinan farmers believed only pod borers were important and not beanfly. Only when they saw trials that treated during the first week of crop emergence did they change their practice (Litsinger et al. 1977). Farmers' misperceptions often lead to wastage of money and chemicals.

5.9.5 Researchers' Decision Methods

One of the basic tenants of IPM is for farmers to undertake corrective actions such as an insecticide application only when an insect pest population attains a level that will cause a sufficient economic loss to warrant control costs termed the economic injury level. Economic thresholds, derived from economic injury levels, are decision tools that are based on a relationship between yield loss and insect abundance (Pedigo et al. 1986). If such a damage function has not been worked out then action thresholds, which are derived empirically, can be used. In the case of rice, action thresholds have been used in place of economic thresholds because damage functions have been found to be highly dynamic due to the tremendous capacity of modern rices to compensate for crop stresses including pest damage (Bandong and Litsinger 1988, Smith et al. 1988). Compensation in turn is dependent on many factors such as crop management, crop maturity, and the number of stresses affecting the crop (Litsinger et al. 2006a, Litsinger 2008b).

The determination of economic thresholds in small farm systems is especially complex because more than strict profit-loss relationships are involved and generally a whole pest complex (insects, weeds, diseases) affects the crop (Altieri 1984). Moreover circumstances at the individual farm level are so highly variable that separate pest-density thresholds should be established to suit individual circumstances. This is of course unrealistic as the alternative of applying a single threshold to a heterogeneous group of farmers because of their vegetational diversity, traditional agro-ecosystems usually enjoy a high degree of natural control. Therefore in those systems with relatively high numbers of natural enemies, thresholds should be adjusted upward. How to make thresholds appropriate to farming circumstances in peasant agriculture remains a major challenge. One needs to plan insect control interventions with those in other pest control disciplines. Altieri's generalization applies more to dryland polycultures than to rice monocultures, especially single crop traditional rice where natural enemy abundance is not as high as in irrigated double cropping due to the long dry fallow.

Despite these limitations, Litsinger et al. (2005) found that action thresholds can be used to predict yield loss with significant accuracy. The problem encountered in their use was the inefficiency of insecticides when applied via knapsack sprayers to adequately control a pest in response to a threshold. This inefficiency is manifested as the "kill coefficient" and is part of the equation used to determine economic thresholds. Waibel (1986) found farmers had lower kill coefficients than researchers (e.g., 64% vs. 39% mortality for stemborers). Furthermore Litsinger et al. (2005) found kill coefficients based on the knapsack sprayer to be too low for adequate control in response to thresholds.

5.9.6 Farmers' Decision Methods

Farmers have been exposed to two different extension messages regarding insecticide decision making on modern rices. The first in the 1970s was prophylactic based with applications timed to specific crop growth stages without monitoring, while since in the 1980s, farmers were encouraged to monitor and apply insecticide when pest density reached a specified level. Kenmore et al. (1987) believed farmers innately preferred the more simple crop stage-based insecticide approach, but since insecticides became increasingly costly, farmers could not afford protection over the entire crop cycle. Bandong et al. (2002), on the other hand, concluded Filipino farmers limited their usage by applying when an intolerable loss was perceived to be imminent due to economic necessity.

5.9.6.1 Three Decision Modes

KAP studies showed that farmers' insecticide decisions can be divided into three types: (i) prophylactic or based on the crop growth stage, or based on crop monitoring regarding (ii) pest population density or (iii) amount of damage. The mode of decision making varied extensively by location. In China in the late 1950s to end of 1970s, decisions about rice production were made by commune team leaders and not individual farmers. But a more recent a KAP survey in Zhejiang found 69% of farmers' spray decisions were prophylactic with only 17% utilizing infestation in one's own field and 14% when an infestation occurred in a neighbor's field (Hu et al. 1997). But this seemed to be the exception as KAP studies elsewhere showed farmers do not predominantly make insecticide decisions by prophylactic spraying.

A mix of the three modes was most commonly employed, the degree of any one mode varied by site.

One of the first studies occurred in rainfed rice areas of the Philippines (Litsinger et al. 1980) which found that only 33% of insecticide applications were prophylactic with 37% based on plant damage and 29% presence of pests on rice. Plant damage symptoms were either damaged plants (37%), change of plant color (24%), floating leaves (9%), or deadhearts (2%). Waibel (1986) reported surveys in the Philippines that showed less than 10% of insecticide applications were calendar based with 50–60% of decisions being made upon observing the pest or its damage. In another KAP study in the Philippines found farmers used a mixture of the three decision modes rather than following any one (Bandong et al. 2002), but most decisions on the main crop were made after crop monitoring (combining insects and their damage) rather than prophylaxis. Prophylaxis was the mode of choice, however, in the seedbed probably because of the high risk farmers place on damage at this stage. Loss of a seedbed may mean significant delay in planting risk of not receiving sufficient irrigation water. Reasons for farmers in Leyte spraying were 27% prevention (prophylactic) and 73% in response to pest infestation (Heong et al. 1992). In Guimba, Fajardo et al. (2000) also noted that two-thirds of the insecticide applications in the seedbed were prophylactic, usually timed within a week after fertilizer application. The remaining applications were based on the presence of insect pests or their damage.

Warburton et al. (1995) reported that farmers in two provinces in the Philippines applied insecticides based on the perceived intensity of infestation in Laguna (34% of applications) and Nueva Ecija (58% of applications) with lower levels prophylactically based. Another study in the Philippines by Rola and Pingali (1993) reported that only 24% of insecticide applications were prophylactic. In Sri Lanka, van de Fliert and Matteson (1990) found most (79%) farmers applied insecticide based on pest monitoring rather than prophylactically. Some of the prophylactic applications may have stemmed from farmers' viewing insecticides in the same light as fertilizers and follow a strict growth stage schedule in terms of application timing and frequency each time they grow the crop (Bandong et al. 2002).

If insecticide cost is not a significant factor, farmers will apply more as insurance (Kenmore et al. 1985). This was corroborated from data reported earlier that Malaysian farmers would apply more frequently if insecticides were given free or were highly subsidized by the government. It is interesting that rice bug, one of the most recognized of rice insect pests, is treated mostly via a prophylactic basis (Bandong et al. 2002). This may be because of its being only one of four insect groups that directly attacks the grains in the field (the other three are stemborers causing whiteheads, katydids, and armyworms cutting rice panicles). Thus farmers have high regard for rice bug damage as noted in other studies (Litsinger et al. 1982, Heong et al. 1992), as farmers do not realize that rice plants can greatly compensate from rice bug damage (Litsinger et al. 1998).

Differences in decision modes noted between sites could have been due to differences in the pest complexes and outbreak histories across sites as well as differences in perception, the extent and kind of training, and risk that occurred for farmers and

Table 5.12 Chronological rice crop production and input usage profiles of two selected farmers in Zaragoza, Nueva Ecija, Philippines 1982–1991[a]

				Seedbed fertilizer				
						N per seedbed area		
Year	Crop	Culture	Cultivar	Appl. no.	Brand	(kg / ha)	Timing (DAS)	Appl. no.
A. Ligazon, 2.5 ha								
‘84	WS	TPR	IR42 Milagrosa Malagkit	1	Urea	323	13	1
‘85	DS	TPR	IR36 IR42	1	Urea		21	1
‘86	DS	TPR	IR64	1	Urea	184	15	1
‘86	WS	TPR	IR64	1	Urea	184	15	0
‘87	DS	TPR	IR64	1	Urea	230	12	0
‘87	WS	TPR	IR42	1	Urea	230	12	1
‘91	WS	TPR	IR60 AG-O-O Milagrosa	1	Urea	184	10	1
M. Espiritu, 2.5 ha								
‘82	WS	TPR	IR36 IR52 IR54					0
‘83	DS	TPR	IR42 IR54 IR56	1	Urea		9	0
‘84	WS	TPR	IR42 C-1000 Milagrosa	1	Urea	159	10	0
‘85	DS	TPR	IR56	1	21-0-0		10	1
‘85	WS	TPR	IR62 "IR98"	1	Urea	92	10	0
‘86	DS	TPR	IR64	1	Urea	153	10	0
‘86	WS	TPR	IR64 IR56	1	Urea	74	14	0
‘87	DS	TPR	IR42 IR64	1	Urea	92	13	1
‘87	WS	TPR	IR66 IR42	1	Urea	74	9	1
‘91	WS	TPR	IR64 RC2	1	Urea	77	11	1

Table 5.12 (continued)

Seedbed insecticide		Main crop fertilizer						
				Dosage (kg / ha)				
Brand	Timing (DAS)	Appl. no.	Brand	N	P	K	Timing (DAT)	Appl. no.
Brodan EC	16	0						0
Hytox WP	24	1	Urea + 14-14-14	47	1	1	13	0
		2	Urea	46	0	0	50	
Azodrin EC	17	1	Urea	46	0	0	10	0
		1	Urea	46	0	0	18	0
		1	Urea	69	0	0	14	0
		2	Urea	29	0	0	41	
Brodan EC	18	1	Urea + 14-14-14	44	6	6	26	0
Thiodan EC	16	1	Urea + 17-0-17	57	0	20	15	0
		1	16-20-0	19	23	0	18	na
		2	Urea	29	0	0	34	
		1	Urea	64	0	0	16	na
		2	Urea	37	0	0	38	
		1	14-14-14	11	11	11	36	1
								2
Azocord EC	18	1	Urea	48	0	0	11	1
		2	Urea + 16-20-0	39	13	0	19	
		3	Urea + 16-20-0	29	11	0	41	
		1	Urea	37	0	0	0	1
		2	16-20-0	16	20	0	35	
		3	Urea + 16-20-0	29	5		40	
		1	Urea	44	0	0	0	1
		2	Urea	58	0	0	37	
		1	Urea	52	0	0	13	1
Cymbush EC	28	1	Urea	70	0	0	0	1
		2	Urea	60	0	0	22	
		3	Urea	15	0	0	35	
Brodan EC	21	1	Urea + 14-14-14	45	3	3	0	1
		2	Urea	31	0	0	38	
Endox EC	27	1	Urea + 14-14-14	44	6	6	10	1
		2	Urea	53	0	0	35	

Table 5.12 (continued)

Main crop herbicide			Main crop insecticide						
Brand	Dosage (kg ai / ha)	Timing (DAT)	Appl. no.	Brand	Dosage (kg ai / ha)	Timing (DAT)	Target pest	Decision mode	Yield (t/ha)
			1	Brodan EC	0.15	34	NR moths	DAM	4.5
			1	Hytox WP + Azodrin EC	0.09 0.13	18	AW	PRO	4.4
			0						5.4
			0						2.9
			1	Azocord EC	0.06	42			5.0
			0						4.2
			1	Thiodan EC	0.14	17			3.5
			2	Thiodan EC	0.14	35			2.5
									2.4
			1	Azodrin EC	0.28	19			na
			2	Azodrin EC	0.30	46			
			0						2.5
Machete EC	0.96	7	1	DDT WP	0.30	19	NR	INS	2.4
2,4-D EC	0.25	38					LF		
Rogue G	1.10	5	1	Azodrin EC	0.35	18	AW	DAM	5.4
			2	Hytox EC	0.39	49	LF	PRO	
			3	Etrofolan WP	0.26	54	RB	PRO	
Saturn-D G	0.44	3	1	Azodrin EC	0.07	18		DAM	3.5
			2	Cymbush EC	0.005	33		DAM	
Rogue G	0.60	4	1	Etrofolan WP	0.17	44		PRO	6.0
Saturn-D EC	0.17	5	1	Azodrin EC	0.07	14	NR,WM	DAM	4.3
			2	Azodrin EC	0.03	34			
Treflan-R EC	0.07	3	1	Azodrin EC	0.07	46			6.5
2,4-D G	0.68	4	1	Azodrin EC	0.07	35		INS	5.1
			2	Azodrin EC	0.07	65			
Grassedge EC	0.30	8	1	Endox EC	0.18	4			4.5
			2	Brodan EC	0.32	6			4.3

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[a] / DS = dry season, WS = wet season, TPR = transplanted rice, DAS = days after sowing, DAT = days after transplanting, EC = emulsifiable concentrate, WP = wettable powder, G = granule, NR = vegetative defoliators Naranga and Rivula, AW = armyworm, WM = whorl maggot, LF = leaffolders, RB = rice bug, DAM = spray when damage, PRO = spray prophylactically, INS = spray when insect

their communities. Ethnicity was noted by Litsinger et al. (1982) to explain differences in approaches to pest control. Heong et al. (1994) concluded that individual wetland rice farmers in either the Philippines and Vietnam showed a wide variation in loss assessment from a given pest infestation level.

Farmers may vary over time in their motivation to use insecticide. For example, farmers whose supply of rice had been decimated by a pest outbreak or by inclement weather are more prone to spray on a prophylactic basis on the next crop when production rather than profit became the central goal (Litsinger 1993). Among the study sites, Koronadal farmers probably were more conscious of pest outbreaks due to their recent history which may explain their behavior to spray more frequently (Bandong et al. 2002). Despite this they were no more likely to spray based on calendar basis than for the other two sites. Tracking individual farmers showed that they do not always follow the same mode each time but engage in all three depending on their perceptions in a particular crop (Table 5.12). Records are not complete, but Mr. Espiritu made two decisions based on a prophylactic basis while three were based on insects and four on damage.

A caveat in the use of monitoring, exemplified in Malaysia, revealed that even though none of the farmers applied strictly by prophylactic decision making, they were divided among: seeing pests in the field (84%), applying when advised by extension officers (26%), and when pesticides were provided by the government (42%) (Heong 1984). Farmers, however, ended up spraying frequently because “seeing the pest” is a very low threshold level meaning that the criterion “pests were readily seen” will occur in all crops. Even though the preponderance of insecticide applications in the Philippines was based on monitoring, farmers’ action threshold levels were usually very low. Rola and Pingali (1993), confirming the results of the current study, found that in 53% of cases farmers sprayed when they saw a single insect in the field. Kenmore et al. (1987) found that farmers sprayed upon seeing a few pests as they believed that waiting until threshold numbers occurred would be too late. Farmers told Brunold (1981) that they would rather err by over-spraying than under-spraying. 63% of Sri Lanka farmers agree with the statement that one should spray as soon as pests are noticed (van de Fliert and Matteson 1990). Some 39% had a personal threshold for brown planthopper that was about half that of researchers.

The challenge for extension services therefore is to guide farmers to raise their threshold levels from a few per field to a few per hill. Farmers often perceive pests as an aggregate rather than by species as researchers do. This attitude was able to be changed in farmer field schools by having farmers count pests and natural enemies and only spray when pests outnumbered them. As ricefields are rich in natural enemies it rarely occurred that pests outnumbered natural enemies in the weekly monitoring exercises.

5.9.6.2 Farmers’ Rules of Thumb to Spray

When faced with uncertainty, people often use decision rules or heuristics (Heong and Escalada 1997a). Heuristics are learned through experience. Without having to retrieve all the information in one’s stored memory, these simple rules help humans organize and interpret new information. Filipino farmers' views that defoliating Lepidoptera are harmful make farmers become victims of pesticide misuse. Factors that affect this perception and pest belief model are composed of four components:

1. Perceived benefits = degree to which action will reduce pest attack or increase tolerance,
2. Perceived barrier = perceived negative aspects of action,
3. Perceived susceptibility = subjective risk of getting attacks if no action is taken, and
4. Perceived severity = severity of attack.

The theory of reasoned action was used to study relationships between attitudes and behavior and is composed of two aspects (Heong and Escalada 1999):

1. Behavior intention as influenced by attitudes toward behavior and his subjective norms and
2. Attitudes are the extent to which a farmer sees the consequences of the action or is in turn influenced by behavioral beliefs and evaluations of the beliefs. The attitudinal measure can thus be obtained by summing the products of belief and evaluation scores.

Decision making in IPM like all other economic problems involves allocating scarce resources to meet human needs. Initially there is the choice of whether, when, or how to attempt to manage insects with scarce capital or labor (Mumford and Norton 1984). Economic thresholds have been developed on the basis of objective inputs but are unrealistic in working situations when subjective considerations come into play. Thus decision making is normative (based on perceptions) and not purely economic. Subjective considerations are based on changing goals and farmer behavior. These in turn are conditioned by the number of years of similar experiences with the specific pest problem where the outcome was noted. Decisions can also be tempered by how many other decisions are required and if the farmer is tired of making decisions, has a change in goals, and whether crop conditions are similar. Thus the farmer's perception of the problem becomes important as it may not be exactly the situation in the field. Decision making is dynamic in that an action taken in one time can greatly affect perceptions in the next time period.

KAP studies in the Philippines revealed two guidelines used by farmers which are both prophylactic in nature.

When a Neighbor Sprays

Some farmers tend to rely on the advice of others on when to treat. Sometimes they mimic their relatives or neighbors' spraying activities without considering pest populations on their own fields. Rola and Pingali (1993) found that 67% of Filipino farmers interviewed said at times they spray as a result of seeing a neighbor spray. Palis (1998) found that 67% of farmers believed the same way in that after spraying insect pests leave sprayed fields for unsprayed fields. Iloilo farmers also follow this method. They said spraying just after a neighbor sprays keeps insect pests from entering their field that would be repelled from their neighbors.

Once sprayed, in the view of farmers, the chemical acts as a repellent against future invasion and build-up (Brunold 1981). In Guimba the respondents made their own decisions as to when to spray. But, 95% of them said it was important to spray at the same time as their neighbors (Fajardo et al. 2000). Farmers in Java also believe that if a neighbor sprays that insect pests will be repelled and move to their field (Rubia et al. 1996).

This perception does not have any scientific basis, however. Although it is true that some insecticides such as synthetic pyrethroids and neem have repellent properties, they have not been noted to drive pests to unsprayed fields. If all the fields but one were sprayed there is no evidence that insect pests are driven to the unsprayed field. In fact quite the opposite occurs. A trial, where plots of different sizes were left unsprayed, showed an edge effect of depressed insect densities in the unsprayed plots for a few meters along sampling transects (Litsinger et al. 1987).

Spray when Inorganic Nitrogen Fertilizer Added

Most of the farmers in Zaragoza interviewed (66%) stated that for some insecticide applications their timing was influenced by the timing of fertilizer, particularly during the vegetative stage, but even in the seedbed, this was done irrespective of pest density (Bandong et al. 2002). Rola and Pingali (1993) similarly found a significant number of C. Luzon farmers they interviewed (40%) applied insecticide in relation to the timing of the first fertilizer application. The farmers' motive is to protect the now more vulnerable plant. The timing of fertilizer afterward rather than before insecticide application allows time for the softening effect to occur.

Farmers were astute in linking nitrogen application with increases in insect pest abundance and damage. The farmers' belief that nitrogen causes the rice plant to become "soft" is true due to enhanced plant growth (from the greater nutrition) that reduces the density of protective "hard" silica bundles in the tillers (Bandong and Litsinger 2005) and the crop becomes more susceptible ("soft") to insect pest damage. Most rice insect pests have been found to increase in abundance, and feeding rates and survival have been found to increase in relation to application of nitrogen fertilizer (Litsinger 1994).

Insecticide use based on fertilizer use is rarely justified, however, due to the beneficial effect of fertilizer in bolstering the plant's ability to compensate from damage (Litsinger 1993). Field trials have shown that nitrogen application increases the tolerance of the rice plant to insect damage, thus significantly raising action thresholds. Therefore although insect pests benefit, the crop benefits even more. Thus one should not minimize nitrogen usage to rice as a pest management technology. While true that pest numbers increase, yield also increases.

Field trials carried out by farmers forms a part of the farmer field school curriculum to demonstrate the beneficial effect of fertilizer in increasing crop tolerance (Matteson et al. 1994). Rubia et al. (1996) found most Indonesian farmers initially did not understand the concept of compensation. Farmers in Guimba, particularly in the dry season, use N rates much above those recommended (averages of 131–152 kg N/ha in 1989–1991 dry seasons vs. 90 kg N/ha recommended), and have found by trial and error that insecticide can be substituted by fertilizer.

5.9.7 Farmers' Crop Monitoring Methods

Compared to other rice production practices, insect pest control requires frequent assessment and decision making as pests can occur at any time. Rigorous sampling as required by scientists' thresholds is difficult for farmers to carry out. They examine their fields, generally by looking at a few plants in one or several parts of the parcel (subunit of a field) but this manner of sampling is not accurate. It is said IPM is too intellectually complex as it involves pest or damage identification, varietal identification, threshold determination, dosage, volume, and choice of chemical (Escalada and Heong 1992).

Filipino farmers visit their fields at least once a week on average between planting and harvest (Bandong et al. 2002). Reasons for field visitation at the time of a spray decision were grouped into categories and the results varied by location (Table 5.13). Zaragoza and Guimba farmers were more concerned about checking field water levels, whereas Koronadal farmers were primarily concerned about pests. The finding by Waibel (1986) that, although decision making is more likely to be based on scouting, the main purpose for field visitation was normally for other

Table 5.13 Reasons given by Zaragoza, Guimba, and Koronadal farmers for visiting their fields when the decision to use insecticide was made[a]

Site	Crops (no.)	Reason	Responses (%)
Zaragoza	2	Water management	38
		Pest control	25
		Fertilization	13
		Clean bunds or dikes	12
		Pest monitoring	7
		Check crop growth	5
Guimba	2	Water management	52
		Pest control	26
		Pest monitoring	12
		Fertilization	5
		Check crop growth	3
		Clean bunds or dikes	2
Koronadal	4	Pest monitoring	52
		Pest control	22
		Water management	8
		Fertilization	8
		Check crop growth stage	6
		Replant	2
		Removing coconut fronds	2

[a] see Bandong et al. (2002) for farmer sample size.

reasons. Farmers in other Asian countries appeared to be more vigilant. van de Fliert and Matteson (1990) found that most (81%) Sri Lankan farmers visited their fields daily, while in Tamil Nadu, India, Sivakumar et al. (1997) found nearly half of farmers monitored their fields for pests every other day. Increased visitation for pest monitoring is warranted when fields are under threat of the brown planthopper which affected the farmers in the studies in Sri Lanka and India.

5.9.8 Where to Scout for Early Warning

KAP studies showed some farmers had preferred locations to scout first. Such insights come in farming areas where the farmers have learned to trust the project staff who in turn keep probing for more detailed explanations on scouting methods. Parcels near the canal tend to drain more quickly while those down slope accumulate water, particularly after rains. Through experience some farmers preferentially scouted the lowest lying parcels (Bandong et al. 2002). This shows good farmer innovation as there is ample evidence to support the farmers' choice of the wettest parcels as a monitoring site of first choice. A number of rice insect pests are known to be more prevalent in more flooded habitats. The most aquatic is rice caseworm whose larvae have functioning gill-like structures and require standing water for survival (Litsinger et al. 1994). Other species include whorl maggot, yellow stemborer *Scirpophaga incertulas*, black bug, and defoliators (Litsinger 1994).

Farmers with a habit of first going to higher lying parcels mentioned doing so for stemborers and leaffolders (Bandong et al. 2002), but there are no known reports in the literature regarding this micro-habitat preference. Leaffolders are known to be more prevalent in shade under trees which are more prevalent in higher lying parcels (Barrion et al. 1991) while caseworm larvae are blown downwind to the sides of fields where they aggregate to cause heavy damage (Litsinger and Bandong 1992).

Rola and Pingali (1993) found some farmers were not amenable to synchronous planting as they did not want to be the first to plant as they want to be able to see damage on neighboring fields. In C. Luzon some 5% of decisions were made using this rule (Bandong et al. 2002). Attempts by us, however, to utilize earlier planted fields in the development of action thresholds, however, gave erratic results for whorl maggot, defoliators, leaffolder, and stemborer (Litsinger et al. 2005). This was probably because infestations can be highly variable between fields, and although generally true that pest infestations tend to build up over the season, natural enemy activity also increases. The field study concluded that it was more reliable to monitor pests in one's own field.

5.9.9 Crop Monitoring Technique

KAP interviews found farmers developed their own subjective monitoring techniques (Bandong et al. 2002). Farmers' monitoring patterns were only noted in one study where three methods were employed by a small fraction of farmers. In the first method the farmers crossed to other side of the parcel (6%), while others made a zigzag pattern (2%) or walked in a circle (1%). Researchers recommend that monitoring be done from inspecting hills in the field selected along a transect and not from along the borders. Both crossing (Reissig et al. 1986) and zigzag (Shepard et al. 1988) patterns have been suggested by researchers and we see some farmers follow these patterns.

In the study by van de Fliert and Matteson (1990), most (88%) Sri Lankan farmers monitored without entering the field unless they saw something to take a closer look; only 7% inspect >2 hills per hectare. Similar results were found by Bandong et al. (2002) with 66–87% of decision were made from the edge of fields. In Zaragoza these were broken down by crop stage and pest: 85% of decisions in the seedbed, 91% in the vegetative stage, 92% for leaffolders, 81% for plant- and leafhoppers, 91% for stemborers, and 100% for rice bugs.

This begs the question of why don't farmers enter the field to monitor? Scientists believe that assessments cannot be accurately made without inspecting plants from various locations in the field knowing that the distribution of insect pests is not random nor regular. Edge effects are also known to produce anomalies in the data and most insects are very small and one has to bend over the plants to see or dislodge them into the water. This cannot be readily done from the bund. Also bunds are habitats for fire ants thus in the field itself is a more logical choice for monitoring.

In the authors' experience in working with Filipino farmer groups during extension exercises, farmers are quite content to observe researchers and extensionists moving about in a field while they stand on the dikes. Goodell et al. (1982) stated that it was a small victory to persuade farmers to step off the bund to inspect their crop. Farmers, under this situation, generally need to be coaxed to step into the field. It is believed in many Asian societies, farmers are concerned about getting muddy as would happen with a laborer rather than as a manager, particularly those farmers who hire laborers such as in Zaragoza. Those who work in fields are considered lower on the social scale as field work is dirty. A Zaragoza farmer is more likely to enter if he is alone than if a group is present. More Koronadal farmers are prone to enter fields to monitor (43% of occasions) than Zaragoza farmers (11% of occasions), probably because in Koronadal there are fewer landless laborers (Bandong et al. 2002). There is social pressure for the landless in rural communities to seek work in farmers' fields when there is a large pool of landless labor and right to harvest arrangements are made in exchange for labor.

Discussions with farmers in Batangas, Philippines in a dryland rice area revealed that a number share the belief that one should not enter a rice field once the panicles are formed as plant movement will disturb pollination, reducing grain set. This came about during sweep net sampling for rice bugs during the ripening stage of dryland rice in Batangas. We were requested not to enter the field at this time. Knowledge of rice plant physiology, however, would not support the farmers' belief in this case. Rice is self-pollinated and disturbing the plants does not affect spikelet density. This belief, however, may be why many farmers are hesitant to enter their field once the panicles have emerged. It was noted that most farmers spray for rice bug based on prophylactic decision making. Of course walking through the field during spraying will disturb the plants but apparently the threat of rice bug is greater than presumed damage caused from walking. Arida and Shepard (1987) undertook a study to see if walking in the field in earlier crop growth stages was harmful but did not find a yield reduction.

Farmers appear not to have a set idea to enter the field during monitoring and will only enter if a decision cannot be made from the edge (Bandong et al. 2002). Some farmers, short of entering the field, will crouch on the bund and reach into the field to inspect plants for insects or damage. These farmers may tap plants and submerge hills from the bund. Fortunately some of the activities that were the primary reason for the farmer to come to the field cause him to enter the field (weeding, cleaning the bunds, or opening the bund to manage water) and thus insect infestations may be detected indirectly. This step-wise decision process was also noted by Waibel (1986) and Goodell et al. (1982). In Sri Lanka, van de Fliert and Matteson (1990) found that, just as in the Philippines, most of the inspection is done by farmers from the bund.

Vacant strips are left within irrigated rice fields by a few Sri Lankan farmers (15%) for crop monitoring and access to spraying but most say it is a waste of land and yield potential (van de Fliert and Matteson 1990). Actually the edge effect will offset this perceived loss. Plants growing along borders will yield more as would happen if deep ditches are dug for fish in rice-fish culture or monitoring strips. Border plants have less competition and thus yield more per plant than those in the center of the field.

Just as UK farmers spray aphids when they drive along the farm road by seeing the density of their smashed bodies on the windshield (Tait 1983), Asian rice farmers also have rapid assessment methods. For example rice bug is detected by its smell by Kalimantan farmers (Watson and Willis 1985). Filipino farmers often base their insecticide decision on seeing moths (defoliators, caseworm, stemborers, or leaffolders) flushed out while walking along paths (Bandong et al. 2002). This idea of relating flushed moth numbers to field larval infestations was tested in developing action thresholds, but like the earlier planted fields produced erratic results (Litsinger et al. 2005) due no doubt to the activity of natural enemies. While walking through fields it is common to flush up clouds of leaffolder moths producing the expectation of imminent high damage levels. High infestations, however, rarely materialize as leaffolders have many parasitoids and predators.

The small number of farmers who tap hills to dislodge insects have independently developed this sampling technique now utilized by researchers (Bandong et al. 2002). It is quicker than by direct observation, a method also used. Active hoppers and camouflaged larvae are more readily seen when stuck by the surface tension of water than trying to locate them on the foliage. Farmers slap several hills at once rather than focusing on a single hill as recommended by researchers in order to get a count on a per-hill basis. Researchers also count predators on the water surface, not just the pests.

Submerging hills to dislodge foliage feeding larvae is done by a handful of farmers and is an innovative method and does work to cause the larvae to float, especially on a young crop (Bandong et al. 2002). Most commonly found are defoliators such as semi-loopers which have small bodies and long setae and thus float. Armyworms and cutworms, however, sink due to their larger biomass and lack of long setae. It is a good idea to look for the larvae in the field before spraying as if the population has mostly pupated the insecticide will not have the desired effect.

Filipino farmers related that they sampled more hills when pest populations were high. No farmer interviewed, however, sampled a total of 20 or more hills during any one monitoring day as recommended (Bandong et al. 2002). In Sri Lanka, van de Fliert and Matteson (1990) found that only 7% of farmers inspected more than two hills of rice upon entering.

There was a large variation among farmers in their perceptions. Most Javanese farmers applied insecticides when they saw deadhearts, whiteheads, egg masses, or even one moth, especially if the densities were increasing from the last visit (Rubia et al. 1996). In rainfed rice areas of the Philippines farmers noted change of color of plants (24%), floating leaves (9%), and deadhearts (2%) as early warning indicators (Litsinger et al. 1980). Honduran farmers generally examine their fields by observing some of the plants in one or more parts of a parcel (Bentley and Andrews (1991). They do not have the ability or interest to calculate percentages. They tend to overreact to visible pests or damage as any amount is excessive.

5.9.10 Sampling Units

Within a group of farmers there exists a wide divergence in sampling techniques. What is interesting is that there is a small number of farmers who appear to be more quantitative in their approach to pest monitoring than the general population which tend to favor sampling small areas. From survey results (Bandong et al. 2002), pest and damage densities of the common rice insect pests were expressed by some farmers in units used by researchers such as fractions and percentages as well in whole numbers in units of several rice hills, distance of rice rows, and per panicle. In addition leaffolder damage was expressed in terms of numbers of damaged leaves per several hills.

Farmers' sampling methods, however, are not rigorous in the experience of Waibel (1986). Units of measure are insects per hill (30% of farmers), 18% on insects per unit area, 15% examine individual tillers, 2% use leaves, and 8% use number of insects per field, but 27% have no clearly defined method and use the general appearance of the crop. Leaf pests are normally expressed in terms of levels of damaged leaves. For brown planthopper, the number of infested hills was used or number of insects observed per hill.

Farmers' unit of measure in C. Luzon was the parcel not individual plants or hills (Bandong et al. 2002). As insect distribution is non-uniform, damage usually occurs in patches due to the fact that most insects oviposit in masses. Patch size was noted to increase or not on a per parcel basis. Researchers utilize different units of measure for action thresholds based on percentage damaged leaves or insect pest

Table 5.14 Reasons given by Zaragoza farmers for using insecticide against leaffolders over two cropping seasons[a]

Farmer responses	Farmers who applied (%)	Applications (%)	
		Mode	Among users
	88		
Prophylactic		21	
Crop age			17
Upon fertilization			2
Seeing neighbor spray			2
Observing damage		70	
Scouting method			
– Walking along bund			56
– Seek low-lying parcel			10
– Seek high-lying parcel			2
– Enter field			6
Qualitative		37	
– Sparse damage over whole field			23
– Damaged leaves (yellow or white)			4
– Patches of damage over whole field			4
– Size of patches increasing from last observation			4
– Dense damage over whole field			2
Quantitative		33	
– Few (<5) damaged leaves per several hills			25
– Many (>10) damaged leaves per several hills			4
– Few (<5) damaged leves per parcel			2
– Many (>20) damaged leaves per parcel			2
Presence of insect		9	
Scouting method			
– Walking along bund			7
– Enter field			2
Qualitative		9	
– Moths flushed from walking along bund			9

[a] see Bandong et al. (2002) for farmer sample size.

density on a per hill basis (Reissig et al. 1986). Farmers tend to assess insect density and damage more in qualitative than quantitative terms, often utilizing the whole parcel as the unit of measure as the example from leaffolders shows (Table 5.14). Farmers note any change in patch density and size and may base their decision on the rate of change over time often without checking pest identification (Bandong et al. 2002).

5.9.11 Pest Density and Damage Assessment

Farmers have difficulty in making sound decisions on when to apply insecticides based on observed insect pest abundance. They are generally highly conservative and will spray after seeing damage to one panicle or seeing very few insect pests.

Farmers making an estimate of percentage whitehead infestation, 75% of farmers overestimated by >5% based on field counts (Lazaro et al. 1993). In Hunan China, farmers lacked knowledge of thresholds and yield loss and they overestimated damage caused by insect pests particularly leaf feeders (Shao et al. 1997). In Chhattisgarh, India farmers were prone to spray upon seeing 1–5 plants damaged in a whole field. Also Laguna farmers who complained of spiders making copious webbing on a few plants dismissed them as pests when the threat to the crop was insignificant. Farmers' lack of understanding of the potential of different pests to multiply is apparent as they cannot distinguish between epidemic pests from chronic ones. The latter are the most common and will not immediately increase to the extent that causes economic loss, thus farmers can wait and continue to monitor their abundance. Their immediate reaction on pests such as locusts or planthoppers is to kill them before they multiply. Such behavior shows the fear that farmers have of pests becoming suddenly abundant and destroying their crop. Farmers are surprised as they do not adequately monitor their fields. No farmer should be surprised of an outbreak. Researchers who know the insect pest reproductive capacities and immigration potentials can teach farmers these distinctions. Laguna farmers can make the distinction between plant eaters and plant pests among herbivores, but it is based on a species distinction rather than on population level distinction. Thus the idea behind IPM of consciously monitoring pest populations will need to be emphasized in training programs in order to be adopted by farmers.

5.9.12 Insecticide Usage

Rice farmers in many countries consciously opt for insecticides as corrective control measures against insect pests. Chemical control is achieved with timely applications of appropriate insecticides using lethal dosages. A number of KAP surveys have assessed farmers' technical abilities in selecting the right materials and applying them in a safe, effective and timely fashion with good crop coverage.

The multi-year farm record keeping survey undertaken in four irrigated, double-crop sites in the Philippines quantified insecticide usage in the seedbed and main crop. In the seedbed there were differences between sites in insecticide usage in both wet and dry seasons. In Zaragoza more than two thirds of farmers (66–76%) applied insecticide to wetbed seedbeds, whereas just more than half (52%) of Guimba farmers did (Table 5.15). Lowest usage was among Koronadal farmers (35–43%). There was little or no difference between seasons in the two C.Luzon locations with respect to insecticide usage. Slightly more farmers in Koronadal applied insecticide to the seedbeds in the second (43%) than first (35%) crops. Many fewer Koronadal farmers applied insecticide to *dapog* (13–21%) seedbeds. In Calauan, however, where only *dapog* seedbeds are planted, usage was very high, particularly more in the wet season (87%) than dry season (53%).

In the main crop no two farmers managed their rice crop in the same way, varying mostly in input usage regarding material, dosage, timing, and frequency. Insecticide

Table 5.15 Seedbed insecticide usage in irrigated, double-cropped rice in four locations in the Philippines, 1983–1991[a]

Site	Crops (no.)	Users (%)	Appl. no.[b]	Application frequency (%) by application number			Timing (DAS)[c]			Dosage (kg ai/ha) per seedbed area/ha		
				1x	2x	>2x	1st	2nd	>2nd	Common spray[d]	Synthetic pyrethroids	Granules
Wet/first season wetbed transplanted crops												
Zaragoza	8	76	1.3	75	22	4	19	27	28			
Guimba	4	52	1.0	98	2	0	16	27		0.89	0.079	0.25
Koronadal	5	35	1.0	98	2	0	15	22		0.54	0.053	0.34
avg		**54**	**1.1**	**90**	**9**	**1**	**17**	**22**		**0.71**	**0.066**	**0.295**
Dry/second season wetbed transplanted crops												
Zaragoza	6	66	1.4	74	14	12	18	24				
Guimba	5	52	1.0	93	6	0	17	24	23	0.96	0.107	0.95
Koronadal	5	43	1.0	96	4	0	13.8	16		0.57		
avg		**54**	**1.2**	**88**	**8**	**4**	**16**	**22**		**0.76**		
Wet/first season dapog transplanted crops												
Calauan	3		1.1									
Koronadal	r4	21	1.0	95	5	0	12	24		0.12		
Dry/second season dapog transplanted crops												
Calauan	r3		1.0									
Koronadal	r4	13	1.0	100	0	0	20			0.91		

[a] 20–40 farmers interviewed each season.

[b] Insecticide users only.

[c] DAS = days after sowing.

[d] Organochlorine, organophosphate, carbamate classes.

usage is a case in point. The results showed that, among the farmers sampled, a wide range of 37–100% farmers used insecticides depending on the location and crop (Table 5.16). Lowest usage was in Guimba in direct seeded rice, probably because farmers had to economize more as irrigation water from a communal electric pump which was very expensive, particularly in the dry season. In Calauan, 99% of farmers used insecticide compared to 92–98% in Koronadal, 87–91% in Zaragoza, and 37–75% in Guimba.

Farmers who do not understand the pest resistance status of their crop are likely to spray more than necessary. Yield loss studies have shown that Filipino farmers tend to over-apply insecticide (Kenmore et al. 1985). Farmers, however, were spraying for hoppers but did not know the varieties they were planting were resistant which could save them $50/ha per season not to spray (Goodell et al. 1982). Marciano et al. (1981) concluded that the number of applications carried out by Laguna farmers did not seem to justify usage based on insect densities in the field.

Insecticide usage on rainfed wetland rice is less than on irrigated rice as determined from a KAP study in the Philippines (Litsinger et al. 1980). In Pangasinan province only 27% of farmers sprayed whereas in Iloilo double the number did but this covered only 54% of rice fields. Of those farmers that applied, some 70% among users applied only once. While in Iloilo of those that applied, 59% only applied once with a maximum of 3–5 times per crop The retail value of the insecticide applied was a low $5/ha in Pangasinan and $4/ha for Iloilo among users. Insecticide usage on dryland rice is essentially zero as determined from Tanauan, Batangas (Litsinger et al. 1980) and Claveria. Low yields typical of dryland rice make it uneconomical to justify chemical purchase.

5.9.13 Complexity for Farmers

5.9.13.1 Many Brands of Insecticides

Goodell et al. (1982) posed the question, how could farmers choose the right insecticide? She found there were dozens of insecticides under a wide array of brand names that changed every few years and sometimes the same one was sold under a different brand by the same company, and with many specialized insecticides requiring different dosage rates (e.g., synthetic pyrethroids), some in the metric system and some not. To make matters worse, a number of the most popular insecticides were implicated in making the pest situation worse, a counter-intuitive phenomenon that farmers, and even some researchers, find hard to believe.

Despite farmers' whole hearted acceptance, insecticides represent a highly complex technology particularly in reference to the number of brands in the market. The vast array of available commercial insecticides and attendant brand names, formulations, and prices each with different efficacies against a range of pest species complicates the selection process. Bernsten (1977) recorded 38 brands of insecticides used on rice in C. Luzon from a sample of 191 farmers interviewed. Carbofuran granules was the most used product (22% of the area), but eight brands were used

Table 5.16 Insecticide usage in the main crops of irrigated, double-cropped rice in four sites, Philippines, 1981–1991[a]

Site	Crops (no.)	Users (%)	Appl. no.[b]	Application frequency (%)					Timing (DAT/DAS)[c]					Spray volume (li./ha)	Dosage (kg a.i./ha)		
				1x	2x	3x	4x	>4x	1st	2nd	3rd	4th	>4th		Common sprays	Synthetic pyrethroids	Granules
Wetbed transplanted crops																	
Wetseason																	
Zaragoza	8	94	2.4	24	37	25	7	7	22	38	50	56	58		0.20	0.013	0.33
Guimba	5	77	1.4	82	15	1	0	2	26	42	43	36	46		0.25	0.054	0.19
Koronadal	5	93	3.2	11	29	30	18	12	22	37	51	56	63	220	0.23	0.054	0.39
avg		**88**	**2.3**	**39**	**27**	**19**	**8**	**7**	**23**	**39**	**48**	**49**	**56**	**220**	**0.23**	**0.040**	**0.30**
Dryseason																	
Zaratgoza	6	91	2.3	36	29	19	9	8	22	38	49	53	60		0.20	0.041	0.71
Guimba	6	75	1.6	45	46	6	3	0	22	35	44	56			0.19	0.034	
Koronadal	6	92	2.8	21	26	27	17	12	20	36	49	59	67	224	0.23	0.026	0.87
avg		**86**	**2.2**	**34**	**34**	**17**	**10**	**7**	**21**	**36**	**47**	**56**	**64**	**224**	**0.21**	**0.034**	**0.79**
Dapog transplanted crops																	
Wetseason																	
Calauan	4	99	2.8											245	0.23	0.013	0.41
Koronadal	4	98	2.8	24	23	30	12	12	23	39	51	61	82	167	0.25	0.006	
avg		**99**	**2.8**	**24**	**23**	**30**	**12**	**12**	**23**	**39**	**51**	**61**	**82**	**206**	**0.24**	**0.010**	**0.41**
Dryseason																	
Calauan	3	99	2.0											245	0.22	0.023	
Koronadal	5	95	3.1	22	26	23	13	17	25	42	49	55	62	208	0.22	0.013	
avg		**97**	**2.6**	**22**	**26**	**23**	**13**	**17**	**25**	**42**	**49**	**55**	**62**	**227**	**0.22**	**0.018**	
Direct seeded crops																	
Wetseason																	
Zaragoza	2	87	2.1	30	43	12	11	4	30	47	52	62			0.21	0.019	0.73
Koronadal	1	100	2.3	40	20	20	10	10	22	36	40	52	78	173	0.19	0.016	
avg		**94**	**2.2**	**35**	**32**	**16**	**11**	**7**	**26**	**42**	**46**	**57**	**78**	**173**	**0.20**	**0.018**	**0.73**
Dryseason																	
Zaragoza	3	94	2.0	32	38	18	7	4	27	49	57	69	46		0.19	0.021	0.67
Guimba	2	37	1.5	75	9	0	9	4	29	28	36	46	68		0.19	0.045	0.54
Koronadal	3	97	2.5	27	36	11	11	11	31	47	52	53	64	186	0.19	0.010	
avg		**67**	**2.0**	**51**	**23**	**6**	**10**	**8**	**30**	**38**	**44**	**50**	**66**	**186**	**0.19**	**0.028**	**0.54**

[a] 20–40 farmers interviewed each season per site.

[b] Insecticide users only.

[c] DAT = days after transplanting, DAS = days after sowing for direct seeding.

in 75% of the area covered. Liquids were more popular than other formulations. The computations necessary for dosage determinations add further difficulties to proper usage.

Farm record keeping data from four sites in the Philippines revealed 40 kinds of insecticides comprising 64 brands (Table 5.17). The most popular were the highly toxic organo-phosphate materials with monocrotophos at the top. This insecticide is banned in a number of countries because of the danger it poses to farmers applying without protection. There were seven brand names for methyl parathion and four each for endosulfan and BPMC. A natural product derived from a pathogenic bacterium *Bacillus thuringiensis* (Bt) was included but was not popular. Also recorded was limited usage of some indigenous botanical based products, a detergent, and kerosene. Only those products that averaged 1% usage in any one crop were included in the list.

5.9.13.2 Assessment of Farmers Competency with Insecticides

Farmers spray to keep pests off the crop rather than prevent yield loss (Heong et al. 1995b). In Leyte 80% of applications were misused either against the wrong pest or the wrong time (Heong et al. 1995b). Leyte farmers erroneously target rice bug at other stages than milky stage, even tillering stage. Insecticides applied against leaf feeding insects such as leaffolder in the early crop stages when populations were low did not increase yields. The economic injury level for leaffolder is 5–6/hill, a rarity as field averages are normally <1 larva/hill. Farmers target ladybeetles and hoppers, the former are predators and the latter are not important at low densities and for which genetic resistance is available. Some 78% of farmers sprayed in the early crop stages, despite low pest infestation or imminent threat. Such practice is not only wasteful but damage the predator-prey ratio that may lead to secondary pest outbreaks (Way and Heong 1994).

An understanding developed by researchers in the 1980s was that insect pest problems stemmed from injudicious use of insecticides, especially prophylactic application of broad spectrum materials (Heong 1998). In the tropics, ricefields harbor a diverse mix of natural enemies that normally contain most pest problems if not disturbed by insecticides. Chemical control as practiced by farmers is ineffective as levels of control exerted are far less than desirable (Litsinger et al. 2005).

Farmers also react to insect damage rather than to the living pest, thus the insect is often gone by the time they apply. Common dosages per hectare average 0.2 kg ai/ha based on farmer surveys as opposed to 0.4 kg ai/ha as recommended based on field trials where 80% control is the cutoff for recommending an insecticide (Litsinger et al. 2005). Dosage trials at IRRI, undertaken to see if the farmers' practice was viable, caused recommended dosages to be reduced from 0.75 kg ai/ha to 0.4 kg ai/ha, but farmers' spray volumes are generally less than 300 liters per hectare (Table 5.16). It is recommended that farmers increase their spray volume as the crop grows. In older rice farmers should use 500 liters/hectare. Insect control practices as mentioned in national recommendations are dominantly usage of insect resistant varieties and the use of insecticides. Most farmers spray for chronic pests for

Table 5.17 Popular insecticides applied to the main crops of irrigated, double-cropped rice in four locations, Philippines, 1981–1991[a]

Common name	Applications per crop/location (%)				
	Zaragoza	Guimba	Koronadal	Calauan	mean
No. crops	14	11	11	7	
Years	1981–91	1984–90	1983–91	1986–90	
SPRAYABLES	**98**	**92**	**99**	**93**	**95**
Organophosphates	*44*	*57*	*59*	*26*	*46*
monocrotophos	35	47	25	25	33
methyl-parathion	5.0	3.3	24.3	0.5	8.3
azinphos-ethyl	4.0	5.0	5.8	0.5	3.8
chlorpyrifos	0.3	1.7	2.2	0	1.0
triazophos	0	0	0.8	0	0.2
fenitrothion	0.8	0	0.3	0	0.3
methamidophos	0	0.3	0	0	0.1
malathion	0	0	0.5	0	0.1
Organochlorines	*12*	*4*	*3*	*21*	*10*
endosulfan	9	4	3	21	9
endrin	1.5	0	0	0	0.4
DDT	1.3	0	0	0	0.3
Carbamates	*17*	*3*	*9*	*4*	*8*
MIPC	16	0.3	3.7	4	6
BPMC	0.5	1.7	3.8	0	1.5
methomyl	0.8	0.7	0.5	0	0.5
carbaryl	0	0	0	0	0
carbofuran	0	0	0.2	0	0
Pyrethroids	*11*	*10*	*14*	*0*	*9*
cypermethrin	11	10	7	0	7
deltamethrin	0	0	5.5	0	1.4
permethrin	0	0	1.7	0	0.4
fenvalerate	0	0	0.2	0	0
cyhalothrin	0	0	0.2	0	0
Other Sprayables	*0.5*	*1.3*	*1.7*	*0*	*0.9*
ethofenprox	0	1.3	1.7	0	0.8
fentin hydroxide	0.3	0	0	0	0.1
Bacillus thuringiensis	0.3	0	0	0	0.1
Spray Mixtures	*12*	*18*	*13*	*42*	*21*
chlorpyrifos + BPMC	9	11	5	36	15
monocrotophos + cypermethrin	2.5	4.7	0.7	0	2.0
fenitrothion + malathion	0	0.3	0.0	0	0.1
azinphos-ethyl + BPMC	0	2.0	1.8	0	1.0
phenthoate + BPMC	0	0	5.2	0	1.3
MTMC + phenthoate	0.5	0	0	6.0	1.6
GRANULES	**3**	**8**	**0**	**8**	**4**
gamma–BHC	0	0.3	0	0	0.1
diazinon	0.8	0	0	1.0	0.4
carbofuran	1.8	7.3	0.2	6.5	3.9

[a] Average of wet and dry seasons, each season 15–30 farmers were interviewed regarding input usage.

which there are no resistant varieties, thus insecticides remain the dominant control practice leading to 3–4 applications per crop. Genetically modified Bt-rice would overcome this problem as Lepidoptera are the main targets which can be controlled by the biocontrol agent. However there is political and cultural resistance to these varieties being adopted.

Waibel (1986) stated that farmers overestimate losses but he showed economic thresholds as insecticide guidelines were economical. Litsinger et al. (2005) showed thresholds were economical in some cases only, but underscored the fact that modern rices have high capacity to tolerate damage when well managed and with favorable solar radiation during grain ripening. When environmental and health costs are factored thresholds become more attractive (Rola and Pingali 1993). Most farmers overestimate the importance of insect pests and are strongly motivated to use insecticides. Thus large amounts of insecticide are applied unnecessarily and are unlikely to result in an economic return. Surprisingly Litsinger et al. (2005) found the farmers' practice was at times economical even with low control.

It is evident that farmers' insecticide use is not based on economic rationality (Heong 1998). This is supported by how farmers make pest control decisions. Application was biased largely on farmers' perceptions of damage and high expected losses. Most (66%) say that pesticides are specific only against a range of pests (Litsinger et al. 1980).

5.9.14 Factors Influencing Farmers to Use Insecticides

Farmers are influenced by peer groups such as pesticide dealers and extension agents and over influenced by outbreaks that had occurred in the area even if not in their field. Pests were mentioned as being important which have not caused much damage in their regions since the tungro epidemics a decade previously. These peer groups over-generalize outbreaks that occur in other areas. The perceptual pathologies of IPM programs are, according to Waibel (1986), largely the outcome of farmers' attitudes affecting their responses to information they get from government programs.

Leyte farmers are risk averse and spray when insects are spotted or before (prophylactic) (Escalada and Heong 1993). Emotions of fear are evoked thus farmers spray when only a few insects are present. Promotional marketing methods are used to influence farmers to spray. Some 60% of Leyte farmers said they would spray even if they did not see the pest.

Advertising and pesticide sales agents have influenced unfavorable attitudes toward insect pests. Messages to use insecticides far outnumber those that do not. Farmers therefore have developed risk averse attitudes with little economic rationale toward insecticide use. In addition negative motivators of fear, ignorance, and passivity cause farmers to become risk averse and use insecticides as insurance. Heong et al. (1995a) noted the following factors that influence insecticide usage:

1. Advertisements,
2. Over-reaction to pest density/damage,

3. Association of insecticide with modernism,
4. Equating pesticides as medicines,
5. Ease of use,
6. Government supplied forecasting information,
7. Equating pesticides as fertilizers as being necessary,
8. Quick killing effect, and
9. Negative motivators of fear, ignorance, and passivity thus become risk averse and use insecticides as insurance.

Tjornhom et al. (1997) showed pesticide misuse was associated with the high value farmers place on advice from chemical company representatives, cooperative members, and visits by local technicians. Many C. Luzon farmers spray on sight and this attitude was at least partly due to past experience with varietal resistance breaking down (Kenmore et al. 1985).

Norton and Mumford (1993) pointed out that decisions are made on farmers' perceptions which are based on earlier experience with the problem. If the previous action, such as sprays has resulted in good harvests, then farmers will continue to spray as usual and not base the decision on the pest populations but on previous behavior. To change farmers' misperceptions, new elements must be introduced into the cognitive structure, e.g., different perception or information which introduces conflict to motivate change (Heong and Escalada 1997a).

5.9.14.1 Insecticide Selection and Purchase

In Nueva Ecija province in the Philippines, insecticides selected by farmers were with few exceptions those that were recommended at the time (Fajardo et al. 2000). Just 59% of applications in Sri Lanka were those chemicals recommended for the specific pest, but the proportion of farmers that could name an appropriate chemical was less that those applying it (van de Fliert and Matteson 1990). In W. Java a survey was carried out as part of IRRI's Constraints Program in Indonesia asking farmers to name a recommended insecticide for three different pests (Nataatmadja et al. 1979). Only 51% of farmers gave a correct answer for brown planthopper, and 60% of farmers were correct with stemborers and gall midge. The constraints work illustrated the importance of selecting the correct insecticide and applying the proper rate.

The farmer operator rather than the landlord makes the decisions on pesticide usage in Iloilo, Philippines (Brunold 1981). In another study in the Philippines, 31% of women interviewed purchased insecticides and 21% occasionally made control decisions (Warburton et al. 1995). Liquid insecticides are more popular because they come in small sizes whereas other formulations such as granules do not (Cordova et al. 1981). Similarly in another KAP study in rainfed areas in the Philippines, farmers preferred cheap broad spectrum sprayable insecticides with <5% opting for granulars (Litsinger et al. 1980).

The record keeping survey in the four Philippine sites over a decade looked at insecticide usage in the seedbed and field. Sprayable formulations were much more

Table 5.18 Popular insecticides applied to the seedbeds of irrigated, double-cropped rice in three locations, Philippines, 1981–1991[a]

Common name	Zaragoza	Guimba	Koronadal	Total
SPRAYABLES	97	97	100	98
Organophosphates	54	58	77	66
monocrotophos	45	37	30	36
methyl-parathion	2	7	44	23
azinphos-ethyl	7	14	3	7
diazinon	0	1	0	0
triazophos	0	0	0	0
chlorpyrifos	1	0	0	0
fenitrothion	0	0	0	0
Organochlorines	8	5	1	4
endosulfan	5	5	1	3
endrin	2	0	0	1
DDT	1	0	0	0
Carbamates	16	4	12	11
MIPC	12	1	3	5
BPMC	0	1	9	4
carbaryl	2	1	0	1
methomyl	2	2	1	1
Synthetic Pyrethroids	7	13	1	5
fenvalerate	0	1	0	0
deltamethrin	1	0	0	0
cypermethrin	6	12	1	5
Others	1	1	0	0
ethofenprox	0	1	0	0
Bacillus thuringiensis	1	0	0	0
Spray Mixtures	11	18	10	12
chlorpyrifos + BPMC	9	14	6	9
monocrotophos + cypermethrir	2	4	0	1
azinphos-ethyl + BPMC	1	0	0	0
phenthoate + BPMC	0	0	4	2
GRANULES	4	3	1	2
carbofuran	3	2	1	2
diazinon	1	1	0	0
Total	100	100	100	100

[a] 20–60 farmers interviewed per crop, see text for more details.

popular (98% of applications) than granules (2%) in the seedbed, with organophosphates predominating (66%) over mixtures (12%) and carbamates (11%) (Table 5.18). The most popular chemicals were monocrotophos (36%), methyl-parathion (23%), and chlorpyrifos + BPMC (9%). There were some differences in farmer preference between sites. Koronadal farmers selected methyl-parathion much more (44%) than in Guimba (7%) or Zaragoza (2%). Guimba farmers used relatively more azinphos-ethyl (14%) than other sites (<7%). Synthetic pyrethroids were more popular in Guimba as well with cypermethrin averaging 12% of all applications compared to 6% in Zaragoza and 1% in Koronadal. MIPC was most popular in Zaragoza (12%) compared to Koronadal (3%) and Guimba (1%). There were noticeable differences in the kinds of insecticides used in the *dapog* crop between the first and second crops but these are not considered significant because of the few number of users. No granules were used on *dapog* seedbeds.

Farmers overwhelmingly preferred sprayable (average of 96% of occasions) to granular insecticides in the main crop (Table 5.17). Koronadal farmers utilized the least number of granular materials with only 1% usage in the first wetbed transplanted crop. The highest occurrence of granular formulations (14%) was recorded by Guimba farmers for direct seeded rice. Carbofuran was the most preferred among granular compounds. Among the sprayable formulations, organophosphate materials were most preferred (53% of applications) compared to organochlorines (6%), carbamates (10%), and synthetic pyrethroids (12%). Spray formulations with a mixture of more than one compound were utilized on 15% of occasions. The most popular insecticides were monocrotophos (35% of applications), methyl-parathion (11%), cypermethrin (9%), and the mixture of chlorpyrifos + BPMC (8%), MIPC (7%), and azinphos-ethyl and endosulfan (both 5%).

There were noticeable differences between sites on the preference of some materials. MIPC was most preferred in Zaragoza than the other sites. Only the organochlorines insecticides endrin and DDT were recorded for Zaragoza farmers. Methyl parathion, deltamethrin, and phenthoate + BPMC were most preferred in Koronadal. Guimba farmers utilized the fewest kinds of insecticides.

When asked about preferred insecticide formulations, 90% of Guimba respondents opted for sprayables because: (i) they are easier to use, (ii) give better coverage, and (iii) are more effective than granular formulations (Fajardo et al. 2000). One farmer believed that granules are less safe for the applicator to use. Those (5%) who preferred granules mentioned that follow-up spraying was normal. Five percent said that all formulations are equally effective.

There was a noticeable improvement in the insecticides used by Philippine farmers in terms of toxicity and human safety. In 1966 the dominant insecticides were highly toxic: m-parathion, endrin, endosulfan, and coumaphos (Cordova et al. 1981). These were mostly replaced by less dangerous materials in the ensuing decades.

5.9.15 Source of Funds for Insecticide Purchase

Rainfed farmers in the Philippines when surveyed point to different sources of cash to purchase insecticides (Litsinger et al. 1980):

1. Personal savings (63%),
2. Bank loan (62%),
3. Friend (18%),
4. Neighbor (15%),

5. Relative (12%),
6. Cooperative (11%), and
7. Private money lenders (3%)

In Batangas, Philippines where dryland farmers sell vegetables to nearby Manila, 64% of farmers obtain bank loans to buy inputs. Most (73%) Filipinos surveyed said they purchased insecticide at least one week ahead of usage. Farmers in Sri Lanka who spray a lot receive informal credit (van de Fliert and Matteson 1990). Only 23% of farmers took loans to buy inputs mainly from relatives, neighbors, and banks. Malaysian farmers are better off than most in Asia as the government subsidized much of production costs, therefore chemicals were bought with cash and only a few took out a loan (Heong 1984).

The Philippine national program to promote the Green Revolution in rice, Masagana 99, began in 1973 where credit was extended by the government through extension agents. Farmers were to follow a "cook book" (prophylactic) approach to insecticide application with a total of four beginning in the seedbed. Farmers were even given insecticides in kind before the crop was transplanted. Cash-strapped farmers repaid in rice after harvest at amounts which translated to high interest rates. Most farmers, however, viewed credit as a gift and defaulted. Farmers knew that there were not enough jails to hold them nor budget to feed them if arrested. As a result the scheme ended in 1977. Afterwards rice buyers and agro-input dealers who supplied pesticides to farmers before the growing season extended credit, but farmers were free to apply as many times as they wanted (Bandong et al. 2002).

5.9.16 Land Ownership

A large proportion of the irrigated farmers in the Philippines are leaseholders or tenants rather than owner-operators. These farmers have a free choice in selection of agro-inputs as Filipino landlords do not involve themselves in the day to day management as they are mostly absentee, residing in cities far away and only come at harvest to get their share. Tenants in Sri Lanka spray more because some get inputs from the landlord and as the goal of the farmer is highest yield they have to earn their living from their share of the harvest (van de Fliert and Matteson 1990).

5.9.17 Application Technique

Most farmers (87%) interviewed stated that no specific skills are required to spray properly (Litsinger et al. 1980). Farmers have a good grasp on knowledge of application technique. In addition most farmers spray in the morning 81%, while 90% say that full coverage is best. Some 85% know rain washes pesticide off of plants while 81% increase the dosage in response to higher infestation levels. In a number of areas in the Philippines, farmers practice synchronized spraying among fields in the community (Pineda et al. 1984). This has the advantage of minimizing the recolonization of ricefields from nearby areas later in the crop (Joyce 1985). Their main fault is the low spray volumes applied thus as most are contact chemicals the plants are not adequately covered with product.

5.9.17.1 Frequency and Timing

From the large record keeping survey in four locations, detailed information on timing and frequency of application has been obtained both in the seedbed and main crop.

In the seedbed Zaragoza farmers applied slightly more insecticide averaging 1.3–1.4 applications (calculated for only those who used insecticides) than in Guimba, Koronadal, and Calauan (1.0–1.1 times per crop) (Table 5.15). In Koronadal usage on wetbeds was higher (35–43%) than *dapog* (13–21%). Among insecticide users in Zaragoza, 14–22% applied two applications and 4–12% more than two applications to the wetbeds for both seasons. In Koronadal only 5% or fewer farmers applied more than once to *dapog* beds. Greatest usage by a single farmer reached four applications.

Zaragoza farmers tended to delay their first application (18–19 days after sowing or DAS) more than those from Guimba (16–17 DAS) or Koronadal (14–15 DAS) over both first and second crops. Timing of the second application was similar for Zaragoza and Guimba farmers (24–27 DAS) and later than for Koronadal farmers (16–22 DAS) for wetbeds. Zaragoza farmers applied most of their applications 2–3 weeks after sowing (WAS), whereas farmers from Guimba and Koronadal applied most 1–2 WAS on wetbeds. A greater percentage of Koronadal farmer-users applied after 4 WAS on *dapog* seedbeds in the second (25%) but not the first (0%) crop.

Application frequency on the main crop varied widely by site (Table 5.16). The lowest came from Guimba farmers who averaged 1.4–1.6 applications per crop among users, whereas Koronadal farmer-users averaged the highest at 2.3–3.2 applications. Zaragoza and Calauan farmers were in between averaging 2.0–2.4 and 1.8–2.2 applications per crop, respectively. The range of values by any one farmer in the survey per crop ranged from 2 to 10, the largest value occurred several times by different farmers in Koronadal where maximum usage ranged from 6–10 applications over all crops. There was no trend in the extreme values for the Koronadal site as extremes occurred in 1984 and 1987. There was a trend to decrease insecticide applications from 1986 onwards in Zaragoza where extreme values decreased from 5–8 to 3–4 applications. There was no indication that usage varied by season but only a slight indication that direct seeded (pre-germinated) rice on average received fewest applications (1.4–2.5) compared to wetbed (1.4–3.2) and *dapog* (1.6–2.8).

In Guimba 75–82% of farmers who used insecticides applied only a single time with the exception of the second wetbed crop where 45 and 46% applied once and twice, respectively (Table 5.16). In Koronadal with highest insecticide usage of 20–30% of the farmers averaged over three applications per crop. Zaragoza farmers averaged 11–17% and Guimba 2–13% usage over three applications. The median application frequency was twice averaged over all sites for all farmers.

The first application was timed from 20 to 26 days after transplanting (DAT) for transplanted crops which was quite consistent regardless of season or site (Table 5.16). For direct seeded crops the range was 22–31 DAS. With few exceptions the second application occurred on average 13–17 days later. The third applications ranged from 43 to 51 DAT or 36–57 DAS for transplanted and direct seeded crops, respectively. Average timings became less discernible beyond the third application as those farmers who applied more times had shorter intervals between applications. Therefore there was no consistent pattern beyond the third application.

Cumulative frequency distributions showed significant differences between sites. In wetbed crops in the wet season, Guimba and Zaragoza farmers had applied over half of their applications by 3 weeks after transplanting (WAT) and 4 WAT, respectively (Fig. 5.3A). A significant number of applications occurred in the later crop growth stages in Koronadal as very few applications occurred during the first three weeks. Greatest insecticide activity among Guimba farmers occurred from 2 to 6 WAT, but 2–9 WAT in Zaragoza and 4–11 WAT in Koronadal. A similar pattern prevailed in the dry season for Guimba and Zaragoza, but the pattern for Koronadal farmers became highly similar to that of Zaragoza farmers where greatest usage occurred 2–9 WAT (Fig. 5.3B). A linear relationship between application rate and crop age was more evident in the *dapog* culture in Calauan and Koronadal from 2 to 11 WAT (Fig. 5.3C). For direct seeding 75% of the applications occurred from 1 to 6 WAS, whereas in Zaragoza and Koronadal this level was not reached until 8–9 WAS (Fig. 5.3D). In Guimba relatively few applications occurred from 7 to 12 WAS.

The survey revealed that farmers often mixed several brands of insecticides together when applying to the field. Highest incidences of mixing brands occurred in Zaragoza with 11–12% in wetbed culture in the wet and dry seasons (Table 5.19). Less occurred in direct seeded rice. Fewer cases of mixing insecticides occurred in Guimba which averaged 11% mixtures for wet season wetbed and direct seeded dry season crops. Least mixing occurred in the wetbed dry season culture 2%. Lowest site averages occurred in Koronadal a site with the highest insecticide usage and averaged 4% mixtures over all crop cultures. Highest usage was in wetbed and *dapog* with least in direct seeded. Farmers often mixed insecticides that were already composed of two insecticides thus they were mixing mixtures. This is an ill-advised habit as on other crops this quickly leads to insecticide resistance and is wasteful. Insecticide resistance on rice has been recorded particularly in Japan and Taiwan where farmers apply frequently and at high dosages (Nagata and Mochida 1984). What saves farmers in other countries is the small field size and independent decisions of farmers concerning what products they use thus there is a wide and diverse mosaic of materials as well as low dosages. More important is insecticide resurgence which has been much more common (Gallagher et al. 1994).

Surveys of farmers in Leyte, Nueva Ecija, and Vietnam resulted in positive correlations that established those farmers who apply early also apply late in the crop, thus applications were not independent (Heong et al. 1995b). Thus those who applied both early and late may have been risk averse, inclined to use more inputs, and to be better off economically.

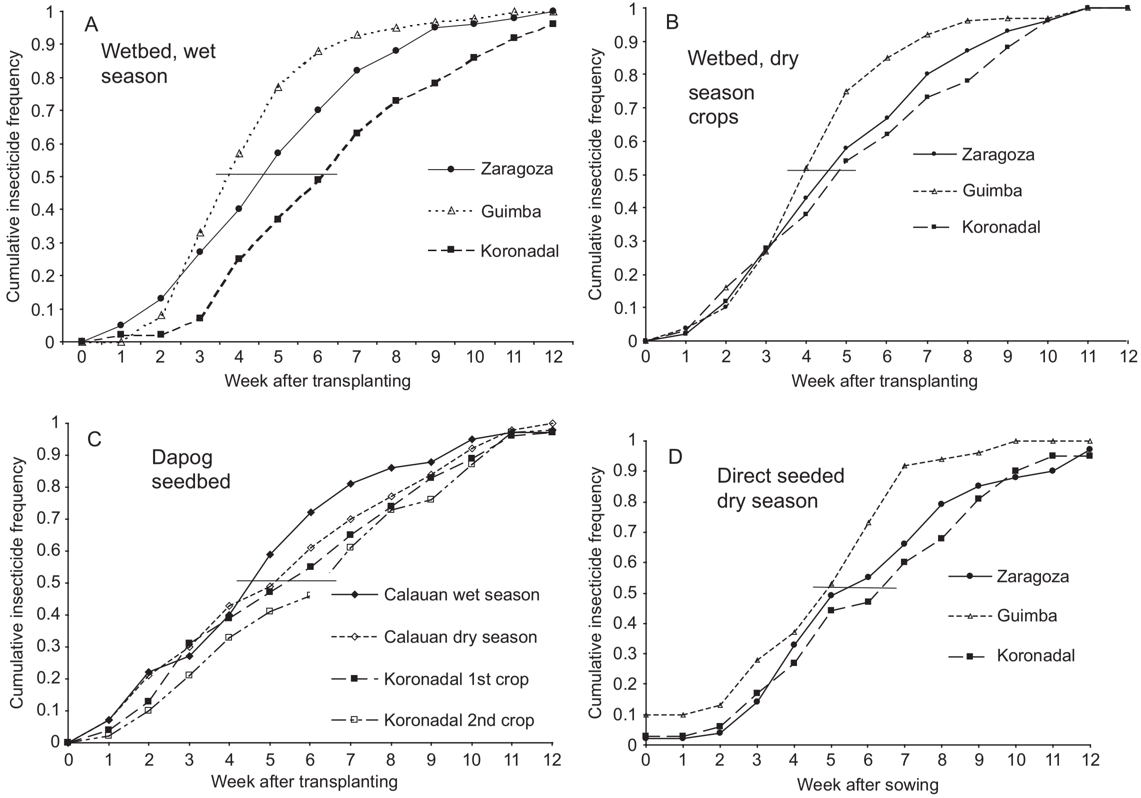

Fig. 5.3 Cumulative frequency of insecticide application by growth stage for four sites in the Philippines segregated by crop season and rice cultural method. Data based on farmers surveys undertaken from 1981 to 1991. Horizontal line represents 50% of frequency

Table 5.19 Frequency of agrochemical applications as mixtures of more than one brand in irrigated, double-cropped rice in three locations in the Philippines, 1981–1991

Agrochemical	Applications per crop as mixtures (%)[a]																
	Zaragoza					Guimba				Koronadal							
	Wetbed		Direct seeded		Site avg	Wetbed		Direct seeded	Site avg	Wetbed		Dapog		Direct seeded		Site avg	Grand avg
	WS	DS	WS	DS		WS	DS	DS		1st	2nd	1st	2nd	1st	2nd		
Seedbed																	
Fertilizer	0.8	4.5			**2.7**	12.9	20.9		**16.9**	0	0.9	0	1.1			**0.5**	**6.7**
Insecticide	3.0	3.4			**3.2**	5.0	0		**2.5**	1.0	0	0	0			**0.2**	**2.0**
Main crop																	
Fertilizer	34	31	47	19	**33**	68	62	72	**67**	9	7	12	7	40	20	**16**	**39**
Insecticide	12.0	11.1	10.2	6.7	**10.0**	11.4	2.1	11.1	**8.2**	5.0	5.0	3.3	4.6	0	3.1	**3.5**	**7.2**
Herbicide	2.3	4.1	0	0	**1.6**	0	1.3	0	**0.4**	1.6	0.9	0	0	0	0	**0.4**	**0.8**

[a] WS = wet season, DS = dry season.

5.9.17.2 Dosage

Use of sublethal dosages is not only ineffective and wasteful but can cause pest resurgence. C. Luzon farmers told an anthropologist that they were satisfied that they were applying enough insecticide in proper concentrations (Goodell et al. 1982). Filipino farmers often overestimate control effectiveness (Waibel 1986). In reality they under-dose to the point of risking that the chemicals are not toxic to insects (Litsinger et al. 2005). The dosage-mortality relationship is not linear and mortality only occurs once the threshold level of mortality (as with drugs) is reached which most farmers do not achieve. Farmers also do not realize that some insecticides are active at very low dosages (such as synthetic pyrethroids) while the rest are active only at higher dosages (they under-dose both, see Table 5.16). What is amazing is that they do not perceive they are not achieving good control. Most likely farmers see the pest damage decrease which is probably from the activities of natural enemies more than the chemical. Understanding dosages is extremely complex for farmers and is in reality impossible to teach to farmers who have limited math skills. Farmers in Zhejiang, China on the other hand were surveyed and found they over-used pesticides by making cocktails (mixing several pesticides in the same tank-load), applying frequently, and overdosing excessively (Hu et al. 1997).

The farm record keeping survey spanning over a decade documented Filipino farmers' insecticide dosages in the seedbed and main crop. Dosages in the seedbed were high when calculated on the stated area of the seedbeds in both Guimba and Koronadal where they were determined (Table 5.15). Common sprays were applied at slightly higher dosages in Guimba (0.57–0.61 kg ai/ha) than Koronadal (0.39–0.42 kg ai/ha). These dosages are at or higher than those recommended (0.40 kg ai/ha) based on seedbed area. Synthetic pyrethroids were generally under-dosed (0.052–0.059 kg ai/ha) compared to recommendations (> 0.10 kg ai/ha). Granules were also under-dosed (0.23–0.44 kg ai/ha) compared to recommended levels (> 0.50 kg ai/ha).

On the main crop, organochlorine, organophosphate, and carbamate insecticides in spray formulations (termed common sprays) were applied in dosages that ranged from 0.18–0.24 kg ai/ha (Table 5.16). There was no apparent trend by site, crop culture or season. Similarly with synthetic pyrethroids the observed ranges (0.006–0.054 kg ai/ha) were without a noticeable trend (dosages should be 0.010–0.025 kg ai/ha). Farmers therefore were within the range of effective dosages with synthetic pyrethroids and would have had good efficacy, but represent only 10% of applications (Table 5.17). With granules higher dosages were observed in the dry seasons (0.54–0.87 kg ai/ha) compared to wet season (0.19–0.39 kg ai/ha) for wetbed but not direct seeded crops. Granules are effective at 0.75–1.5 kg ai/ha, thus most farmers were below this level and granules require standing water of >10 cm for them to work well (Bandong and Litsinger 1979).

The dosages were graphed in cumulative frequency distribution which showed that half of the common insecticide applications (not including synthetic pyrethroids and granulars) were below 0.20 kg ai/ha in Zaragoza, Guimba, and Koronadal (Fig. 5.4). Over 90% of all insecticide applications were below the recommended rate of 0.40 kg ai/ha for all comparisons. What is remarkable about the data was the

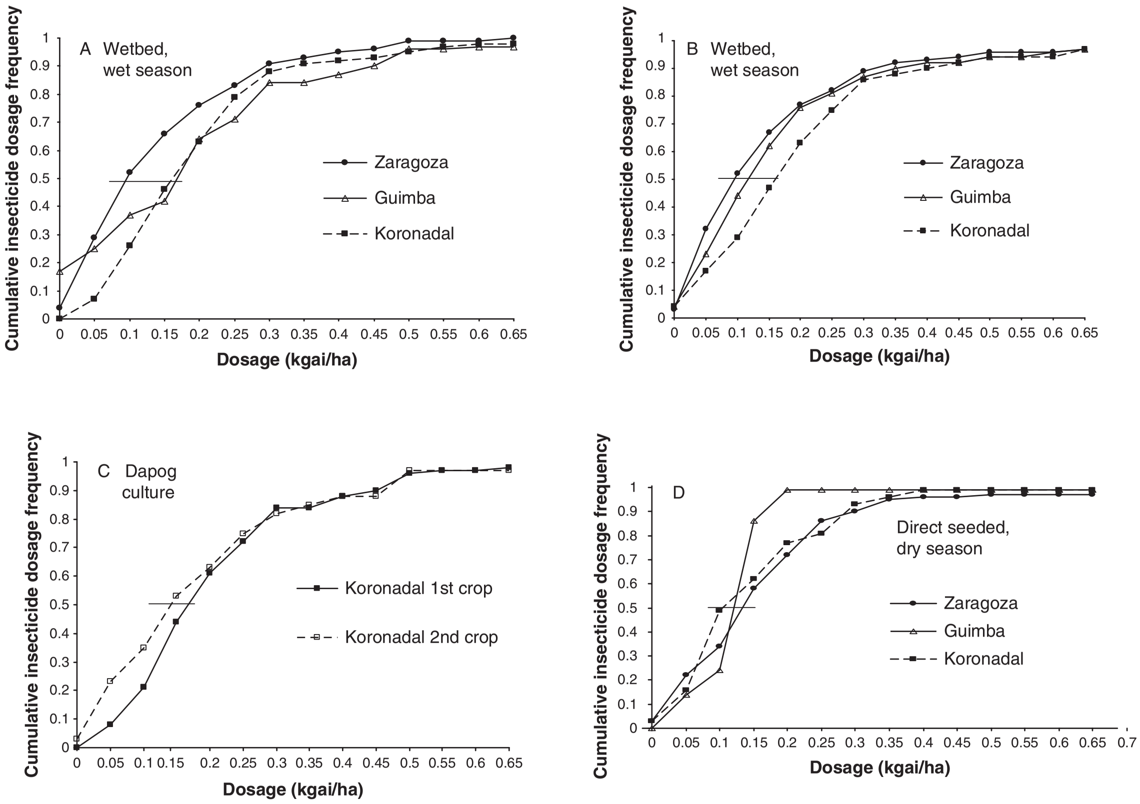

Fig. 5.4 Cumulative frequency of insecticide applications by dosage in three sites in the Philippines segregated by crop season and rice cultural method. Data based on farmer's surveys undertaken from 1981 to 1991. Horizontal line represents 50% of frequency

consistency of insecticide dosages over sites, rice culture and season. As mentioned in other sections of the chapter dosages of 0.20 kg ai/ha are not lethal to most rice insect pests. These insecticides were originally recommended at a dosage of 0.75 kg ai/but trials at IRRI revealed that the dosage could be reduced to 0.40 kg ai/ha but no further.

Waibel (1986) also noted that farmers in his surveys also under-dosed from 0.20 to 0.30 kg ai/ha. Similarly Marciano et al. (1981) found Laguna farmers under-dosed 35–40%, and used less than recommended spray volume. Tank mix concentration was properly followed but the number of sprayerloads needed to be increased. Farmers use low water volumes and select nozzles which project the spray to reduce the number of passes through the field, but as a result severely under-dose (Bandong et al. 2002).

In the favorable rainfed areas of the Philippines, insecticide dosages ranged from 0.03 to 0.38 kg ai/ha (Litsinger et al. 1980). Farmers determined the dosage by reading insecticide labels (77% of respondents) or guessed (13%). They measured insecticide from the bottle via the bottle cap (69%), spoons (26%), graduated cups (10%), or guessed (5%).

The survey of Litsinger et al. (1980) asked farmers to list the constraints they faced in achieving more lethal dosages and there were many:

1. Lack of pest recognition,
2. Lack of capital,
3. Lack of knowledge of pesticide application,
4. Aversion to debt,
5. Lack of labor,
6. Lack of sprayers,
7. Unavailability of pesticide locally,
8. Disbelief that the yield increase from pest control was enough to warrant usage, and
9. Toxic effects of pesticide to operator.

The last constraint is perhaps the most real as farmers insisted they would not increase their spray volume so the only way to increase dosage was to put more insecticide in each tank load. As farmers typically walk through the spray path, contact with insecticide is inevitable and even more so as they do not don protective clothing.

5.9.17.3 Farmers' Use of Sprayers

In the Philippine farm record keeping survey, it was found that farmers applied insecticide with stainless steel, lever-operated knapsack sprayers with a capacity of 19 liters as being most popular. Smaller ones are 15 and 11 liter capacity. Farmers use the same sprayers for herbicides but know to wash them thoroughly before use.

Heong (1984) determined that most (85% of respondents) Malaysian farmers in irrigated rice areas owned sprayers (knapsack 64%, motorized 18%, both 18% among owners). For those who do not own they can contract spraying using equipment loaned by neighbors and equipment borrowed from the government or pay others to spray. This survey of sprayers, in fact, contributed to improved research and extension and identified urgent needs for improving knapsack sprayers, training farmers in sprayer techniques, and improving the quality of locally produced knapsack sprayers. It led to sprayer clinics being established (Norton 1993). In India it is common for farmers to rent sprayers for less than $1/day or to hire someone. Also farmers do not fill the sprayers full as they believe air is needed. Some only fill a 15 liter sprayer with 10 liters of water. The most popular sprayers in Chhattisgarh are made of plastic and leak from the loose seal at the cap and thus are extremely dangerous to use. Farmers balk at purchasing better made sprayers.

In rainfed rice culture in the Philippines all farmers had access to sprayers (Litsinger et al. 1980). Ownership was 65% of farmers and 59% had used sprayers for more than 10 years. Water availability is a problem for 31% of farmers. Interestingly rainfed wetland farmers experienced greater problems than the dryland rice site of Batangas (22%). Farmers in Batangas use wells and ox drawn sleds with metal oil drums to bring water to the field. Fewer farmers had problems in Pangasinan (25%) than Iloilo (44%). Sprayer size was 11–19 liters but 15 liters was most popular (54%). Many farmers found the 19 liter size as too heavy. Some 13% of farmers contract helpers from time to time. Some 65% of farmers in Sri Lanka hired labor locally for land preparation, as well as harvesting (62%), crop establishment (45%), pesticide application (43%), and weeding (33%) (van de Fliert and Matteson 1990).

5.9.17.4 Spray Volume

In the large survey in four Philippine sites spray volume was determined for Koronadal farmers which ranged from 173–220 liters/ha, while that in Calauan was higher (245 liters/ha) (Table 5.16). In Koronadal, slightly higher spray volumes occurred in transplanted wetbed crops (214–220 liters/ha) than in direct seeded crops (173–181 liters/ha). Half of the applications in Koronadal were less than 150 liters/ha and 80% less than 200 liters/ha, the recommended volume (Fig. 5.5). The maximum volume per farmer was 550 liters/ha. Most farmers in Guimba used a spray volume of 8–20 tank-loads or 128–320 liters/ha (mean $= 144 \pm 34$ liters) which is much less than recommended (300–500 liters/ha) increasing with crop growth (Fajardo et al. 2000). This data agrees with that of Waibel (1986) to confirm that farmers use low spray volumes. In Chhattisgarh a survey of 80 farmers revealed a mean spray volume of 202 liters/ha.

5.9.17.5 Safe Use Practices

Safety considerations among farmers appear to be lacking in all sites in the rainfed survey (Litsinger et al. 1980):

1. No farmer knew that pesticides can enter through skin,

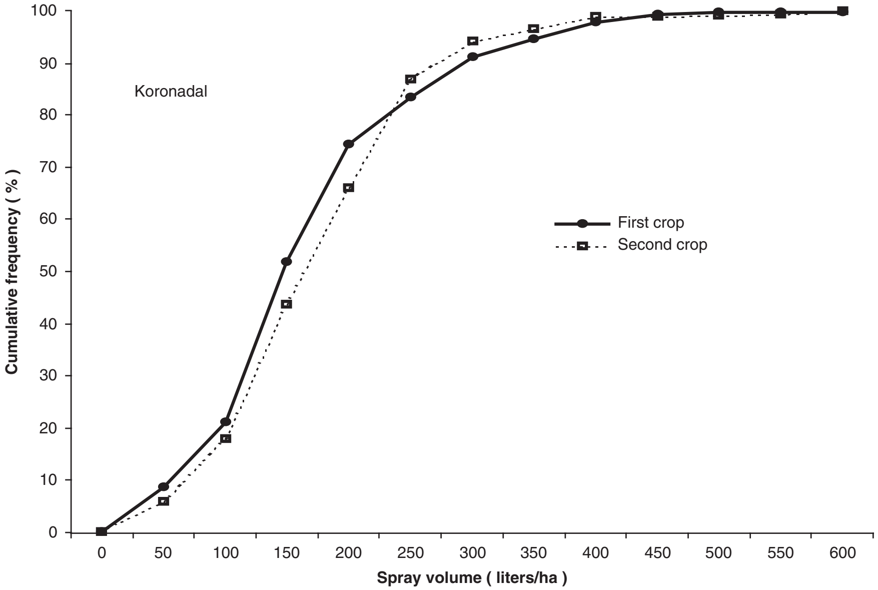

Fig. 5.5 Cumulative frequency of water volumes employed by farmers in applying insecticides, Koronadal, Philippines, 1983–1991. See Table 5.15 for information on the farmers interviewed

2. Most farmers (69%) take precautions not to inhale the pesticide while spraying with a handkerchief around nose,
3. But some farmers do take some precautions:
   a. The safety period before it is safe to eat a sprayed vegetable is >5 days according to 61%, and
   b. 28% feared using pesticides (endrin, carbofuran, methyl parathion mostly)

Most farmers felt insecticides were the most toxic because:

1. Bad odor 41%
2. Personal experience 20%
3. Knew from label 13%
4. Inherently dangerous 11%
5. Harmed animals 9%
6. Affects the skin 6%

Therefore the farmers have this misperception that the way to avoid poisoning is only not to breathe or eat the chemicals (keeping off the skin is not considered important) (Warburton et al. 1995). Farmers need to take more precautions when measuring product in the spray tank as they are dealing with concentrated insecticide. Often farmers use only the bottle cap which is bound to spill on their skin as these are not meant for this purpose and they have no gloves. They should not spray in front while walking through the spray path and they should wear protective clothing on their legs and wear rubber boots. One method is to wrap a sheet of plastic around the waist to act as a water repellant. If clothing gets soaked with pesticide tainted solution this acts as a wick causing the chemical to enter the body. Lastly farmers should repair leaky sprayers as if they solution spills down their back while spraying the wicking from their soaked clothing becomes highly hazardous.

In Laos Rapusas et al. (1997) asked farmers what precautions they took while spraying and the most commonly mentioned precaution was not to spray at all (27%of respondents). Some 12% were wore long trousers and long sleeves and covered their mouth and nose (10%) while spraying. Some 10% were also aware that eating or smoking should be avoided, 8% took a bath after spraying, and 5% refrained from entering recently sprayed fields. A few of the 463 farmers interviewed said they kept pesticides away from children and animals and rinseate from sprayers was not dumped into canals or rivers.

5.9.17.6 Negative Effects on Environment

Surveys in Thailand, Cambodia, Laos, and Nepal among rainfed rice farmers showed they were aware that useful paddy organisms would be killed if they used insecticides (Fujisaka 1990). In the Philippines it is said there are three harvests in a rice field. First is to harvest rice, second is to harvest the rats that eat the rice (barbequed delicacy in the countryside), and third are the aquatic organisms in the paddy. After harvest one can see farmers fishing out aquatic organisms from the stagnant pools left in the drained field. Such food enriches local diets. Poorer farmers in many areas traditionally harvest snails, fish, and crabs from the ricefield to supplement their diet. In irrigation canals farmers collect an aquatic plant *kangkong Ipomoea aquatica* to use as a vegetable but their health is jeopardized as it absorbs and concentrates pesticides (Tejada and Magallona 1985). One of the comments of farmers after successful IPM programs is how many of the aquatic organisms have returned to their fields. Many of these organisms are highly sensitive to insecticides. It is beyond the scope of this chapter to detail much of this but the reader is referred to Pingali and Roger (1995).

5.10 KAP of Weeds

5.10.1 Identification and Damage Caused

Bentley (1989) noted that Honduran farmers possess an impressive knowledge of plants (and by extension weeds) growing in their surroundings, having a name for each and knowing about their utility and ecology. Ivory Coast rice farmers according to a survey by Adesina et al. (1994) also know weeds very well but will produce a shorter list of species than one developed by scientists. This is due to the fact that farmers place higher importance on only a few of the prevailing weeds and may lump two closely related species. If farmers do not give high importance to a weed, they are unlikely to want to control it. They consider some weeds which are used for food or medicine or have the ability to suppress other weeds as beneficial (Altieri 1984). This same view was shared by farmers in SE Mexico who have a "non-weed" concept where non-crop plants are classified according to use potential and complementary positive effects, on the one hand, with negative effects on soil and crops on the other. Such classifications indicate that local farmers understand the intricate role of non-crop plants in their agricultural activities. Thus instead of considering all weeds as noxious, certain weeds are allowed to remain in the field.

In many parts of Asia, rice farmers routinely submerge weeds that they just pulled from the field back into the paddy mud, roots up. This is a convenient way to control them and also is a source of green manure. Filipino farmers were observed pushing young water hyacinth plants under the soil while weeding, in this way weeds serve a useful purpose. In Chhattisgarh farmers know those weeds that will not regenerate if buried so roll them into a ball and push them into the soil. Those species that will regenerate (with runners) are thrown on the bunds to desiccate or can be used as fodder. In Guatemala, weeds are allowed to grow in order to feed cattle even they know letting them grow tall will lower yield of their crop (Altieri 1984). In Java where rice farms are at their smallest there are no weeds as all are harvested for fodder.

Rice farmers in the Ivory Coast were asked to cite all the weeds they knew as pests and identify the most important (Adesina et al. 1994). They noted *Chromolaena* has vigorous regrowth and requires more labor to remove. *Centrosema* entangles young plants and is difficult to remove. *Rottboellia* has irritating hairs. *Echinochloa* is difficult to distinguish from rice. Some weeds such as *Ageratum* and *Euphorbia* rapidly form a dense canopy. The farmers noted some weeds have become more important in recent times while others less so.

Most farmers believe they know how to control weeds thus undervalue them compared to insect pests and diseases which give them more problems. A survey in Guimba, Philippines found farmers agreeing with researchers on the composition of weed species (Fajardo et al. 2000). However on the main crop only 40% of the farmers regarded weeds as a major problem in their fields but all applied herbicides to control them. Farmers may have misunderstood the question to mean weeds were not a problem *to them*. This is a common misunderstanding of the question by farmers thus those who survey farmers need to make the distinction between whether if uncontrolled farmers think weeds are a problem or if farmers rank weeds high because they are difficult to control. Although weeds were considered a secondary problem by the farmers, most farmers believed that weeds, if left uncontrolled, could cause 50% yield reduction. Research shows that almost 100% of yield is lost without weeding, particularly in areas with less water control. Another indication of the importance of weeds is that all farmers interviewed used herbicides and over 90% carried out labor-intensive hand weeding to keep their fields free of weeds. Traditional cultivars are more competitive with weeds but are less responsive to weed control. On the other hand, modern cultivars are less competitive with weeds but are more responsive to weed control, thus farmers have increased their time weeding with adoption of modern cultivars.

Both farmers and researchers in Guimba observed that all fields were infested by *Paspalum distichum* and *Echinochloa* spp. [*E. glabrescens, E. oryzoides*]; 85% were infested with *Monochoria vaginalis*; and 65% were infested with sedges [*Fimbristylis miliacea, Scirpus supinus, Cyperus iria*]. Other weeds of minor importance were *C. difformis, Ipomoea aquatica, Eclipta prostrata*, and *Ischaemum rugosum*. But farmers did not distinguish among species of *Echinochloa*. 60% of the respondents regarded *P. distichum* as the most important weed, while 25% stated that *Echinochloa* spp. were. 15% thought that other weeds, such as *M. vaginalis* and sedges were most important. Thus weed incidence is to a large part site specific. This interpretation basically agrees very much with researchers in terms of the site specific nature of weeds and the weed importance.

Guimba farmers showed they have a sophisticated understanding of the role of weeds in ricefields and listed eight ways in which weeds negatively affect yield and rice farming (Table 5.20). High on the list were competition for nutrients, lower yields, reduced tillering, and difficulty in harvest. They also estimated that weeds reduced yield by 12–49% in the dry season and 12–55% (mean 36%) in the wet season. Such ranges in loss were corroborated by IRRI researchers who hand weeded small plots on farmers' fields above the weed control level practiced by farmers. This method is a way to measure the degree to which farmers' weed control methods are effective. If there is no difference in yield between extra weeded plots and farmers' fields then the farmers' practice is optimal.

Filipino farmers are said to allow *Echinochloa crus-galli*. to grow side by side with rice (Moody 1990). The grassy weed is said to drive away birds because of the long awns and thus protects rice from attack. In reality *Echinochloa* may attract birds to rice fields as a source of food.

5.10.2 Evaluation of Control Practices in Irrigated Rice

Rainfed farmers in Sri Lanka stated they experienced fewer weed problems than irrigated farmers and combat weeds by hand weeding and water management (van de

Table 5.20 The negative effect of weeds as stated by farmers, Guimba, Nueva Ecija, 1986 dry season

Problem caused by weeds	Respondents (%)[a]
Competition for nutrients	70
Lower yields	40
Reduce tillering	30
Difficulty in harvesting	20
Stunt crop growth	15
Difficulty in land preparation	10
Alternate hosts for insect pests	5
Hamper irrigation	5

[a] Total adds up to more than 100% because most farmers gave more than one answer.

Fliert and Matteson 1990). Farmers in general are knowledgeable about the importance of timely weeding but still have problems in weed control due to inadequate water supply and misuse of herbicides. 31% used the right type of herbicides at the right development stage but only 9% used them at the appropriate rate. The farmers complained that even though they used herbicides, they end up undertaking significant hand weeding. They have a choice between direct seeding or transplanting to establish their crop. The latter requires less herbicide and weeding (93% believe so) but more labor.

Watson and Willis (1985) found farmers in Kalimantan select tall droopy-leaved rice varieties to compete with weeds particularly on newly cleared fields. More weeding was needed in older fields when grasses appear. Weeding is curative, however, and is only done when weeds threaten to overwhelm the crop – too late to prevent significant loss. In NE Thailand burning rice stubble controls weeds (Brown and Marten 1986). Surveys in Thailand, Cambodia, Laos, and Nepal in rainfed rice found farmers noting that weed control was not such a problem due to good land preparation, use of the stale seedbed method, and hand weeding (Fujisaka 1990). Kenmore et al. (1987) noted Filipino farmers control weeds well and use crop husbandry practices and herbicides. On the contrary, the authors concluded that the use of insecticides was not as well carried out by farmers as herbicides. An explanation is that the effect of not using herbicides well is immediate, whereas of not applying the right amount of insecticides is not.

Farmers can be innovative. In parts of India where wild rice *Oryza sativa* f *spontaneum* is a serious weed problem farmers have taken to planting a purple colored rice variety (red rice) Shayamala. When the crop is about a month old the green wild rice plants can be easily distinguished from those of rice and can be readily removed by hand. The farmer would perform this operation only after a season with high incidence of wild rice.

The "loop survey" in the Philippines (Cordova et al. 1981) in which IRRI economists periodically interviewed the same farmers every five years, showed that irrigated rice farmers adopted herbicide technology on a linear scale from 1965 to 1975, rising from 9 to 58% users. The farm record keeping survey in the Philippines documented detailed herbicide usage by farmers. The survey served as a report card on farmers' mastery of herbicide usage pointing out their resourcefulness as well as deficiencies in certain areas. We found that herbicides were used only minimally in the seedbed in the four irrigated rice sites. In the field we found that herbicide usage was generally high as in three of the four sites an average of 73–100% of farmers applied them. Thus farmers have been high adopters of herbicides as a labor saving technology. Overall, herbicide usage varied widely between sites and crop cultures and to a certain extent seasons (Table 5.21).

Sprayable formulations are delivered by stainless-steel, lever-operated, knapsack sprayers (15–19 liter capacity) while granular herbicides are broadcast by hand. Fewest herbicide users were in Zaragoza with only a mean of 45% of farmers, as crop culture averages. Least usage in a year occurred in Zaragoza in the 1986 wet season wetbed crop with only 21% of farmers and 14% of farmers in the 1983 direct seeded wet season crop. In Zaragoza irrigation comes from a large river diversion

Table 5.21 Herbicide usage on irrigated, double-cropped rice in four locations, Philippines, 1981–1991

				Application frequency (%)				Timing (DAT/DAS)[a]		Dosage (kg ai/ha)	
Site	Crops (no.)	Users (%)	Appl. no.	1x	2x	3x	Pre-emergence appl. (%)	Pre-emergence	Post-emergence	Sprayables	Granules
Wet/first season wetbed transplanted crops											
Zaragoza	6	35	1.1	89	10	1	76	7	28	0.24	1.12
Guimba	4	73	1.0	100	0	0	100	4		0.44	
Koronadal	5	90	1.1	95	5	0	93	25	46	0.48	
	avg	**66**	**1.1**	**95**	**5**	**0**	**90**	**12**	**37**	**0.39**	**1.12**
Dry/second season wetbed transplanted crops											
Zaragoza	3	46	1.1	94	6	0	80	5	29	0.18	0.86
Guimba	5	100	1.0	100	0	0	98	4	26	0.46	
Koronadal	6	89	1.1	96	4	0	96	27	46	0.54	
	avg	**78**	**1.1**	**97**	**3**	**0**	**91**	**12**	**34**	**0.39**	**0.86**
Wet/first season dapog transplanted crops											
Calauan	4	87	1.1							0.40	
Koronadal	4	92	1.1	93	8	0	88	14	35	0.45	
	avg	**89**	**1.1**	**93**	**8**	**0**	**88**	**14**	**35**	**0.43**	
Dry/second season dapog transplanted crops											
Calauan	3	89	1.0							0.66	
Koronadal	5	91	1.1	90	8	2	93	15	41	0.46	
	avg	**90**	**1.1**	**90**	**8**	**2**	**93**	**15**	**41**	**0.56**	
Wet/first season direct seeded crops											
Zaragoza	2	52	1.8	61	39	0	80	7	51	0.37	1.39
Koronadal	1	90	1.3	56	44	0	100	8		0.44	
	avg	**71**	**1.6**	**59**	**42**	**0**	**90**	**8**	**51**	**0.41**	**1.39**
Dry/second season direct seeded crops											
Zaragoza	1	45	1.0	100	0	0	94	3	38	0.23	
Guimba	2	91	1.1	97	4	0	100	4		0.32	
Koronadal	3	94	1.3	76	24	0	100	5		0.47	
	avg	**77**	**1.1**	**91**	**9**	**0**	**98**	**4**	**38**	**0.34**	

[a] DAT = days after transplanting, DAS = days after sowing.

system and farmers maintain higher water depths in their fields than is true of the other sites typified by smaller irrigation systems. Farmers in Calauan (90%) and Koronadal (90%) were highly consistent on average between crops, whereas in Guimba only 73% used in the wet season compared to 91–100% for dry season crops. In Calauan the lowest usage per year was 78% in the 1985 wet season and in Koronadal 62% in the 1987 second wetbed crop. Overall there was a slight indication that more farmers chose herbicides in the dry season crops compared to the wet season.

Except in wetbed crops in Zaragoza, sprayable formulations were more preferred than granulars (Table 5.22). The pre-emergence herbicide butachlor was the most preferred sprayable material for transplanted crops by farmers in Calauan (84–97% of applications). In direct seeded rice with pre-germinated seeds, Zaragoza farmers preferred pretilachlor (34–56% of applications) in both wet and dry seasons. Guimba farmers who direct seeded in the dry season also selected pretilachlor (61% of applications). Koronadal farmers who direct seeded preferred pretilachlor in the second crop (53% of applications) but 2,4-D + piperophos in the first crop (46% of applications). Koronadal farmers selected mixed formulations of sprayable herbicides which ranged from 19–69% of all applications. Zaragoza farmers selected granular herbicide formulations for wetbed transplanted crops in both the wet and dry seasons which predominated in 55–60% of total applications. The most preferred materials including mixtures were butachlor; 2,4-D; MCPA; and pretilachlor.

With the exception of direct seeding rice culture, farmer-users averaged only one application per crop (Table 5.21). In the wet or first rice crop from 39–44% of farmers who used herbicides in Zaragoza and Koronadal applied a second time. The most number of applications recorded was three which occurred in less than 13% among farmer users on any crop (the 1986 second *dapog* crop in Koronadal).

Choice of pre-emergence herbicides varied widely by site, season, and crop culture (Table 5.21). Highest usage by site was in Guimba (77–79% of all applications). Koronadal farmers used pre-emergence chemicals sparingly in wetbed and *dapog* crop culture (14–24% of all applications), but were among the highest (67–98%) in direct seeded crops. Farmers planting direct seeded crops utilized the most pre-emergence applications (43–98%). Zaragoza farmers used more pre-emergence herbicides in the dry season for both wetbed (70 vs. 53%) and direct seeded (94 vs. 43%) crops.

Timing of pre-emergence herbicides averaged 3–5 days after transplanting (DAT) or days after sowing (DAS) for all crops (Table 5.21). Post-emergence applications were timed 8–38 DAT or DAS with no trend evident by crop culture or season. Zaragoza (21–38% of applications) and Koronadal (11–32%) farmers generally timed their post-emergence applications later than those in Guimba (8–12%) over all crops.

The cumulative frequency distribution graphs for herbicide applications by crop age showed for wetbed, wet-season crops that Guimba farmers had applied over 95% of total applications by the first week after transplanting (Fig. 5.6A). Zaragoza farmers also had a high rate of pre-emergence applications but continued to apply post-emergence applications until the seventh week after transplanting. Koronadal farmers applied the most during 4–5 weeks after transplanting (WAT). Similar trends

Table 5.22 Popular herbicides applied to irrigated, double-cropped rice averaged by site, crop culture, and season in four locations, Philippines, 1981–1991

Common name	Applications per crop (%)[a]																			
	Zaragoza					Guimba				Koronadal							Calauan			
	Wetbed		Direct seeded		Site avg	Wetbed		Direct seeded	Site avg	Wetbed		*Dapog*		Direct seeded		Site avg	*Dapog*		Site avg	Grand avg
	WS	DS	WS	DS		WS	DS	DS		1st	2nd	1st	2nd	1st	2nd		WS	DS		
Sprayables	**45**	**34**	**96**	**100**	**69**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**92**
Single compounds	*31*	*16*	*59*	*90*	*49*	*85*	*88*	*83*	*85*	*78*	*81*	*70*	*54*	*31*	*53*	*61*	*100*	*100*	*100*	*74*
2,4-D	18	4	4	6	8	0	0	0	0	6	7	11	4	0	0	5	16	3	10	6
MCPA	3	10	4	0	4	0	2	0	1	1	0	0	3	0	0	1	0	0	0	1
butachlor	10	2	17	28	14	84	69	22	58	69	71	59	47	8	53	51	84	97	91	54
pretilachlor	0	0	34	56	23	1	17	61	26	1	1	0	0	23	0	4	0	0	0	13
pendimethalin	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	1	0	0	0	0
Mixed sprays	*14*	*18*	*37*	*10*	*20*	*15*	*12*	*17*	*15*	*22*	*19*	*30*	*46*	*69*	*47*	*39*	*0*	*0*	*0*	*18*
2,4-D + piperophos	6	6	29	5	12	3	9	11	8	15	12	22	33	46	30	26	0	0	0	11
2,4-D + butachlor	2	0	0	5	2	0	1	0	0	1	2	0	3	0	0	1	0	0	0	1
2,4-D + triobencarb	6	2	8	0	4	12	2	6	7	6	5	8	10	23	17	12	0	0	0	6
MCPA + trifluralin	0	10	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Granules	**55**	**66**	**4**	**0**	**31**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**8**
Single compounds	*50*	*60*	*0*	*0*	*28*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*7*
2,4-D	21	36	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
MCPA	15	6	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
butachlor	14	18	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Mixed granules	*5*	*6*	*4*	*0*	*4*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*1*
2,4-D + butachlor	1	6	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4-D + thiobencarb	2	0	4	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MCPA + trifluralin	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

[a] WS = wet season, DS = dry season, direct seeding used pre-germinated seeds, see Table 5.21 for details on sampling size.

continued for the wetbed dry season crop for Guimba and Koronadal farmers, but Zaragoza farmers applied earlier showing a greater proportion of pre-emergence applications. *Dapog* crops showed a marked contrast between Calauan and Koronadal farmers (Fig. 5.6B), where farmers from the former site applied at the time of transplanting or earlier. Herbicide timing in *dapog* culture mirrored that in wetbed culture where Calauan farmers applied herbicide within the first two weeks while those in Koronadal were more delayed (Fig. 5.6C). There was a slight difference between rice cultures in Koronadal as wetbed culture most applications occurred from 3 to 5 WAT whereas in *dapog* for the second crop particularly most applications occurred by 3 WAT. For direct seeded crops, Koronadal and Guimba farmers had applied most applications by the second week after sowing whereas in Zaragoza some 20% of farmers delayed until the nineth week (Fig. 5.6D).

Herbicide rates in general were several-fold lower than those recommended on the label (0.50–1.00 kg ai/ha). Farmers applied an average dosage of 0.18–0.55 kg ai/ha per crop (Table 5.21). As a site, Zaragoza farmers applied lowest mean dosages (0.18–0.37 kg ai/ha). There was no other observable trend for crop culture or season. Zaragoza farmers used the highest amount of granular herbicides and averaged 0.86–1.39 kg ai/ha. Still dosages were about half of those recommended. The frequency distribution graphs of dosages showed that over half of the applications by Zaragoza wetbed farmers were severely under-dosed – less than 0.15 kg ai/ha (even some 18% applied at rates less than 0.05 kg ai/ha), whereas more than half of Guimba and Koronadal farmers applied at rates above 0.40 (Fig. 5.7A). In the dry season wetbed crop, 80% of Zaragoza farmers applied at rates less than 0.20 kg ai/ha, whereas more than half of Koronadal farmers applied at rates above 0.50 (Fig. 5.7B). A similar trend was noted for Koronadal *dapog* farmers as over half applied at rates above 0.45 kg ai/ha (Fig. 5.7C). This was remarkably consistent for both first and second crops. Farmers who direct seeded in the dry season averaged similar dosage distributions as wetbed dry season farmers (Fig. 5.7D) with half of Zaragoza farmers averaging herbicide dosages of less than 0.20 kg ai/ha while over half of Koronadal farmers averaged more than 0.45 kg ai/ha per application.

A more detailed survey in Guimba by a multidisciplinary team (Fajardo et al. 2000) found a surprisingly high 35% of farmers who used herbicide in the seedling nursery. 85% of those chose butachlor and 15% applied a tank mixture of butachlor plus Rilof H (piperophos + 2,4-D) with knapsack sprayers. Herbicides were applied before seeding – 29% of the farmer-users applied them 7 days before seeding (DBS), 57% at 4 DBS, and 14% at 3 DBS. Furthermore farmers knew preventing weed growth in the seedling nursery occurs through site selection (for least weedy areas) and land preparation. Weeds, pulled and transplanted with rice seedlings, cannot be controlled with herbicides, and hand weeding is impractical. But some farmers stated that weed control in the nursery was a problem despite more than adequate tillage. Strategies to prevent weeds in the nursery are warranted such as a low cost herbicide application or longer periods between harrowings. Delaying a few days between tillage operations allows weed seeds to germinate and the resulting seedlings are readily killed by tillage. Longer periods between tillage operations also helps to control creeping weeds such as *P. distichum*.

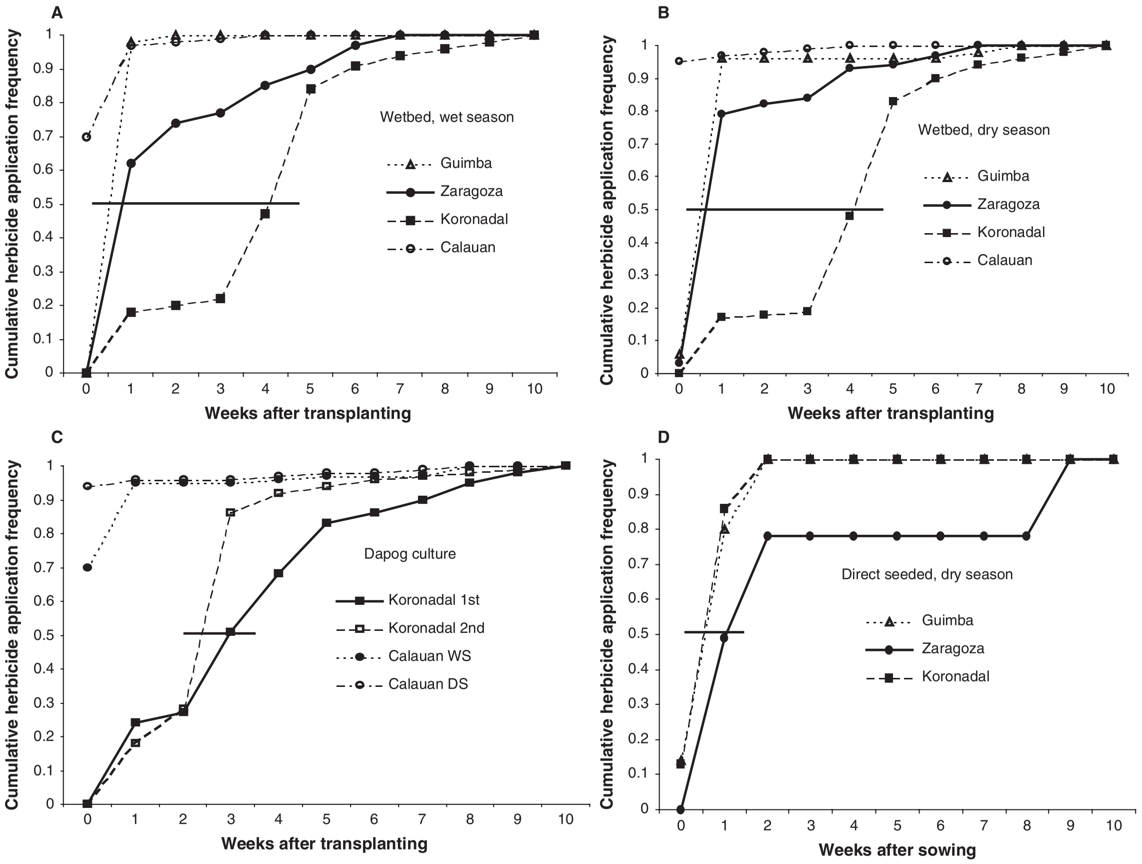

Fig. 5.6 Cumulative frequency of herbicide applications by rice culture and season in three irrigated rice sites in the Philippines. Data based on farmers surveys undertaken from 1984 to 1991. Horizontal line represents 50% of frequency

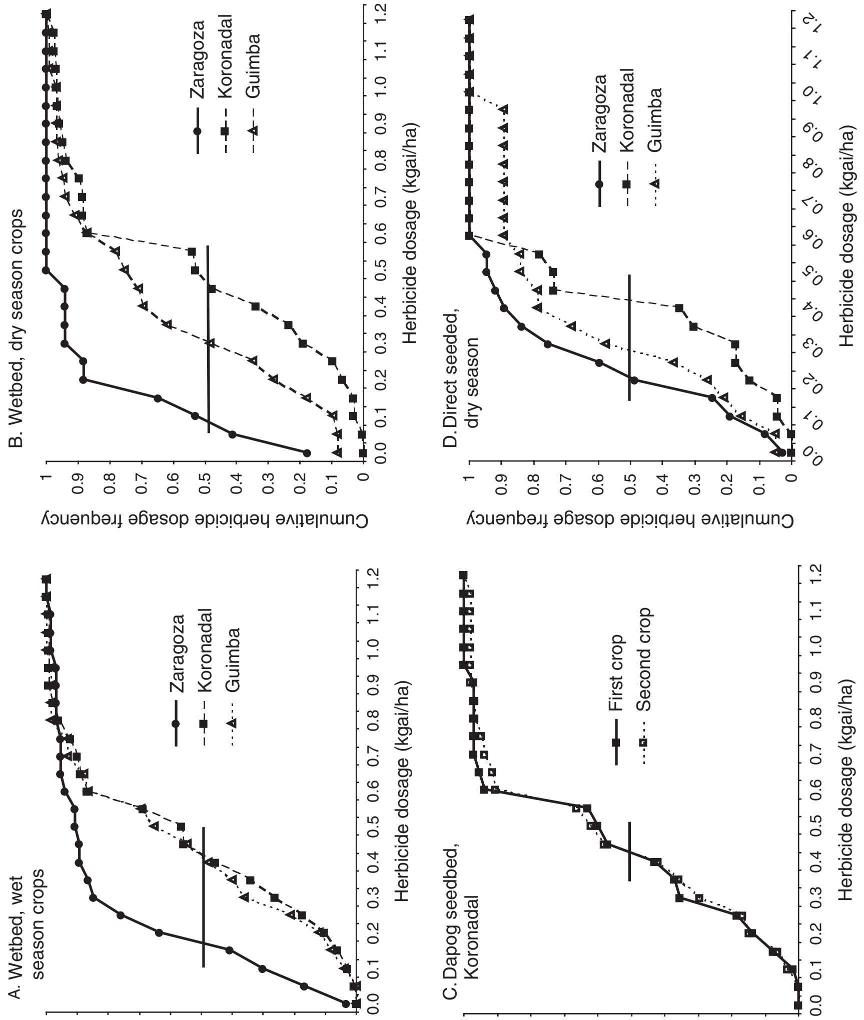

Fig. 5.7 Cumulative frequency of herbicide applications by dosage for three sites in the Philippines segregated by crop season and rice cultural method. Data based on farmers surveys undertaken from 1984 to 1991. Horizontal line represents 50% of frequency

Rao and Moody (1988) reported from observing and interviewing Guimba farmers that weeds emerging in the seedling nursery, which were inadvertently transplanted together with rice, caused yield losses ranging from 18% to as much as 35%. Using herbicides in the seedling nursery is not commonly practiced by Filipino farmers and is usually not given attention by herbicide manufacturers. This omission may be because farmers generally do not recognize the yield losses caused by transplanted weeds (mostly grasses such as *Echinochloa* spp.). Those farmers who used herbicides in the seedling nursery applied low rates. Farmers reported that they feared phytotoxicity if higher rates were used.

On the main rice crop 95% of Guimba farmers used butachlor while others used 2,4-D; MCPA; or Rilof H alone or in combination with butachlor. Application of butachlor was mostly timed at 1–5 DAT (latest was 7 DAT). When used, 2,4-D was applied at 14–21 DAT, MCPA at 44 DAT, and Rilof H at 2–4 DAT. The spray volume per hectare (mean $= 143 \pm 37$ liters, range = 64–272 liters) was about the same as that used for insecticide. All farmers interviewed applied butachlor at a rate lower (most 0.20–0.30 kg ai/ha with a mean $= 0.38$ kg ai/ha) than the label recommendation of 1.0 kg ai/ha. Follow-up research found that rates as low as 0.50 kg ai/ha were justified in direct seeded rice culture but control dramatically dropped below this level.

Guimba farmers said control of *P. distichum* and *Echinochloa* spp. was considered by half of the farmers to be equally difficult because: (i) herbicides cannot kill them, (ii) they produce many seeds (particularly *Echinochloa* spp.), (iii) have dense roots, (iv) decompose slowly, or (v) germinate readily (Fajardo et al. 2000). 21% of the respondents regarded *P. distichum* as the most difficult weed to control because of its fast growth and slow decomposition. Another 18% mentioned *I. rugosum* as equally difficult to control for the same reasons. These observations show farmers have great knowledge of weed ecology and control. According to most farmers (74%), butachlor can control *M. vaginalis* and sedges (*F. miliacea, C. iria*, and *Scirpus supinus*). A few farmers (37%) said that *Echinochloa* spp. (*E. glabrescens, E. oryzoides* and *E. picta*) can be controlled by butachlor. All of the respondents said that *P. distichum* cannot be controlled by butachlor; 55% said that butachlor cannot control *Echinochloa* spp. either.

The majority of farmers supplemented herbicide application with hand weeding. 45% did two additional hand weedings: (i) to increase yield, (ii) for ease of harvesting, (iii) to lessen competition, (iv) induce tillering, and (v) to promote faster crop growth. 35% performed only one additional hand weeding to lessen competition. Three additional hand weedings were carried out by 15% of the farmers to reduce harvesting and threshing losses and to “totally eradicate weeds”. One farmer did not do any supplemental hand weeding because he claimed that he already had adequate weed control resulting from good land preparation and the use of herbicides.

Additional comments made by farmers about herbicides that were questioned by researchers included: (i) 2,4-D is for the control of *M. vaginalis, F. miliacea*, and *C. iria* (20%); (ii) Lambast (a brand name of butachlor) is more effective than Machete (another brand of butachlor)(10%); and (iii) MCPA controls broadleaved weeds and sedges but not *P. distichum* or the *Echinochloa* species (5%). *M. vaginalis* is a serious weed in paddy fields but is more easily controlled by herbicides when applied at the correct rate and time. Most farmers said that butachlor prevented seeds of *M. vaginalis, F. miliacea, C. iria*, and *S. supinus* from germinating, but herbicides only affect germinating weed seeds (Fajardo and Moody 1990). A few farmers believe that 2,4-D applied post-emergence is for the control of some broadleaved weeds and sedges which is supported by research (Moody 1977). The allegation that Lambast is less effective than Machete is hard to understand because both are brands of the same product. Perhaps adulteration is the reason for the discrepancy.

5.10.3 Rainfed Rice Production Systems

Many polycultures have built-in pest protection mechanisms. For example in forested slash and burn rice, maize, cassava intercropping culture in Sumatra, Indonesia, as determined from a diagnostic survey (Fujisaka et al. 1991), is a stable system if a sufficient fallow period is followed. Yields are low and the burning, needed to clear up the cut brush and small trees, controls weeds and soil pests as well as provides nutrients. Seeds are sown with a dibble stick. Weediness and low fertility cause farmers to be limited to three years of cropping without resort to heavy inputs of hand weeding labor. Rice is grown only in the first year with cassava lasting until the third year.

Weed control by rainfed wetland farmers in Orissa, Madhya Pradesh, Bihar, and Uttar Pradesh in India is called bushening which was described during a diagnostic survey (Fujisaka 1991). The direct seeded (dry) fields are plowed around 30 DAS when there is a minimum of 2–3 cm of water standing in the field. The chisel plow loosens the soil, uproots and incorporates weeds, disturbs the roots of the rice plant which are stimulated to tiller more, and aerates the soil. A dozen or more passes are made (laddering) in different directions with a leveling plank with large spikes on one side that rip out mainly grassy weeds including rice. Uprooted rice plants are re-transplanted into open areas as a means of evening the stand called “gap filling”. They also report this method lessens pest incidence by knocking insects off the plants. Soil aeration from the plowing improves nutrient uptake. The method is highly labor intensive and Indian researchers have been trying for years to replace the method particularly in irrigated areas. Only in systems with more reliable irrigation delivery and where weeding labor is readily available will farmers desist using this method. It is to be noted that pre-germinated herbicides have been attempted to be used in these areas with little achievement as farmers have not been as successful as irrigated rice farmers in mastering them. One of the major weeds is wild rice which cannot be controlled by herbicides and only by hand weeding near harvest (for the benefit of the next year’s crop).

5.11 KAP of Plant Diseases

5.11.1 Identification and Damage Caused

Farmers appear to know much about their crops, animals, soil, and flora including weeds, but less about insects and little of plant diseases (Trutmann et al. 1993). Plant diseases in general present greater problems of understanding for farmers than the other pest groups. Farmers often relate disease symptoms to soil deficiencies or other abiotic causes. In Chhattisgarh, India farmers will call blast, bacterial leaf blight, zinc deficiency and even planthopper burn by the same descriptive term called *ghulasa* which translates as a browning or burning. Many disease symptoms have names but farmers either consider them non-important or do not realize they are caused by something living and thus can be managed. Most are unaware of micro-organisms and only perceive their consequences as diseases indirectly. Those that do realize a disease relate it to human health and they manage conditions that promote good health rather than treat disease symptoms (Bentley and Thiele 1999).

Filipino farmers believe that tungro a virus disease can be spread by air, water, and soil is consistent with their perception that is like germs that attack humans such as AIDS. Farmers are unaware that diseased plants are a source of inoculum for green leafhoppers and see little urgency in their removal. They know that tungro is connected with insects, although they are not always clear which ones. The recommendation of an insecticide for a plant disease such as tungro must be confusing to farmers who readily apply insecticides for fungal diseases as well.

Only 19% of Sri Lankan farmers recognized plant diseases of rice in the field (van de Fliert and Matteson 1990). Diseases, even when recognized, were not considered as important problems by farmers when asked to name their pest problems. In the same study only 4% used fungicides on rice. When shown a specimen of fungal infection only 4% could identify it as a fungus. Some farmers ignorantly spray insecticides for disease problems or a fungicide for an insect pest. Farmers in the Ivory Coast had a difficult time diagnosing diseases (Adesina et al. 1994). Disease symptoms such as brown spotting are often confused with nutrient deficiencies, toxicities, and drought. The presence of spots was believed to have no impact on yield.

Kalimantan farmers appeared indifferent to leaf spotting particularly in an early crop (Watson and Willis 1985). Bentley (1989) noted Honduran farmers' agricultural ability is uneven and they know more about large and stationary plants than they do about small mobile insects and even less about diseases. They have words to describe the damage from diseases but the name they use does not support any causal agent. Bentley concluded they are unaware of the causal agent but know its relationship to the environment, i.e., more prevalent when humid. When farmers were taught about maize diseases and shown spores via a microscope that were the reproductive forms and taught how disease spreads by wind or soil or water, a farmer went home and planted maize in a field that had not been planted to maize in several years. He reasoned that the soil borne spores would have died by then. Thus we see that at least some traditional farmers can assimilate new information even when it contradicts previously held notions.

Malaysian farmers were shown photos of tungro virus disease in a rice field and 77% identified it correctly by name and some 10% said it was caused by insects while 6% did not know what it was (Heong and Ho 1987). A photo of green leafhopper, the vector, produced 85% correct answers by farmers but only 70% knew it transmitted the disease. Some farmers misidentified tungro as being iron toxicity or other causes. When asked to speculate on what conditions favored tungro, 54%

said they did not know, while others correctly said staggered planting (17%), being unable to dry the fields (10%), and high green leafhopper densities (9%).

Litsinger et al. (1980) found tungro is well known in the rainfed wetland rice areas surveyed in the Philippines. Farmers had names for rice fungal and bacterial diseases when shown photographs or plants in the field. But very few knew the symptom described were diseases caused by microorganisms. A few (8%) Pangasinan farmers surprisingly correctly named grassy stunt from a photo (it is not a common disease anywhere in the Philippines). Batangas farmers had names for virus disease symptoms but no recognition of specific virus diseases.

In irrigated areas of the Philippines farmers observing fungal disease symptoms were mistaken as insect in origin thus their presence was highly correlated to insecticide use in Laguna (Marciano et al. 1981). However this same group of farmers recognized nine different rice diseases including two bacterial in origin, five fungal, and two viral. Thus the diseases were recognized but the farmers did not understand that fungal diseases need to be controlled by a fungicide. We also noted Filipino farmers applying insecticides against symptoms of soil problems. Bentley and Thiele (1999) as well noted the same with Honduran farmers.

In Guimba the interdisciplinary team found that 90% of the respondents said they recognized tungro as a rice disease; 5% also named rice blast *Pyricularia oryzae*, while 10% knew of no rice diseases (Fajardo et al. 2000). Tungro is endemic to the Guimba area thus farmers were more aware of the problem. The farmers recognized a tungro-infected plant as stunted with yellowish leaves, while 20% also said that tungro-infected plants had brown spots and drying leaves. Researchers, but not farmers, observed sheath blight [*Rhizoctonia sola*ni], sheath rot [*Sarocladium orzyae*], stem rot [*Sclerotium oryzae*], bacterial leaf streak [*Xanthomonas campestris* pv *oryzicola*], bacterial leaf blight [*Xanthomonas campestris* pv. *oryzae*], and false smut [*Ustilaginoidea vierns*].

5.11.2 Evaluation of Control Practices

5.11.2.1 Traditional Methods and Superstitious Practices

The knowledge of traditional farmers is often broad, detailed, and comprehensive. Although traditional farmers may not know what fungi, bacteria, or viruses are, in many cases they have effective, time tested practices for managing them. Glass and Thurston (1978) stressed that traditional agricultural practices must be understood and conserved before they are lost. For example in Peru before the arrival of Spanish, the Incas instituted a strict seven year rotation on potato farming enforced by law. This is now believed to be a cultural control for cyst nematode.

The Ayamara Indians in Peru have many myths to explain the origin of plant diseases as well as beliefs: entrance into a field of animals in heat, pregnant or menstruating women, drunk men, or people or animals when the dew is on the ground are all thought to cause disease (Thurston 1990). They dust their crops with ash, spray them with fish water infusion, place branches of a herb (traditional insect repellant) between plants, and rogue diseased plants. They also carefully select seed and practice crop rotation and do not plant when the moon is full or the sun has a halo.

From their studies, Bentley and Thiele (1999) concluded that traditional practices are a mixture of the useful and useless. Farmers nevertheless have come up with cultural methods for disease control even though they do not know the concept of plant disease as being living organisms different than insects. Therefore they are trying by trial and error to find remedies for such symptoms. The challenge is to sift the wheat from the chaff.

It is noted that farmers exchange seeds with neighbors even seeds of the same variety on a regular basis or when they observe that any particular variety tends to accrue pest problems if grown on the same land for several years (Matteson et al. 1984). They will select seed from a neighbor from fields which are not full of mixtures of off types and the crop is vigorous. This practice may also be for disease control as local strains of particularly fungal diseases can become adapted to the same genotype if planted for many years in one place. Maize plants seen in Angola after 25 years with no new germplasm introduction were severely infected with fungal diseases.

In a survey in Malaysia most (95%) farmers had attempted to control tungro virus during an outbreak, and 61% said the crop recovered as a result (Heong and Ho 1987). Some of the methods used were traditional or superstitious, tried by 33% of the farmers and included: (i) spreading kitchen or padi husk ash, (ii) pushing a branch of the *Sapium indicum* tree or a piece of bamboo painted red into the paddy mud, (iii) scattering branches of Lantana in the field, and iv) spreading salt. Filipino farmers said they applied sand to control *Cercospora* leaf spot disease on rainfed rice (Litsinger et al. 1980).

5.11.2.2 Cultural and Other Control Methods

Most practices of traditional farmers for disease management in developing countries consist of cultural controls (Thurston 1990). Some practices of traditional farmers are: altering plant and crop architecture, burning, adjusting crop density or depth or time of planting, planting diverse crops, fallowing, flooding, mulching, multiple cropping, planting without tillage, using organic amendments, planting on raised beds, rotation, sanitation, manipulating shade, and tillage. Most but not all are sustainable.

Farmers responded poorly to a campaign in Malaysia with extension officers giving away paraquat herbicide to destroy rice ratoon infected with tungro in order to quell an epidemic in the Muda scheme (Heong and Ho 1987). They knew they had tungro in their fields but were unable to perceive that the infected stubbles after harvest could transmit the problem to the next crop (Kenmore et al. 1985). When asked what steps they would take next season if attacked, they replied: (i) insecticides (79% of farmers), (ii) destroy diseased plants (2%), (iii) do nothing (9%), (iv) use fertilizer (4%), and (v) if their neighbors' fields were attacked would also spray insecticide (55%).

Among other methods recommended in the tungro control campaign were: (i) burning affected crop after harvest and (ii) hand weeding (Heong and Ho 1987). A range of strategies for tungro was suggested by farmers during the survey:

1. Insecticide in nursery (23% of farmers),
2. Early detection and control (19%),
3. Clearing fields (10%),
4. Drying fields (5%),
5. Growing resistant varieties (5%),
6. Synchronous planting (4%),
7. Organizing community-wide control (2%),
8. Using less fertilizer (1%), and
9. Roguing infected plants (1%)

When asked about the synchronous planting water delivery plan to create a rice free period, 90% agreed to it; for those who disagreed their reasons were: (i) loss of income (63% of farmers), (ii) farmers would be forced to plant late (13%), or (iii) they believed the strategy would not work (25%) (Heong and Ho 1987).

The Malaysian government recommended dry season fallow for one month by shutting off the water: (i) to save water, (ii) improve crop scheduling, and (iii) to dry out the soil to prevent weed and ratoon growth. After the fallow period was initiated, tungro was controlled and so 90% of farmers were in favor of it. Farmers, however, were not convinced of the cultural control methods but this was based on their lack of knowledge that they were really required to control a disease as well as an insect. Farmers exhibited risk averse strategies when they reacted when neighbors sprayed. Muda farmers actually spent little time on their farms, some 15 full working days per season and only 1% of their time in crop protection.

In Guimba farmers said most farmers controlled diseases by: (i) spraying insecticides (53%) (for tungro and fungal/bacterial diseases) or (ii) by roguing infected plants (18%), while (iii) 29% did nothing (Fajardo et al. 2000). In terms of chemical disease control, (i) 76% knew of no chemicals to control rice diseases; (ii) 18% said that insecticides such as monocrotophos, chlorpyrifos + BPMC, or DDT can control tungro (insect vectors), and (iii) 6% said that copper oxychloride and edifenphos can be used for the control of blast.

5.12 KAP of Vertebrate Pests

5.12.1 Identification and Damage Caused

Of all the pest groups, farmers recognize vertebrate pests best as they are large and are prevalent mostly in crops. They are also noted because they often are highly destructive and feed on grains. Rice plantings near forested areas are beset by the depredations of often a wide array of vertebrate pests that can run the gamut from elephants, rhinos, monkeys, squirrels, and pigs (Grist and Lever 1969, Fujisaka et al. 1991). These forest animals are highly attracted to a grain crop, as in the forest, food items are scarce. Some pests such as pigs and rhinos do not eat rice plants but like to bed down in rice fields, with disastrous consequences on the crop. To make matters worse some are diurnal (monkeys) while others are nocturnal (pigs, rhinos) causing many sleepless nights and days for vigilant farmers and their families.

From diagnostic surveys in Thailand, Cambodia, Laos, and Nepal, rainfed rice farmers said rats eat the crop and open tunnels in bunds to cause water loss (Fujisaka 1990). Farmers notice rat population fluctuations and species distribution. Rats are especially a problem in late planted fields and ratoons in Kalimantan (Watson and Willis 1985)

Factors affecting the extent of damage by squirrels as stated by farmers in the Ivory Coast are: (i) sowing date, (ii) type of variety, (iii) plant architecture, (iv) presence of awns, (v) date of maturity, and (vi) season (Adesina et al. 1994). Kalimantan farmers said birds attack in flocks early in the morning and 1 h before sunset (Watson and Willis 1985). They are worst near forests or trees where they roost.

5.12.2 Evaluation of Control Practices

Ivory Coast farmers, to combat squirrels, build fences requiring much labor, while others: (i) dig up burrows, (ii) set out traps, (iii) burn surrounding fallow fields, (iv) use hunting dogs, and (v) guns (bush meat) (Adesina et al. 1994).

Rat control in rainfed ricefields in a number of Asian countries is by: (i) traps, (ii) poisoned baits, and (iii) digging burrows (Fujisaka 1990). Removal of weeds by hand by Claveria farmers was astutely seen as having additional benefits of removing habitat for rats. Flooding the field was seen as having the dual effect of weed and rat control. The beneficial effect of flooding against weeds is well known, but Philippine rats prefer aquatic habitats thus there would be little benefit from this method.

Kalimantan farmers have many control methods for rats (Watson and Willis 1985). The techniques are both preventative and curative. Farmers claim to select tolerant varieties that have (i) thick stems, (ii) hard tillers, (iii) bitter hulls, and (iv) firm rooting to prevent lodging. Farmers clear out above-ground rat nests. They plant fields in groups for synchronous harvesting to dilute damage. They sow rice in burned areas which are said to be avoided by rats. They cover seed holes with ash. They sow wet seeded rice to encourage quick sprouting, or if they transplant they raise the water level in the field. Also they isolate seedlings from embankments. Rat repellants are made from mashing and soaking sugarcane refuse and spraying it on the field. Many of these methods have questionable value but should be tested by researchers.

The Kalimantan farmers also have some superstitious practices such as they burn rats and sprinkle their ashes in the field or they leave rat bodies to rot on a stake in the field for “the others to see” and “be afraid to enter” (Watson and Willis 1985).

More pragmatic solutions of rat baits are used. The most common rat bait is the acute poison zinc phosphide which produces a rapid killing effect. Rats soon learn to avoid acute bait in a behavior called "bait shyness". Anti-coagulants were developed to overcome bait shyness as they work to prevent vitamin K synthesis, thus rats bleed to death (vitamin K is a key constituent in the chemical process of coagulation of blood). But farmers do not like such rodenticides as they cannot see the dead rats, thus believe the poison is ineffective. Farmers cooperate in rat control campaigns such as beating foliage and driving them into openings to be killed by sticks or machetes.

Rodent and bird control methods in the Philippines as noted by a questionnaire consisted of: (i) scarecrows (55% of respondents), (ii) flags (57%), (iii) tin cans (29%), and (iv) crosses (29%) (Catholicism is the major religion) (Litsinger et al. 1980). Other methods mentioned by farmers for bird control were: (i) hanging plastic string above the crop, (ii) clapping bamboo sticks, and (iii) using bamboo propellers.

Birds are controlled with: (i) scarecrows, (ii) synchronous planting (synchronous ripening), and (iii) vigilance for birds around fields from before dawn to dusk (Fujisaka 1990). For birds, hard seeds (8%) and long strong awns (5%) were mentioned as qualities of resistant varieties by Claveria farmers. Ivory Coast farmers use: (i) slingshots, (ii) tin cans for noise, (iii) scarecrows, and (iv) repellant wild plants. Rituals were preformed using a special plant where the parts were placed in the field and the person applying has to be the last to leave (Adesina et al. 1994). In Cambodia farmers use cassette magnetic tape which they unwind from the reel and string around their field. Sunlight reflects off of the surfaces of the wind blown tape which acts as a repellant (Jahn et al. 1997).

Kalimantan farmers combat birds by: (i) scarecrows, (ii) noise makers such as strings of metal above the fields in mature fields, (iii) seedbeds are camouflaged by ash or weed mulch, and (iv) fields are guarded cooperatively (Watson and Willis 1985). In Claveria 8% of dryland farmers used scarecrows for bird control (Table 5.8).

5.13 Pest Group Ranking in Terms of Importance

This section looks at how farmers cross evaluate the various pest groups with each other. Among pest groups, 34 irrigated farmers in Guimba, C. Luzon polled considered insects (45% of the respondents) and weeds (40%) to be of greater concern than diseases (15%) (Fajardo et al. 2000). Through experience, farmers realize that neglect of weed control practices will invariably result in significantly reduced yield. By contrast, insect pests and diseases are less chronic and severe, thus are perceived to be less threatening to yield. Weeds were probably ranked of lower importance than insects because farmers can more readily manage them. Most insects are recognized by farmers but their effects are more subtle and are more difficult to control than weeds.

Two other groups of farmers expressed opinions on the most important pest groups. In Ivory Coast farmers considered that weeds were most important (100%) followed by birds (84%), rodents (60%), insects (40%), and diseases (9%) (Adesina et al. 1994). While in Java most farmers believed rats (89%), insects (82%), and diseases (77%) were important problems causing substantial yield loss in irrigated rice (Rubia et al. 1996).

The researchers assessment of the most important pest groups agrees with the field surveys. The lesson is that research should not be focused on only one pest group as all must be seen as a part of a complex of constraints and farmers may be unwilling to adopt new farm practices designed to reduce insect pests if they ignore or exacerbate other serious agricultural hazards (Conelly 1987).

In a rainfed rice site in N. Luzon in the Cagayan Valley, farmers ranked their pest problems among all groups (Litsinger et al. 1982). Three insect pests were ranked highest (rice bug, caseworm, and armyworm) followed by rats and birds. Tungro disease ranked number ten even though the disease was not present in the site and discolored grains ranked number 14. Weeds were not considered in the evaluation.

In Claveria most (93%) dryland rice farmers mentioned a number of pests that caused outbreaks based on their experience exclusive of weeds. Of those responding outbreaks were most common with rats (68% of respondents) and rice bug (33%) (Table 5.23). Some farmers gave more than one answer but none mentioned diseases. Weeds were not considered in this study. Farmers were asked to rank the pests they recalled in terms of importance and rice bug ranked highest (6.9). If

Table 5.23 Local names of rice pests recalled by upland farmers during the interview process and their relative importance.[a] Claveria, Misamis Oriental

Common name		Farmers responding		
English	Local	Causing outbreak	(%) Recall	Importance Index[b]
Rice bug	Tayangaw, piyangaw	33	67	6.9
Stemborer deadhearts	Buko	0	65	4.9
Rats	Ilag	68	52	4.5
Birds	Langgam, maya	20	55	4.1
Root aphids	Bunhok, dagabdab, Iayabc	12	45	4.0
Stemborer whiteheads	Buko	0	52	3.9
White grubs	Ingan, bunlod	13	28	2.3
Seedling maggot damage	Tag't, undol-undol, dugy, lagos	0	27	1.8
Leaffolder worms damage	Ulod Likis-likis, lok-lok	0	3	1.8
Locusts	Dulon, duwon	19	18	1.3
Armyworms	Ulod	7	17	1.2

[a] n = 60, 93% of farmers responding.

[b] Farmers were asked to rank each pest they named and the most important was given a value (index) of 10 if it were not mentioned it received a value of 0, thus a higher number indicates greater importance in severity and commonness.

all farmers had ranked rice bug of highest importance it would have scored a 10. Stemborers ranked high in importance for both deadheart and whitehead damage. Farmers associated stemborers by the damage they caused as was also the case with seedling maggot which they only know by its damage symptom. They do not know a fly causes it but know it is an insect.

Omnipresent stemborers are chronic pests but rarely become as significant as rats and birds. When asked to recall their pest problems rice bug was most commonly mentioned. But if stemborer deadhearts and whiteheads were combined they would have been the most commonly mentioned pest guild. Farmers know both symptoms are caused by the same group of insects although there are some five species involved which they do not distinguish. Other pests recalled the most were rats, birds and root aphids. The latter cause stunting which they give a name based on the damage symptom.

5.13.1 Trends in Pest Control Practices Over Time

5.13.1.1 Agro-Input Usage

The farm record keeping survey conducted over 10 years in the Philippines enabled trends in agro-input usage to be plotted. In Fig. 5.8A the data from the four sites was combined with earlier data from the "loop survey" covering the period from 1965 to 1977 (Cordova et al. 1981). Insecticide users was defined as the frequency of application among the respondents in the figure. In 1965 few farmers applied insecticides on rice but this number dramatically increased to a peak in 1977 when the government low interest credit program heavily subsidized insecticides. Further subsidies were in effect until 1984. Whereupon insecticide usage declined at a steady rate. Wet and dry season data were highly similar and decreased dramatically from the high of almost an average of five insecticide applications per crop per farmer to 0.5 applications in 1990, returning to pre-Green Revolution levels. The farmers in the farm record keeping dataset had minimal contact with extension workers and the decline was attributed to farmers learning on their own that insecticide application was less useful, a fact now supported by research (Heong 1998, Litsinger et al. 2005).

Linking herbicide usage with the loop survey data also gave a trend of increase, this time until the mid-1980s before declining into the 1990s due to the withdrawal of subsidies (Fig. 8B). The peak ranged over a decade where some 60–70% of farmers used herbicides. There was a somewhat higher usage in the dry season probably because farmers expected higher yields, but this was not the case with insecticides. Weed control, however, leads to higher yield gains than is the case with insect control. Farmers learned to control weeds with a single application supplemented by hand weeding and ponding. Zaragoza farmers with more access to irrigation water were able to pond their fields at greater depths to the extent that they did not need to use herbicides as much as in other sites even on direct seeded rice where they relied on higher seeding rates.

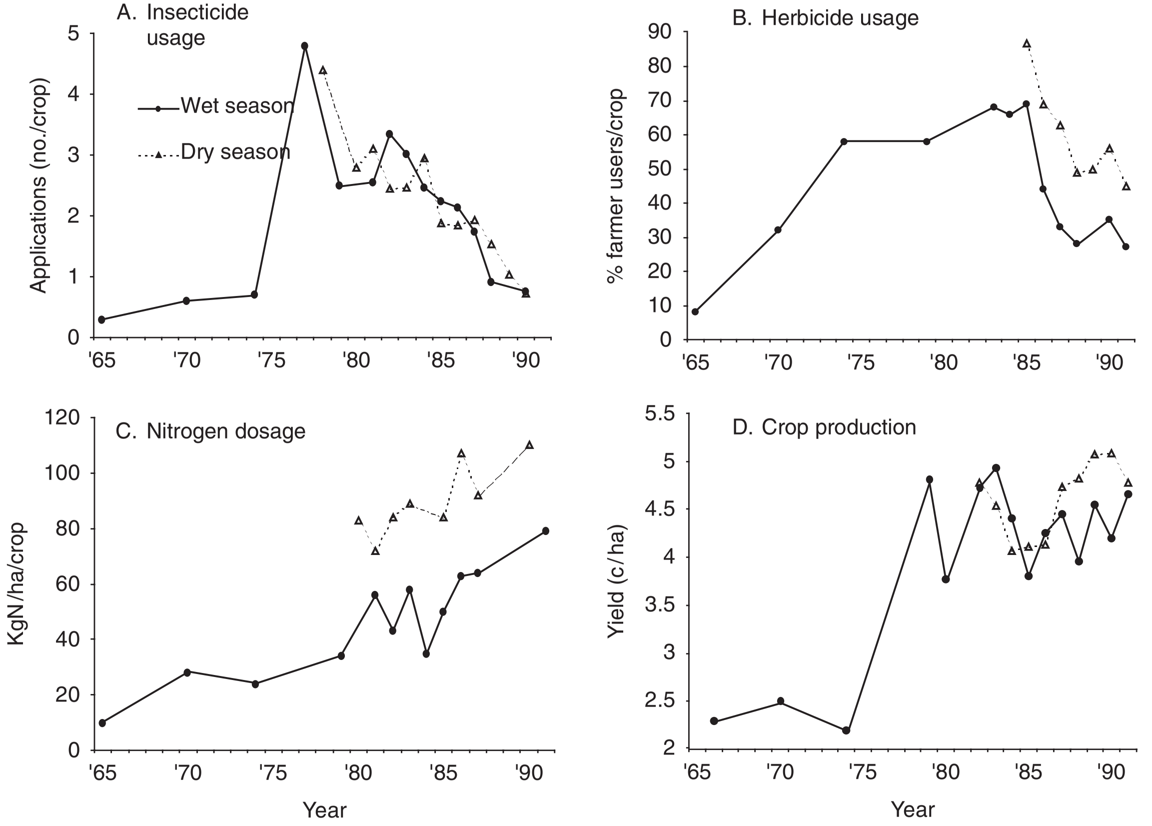

Fig. 5.8 Trend in agro-input use and crop production in irrigated, double- rice culture as determined from farmer surveys in four locations in the Philippines, 1965–1991. Data from 1965 to 1977 are from Cordova et al. (1981), from 1977 from Kenmore et al. (1985), and from 1979 to 1991 from farm record keeping of 20–40 farmers per crop

Farmers use of nitrogen increased linearly since 1965 when the base rate was 10 kg/ha in the wet season crop (Fig. 8C). It rose up to over 70 kg/ha by 1991, the last data point. Nitrogen rates were higher in the dry season, again as with more solar radiation and no typhoons dry season cropping is less risky and more productive. Fertilizer subsidies remained but farmers transferred their savings from pesticide to nitrogen which is supported, at least in the insecticide component, by the conclusions of studies that showed greater use of nitrogen fosters crop compensation from insect pest damage (Litsinger 1993 Fig. 3.4). Farmers no doubt learned this by trial and error explaining their deviation from recommended practices (Table 5.1).

Despite the removal of pesticide subsidies, average yields made a marked increase from 1985 onwards to 1990, the end of our dataset (Fig. 5.8D). Dry season yields still tended to be higher than those in the wet season in the typhoon plagued N. Philippines which contained three of the four sites.

Farm record keeping data revealed trends in insecticide and herbicide materials over the decade of surveys. For insecticides (Fig. 5.9A), organo-phosphates remained the most popular, while pyrethroids increased. Carbamate materials declined over the period while organochlorines initially decreased but endosulfan became popular once more in 1991, offsetting the trend. Carbamates are particularly marketed for leafhoppers and planthoppers whose densities declined as insecticides were less used allowing resistant varieties to have longer field lives. Mixtures, notably chlorpyrifos+BPMC became increasingly popular although cyclic and was marketed as a broad spectrum material. Butachlor was the most popular herbicide especially in the late 1980s when direct seeding became popular (Fig. 5.9B). 2,4-D declined steadily as a sole material but was a popular component of mixtures that had broad spectrum efficacy against more weed groups.

5.13.1.2 Individual Farmer's Practices Over Time

In Zaragoza, as in the other sites, farmers were interviewed each season for the farm record keeping dataset to determine their inputs. It was not designed to follow individual farmers over time but by chance, in a few instances, some were. We present data from two Zaragoza farmers by crop 1982–1991. Interestingly, when we examined these two farmers over a number of seasons we found as much variation in agricultural practices as noted between the farm population has a whole (Table 5.12). Two farmers were monitored over seven to ten seasons. The first farmer Mr. Ligazon still grew traditional varieties from time to time and had a standard practice across seasons only in fertilizer usage in the seedbed and herbicides (none used). All other practices were different each season. In five of the seven seasons he sprayed a single insecticide application to the seedbed, selecting some four kinds. Fertilizer application to the main crop varied from one to two times using four different materials with the first application from 10 to 26 DAT. Only in one crop did he not apply fertilizer. Nitrogen dosage was quite steady crop to crop. Insecticide application varied from 0 to 2 times; usage occurred in only four of the seven seasons with four products although he made

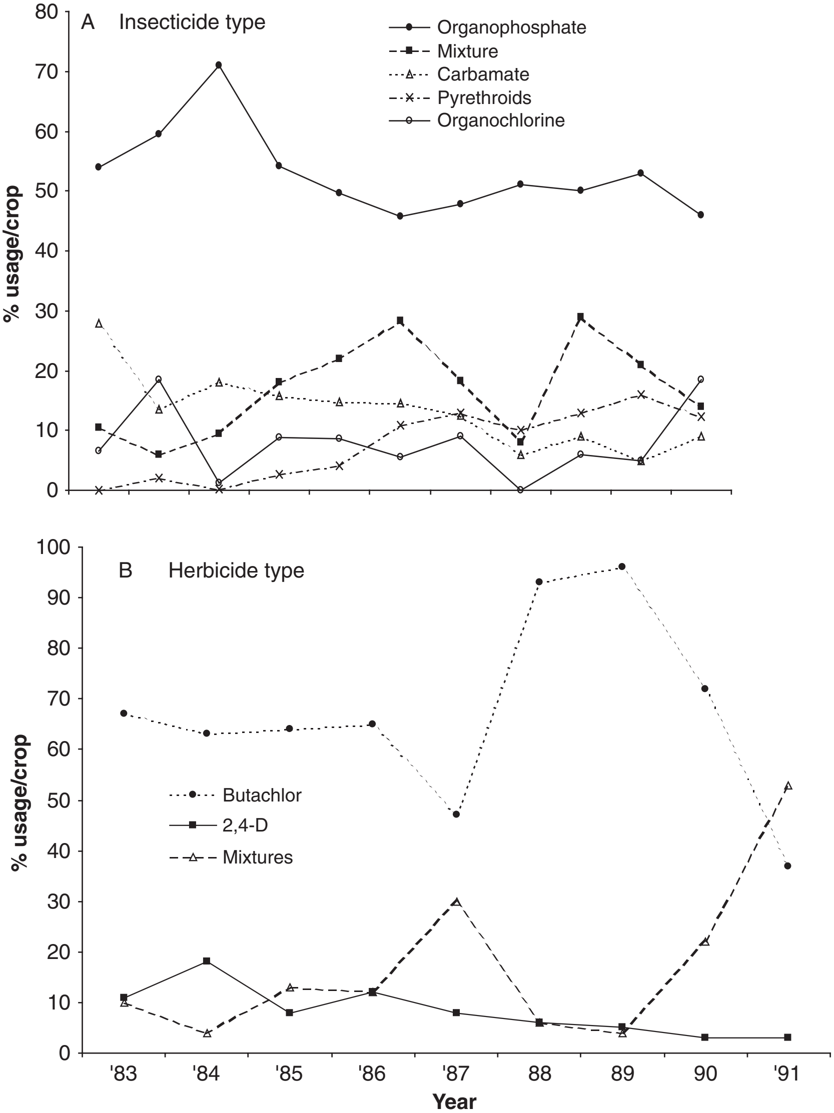

Fig. 5.9 Trend in insecticide and herbicide types over the period of farm record keeping in four irrigated rice sites in the Philippines, 1983–1991. Data are from surveys of 20–40 farmers per crop in each site

a mixture once. Yield of modern rices varied dramatically from 2.9 to 5.4 t/ha per crop.

The second farmer Mr. Espiritu planted nine modern rices and often up to three varieties per season. Except for one occasion he used fertilizer in the seedbed and sprayed insecticide to the seedbed only four times in ten. He always used fertilizer on the main crop but varied the number of fertilizer and insecticide applications up to three times. He applied seven kinds of insecticides, even once using DDT sold by traders selling house to house from stock illegally acquired from public health programs. Reasons for spraying were prophylactic as well as the presence of insects or their damage. Yields also fluctuated greatly from 2.4 to 6.5 t/ha per crop.

This individuality shown among farmers in products used is partly due to having so many choices as, in the Philippines, there is a thriving business in input supplies and many local businessmen and farmers are seed dealers. Small formulators take advantage of farmers' curiosity to try new technologies by introducing new brands each year and as farmers do not know that most these are not new products, but just new packaging of the same array of insecticides. Older and cheaper chemicals are preferred by farmers due to more affordable prices. Farmers are motivated to experiment with new brand names in the hope of finding better products. Goodell (1984) mentioned the confusion that exists in the range of choices available to farmers and the lack of a more unified process of narrowing down the choices to the better products. Recent studies show that the farmers' preferred method of knapsack sprayer application results in suboptimal levels of control (Litsinger et al. 2005). The results pose a question for economists who have classified farmers on the basis of yield placing them into three categories with the top one third at levels equal to those of research stations (Pingali et al. 1990). What class do Mr. Ligazon and Mr. Espiritu belong to?

5.13.1.3 Survey Parameter Correlations

The datasets derived from the farmer surveys in three irrigated rice sites (Zaragoza, Koronadal, Guimba) in the Philippines were analyzed to determine relationships between variables. It should be kept in mind that significant regressions do not prove cause and effect relationships but can provide valuable insights to be followed up by more detailed studies. The linear regressions are presented separately by site and season in Table 5.24.

The data indicated that highest users of fertilizer and herbicide also applied more insecticides. The positive relationship of these two inputs has been cited by Kenmore et al. (1985). In addition the timing of the first fertilizer application was correlated to the timing of the first insecticide application. This relationship was found to hold true as Filipino farmers believed that applying fertilizer predisposes the rice crop to greater insect damage (Fajardo et al. 2000, Bandong et al. 2002). Those promoting IPM, however, would take issue with the prophylactic application of insecticides based on other input usage and not on insect pest populations in the field.

In Guimba significant correlations between yield and field area occurred in both wet and dry seasons. This can be explained in that the irrigation systems are deep tube wells and those farmers with larger holdings often exert more political pressure among the farmers in the command area to direct more water to their fields. This was a common complaint among the disenfranchised farmers in the area. In addition higher seeding rates were correlated with higher yields only in Guimba. The explanation for this may be that Guimba farms suffered from the greatest number

Table 5.24 Linear regression analysis correlations of crop production variables in three irrigated, double-cropped rice sites in the Philippines. Data is taken from farmer surveys in Zaragoza and Guimba, Nueva Ecija and Koronadal, South Cotabato, 1983–1991

Y variable	X variable	Correlation coefficient (r)[a]					
		Zaragoza		Guimba		Koronadal	
		WS	DS	WS	DS	1st	2nd
Fertilizer applications number per field	Insecticide applications number per field	0.26***	0.18**	0.16**	0.18**	0.37***	0.20***
Herbicide rate	Insecticide rate	0.20***	0.40***	0.24***	0.26***	0.20***	0.21***
Date 1st fertilizer application field	Date 1st insecticide appln. field	0.32***	0.22**	0.32***	0.33***	0.33***	0.20***
Yield	Area of field	ns	ns	0.23***	0.31***	ns	ns
“	Seeding rate	ns	ns	0.13*	0.17*	ns	ns
“	Seedbed N rate	0.26***	ns	0.15*	0.18*	ns	ns
“	NPK rate in field	ns	0.33***	0.47***	0.55***	0.15*	0.16**
“	N rate in field	ns	0.35***	0.41***	0.58***	0.14*	0.22***
“	P rate in field	ns	ns	0.20***	0.25***	ns	ns
“”	K rate in field	ns	ns	0.29***	0.31***	ns	ns
“	Date 1st fertilizer application in field	ns	0.25*	ns	ns	ns	ns
“	Date 2nd fertilizer application in field	ns	0.29*	ns	ns	ns	ns
“	Rate 1st N application in field	ns	ns	0.26***	0.34***	0.17**	0.13*
“	Rate 1st P application in field	ns	ns	ns	ns	ns	ns
“	Rate 1st K application in field	ns	ns	0.24***	0.35***	ns	ns
“	Pre-emergent herbicide rate	0.22***	0.26**	ns	ns	ns	ns
“	Post-emergent herbicide rate	ns	ns	ns	ns	0.14*	ns
“	Date of pre-emergent herbicide application	ns	0.28*	ns	ns	ns	ns
“	Insecticide usage in seedbed	ns	ns	ns	ns	ns	ns
“	Number of insecticide applications	0.25*	ns	ns	ns	0.27*	ns
“	Insecticide dosage per application	ns	ns	ns	ns	ns	ns
“	Insecticide spray volume					ns	0.13*
“	Crop maturity	ns	0.28*			ns	0.31*

[a] WS = wet season, DS = dry season, levels of probability: ns = $P > 0.05$, $^{*} = P \le 0.05$, $^{**} = P \le 0.01$, $^{***} = P \le 0.001$.

of crop stresses among the sites (water deficiency, weeds) and higher seeding rates have been shown to aid the crop in tolerating stemborer (Litsinger 1993) and whorl maggot (Bandong and Litsinger 1986) damage.

Usage of N in the seedbed was positively correlated with yield in Guimba in both growing seasons, but only in the wet season in Zaragoza. Nitrogen enhances crop vigor and improves the crop's ability to withstand crop stresses. The interpretation is less clear cut. As mentioned, crop stresses were more prevalent in Guimba. Farmers in Zaragoza told us that they use fertilizer in the seedbed not for yield but to make it easier to pull seedlings as when fertilizer is used roots do not penetrate deep into the soil. Less stress on the seedlings from reduced transplanting shock also would translate into higher yield.

In the field, fertilizer usage (NPK) and particularly N was positively and significantly correlated with yield increases in all crops compared with the exception of the wet season in Zaragoza. The positive relationship between fertilizer and yield is no surprise but its lack of response in Zaragoza during the wet season is probably due to the high frequency of typhoons. Farmers in Zaragoza, being at the tail end of the irrigation system, typically plant late and therefore the crop matures during the months of the most frequent typhoons, particularly those with the strongest winds. The amount of N applied in the first fertilizer application was correlated with yield only in Guimba and Koronadal, the latter only in the seasonal data sets but not by crop culture. Interestingly P and K usage when isolated from use of N was only significantly correlated with high yield in Guimba. Highest dosages of N were used by farmers in Guimba thus balancing the nutrients may have been the reason for the positive relationship.

The timing of the first and second fertilizer applications had only a significant relationship with yield in the Zaragoza dry season crop. This was the highest yielding of all site x season combinations in the study (Litsinger et al. 2005) and therefore timely application of fertilizer was perhaps more important than in other sites. The rate of the first N application was important in all sites except Zaragoza. On the other hand the rate of the first application of P was unimportant in all sites, whereas K was important only in Guimba. We have no explanation for these results.

Rates of the only pre-emergence herbicides were correlated to high yield in both seasons in Zaragoza but not in the other two sites. Zaragoza farmers have the lowest usage of herbicides and depend mostly on ponding for weed control. Labor for hand weeding is difficult for farmers to arrange as well. Farmers tend to under-dose herbicides thus there appears to be a distinct advantage among those farmers who use herbicides to use more effective rates. Only in the first crop in Koronadal was the rate of post-emergence herbicides correlated with high yield showing that late season weeds are more important to the crop. In Koronadal the first crop is higher yielding and thus removing weeds would have a more significant effect. In the other sites, weed control by ponding, pre-emergent herbicides, and hand weeding appears to be effective. The date of the pre-emergence herbicide application was *negatively* correlated to high yields in the dry season in Zaragoza, meaning that the earlier the application the greater was the effect. This stands to reason as weeds are smaller and more vulnerable.

It was no surprise that insecticide usage in the seedbed did not translate into improved yield. There is little insect damage to the seedbed and initially in the insecticide check method we included the seedbed as a growth stage but dropped it after two years as no losses were recorded in four sites (Litsinger et al. 1987). Total number of insecticide applications was positively associated with higher yields in only the wet season crops in Zaragoza and Koronadal but not in Guimba or dry season crops. Greater stresses occur to the rice crop in the rainy seasons thus alleviation of some stress probably translated into higher yields. Marciano et al. (1981) found rice yield was independent of the number of insecticide applications in irrigated rice in Laguna province.

Average insecticide rates per application showed no correlation with yield in any site probably because the top of the range still was only marginally lethal. Studies have shown that insecticide usage on rice is not economical in most occasions due to the poor control (Litsinger et al. 2005). Improved insect control can come from more thorough coverage of the rice crop. During the second rice crop in Koronadal there was a correlation with spray volume to yield and this crop has less rainfall thus insecticide sprays had longer residual activity on the crop. The overall range, however, was much below recommended amounts to explain the weak correlation.

Crop maturity measured only in Zaragoza and Koronadal was positively correlated to high yields in only the dry season crops. It has been shown that extending the growth of rice through longer maturing varieties allows greater compensation to occur and hence higher yields (Litsinger et al. 1987). It was significant that the correlations were only in the dry season during greater solar radiation and thus higher yield potential.

5.14 Feedback to Research

5.14.1 Making Technology in a More Usable Form for Farmer Adoption

The approach to enhancing farmer management of high-productivity, high-input systems has primarily been one of blanket recommendations but following them without understanding enhances farmers uncertainty. It has been well established that uncertainty is a driving force in farmer behavior and that farmers act rationally given their grasp of the available alternatives and their comprehension of cause and effect relationships (Price 2001). Any new technology should be modified by a period of adaptive research before it is introduced into a location, the process of which forms the central theme of farming systems research (Zandstra et al. 1981). Researchers therefore should not only look at the technical worth of a given practice but also in relation to the socio-cultural milieu into which it is to be introduced. Failure to do so, particularly among the more capital intensive technologies, leads to non-adoption (Fujisaka 1991, 1993).

A finding of the IPM training project in C. Luzon, Philippines was that researchers began to realize more ways in which tailoring technology to the realities of farmers could be improved (Goodell et al. 1982). The farmers in the project did not directly demand this of the scientists but unwittingly did so by requesting the scientists to conduct an IPM course in exchange for their willingness to try group management. While training helped farmers and researchers to become acquainted and began a process of vocabulary sharing, it became clear that the technology should provide farmers with much more concrete, systematic, and equilibrium-focused management practices and perceptions. The exchange would be essential in the technology development process. It is difficult to imagine any technology as in-place before scientists have involved themselves in extension efforts. In retrospect we realized that scientists too often drop out of the process of technology development long before it has been completed. The discipline of bringing technology fully to the level at which farmers can use it should be central to all research in technology development.

It was concluded that researchers were reluctant to examine whether the central components of IPM technology actually pay off at the field level, such as pesticides and seeds being subject to no effective monitoring, they hand over highly inappropriate technology to extension agencies which hardly exist at the village level (Goodell 1984a). Researchers must determine if the technologies are economical as practiced by the farmer. Goodell questions whether IPM is worth the farmers' effort?

That economic returns of IPM to the farmer are relegated to the periphery of research rather than receiving top priority suggests that scientists and policy makers expect farmers simply to obey what they dictate (Goodell 1984a). But the poverty of farmers may give them less rather than more incentive to adopt IPM. Are we serious that the technology should actually be implemented at the field level? If so we must ask whether it is worth a farmer's investment.

There is a need to streamline technology to suit farmers' aptitudes as IPM technology is very complex. Here are the four steps that technology must pass to be in a more usable form for farmer adoption (Heong 1999):

1. *Research*: Research has focused on technology generation and evaluation with limited emphasis on adaptation, integration, dissemination, and adoption in what should be a continuous and dynamic process between science and practice. Research may stop too soon creating a fatal gap.
2. *Synthesis*: Information not in a form that can be assimilated into the farming system.
3. *Distillation*: Information may be too complex.
4. *Communication*: Information does not reach the farmer in a form that can be useful caused by language, jargon, and selective hearing on the part of the recipient.

We share some lessons learned from the IPM training project in C. Luzon, Philippines (Goodell et al. 1982, 1990):

Initial expectations and assumptions	Findings	Comments	How the project changed
A. Technological information			
1. IPM for resource-poor farmers must concentrate on labor-intensive rather than capital intensive technologies	Farmers almost invariably prefer chemicals to other low labor technologies but most farmers can only afford one well timed application	Poor farmers do not wish to work harder than wealthier farmers; they too seek ways to minimize physical labor	The project no longer assumes it can rank farmers' resource allocation priorities. Research should rely on a menu approach providing farmers with options that have different capital:labor requirements
2. Farmers ineffective use of insecticides (low spray volume and low dosages) can be remedied by more educated measurements	Excessive frequency of farmers' insecticide has been reduced as a result of training but dosages and volume are still too low. No effective method is know to bridge this gap	Farmers were afraid for health reasons to increase the concentration of insecticides in spray tanks, they also did not want to allocate more labor to increase spray volume per hectare	The project focused on finding ways to eliminate insecticide usage through more emphasis on yield loss studies and to exploit modern rices ability to compensate for losses by better agronomic management
3. Control of key pests early in the first season is an important component of IPM. Its value will be evident to farmers	Farmers use very short time horizons in their crop protection strategies even when managing IPM pests and mastering scientific explanations	Farmers scrupulously avoid possible unnecessary expenses	Anthropologist hired to understand farmers' cognition (perception or lack or process of knowing) time and risk management
4. Substitution of economic thresholds for prophylactic pesticide application is essential for resource-poor farmers	Farmer' crop protection strategies are almost solely responsive to empirical evidence of damage or observable presence of pests	Project is left with a difficult challenge; for some pests, the best control is preventative	Project sobered by much lower expectation of adoption rates when technology innovation requires farmers to think in terms of prevention rather than suppression

5.14.2 Challenge for Research to Find Alternative Methods to Pesticides

KAP studies showed that farmers know and practice a wide range of cultural control methods in C. Luzon. There was a need to broaden the IPM tool box of technologies for insect pest control as the two key methods recommended were host plant resistance and chemical control. The latter technology compromises the beneficial effect of natural enemies leading to resurgence and secondary pest outbreaks spawning new biotypes which shorten the field life of insect resistant varieties. Teaching farmers to use more insecticides, encouraged initially in the launch of the Green Revolution, needed to be reversed in order for the farmers to benefit from the rich natural fauna and greater stability of genetic resistance.

Two cultural control methods were emphasized in farmer training programs. The first was to encourage farmers to plow down the stubble immediately after harvest for stemborer and disease control. The farmers told the researchers that this method was too expensive and impractical. An additional irrigation would have to be given in order to be able to till the soil which had dried. It proved very difficult to organize the additional off season irrigation. Farmers also did not see the need to control something that was not imminent (Goodell et al. 1982).

Researchers also believed that soil incorporation of carbofuran or fertilizer is so profitable that Filipino farmers will try it despite initial expense but later found farmers do not incorporate insecticide granules before transplanting nor basally apply N (Fujisaka 1993). In addition sustained baiting for rat control was seen is a valuable addition to or replacement of farmers' practices. Sustained baiting turned out to be less attractive than current methods as farmers cannot see the rats die so do not give the method credence.

The second cultural control method was synchronous planting which would be most effective if carried out over a large area. However there was not enough research information on the specifics of how the method would be implemented (Goodell et al. 1982). The key question was what is the minimum area that was required as it was impractical in terms of water delivery to have the whole 200,000 ha of the irrigation system plant at the same time. The second question was what was degree of coordination that was expected in terms of planting date variability that would be allowed between the fields.

Both of these methods suffered the same problem of farmers not placing a high priority on insect control in terms of the effort required (Goodell 1984b). Despite these caveats farmers after numerous meetings agreed to follow synchronous planting and a project developed which spurred a large research program that eventually answered the two questions as well attempted to involve farmers in a 2,000 ha synchronous planting scheme (Loevinsohn et al. 1993). The farmers were willing to follow synchronous planting because one of the benefits was earlier water delivery which would mean harvest before the season of the large typhoons damage wet season crops.

But the synchronous planting pilot project in the end failed as the water management engineers could not control the release of the water as the irrigation system was also one of the main suppliers of electricity to Manila, thus when the power grid needed more electricity, water was released from the dam irrespective of the irrigation needs of rice farmers. This priority for the urban masses in Manila trumped that of the farmers and the flow occurred often without warning. The project, however, was instrumental in popularizing the technology which was successfully followed in Indonesia and Malaysia in systems where delivery water was given greater priority to farmers' needs (Koganezawa 1998, Litsinger 2008a).

5.14.3 Research Methods Need to Be Developed to Validate IPM Inputs

The C. Luzon farmer training project underscored the need to develop methods to validate resistant varieties and identify adulterated pesticides/fertilizers. Goodell (1984a) found that Filipino farmers who believed they were planting resistant rices, when tested in IRRI's greenhouses, revealed $>$ 40% were highly susceptible to brown planthopper. Thus farmers did not have the variety they believed they did. Similarly 70% of pesticide bottles were found to be adulterated, either significantly diluted and substituted with less effective or out-of-date materials. Adulteration is common in a number of neighboring countries (Nesbitt et al. 1996).

In Chhattisgarh farmers have developed simple tests (dissolving urea in water or by odor or feel for rock phosphate) to determine if inorganic fertilizers are bogus or not. Most countries have Bureaus of Standards whose job it to monitor pesticide and fertilizer quality in the marketplace to determine if products are genuine. Similar government agencies have the same role with drugs sold in pharmacies. The agencies invariably exist but most are so underfunded that that they are impotent. NGOs have become involved in a number of countries to lend support to government efforts. There is a need to make a few convictions against some of the dealers that adulterate products. The chemical industry is also highly supportive of such measures and would be a collaborator.

5.14.4 How to Deal with Multiple Pests and Stresses

Goodell (1984a) concluded that because of the way scientists are taught to think linearly that recommendations are made for single pests whereas farmers who think contextually look at the whole field and all the problems before making a control decision. Farmers therefore need measures of how to deal with multiple pests that occur in the same growth stage.

In response to this need, data was analyzed from field trials that incorporated the concept of multiple pests in terms of defining action thresholds of several insect pests occurring in the same growth stage (Palis et al. 1990). Yield loss trials also point out that the more stresses acting on a crop the greater the yield loss as there is less ability of the crop to compensate (Savary et al. 1994, Litsinger 1993, 2008b).

Litsinger et al. (2005) concluded that farmers, rather than measuring the incidence of each stress, need to assess the number of stresses attacking the crop at one time. Due to the compensating ability of modern rices, the farmer needs to remove only some of the stresses freeing the crop to compensate for the rest. The farmer can chose to tackle stresses that are most feasible and economical to deal with as an IPM strategy.

5.14.5 Build on Farmers' Knowledge and Farmer First

Chambers et al. (1989) has observed that there are some things that farmers know that scientists don't and vice versa, also there are some things that both know as well as don't know. Farmers and scientists both tend to know the growth stages of crops and the benefits of irrigation (Bentley 1992c). But both groups were oblivious of the detrimental ecological effects of pesticides at the start of the Green Revolution. In the foregoing sections Goodell et al. (1982) pointed out that in attempting to introduce IPM concepts to farmers, researchers began to realize the original questions were backwards. If technology is to be used by farmers its development must start with them and not at the research stations.

5.14.5.1 Indigenous Technical Knowledge

Farmers may have a lot to contribute to the development of appropriate agricultural technologies. Traditional peasant systems of agriculture are not primitive leftovers from the past but are, on the contrary, systems finely tuned and adopted both biologically and socially to counter the pressures of what are often harsh and inimical environments (Haskell et al. 1980). These systems often represent hundreds if not thousands of years of adaptive evolution in which the vagaries of climate, the availability of land and water, the basic needs of the people and their animals for food, shelter and health have been amalgamated in a system which has allowed society to exist and develop in the face of enormous odds.

A potential wealth of unexplored information on crop protection in traditional agriculture appears to await investigation and documentation (Glass and Thurston 1978). We must learn from the practices of traditional agriculture. Rice culture, even though it appears to be a monoculture, has surprising diversity. In traditional, low-intensity farming systems, pests were controlled by a variety of cultural methods including burning stubble, flooding, crop rotation, and the use of pest- and stress-tolerant varieties (Zelazny et al. 1985). Food webs of pests and regulatory organisms are highly intricate and interwoven, as due to the large world wide area of domesticated rice, many pests and natural enemies have transferred to it from the grassland it replaced (Schoenly et al. 1996). Flooding reduces the diversity of soil fauna which is replaced, however, by a diverse flora and fauna in the paddy water (Settle et al. 1996). Local people depend on aquatic organisms for protein which farmers harvest after draining the field or by nets; this particularly true for river diversion irrigation systems which would include fish (Fernando et al. 1980).

We have argued that obtaining information on KAP of local farmers is a necessary step in IPM programs. It may be found that:

1) Farmers may have found ways of coping thus do not need a new technology,
2) On the other hand they may have wrong perceptions and attitudes that must be addressed if improvements are to be made, or
3) Embracing useful farmers' knowledge and practices in IPM programs will improve acceptability of newly introduced practices (each side meeting the other half way rather than a total replacement) (Kenmore et al. 1985).

Therefore it is essential that IPM programs are designed to include local pest control practices as much as practical. KAP studies have explored not only how particular farming communities perceive their natural environment, but also describe their technological inventory against pest infestation (Gabriel 1989).

5.14.5.2 Comparison of Farmers' to Recommended Practices Produces New Research Teads

One way to start an IPM project is to compare farmers' practices with national recommendations to see where they are similar or differ. Shao et al. (1997) in Hunan, China, found large gaps exist between farmers' practices and research recommendations as farmers used only 30% of recommended practices. They concluded that an important first step is to understand what farmers think, perceive, and practice.

In Guimba we saw that farmers have evolved their own set of practices and only follow some of the national recommendations (Table 5.1). Farmers still have room for improvement. For example the importance of weeds in the seedbed was discovered by KAP investigations by observing farmers on a daily basis. Losses were very high from farmers who transplanted weeds. Thus a low cost technology using $1/ha worth of herbicide can resolve the problem. On the other hand, taking the lead from farmers, trials were carried out to study the effect of their practices of increased N and increased seeding rates. We found that the crop's ability to tolerate stemborer damage occurred with their "high" N level and "high" seeding rates with a favorable result obviating the need for chemical control (Litsinger 1993). It was more practical to use higher rates of N and seed than to spray.

The Guimba KAP survey which compared existing farmers' practices in rice culture with the national recommendations produced an agenda for new research directions and underscored the need to rethink experimental methods (Fajardo et al. 2000). Adaptive researchers should look closer at practices that differ between farmers and researchers and ask if the farmers could be right under their local conditions. Studies have shown that farmers continually experiment with production practices in an effort to improve upon them and that each crop is an experiment (Litsinger 1993).

The reason that IRRI agronomists concluded that lower seeding rates, fewer seedlings per hill, and lower N rates were optimal is that these variables were studied one at a time in a reductionist fashion under ideal conditions where insecticide application eliminated pest damage, water levels were ideal, etc. These optimal management practices resulted a relatively stress free condition that is not the reality in most rice fields. Farmers therefore found that increasing inputs had the effect of attaining higher yields under their conditions. When the agronomist tested these levels he concluded that they were wasteful and similar results were achieved more economically at lower levels. Thus the researcher and farmer each found the ideal set of practices for their respective environments but it is significant that these were different environments.

The differences can mostly be explained by the two divergent approaches to technology development (Litsinger 1993). Most of the recommended practices were developed in replicated experiments on research stations with the results tested in farmers' fields. This reductionist approach involved a series of experiments where only one or two variables were tested at a time while holding the other practices constant under stress-free conditions. Farmers, on the other hand, evolved their practices in a holistic manner by trial and error under a background of dynamic stresses. The holistic approach to experimentation, varying one or several practices among those comprising a crop production system, allows expression of a multitude of interactions. The reductionist approach, on the other hand, is designed to prevent unwanted interactions.

The scale of the trials also is vastly different leading to errors in extrapolation. Researchers lay out 25–100 m^2 plots while farmers test new ideas on a scale 10 to several hundred times larger. For example, it may be easy to evenly sow a dry bed nursery of 5 m^2 but if this were done on a scale of 500 m^2, the tedious work would result in less even seed distribution. A classic example is the mud ball method of incorporating urea into balls of mud and then distributing them among groups of four hills, stepping on each one to push it into the soil where it will release nitrogen slowly. The technology is sound and in a small plot is feasible but in terms of a 1 ha field it is unrealistic at today's price of labor. Both researchers' (reductionist/scientific) and farmers' (holistic/traditional) approaches have significant contributions to make, but the resultant best fit is highly location specific. In general, farmers need assistance in understanding scientific farming while researchers need feedback from farmers on the performance of new technologies under farm conditions.

More attention should be given by researchers to potential interactions between practices that may vary by location. Many are presented in Litsinger (1993). Interactions, particularly those involving pests, are normally prevented in traditional experiment station trials by the elimination of pest damage altogether (in agronomic trials) or selectively (in pest control trials), usually by heavy use of pesticides. On the other hand, farmers, are contextual thinkers and look at pest complexes and the crop as a whole.

Farmers' practices should be elicited and reviewed objectively. Not all farmers follow the same set of practices and as we saw even the same farmer can change them dramatically season to season, so that more attention should be placed on the most commonly mentioned responses. Also the criteria used by farmers to favor a certain practice may be due to risk aversion behavior or less labor requirement rather than because it obtains a higher yield. Surveys should be able to discover the range of farmers' responses. For example the number of interpretations mentioned

Table 5.25 Agronomic and pest management practices noted from the survey[a]

Practice	Purported Effect on Yield	Purported Benefit
1. Transplant older seedlings	Lower on early but not on medium duration cultivars	Less breakage of pulled seedlings, more flood tolerance, more tolerance to insect pests and diseases, more competition against weeds
2. Straight, rather than random rows, where labor is cheap	None	Mechanical weed control
3. N applied to seedling nursery	None	Ease (less cost) in pulling seedlings (vs blast)
4. P K rates dependent on fertilizer formulation commercially available	None	None
5. Increase in N leads to greater tolerance of pest damage	Increases	Less risk of insect damage at expense of higher N cost (vs greater weed competition)
6. Wetbed preferred over drybed seedling nursery	None	Less risk of seedling nursery failure from bird or rat damage, heavy rains, ease of pulling seedlings: Fewer weed problems
7. Higher seeding rates	Increase in certain conditions	Less risk of insect damage at expense of higher seed cost: Weed suppression
8. Farmers pond deeper water because less reliable water	Lower (if $>$ 20 cm)	Less risk from drought stress: Better weed control
9. Use of cultural practices can mean that lower herbicide dosages are effective	None	Less cost for herbicide

[a] Adapted from Fajardo et al. (1990).

by Guimba farmers in Table 5.25 should lead to verification trials. Follow-up, short surveys can be carried out as well to allow further clarification.

5.14.5.3 Farmer-Led Research

The sustainable agricultural movement has an admirable tendency to work more closely with farmers and to respect traditional knowledge and practices. Researchers participating with small farmers to strengthen, invent or reinvent appropriate technology should understand that farmers have information gaps in certain predictable domains of knowledge. Field workers may wish to identify these gaps and help fill them in while relying on farmer knowledge to help improve the quality of on-farm research and repay collaborating farmers with useful information (Bentley 1989).

Farmers are often viewed as objects of study rather than collaborators or real people providing valuable input. IPM has to be built from the client up rather than from the researcher down (Bentley and Andrews 1991). Documenting farmers' experience and knowledge as valid in their specific context and using their inputs, approaches, and ideas not only strengthens their self-esteem, but also contributes to a balanced research partnership between farmers and researchers (Björnsen-Gurung 2003). Goodell et al. (1982) sagely remarked that the only conclusion that can be made is for the farmers themselves to do the fine tuning, preferably in groups. If technology is to be used by farmers, its development must start with them and not on the research station. Farmers experiment to satisfy curiosity, to solve problems, and to adopt technology. Farmers are by nature experimenters, in that many continually try out and adjust their practices and uses of plants in response to changing conditions. That is, "a farmer is a person who experiments constantly because he is constantly moving into the unknown".

According to Norton and Mumford (1993), due to not understanding farmers, researchers may be trying to answer the wrong questions or at developing inappropriate technologies. Farming systems research programs pioneered the concept of farm description to understand the current cropping systems before making interventions for their improvement (Zandstra et al. 1981). The next gap we need to close is the farmer-scientist gap or we will remain as described: the scientist is as distant to the farmer who the scientist claims to be benefiting by his research as the moon is from the earth (Fujisaka 1991). When farmers are seen as experimenters and innovators, other views also change. More dynamic and flexible research processes building on farmer research interactions and supporting farmers' innovation become possible. Farmers have much of importance to say to scientists, and farmers' methods of practical research are complimentary to those of scientists. Experimentation by farmers has long been under-perceived. Farmers by the very act of farming are carrying out adaptive research which is often ignored by planners and scientists.

Farmers in many traditional agricultural societies are not at all adverse to experimentation. Experimentation is probably as natural as conformity in traditional communities (Brosius et al. 1986). The farmer field school training method which has pioneered the farmer-led research movement, emphasizes the farmers as an experts due to their accumulated experiences. Researchers believe that pests significant to a site can be specified beforehand for all practical purposes in training programs. Farmers and researchers should conduct trials on pests that appear during the current season and should be vigilant to take advantage of whatever nature gives.

5.14.5.4 Examples of Farmers' Knowledge in Generating "New" Technologies

Participation not only means farmers' physical presence but also the use of their knowledge and expertise (Björnsen-Gurung (2003). Understanding potentials and drawbacks of their local knowledge system is a pre-requisite for constructive collaboration between farmers, scientists, and extension services. Farmers are behind many of the recommendations that researchers then undertake research to confirm. These examples were gleaned from KAP studies in the Philippines by IRRI's Farming Systems Program for improved weed and insect pest control. Farmers were shown to have keen sense of observation and linking cause and effect:

1) Farmers under-dose both herbicides and insecticides but field trials showed that dosages based on manufacturers' recommendations can be reduced 50% with no loss in efficacy,

2) Farmers, perhaps to avoid phytotoxicity by using the same knapsack sprayer for herbicides and insecticides, decant herbicide directly on top of the flood water which allows it to spread evenly over the field, research found that it was effective,
3) Mixing liquid herbicide with fertilizer, typically urea as other fertilizers "melt" or with sand and broadcast the mixture on the field with no need for a sprayer. These methods are simpler, more economical, and less phytotoxic,
4) Spot weeding rather than weeding the whole field,
5) Use of weeds as livestock feed. Harvesting rice and weeds was as profitable as intensive weeding and harvesting grain only,
6) Pest damage is additive combining all species that cause similar injury such as defoliation,
7) Pre-transplanting chemical treatment of seedlings for whorl maggot control such as seedling soak based on farmer practice (farmers deduced a carryover effect of systemic insecticide applied in the seedbed to the main crop),
8) Synergism of early season pests: rice whorl maggot is not serious in isolation but only in certain contexts with other stresses,
9) Monitoring earlier planted fields as a sign of pest buildup,
10) Prioritizing monitoring first in low lying fields which are more aquatic locations for whorl maggot, caseworm, defoliators or shady portions of fields for leaffolders,
11) Inspecting the downwind side of a field for caseworms which float inside tubes of rice leaves, and
12) Submerging young seedlings to dislodge camouflaged defoliators green larvae for rapid counting (they float)

The following are farmer thoughts regarding weed ecology and control, innovations, and practices that illustrate farmers' ability to classify, choose, improvise, adapt, and test based on their particular circumstances (Moody 1994):

1) Wet seeded rice culture has greater weed problems than transplanted rice. The competitive advantage of transplanted rice is due to the size difference between rice seedlings 15–30 cm tall and weeds just germinating. In wet seeded rice hand weeding is more difficult and the crop is more sensitive to pre-emergence herbicides,
2) Bury weeds into the mud as green manure was validated by research but has to be young weeds that can produce 6–8 kg N/ha and 200 kg C/ha and 18% yield increase,
3) Good water management is needed for enhanced herbicide effectively has been shown experimentally,
4) Knowledge of shift in weed species over time from *Echinochloa* spp. to *Ischmaemum rugosum* particularly in wet seeded rice as a result of poor water management, application of the wrong herbicide, failure to apply herbicide at the correct time, and planting contaminated seeds,
5) Removing weeds late in a crop as control on the next crop (such as *Echinochloa* seed heads and wild rice), and

6) Transplanted rice with weeds growing in the seedbed leads to very high losses. From this observation came a low cost control of grasses in the seedbed with a small amount of herbicide.

There are not as many examples regarding plant pathology probably because farmers often do not recognize the many plant diseases as something that can be affected by management (ie., are living), but also there are fewer options in terms of management. The main control for the fungal and bacterial diseases is genetic resistance. The farmers' method of careful seed selection from well adapted and healthy plants is a sound practice as is sorting through seed by hand to remove off types and diseases and small seeds before sowing. This may explain the farmers' widespread habit of finding new sources of seed from neighbors' fields every three or so years. The dryland farmers in Sumatra who mix up to ten rice cultivars in a single field is a sound strategy to temper the effect of blast disease (multi-line).

With the exception of sustained rat baiting with anti-coagulants, all of the practices for rat and bird control mentioned in the KAP section on vertebrate pests come from farmers.

5.15 Feedback to Extension

5.15.1 Farmers' Sources of Information

KAP studies identified the most influential sources of agricultural information to farmers. In the most detailed study in the Philippines (Brunold 1981), the agricultural technician was the most important (89%) closely followed by radio programs (86%) (Table 5.26). Brunold concluded that farmers have the greatest confidence in their technician as he or she is the one with the newest information, and farmers

Table 5.26 The most important sources of information on pest control utilized by irrigated rice farmers, Iloilo, Philippines

Source	Respondents (%)[a]
Extension technician	89
Radio	85
Friends and neighbors	66
Local extension seminars	47
Pesticide dealer	36
Informal group meetings	30
Own experience	15
Head of village	13
Agriculture magazine	10
Training program	9
Extension leaflets	6
Pesticide label	5
TV	1
Chemical company representative	1
On-farm demonstration	1

[a] n = 40 and more than one answer was given, after Brunold (1981).

do not value highly their own experience. Friends and neighbors were also seen as influential. In a study in rainfed areas of the Philippines, which asked what sources did the farmers seek for information on pesticide usage, most relied on their own experience (51%); less important were the extension technician (32%), neighbors (4%), advertisements (4%), pesticide dealers (1%), and radio (1%). In Malaysia where a similar KAP survey was carried out, most irrigated rice farmers in the Muda scheme sought farming advice from government technician (86%) with relatives and friends (6%), or chemical sales representative (1%) much less important (Heong and Ho 1987).

5.15.2 Institutional Constraints

Writing up her observations of IPM extension training in C. Luzon, Goodell et al. (1982) posed the question "Is IPM extension doing its part?" In her project location she found government institutions were not there to support the Filipino farmers, including: (1) extension services, (2) technicians for crop monitoring, and (3) pesticides sales not tied to credit. The research team had to incorporate into the technology many of the components originally expected from government. The only conclusion that can be made is for the farmers themselves to do the fine tuning and extension program.

In a later visit to six Southeast Asian countries Goodell concluded that extension services were often inadequate, as due to the increasing complexity of irrigated agriculture, technicians and their supervisors were found to need more training in both social and intellectual initiative (Goodell 1983). She advised that we must bear in mind that some of the extensionists mistakes can be traced directly to misconceptions on the part of researchers. Escalada and Heong (1992) noted farmers living in remote locations were not visited due to few staff, lack of transport, infrequent and wrong timing of visits, extension workers of wrong culture, language semantics, and competing messages.

5.15.3 Facilitating the Research-Extension-Farmer Dialogue

A conclusion of another anthropologist that worked with biological scientists is that the scientists also have gaps in their knowledge (Bentley 1992c). For example plant breeders easily become blinded in the search for high yielding types rather than to take the time to perform agriculture like farmers do and grow the crop. Scientists tend to see agriculture in a disciplinary reductionist way, sanitized and confined in a petri dish. Top-down extension messages often are irrelevant to farmers.

Many of the limitations of IPM research in the Third World are often the result of researcher isolation and could be alleviated if researchers had more contact with the farmers whom they hope will adopt their recommendations (Goodell et al. 1982). Recommendations from scientists frequently run counter to the farmers' best interests. IRRI scientists advocated burying the stubble after harvest which farm families depend on for many uses. Extended interaction with farmers and technicians sufficient to develop mutual trust can open up scientists to the vast world of farmers' perceptions which bear directly on IPM.

The IPM scientists have numerous ways by which they can enter the world of the small-scale farmer for the optimal development of IPM technology. These include holding small informal field days in which farmers can mix freely with the scientists, offering village level IPM courses through the season attended regularly by the scientist or one of his/her assistants, employing the same villagers over and over again in field experiments and surveillance in part to develop a sustained consultation relationship with them, requesting that farmers help prepare and test IPM instructional material and curricula (Goodell 1984a). However the IPM manager should be wary of traditional approaches for linking with the village such as post harvest questionnaires that are often unreliable and consultation centered on village headmen who "know" what the outsiders want to hear and in any event are frequently exceptional farmers.

Finally the technology is inseparable from the problems and possibilities of extending it to farmers. IPM researchers would find it easier to develop appropriate technology if they became more familiar with some extension agents working at the grassroots level, again by building up a relationship of mutual confidence the researcher could learn the difficulties that extensionists encounter in discussing IPM with farmers and perhaps also the obstacles farmers meet in learning from the extensionists (Goodell 1984a).

In Chhattisgarh, India farmers of tribal origins often earn most of their income from foraging in nearby forests rather than from farming thus have been difficult to incorporate into extension activities thus inqueries should be made as to off-farm income. We cite a another case in point from the C. Luzon farmer training project. The initial assumption of IPM researchers was that because farmers rely on farming for their income they will adopt any "appropriate" technology that offers economic benefits. The findings were somewhat different as interpreted by the anthropologist. Farmers' disinterest in many technologies the project considers appropriate (often substitution labor for capital costs) is frequently explained by the economic importance of off-farm activities not reported in formal surveys or RRAs. Such off-farm activities often reduce the relative impact of IPM innovations on the family budget, minimizing extension success. Many important sources of family income are not readily apparent to outside investigators. Each discipline overemphasizes the contribution to the whole family budget of activities relating to it. The project changed by lowering expectations of adoption rates and potential economic benefits of IPM technologies.

In Honduras encouraging results came about by the intensive interaction of >500 farmers and the fusion of on-farm research and extension (Goodell et al. 1990). This constituted a farmer-scientist-farmer information exchange upon which the program's work depended, with its goal of developing a menu of economically viable pest management technologies from which each producer can choose among a menu of technologies to find those that suit their needs and particular resource mix.

The project's goal was to feed directly into public and private programs serving resource poor farmers rather than undertaking extensive educational campaigns.

Heong and Escalada (1997b) initiated several successful extension projects in Asia to show farmers that they did not have to apply insecticides during the first 40 days of the rice crop. They each began with an understanding of farmers' perceptions and yield loss caused by insect pests in any given area. Research should be based on problems defined from farmer perspectives in order to ensure that results will be adopted. Farmers live in an environment of conflicting messages regarding use of pesticides, thus they needed to start from the farmers' perspectives rather than the researcher's perspectives. Many of farmers' decisions are based on risk aversion and fear of outbreaks and fear of pests migrating from neighboring farms.

5.15.4 Making a More Effective Extension Program

The main extension method in the 1970s and 1980s was the training and visit system. In the T & V method, as it was known, extension workers received a program each week from their supervisors in the top down method. The extension worker lectured to the farmers and demonstrated the week's featured technology. The major criticism of T & V was that the agenda was not decided by farmers. A KAP survey, found that only about 5–20% of the targeted farmers, rarely exceeding 25%, actually attended T & V meetings reflecting lack of interest in the topics (Matteson et al. 1984). Farmers did not "own" the extension program thus showed little interest. In addition technicians usually ended up talking with farmers individually or in pairs. Structured classes held by technicians appeared to stifle intellectual initiative, becoming lectures rather than an opportunity for the technicians to suggest new ideas or bring up particular farmers' difficulties for discussion and specialist advice. Farmers' feedback upward into the plant protection research and policy systems was thus handicapped.

IRRI biological scientists were challenged by anthropologists to take the research reports "off the shelf" and extend them to farmers. A curriculum was developed for an IPM course for Filipino farmers in seven villages in C. Luzon. Each weekly meeting lasted four hours over a 13-week period which followed a rice crop from seedbed preparation to harvest. The effort was made into a research project by testing pedagogical methods for teaching farmers to scout their own fields (Goodell et al. 1982). The project compared two extension methods: (i) the current top-down T & V system and (ii) the anthropologist's bottom-up system where farmers decide the material to be presented in the classes. Classes were held in the field as well. Research showed that IPM skills can be transferred to farmers if an organized course is presented that includes field exercises to raise awareness, followed by weekly follow-up sessions during succeeding crops for farmer group leaders and local technicians. Classes were held in a meeting place next to the field and after a short presentation of a technical subject, the farmers and extension worker went to the field to diagnose field problems of the moment. Different than T & V's central planning method, this part of the training was determined by pests Nature brought that season. This initial testing of this more hands-on learning style, began in 1979, eventually morphed into the farmer field school method some six years later.

The success of the method became apparent as a result of follow-up weekly meetings held in the villages during succeeding rice crops. The meetings lasted several hours and began with the farmers describing what they found while scouting their fields over the past week. The technician listened to what the farmers had concluded and then all went to the field to verify their findings (problem diagnosis and decision making). By making weekly reports the burden was placed on the farmers to monitor their own fields and make a group decision on corrective action. Farmers are highly social, and a program favoring group decisions produces results. If the farmers did not diagnose the problem correctly, a lesson was held in the field showing them the right cause and discussing the recommended remedy.

In Table 5.27 we see the results of a farmer group during the second follow-up season after a 13-week training. These farmers showed good diagnostic skills for problems they previously encountered. Still new problems arose that had not been covered in other trainings thus the value of continued follow-up is shown. In this training method Nature dictates the subjects for training. Farmers later learned to distinguish the various planthopper species during an unusually heavy infestation of whitebacked planthopper. The farmers scored 89% correct problem diagnoses and 56% correct decisions on what action to take.

The value of continual follow-up is shown in Table 5.28 which presents the results of the weekly encounters with a farmer group that had only one season of follow-up meetings and no formal class that was used as a control group in the experiment. Initially untrained farmers had difficulty in problem diagnosis and wanted to apply insecticides at every turn. Becoming familiar with each pest over several weeks of practice, farmers gained confidence and proficiency. Initially they thought bacterial leaf streak was tungro. Later they thought neck rot was armyworm. Ladybeetles were identified as pests. In weeks 6 and 7 they saw two instances of leaffolder, one that had densities that were below action thresholds and in week 7 there were greater densities. In this way farmers could gauge the difference in a light infestation and a heavier one that would cause losses. Farmers still resisted using chronic rat baits and prefer acute bait. It was expected that if the sessions were continued that each year farmers would continue to improve in both groups. Using this model an extension worker could cover two villages a day and eight overall during a season assuming four days in the field and one in the office.

Unfortunately a personal approach places enormous demands on a developing nation's limited extension resources. Moreover some successful programs may not be easily replicable (Matteson et al. 1984). It appears that group learning can be used to advantage in a more unstructured, less authoritarian context. Filipino farmers in classes are unsure of themselves, their ability to experiment, and their own common sense especially when dealing with a new crop production technology and unfamiliar instructors. In this setting they are uncomfortable when asked to think on their own. Frequent group discussions are successful because farmers feel less threatened and learn better from their peers by talking and listening rather than by

Table 5.27 Weekly farmer groups' report to the extension technician from lmbunia village with a farmers' class in 1980, and one previous follow-up season, Zaragoza, Philippines, 1982 wet season[1]

Week after sowing[2]	Farmers' assessment		Extension worker's assessment[3]	
	Problem	Decision	Problem	Decision
5	Caseworm	Apply insecticide	+	+
	Whorl maggot	Apply insecticide	+	+
	Bacterial leaf streak	No action	+	+
	Zinc deficiency	Broadcast fertilizer	+	Apply zinc sulfate
6	Yellowing of leaves	Apply nitrogen	+	+
	Rat damage	Use acute rat poison	+	Use chronic rat poison
	Bacterial leaf streak	No action	+	+
	Whorl maggot	Apply insecticide	+	Keep monitoring
7	Rat damage	Use acute rat poison	+	Use chronic rat poison
	Leaffolder	Apply insecticide	+	Insecticide unnecessary
	Echinochloa weed	Apply herbicide	+	Spot weeding
	Monochoria weed	Apply herbicide	+	Spot weeding
8	Leaffolder	Insecticide unnecessary	+	+
	Bacterial leaf streak	No action	+	+
	Yellowing of leaves	Apply nitrogen	+	+
9	Leaffolder	Insecticide unnecessary	+	+
	Hoppers	Apply insecticide	Whitebacked planthopper	Insecticide unnecessary
10	Leaffolder	Insecticide unnecessary	+	+
11	Spots on stem of panicle	Apply insecticide	Neck rot	Apply fungicide
		Problems (no.)	19	19
		Farmers' correct responses	89%	53%

[1] Farmers' class 1980, follow-up meetings in 1982 dry season.

[2] Weeks 1–3 seedbed, 4–6 vegetative, 7–8 reproductive, 9–10 ripening stages.

[3] + = technican agreed with farmers' decision.

Table 5.28 Week farmer groups' report to the extension technician from Carmen village with only one previous follow-up season and no other training, Zaragoza, Philippines, 1982 WS[1]

Week after sowing[2]	Farmers' assessment		Extension worker's assessment[3]	
	Problem	Decision	Problem	Decision
5	Tungro	Apply insecticide	Bacterial leaf streak	Do not apply insecticide
6	Worms	Apply insecticide	Semi-looper	Insecticide unnecessary
	Leaves damaged	Apply insecticide	Whorl maggot	Insecticide unnecessary
	Caseworm	Apply insecticide	+	Insecticide unnecessary
	Yellowing of leaves	Apply insecticide	Leaffolder	Insecticide unnecessary
7	Leaffolder	Insecticide unnecessary	+	+
	Rat damage	Use acute rat poison	+	Use chronic rat poison
	Bacterial leaf streak	Pesticide unnecessary	+	+
8	Stemborer deadheart	Apply insecticide	+	Insecticide unnecessary
	Rate damage	Use acute rat poison	+	Use chronic rat poison
	Leaffolder	Apply insecticide	+	Insecticide unnecessary
	Bacterial leaf streak	Pesticide unnecessary	+	+
9	Hoppers	Apply insecticide	Whitebacked planthopper	+
	Leaffolder	Insecticide unnecessary	+	+
10	Armyworm	Apply insecticide	Neck rot	Apply fungicide
	Turtle-like beetle	Apply insecticide	Ladybeetle predator	Do not apply insecticide
		Problems (no.)	16	16
		Farmers' correct responses	56%	31%

[1] Follow-up meetings in 1982 dry season but no farmers' class.

[2] Weeks 1–3 seedbed, 4–6 vegetative, 7–8 reproductive, 9–10 ripening stages.

[3] + = technican agreed with farmers' decision.

reading. This sociability in learning meant that technology was rarely criticized during field interviews with individuals, but those same farmers, responding to the same questions as members of a group spurred each other to press the questions or issues further. Farmers trained as a group with frequent discussion as they learned best by talking and listening to their peers. Responding to questions as a part of a group was less threatening and group reinforcement of concepts. In a society where farmers are normally timid, obedient, and dependent and associate science with authority they become easily uncomfortable.

Farmer field schools developed new and positive motivators for developing country farmers through understanding, excitement in learning, and empowerment (Matteson et al. 1994). Methods used have been borrowed from commercial advertising, community organizing, and participatory non-formal education. Focus has centered increasingly on the need to teach IPM knowledge and skills in a consciousness and confidence raising framework that changes people's view of the natural world. Learning about natural enemies fascinates farmers. Local names are developed as often there are no names in local languages for many of them. Natural enemy studies are one of the strongest motivators for farmers to change spraying practices. Farmers were taught to change their classification system to make distinctions between pests and friendly arthropods as well as monitor pest and natural enemy abundance. KAP studies that determined some arthropods are used as children's toys or group dynamics activities can help break the ice and establish rapport, create awareness, and pave a common consciousness so communication can proceed on less ambiguous grounds (Nazarea-Sandoval 1991).

Conventional top down extension training should be replaced by a more robust training process that centers on farmer participation. Adults are most motivated to learn things that relate directly to their life experience (non-formal education). Interest and exhilaration in learning is connected with understanding why things happen as they do and the presentation of knowledge is a tool for action, so that people can change their lives for the better. There is a need for scientists and extension workers to become collaborators, facilitators, and consultants, empowering farmers to analyze their own situation, to experiment, and to make constructive choices. Learning should be dynamic and liberating, spurring people who were passive to become searchers and innovators. The training process and the relationship between extension agent and farmer are changed. Trainers are taught not to answer questions to appear as "experts" but to ask further leading questions. Trainers give farmers missing information when needed but only to enable farmers to observe and think for themselves.

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Chapter 6
Implementing Integrated Pest Management in Developing and Developed Countries

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Abstract Integrated Pest Management (IPM) systems in developed countries are largely based on substantial bodies of available information from a number of sources, including published material, extension agents, contract crop consultants and, more recently, the internet. Delivery systems for this information have traditionally been through extension agents in the USA but the internet is playing a larger role. IPM in developing countries, such as those in Southeast Asia, has been addressed most effectively through massive training of farmers through farmer field schools and farmer participatory research in the region. S.E. Asia is characterized by large numbers of farmers cultivating small plots. Production systems involve substantial amounts of labor inputs, which often put farm laborers at risk from exposure to harmful chemicals. Mechanical devices that replace labor in developed countries are not common in the S.E. Asia region. Technological advances have made an impact mainly through improved plant varieties and cultural practices to enhance yields. IPM training has taken hold throughout the region as a means to establish the farmer as the primary decision-maker and to equip him or her with an understanding of the critical relationship between agricultural output and field ecology. Training programs in all S.E. Asian countries are aggressively spreading the message to "grow a healthy crop" as the first step in establishing sound IPM programs. Results from some IPM programs are presented and discussed but the list is not all inclusive and is always evolving and changing with the farmers' crop mix and increased knowledge of the agricultural ecosystem.

Keywords Integrated Pest Management · IPM · developing countries · developed countries · farmer field schools · farmer participatory research · IPM tactics

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6.1 Introduction

Much has been written on the subject of integrated pest management (IPM) over the past 40 years. As one might expect, most of the published literature is focused on IPM in developed countries (Dent 1991, Kogan 1998, Metcalf and Luckman 2004, Pedigo 1989, Pimentel 1991, Olsen et al. 2003, Smith and Reynolds 1966, CAST 2003, and others). More recent publications deal with "globalizing" IPM (Norton et al. 2005, Maredia et al. 2003) with examples from several parts of the developing world. This chapter will draw heavily on the authors' experiences in S.E. Asia and the USA for the comparisons between implementing IPM in developing and developed countries. Examples presented, however, are not all inclusive and methods and techniques are evolving and changing as IPM systems, worldwide, are refined.

6.2 Implementing IPM in Developed Countries

The impetus for developing IPM programs in the USA came from problems and concerns from overuse of chemical pesticides which was highlighted in Rachel Carson's book Silent Spring (Carson 1962). As early as 1959, Stern et al. emphasized the need for integrating various control tactics in a classic publication entitled "The Integrated Control Concept". As Olsen et al. (2003) pointed out, IPM has over a 40 year history in the USA that combines biological, cultural and chemical techniques into an ecologically sustainable system. This chapter barely touches upon development of IPM in the USA because this is so well documented elsewhere. Instead we will emphasize development and implementation of IPM in developing countries, with major emphasis on Indonesia.

Implementation of IPM in developed and developing countries requires completely different approaches. Many mistakes have been made using developed country models that simply do not work in a developing country context. First, the infrastructure, extension, information and delivery systems are usually not available in developing countries. Developed countries have highly sophisticated extension and information systems readily available to farmers. Also, even if developing counties have extension agents or other agricultural agents, they are limited in number, superficially trained, and often provide only token services to large coverage areas. Also, developed countries have access to information via various published media, agricultural extension agents and the internet. In contrast, many rural agricultural villages in S.E. Asia have only recently gotten electricity. Developed country IPM programs are built on years of research information. This information is generated by US Land Grant Universities, the US Department of Agriculture, private industry and other national and international research institutions. Various tactics include the use of high-yielding varieties with resistances against various diseases and insect pests, field monitoring to determine action or economic thresholds, and highly regulated pesticide testing, sales, and disposal systems. Some crop production industries have their own crop protection specialists that conduct research on various commodities.

A review of IPM in the USA is presented by Olsen et al. (2003). Maredia et al. (2003) provided an overview of IPM in the global arena. A major impetus to the IPM approach in the USA was initiated in 1972 through support from NSF, EPA and USDA for research in five major crops and pine forests. This effort, called the "Huffaker Project", lasted for 6 years and was continued for 6 more years as the "Adkisson Project" funded by EPA, and USDA/CSRS. It required close collaboration between teams of agronomists, ecologists, economists, entomologists, plant pathologists and systems analysts from 18 land-grant institutions. Pimentel's three volume Handbook of Agricultural Pest Management summarized the state of IPM at that time (Pimentel 1991). Seven of the 8 commodities under the Huffaker/Adkisson projects showed a decrease in production costs and yields increased for six out of the eight commodities (Olsen et al. 2003). Risks of crop loss decreased in the three commodities where this was evaluated (Norton and Mullen 1994).

In general, pesticides are still overused by farmers in both developed and developing countries. The propensity to apply pesticides when not needed seems to make farmers feel better about their crops even though serious problems frequently arise, such as resistance, resurgence and negative impacts such as contamination of water supplies, and harm to non-target species such as pollinators, predators, parasitoids and humans (Kishi 2002, Murphy et al. 1999). In the Southeastern USA, applications of insecticides actually caused resurgences of several species of lepidopteran pests of soybean (Shepard et al. 1977). The most likely cause for this rapid increase in pest populations was destruction of natural enemies. Therefore, it is important to understand that application of chemical insecticides, whether targeting pod and stem borers or foliage feeders, may cause non-pests to be elevated to primary pest status.

The basis for most IPM systems in developed, temperate countries involves identifying "damage" or "economic" or "action" thresholds and understanding the role of natural enemies (predators, parasitoids and entomopathogens). Field scouting or sampling programs are usually developed based on this information. Examples include sequential sampling programs that are easy to use, reliable and save time in monitoring pest populations or damage in the field. These have been developed for insect pest species such as cabbage loopers, *Trichoplusia ni* (Hübner) (Noctuidae, Lepidoptera) (Shepard 1973), diamondback moth, *Plutella xylostella* (Linnaeus) (Lepidoptera: Plutellidae) in collard (Smith and Shepard 2004), and many other pests. The economic threshold (ET) idea is not appropriate in a developing country context as this suggests that a "treatment" is necessary at a certain pest or damage level. It also is based on the notion that a pesticide is available and ready for use. The economic threshold idea usually does not take into account natural enemy populations or the constant price fluctuations of chemical inputs and commodity prices. Thus, the threshold is often drastically lowered or ignored altogether to account for perceived "risk".

Some plant protection systems include forecasts of pest problems using environmental monitoring with instruments to help determine if conditions are favorable for certain diseases to occur. In addition, economic analyses are available for selected crops. Precision agriculture, requiring highly sophisticated equipment, including computers, also is increasing in developed countries.

6.2.1 A Field Level Example of IPM Adoption: Collard

Fresh market collard, *Brassica oleracea* (L.) var. *acephala* DC, is one of the most economically important vegetable crops grown South Carolina where the 4,000 acres (1600 ha) grown in the state comprises over one-half of the acreage of brassica crops grown annually. The climate allows year-round collard production which causes pest pressure to be severe in most years. Major insect pests that can be constraints to production include the diamondback moth (DBM), *P. xylostella* and the cabbage looper (CL), *T. ni*.

Pest management strategies are available for lepidopteran pests of cabbage (Maltais et al. 1998, Shelton et al. 1983, 1982, Chalfant et al. 1979, Shepard 1973, Greene 1972) and other brassica crops (Maltais et al. 1994, Stewart and Sears 1988) in North America but collard integrated pest management (IPM) was lacking prior to 1997. Damage thresholds were not available and scheduled applications of insecticides (as often as every four or five days) were made in response to the detection of live caterpillars or the presence of larval feeding damage based on periodic, cursory field examinations.

In response to widespread DBM control failures in 1994, a program to study the DBM/collard pest/crop system was initiated in 1996. Khan (1998) identified resistance to the cryIAc and cryIC endotoxins of *Bacillus thuringiensis* Berliner (B.t.) in DBM. He also found that parasitism by *Diadegma insulare* (Cresson) (Ichneumonidae, Hymenoptera) was low, probably due to the use of broad-spectrum insecticides and high temperatures. Collard growers were informed of the B.t. resistance in DBM and a four-point IPM program was initiated with the following components: (1.) calendar-based applications of insecticides were stopped, including those containing B.t., (2.) fields were systematically monitored and a threshold was used to determine the need for a pesticide application, (3.) broad-spectrum insecticide use for caterpillar control was curtailed, and (4.) augmentative releases of parasitoids, were begun. Growers reported that aphid problems were reduced after curtailing the use of broad-spectrum insecticides for caterpillar management.

Greene (1972) reported that a threshold of 0.1-cabbage looper equivalent (CLE) per plant prevented damage that was economical in cabbage, so this threshold level was used in the collard system. Harcourt et al. (1955) found that CL larvae consumed around 20 times as much leaf tissue as DBM larvae. However, this level was considered too high for collard, so a ratio of 5:1 (DBM to CL), which was used earlier by Maltais et al. (1998), was adopted. Implementation of this program began in 1996 and by 1997, populations of DBM were significantly reduced, the efficacy of B.t. products against the DBM was restored, total numbers of insecticide applications were reduced without losses in marketable yield (J.P. Smith – unpub. data), and the overall economics of summer collard production was improved (Anonymous 2001).

Further refinements of the IPM system included streamlining field scouting techniques. Although there was a reduction in insecticide applications from an average of 14 to an average of less than 6 applications in 10 weeks (time from seeding in plant beds to harvest), field scouts were using a fixed-number scheme (FNS).

A major criticism of the pest management program by producers was that the FNS field scouting required too much time in order to make a decision about whether or not a treatment was required. In addition, an ET specific for collard was lacking.

A study was conducted in response to these concerns with the objectives of: (1.) developing a location-specific ET for management of CL and DBM in collard, (2.) developing and testing a sequential sampling scheme (SSS) for identifying fields with potentially damaging populations of CL and DBM, (3.) comparing the sampling methods that utilized one plant per observation point to those requiring five plants per point, and (4.) comparing the time and precision of the SSS to the more intensive FNS.

The results of this study were published (Smith and Shepard 2004) and disseminated to growers using traditional extension education methods such as growers meetings, field demonstrations with "field day" meetings, fact sheet publications, booklets (Francis et al. 2005) and direct-contact farm visits by extension agents. The work was demonstrated and implemented by large commercial collard growers in the state, and also to limited-resource (LR) farmers with small acreages. The study showed that the 0.1 CLE/plant ET was appropriate for production of marketable collard. Also, the sequential sampling plan was efficient with no differences in population estimates whether one plant was sampled at one-hundred locations or five plants were sampled in twenty locations. Thus, significantly more time was saved using the SSS approach compared to the conventional FNS.

Several large commercial farms that began to use the FNS in the late 1990's never adopted the SSS, although these growers were among the ones who complained about the amount of time required by the FNS. There were a number of reasons for the failure of wide-spread adoption by many growers. Among the most important was that in the late 1990's and early 2000's a number of new insecticides were registered, and many growers switched to these for crop protection. New, "soft" insecticides for caterpillar management such as spinosad, emamectin, indoxacarb, methoxyfenozide, and novaluron gave growers materials that could be used for DBM management without the same level of non-target effects as the older broad-spectrum insecticides. With this number of effective materials, rotation of modes of action could be practiced with less chance of encouraging resistance to a particular mode of action. Initially, excellent management of caterpillars was accomplished without the immediate side effects seen when using older broad-spectrum insecticides such as resurgence of primary and secondary pests and elimination of natural enemies. This led to reduction in emphasis on scouting, failure to scout methodically using the FNS, failure to use the ET to justify applications, and eventual return to calendar-based spray programs. Growers used the new materials in many cases without having adequate scouting data on which a decision could be based to treat. Despite increased use of these new materials, DBM populations in South Carolina were not found to be statistically less susceptible to spinosad (the most widely used material) (L. Walton, DowAgroSciences – unpub. data). However, in neighboring Georgia, where no scouting or ET were used to time or justify insecticide applications for caterpillar on collard, resistance to spinosad in certain DBM populations has been documented; the same study showed increased LC_{50} values in these populations for both indoxacarb and emamectin (Zhao et al. 2006). A particularly disturbing fact about this incidence of insecticide resistance was that in 2001 and 2002, when the field control failures were reported, indoxacarb was not yet registered on collard, the crop on which growers were attempting to manage DBM.

One major consideration was that most of the field scouts were of Hispanic origin and communication of technical information presented a challenge. In Lexington County, almost 100% of the field scouts were from Mexico and were trained to examine the crops for insect pests. They were adept at finding caterpillars and caterpillar damaged plants as well as some other pests but had no formal training in IPM, identification of pests and natural enemies, scouting procedures, and most did not speak, understand, or read English well enough to receive such training in English. In addition, crew chiefs and farm managers who were bilingual did not have adequate technical training to act as interpreters. The authors found that field scouts basically adopted a "better to be safe than sorry" approach to their jobs and if caterpillars could be found in a field, their scouting reports reflected a need to treat regardless of the number or distribution of the pests. By the 2003–2004 season, actual methodical field scouting with record keeping and utilization of an ET was implemented and numbers of insecticide treatments drastically declined.

Several events in 2005 began to change this situation in Lexington County, South Carolina. The resistance problem experienced by the Georgia industry created increased awareness that even with the new, effective materials, the resistance scenario seen in the mid-1990's with the B.t. insecticides could be repeated. Field scouting forms and background instructions were translated into Spanish. Pest management advisors became interested in the SSS when it was demonstrated to them in early 2007 due to the high efficiency and time-savings associated with the method. A post-season evaluation indicated that this approach had been very effective in limiting damage to the crop and numbers of insecticide applications had been reduced compared to FNS.

Powell Smith, in conjunction with the local county agent, carried out two years of demonstrations of SSS and other IPM practices with limited resource farmers in Marlboro County, South Carolina. Although these growers' fields are small, they appreciated the savings in time that the SSS provided, which in their case, also resulted in reduction of insecticide applications with resulting savings in costs. Also, there is an increasing awareness of environmental issues among this group of growers, which has contributed to more interest in reducing numbers of pesticide applications. In Orangeburg County, South Carolina, where a large limited resource farmer is attempting to use the program, the major constraint is the lack of adequately trained and motivated individuals who can be trained to carry out the field scouting.

In conclusion, adoption of any new approach to management of pests on high-value crops will be slow with much trepidation on the part of growers who feel that they may suffer economic loss if the approach is unsuccessful and on the part of field workers whose employment success may depend on how well the crop is protected and/or managed. Being able to successfully demonstrate on significant acreage (with grower groups involved) that the method will not result in increased costs, or particularly increased crop damage, is very important to convince farm operators to try new approaches. Avenues which are successful in improving chances of adoption of IPM in collard at the field level involve proper training of pest management professionals retained by growers. It is particularly important that field scouts have access to bilingual individuals with sufficient technical training to be able to translate or convey fairly complex biological and spatial information to workers in their native language. Demonstrating to field scouts that the SSS was much more efficient than the FNS was the most useful approach toward gaining a greater level of adoption. The SSS agreed with the FNS more than 90% of the time and sampling 5 plants at each sampling site was more efficient that sampling one plant at each site with an overall reduction in field sampling time of 75% (Smith and Shepard 2004).

6.3 Implementing IPM in Developing Countries

A review of early IPM efforts in the Asia and Pacific regions is summarized in Ooi et al. (1992). Most developing country farms are small and heterogeneous. Unlike most farms in developed countries, the IPM decisions in developing countries must be derived locally to be applicable to a particular setting. Due to the absence of "over-wintering", agro-ecosystems in S.E. Asia are ferociously local specific with large variance from field to field and area to area. The authors do not think that the use of the term "IPM Packages" is appropriate as this suggests that all the answers are known and neatly "packaged" and ready for farmer use. Instead, there is a need to empower farmers with knowledge of their crops through FFS and/or participatory research in farmers' fields, workshops, field guides, etc. In some cases, simple messages may be effective in changing behavior about IPM (Heong et al. 1998) but this approach will be effective only in certain circumstances and is very close to the "spray and pray" recommendations that have contributed to the current problems of pesticide overuse and abuse leading to resistance and resurgence in pest populations and poisoning of non-target organisms, including farmers.

Another aspect of IPM in developing countries, that complicates development of sustainable IPM systems, has to do with chemical pesticides. These are often "dumped" on developing countries where there is little or no enforcement of pesticide regulations, even if they exist. In countries like Cambodia, parathion floods into that country from Thailand and the government has literally no regulatory staff in the field to prevent this. Even when pesticides are available to developing country farmers, these farmers are not trained in their safe use. In fact, "safe use" of highly and moderately hazardous pesticides most commonly applied in S. E. Asian countries is all but impossible for small scale farmers (Kishi et al. 1995). It is common to find chemical pesticides that have been banned in developed countries, still being sold freely in developing countries. This presents a huge challenge for IPM, and an ongoing threat to the human and environmental health of poor communities.

6.3.1 Rice

An important outcome of pesticide misuse is that many insects, particularly in tropical lowland rice, have risen to primary "pest" status because of the destruction of the natural enemies that kept pests in check for thousands of years before pesticides were being used. Pesticide overuse was the cause for outbreaks of the brown planthopper (*Nilaparvata lugens* Stål) (Hemiptera: Delphacidae) in Indonesia (Fig. 6.1), the Philippines and in other tropical lowland rice-growing areas of S.E. Asia. These outbreaks prompted the government of Indonesia under President Suharto, to ban 56 kinds of pesticides. The rich compliment of natural enemies, reported by many authors (Settle et al. 1996, Shepard and Barrion 1998, Shepard et al. 1999, Kenmore 2006, Kenmore et al. 1984, Ooi and Shepard 1994, Shepard et al. 2000), quickly brought brown planthopper populations under control after pesticide use subsided with concurrent increases in rice yields (Fig. 6.2).

Sadly, chemical insecticides were part of the "package" of recommendations that were ushered in as part of the green revolution. Other parts of the package included high-yielding varieties, nitrogen fertilizers, large scale investments in irrigation, and wider access to farm credit.

Rice IPM programs in S.E. Asia, through farmer field schools (FFS), laid the foundation for moving the approach to other crops. Major funding by the World Bank and others made the FFS concept the major paradigm for putting IPM on the landscape through empowerment of thousands of farmers. This approach required that researchers and extensionists participate with farmers in farmers' fields to actually carry out field activities so that farmers became empowered with knowledge of IPM principles (Dilts 1990). IPM experiments have been conducted with farmers in their own fields on such things as soil ecology, plant compensation, and benefits of natural enemies. Between 1990, when the first FFS was conducted in Indonesia, and

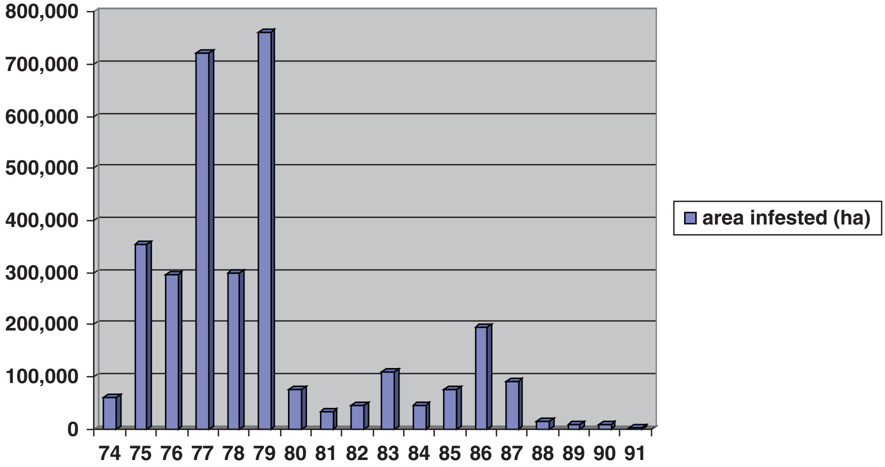

Fig. 6.1 Brown planthopper in rice in Indonesia, 1974–1991
Source: Kenmore (2006).

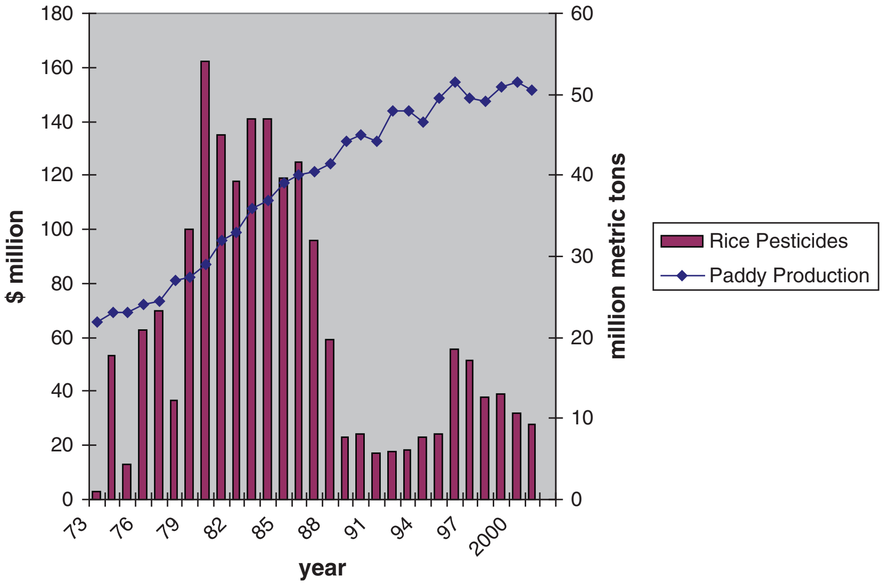

Fig. 6.2 Rice pesticide expenditures and paddy production in Indonesia, 1973–2001
Source: Kenmore (2006).

1999, over two million rice farmers participated in the program (Pontius et al. 2002). Rice yields continued to improve and pesticide use was dramatically reduced in areas where FFS were being carried out (Fig. 6.2). Farmers that participated in rice FFS had significantly higher yields in secondary food crops, produced in rotation in rice-based systems (Hammig and Rauf 1998).

Field studies carried out with farmers in vegetables and soybean showed that insecticide use in these crops was excessive and not economically viable (Shepard et al. 2001). The following are examples of farmer participatory research activities that were conducted for non-rice crops in Indonesia (Table 6.1).

6.3.2 Soybean

Soybean in Indonesia is considered a major "palawija"[1] crop. This crop is the most important non-rice crop with over 1,407,000 hectares grown in Indonesia. A large proportion of soybean is used for human consumption. Even with this large planting area, Indonesia still imports between 600,000 and 800,000 tons of soybean annually. This crop is an important protein source and is the base for food items such as tofu, tempe and others.

The most important insect pests of soybean in Indonesia are pod boring insects, *Etiella zinckenella* (Treitschke) (Lepidoptera: Pyralidae,) and *Helicoverpa armigera* (Hübner), the corn earworm (CEW). Of these, *E. zinckenella* is the most destructive,

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[1] The Indonesian word palawija refers to secondary crops grown in rotation with rice.

Table 6.1 Major[a] IPM tactics that have been tested with vegetable farmers in S. E. Asia

Crops	Tactics
Tomato	Varieties resistant to viruses and fungi Staking (with appropriate variety) Pruning Grafting
Chili	Resistance to viruses
Eggplant	Straw mulching Grafting Host plant resistance to nematodes B.t.-transgenic plants
Shallots	Microbial Control of *Spodoptera exigua* with SeNPV
Onions	VAM and *Trichoderma* Straw mulch Pheromone traps for timing interventions (*Spodoptera litura*) SlNPV (insect virus of *S. litura*) SeNPV (insect virus of *S. exigua*)
Cabbage	Field scouting for *Crocidolomia* Microbial control/spot spraying Hand picking egg masses/larval clusters (also conserves natural enemies for DBM)
Soybean	Early planting in the dry season (to avoid pod-borers/*Etiella* sp. and *Helicoverpa* sp.) Avoiding needless sprays for defoliators
Yardlong beans	Spot treatments for aphids
Citrus	(for Papaya fruit fly control) Sanitation Protein bait sprays Traps to monitor population Early harvest
All vegetable crops	Weed control using stale seedbed techniques

[a] Tactics listed here are not all inclusive. From Hammig et al. (2008).

based on field surveys carried out in Indonesia. The stemfly, *Melanagromiza sojae* (Zehntner) (Diptera: Agromyzidae,), the seedling fly, *Ophiomyia phaseoli* (Tryon) (Diptera: Agromyzidae,), pod-sucking bugs such as *Nezara viridula* (Linnaeus) (Hemiptera: Pentatomidae,) and *Riptortus linearis* (Fabricius) (Hemiptera: Alydidae,) also can be important. Foliage feeders such as *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae,), *Omiodes indicata* (Fabricius) (Lepidoptera: Pyralidae,) and semi-loopers, mainly *Chrysodeixis chalcites* (Esper) (Lepidoptera: Noctuidae,), are often targeted by farmers for insecticide sprays because they are large and conspicuous, but these insects rarely affect yields. Broad spectrum insecticides that target this foliage-feeding complex, often have profoundly negative effects on indigenous biological control agents that control pod borers and pod-sucking bugs in the absence of these chemicals.

There is an abundance of natural control agents in the soybean system and populations of most of the plant-feeding species are effectively regulated by these natural enemies (Shepard et al. 1999) The parasitoid complex is particularly rich on some plant feeding species (Shepard and Barrion 1998). However, it is apparent from pest and natural enemy surveys that some key pests are lacking an effective complement of biological control agents. For example, the pod-boring pyralid, *E. zinckenella* has relatively low levels of parasitism. Only three parasitoid species, *Phanerotoma philippinensis* (Ashmead) (Hymenoptera: Braconidae), *Baeognatha javana* Bhat & Gupta (Hymenoptera: Braconidae), and *Temelucha etiellae* Kusegimati (Hymenoptera: Ichneumonidae) were encountered (Shepard et al. 1999) and no entomopathogens were found.

6.3.2.1 Farmer Participatory Research to Test IPM Strategies in Soybean

Considering all the secondary food crops, soybean stands out as one in which good agronomic practices are often sadly lacking. Farmers and researchers often focus their activities on pest control without first understanding that "growing a healthy crop" is frequently the most important constraint to production. Field studies were carried out with farmers to identify strategies for inclusion in IPM training programs (Shepard et al. 2001). Soybean is usually grown after rice (during the dry season). The following are highlights of farmer participatory research obtained from field studies:

Planting dates profoundly affected the presence of pod-feeding lepidopteran pests such as *Etiella* and *Helicoverpa*. Their populations were higher and yields were lower in late-planted soybeans. These studies underline the importance of a cultural techniques of planting as early as possible to escape build-up of these pod boring pests. In addition, farmers would probably benefit if their early plantings could be synchronized with other farmers. Applications of insecticides caused an increase in foliage- and pod-feeding insect populations and an increase in damage by *Helicoverpa* and *Etiella*. Applications of chemical pesticides decreased numbers of several important arthropod predators such as spiders (mainly, *Pardosa* spp.), staphylinids [mainly *Paederus fuscipes* Curtis (Coleoptera: Staphylinidae)], and ants that build up and keep other soybean insect pests under control.

Little information is known about stem flies and their importance in soybean production. Results from our studies with this potential pest revealed the following:

1. Yield reductions by the stem fly, *M. sojae*, could not be detected except when the stem was attacked below the hypocotyl (van den Berg et al. 2000); thus, there was little justification for insecticide treatments.
2. Although chemical insecticide treatments were aimed at stem flies, these chemicals adversely affected populations of major predators and caused populations of *S. litura* to resurge (Shepard et al. 2001).
3. No yield reductions were caused by *S. litura*. Therefore, it may be a beneficial insect providing food for natural enemies that attack more serious insect pests.

Any IPM strategy that is used in soybean, as in other crops, must involve farmers. Field exercises developed and carried out with farmers will serve to illustrate the principles and practices of IPM. Secondly, devising field studies with farmers can illustrate that foliage-feeding pests such as loopers, *Omiodes* sp., geometrids, lymantriids, and *S. litura*, rarely cause yield losses.

According to Indonesia's Central Bureau of Statistics, about US $2 million is spent annually for insect pest control on soybean. Most of these pest control expenditures occur in the major growing areas in Java and Sumatra where IPM programs are concentrated. Data from field surveys in East Java conducted in 1996 provide information on frequency of sprays, showing that farmers applied from zero to 8 sprays through the season, with an average of 3.4 for the 100 farmers surveyed (van den Berg et al. 1998). Seventy percent of insecticide sprays were applied during the first 45 days after planting, before pod-set, and were mainly aimed at defoliators. Because these pests cause little if any yield reduction, it is clear that insecticide sprays can be reduced without causing economic losses. Thus, IPM strategies that reduce the number of pesticide applications have immediate and direct payoffs to farmers by reducing their costs of production and consequently increasing their profits. If IPM strategies enhance yields as well – which is likely as a result of the program focus to "grow a healthy crop" (Gallagher 1990) with particular emphasis on basic agronomy – then the benefit is increased.

6.3.3 Cabbage

Cabbage is planted to over 67,000 hectares in Indonesia, second only to soybean among non-rice food crops, with a total of 1,417,000 metric tons produced annually. This crop is produced mainly in upland areas of Java, Sumatra and Sulawesi. Major pests of cabbage in Indonesia are the cabbage head caterpillar (CHC), *Crocidolomia pavonana* Zeller (Lepidoptera: Pyralidae) and the diamondback moth (DBM), *P. xylostella*, but the latter is generally kept under good control in most areas by the parasitoid, *Diadegma semiclausum* (Hellen) (Hymenoptera: Ichneumonidae), when chemical insecticides are avoided. *Hellula undalis* (Fabricius) (Lepidoptera: Pyralidae,) and the looper complex can be important locally but are not wide spread problems. We have seen outbreaks of CEW on cabbage in S. Sulawesi.

Diadegma semiclausum was introduced into Indonesia for DBM control in the 1950s (Ooi 1992) and later was distributed to most of the major cabbage-growing areas (Sastrosiswojo and Sastrodihardjo 1986). Even in areas where the parasitoid is firmly established, farmers do not recognize its importance in biological control of DBM and mixtures of chemical insecticides are routinely applied. This action invariably causes resurgence of populations of DBM by reducing parasitoids and other important natural enemies that normally keep it under control. Interestingly, one can ascertain the spray history of a cabbage field depending on the presence or absence of dense populations of DBM. High populations are almost always indicative of heavy chemical sprays; the presence of high levels of CHC usually indicates few or no chemical sprays. This underscores the importance of considering CHC along with DBM in developing an effective IPM program for cabbage (Sastrosiswojo and Setiawati 1992). When chemical sprays for DBM are decreased or terminated altogether, CHC often causes heavy damage. Indigenous natural enemies are not able to keep CHC in check. Recently, several pathogens (mainly entomogenous fungi) have been isolated from field populations of CHC and are being tested by collaborators and farmers in N. Sulawesi.

Another major challenge for cabbage IPM is development of strategies that can help suppress CEW and *Hellula*; the latter occurs mostly in lowland cabbage. Although these pests are sporadic and localized, our extensive surveys throughout major vegetable growing areas revealed heavy populations of CEW in Central Java, South Sulawesi (Malino) and East Java (Batu).

6.3.3.1 Farmer Participatory Research to Test IPM Strategies in Cabbage

Field tests were conducted with farmers to determine if hand picking egg masses and larval clusters of CHC, along with spot applications of *Bacillus thuringiensis* (B.t.), was a practical approach for CHC control (Shepard and Shellhorn 1997). Applications of B.t. and concurrent elimination of chemical sprays would allow *D. semiclausum* and other natural enemies to fully operate against DBM and CHC.

Tests were carried out with farmers in West and North Sumatra to develop an IPM system for DBM and CHC. Treatments included: (1.) Collecting CHC egg masses and larval clusters up to 30 days after transplanting seedlings, then hand-picking plus spot spraying with B.t. (after about 30 days, the egg masses are difficult to find); (2.) Hand picking throughout the season and spraying the entire plot with B.t.; (3.) Standard farmer practice, and; (4.) Untreated control.

Hand picking egg masses and larval clusters plus spot treatments of B.t., resulted in over 90% of the cabbage heads rated as marketable in west Sumatra. The farmers' usual practice provided the highest yields (about the same as hand picking and spot spraying) but 8 B.t. and chemical sprays were applied compared to only 7 B.t. spot treatments when egg masses and larval clusters were hand picked. We concluded that results may have been better by applying B.t. using a backpack sprayer rather than a small hand held sprayer that we used for these studies. In the untreated control plots, nearly 40% of the heads were severely damaged by CHC and were considered unmarketable.

Results were more impressive in North Sumatra where a backpack sprayer was used to apply spot sprays of B.t. This study, planned and executed with personnel from World Education and farmers, revealed that yields and marketability of cabbage were significantly lower in the untreated plots. Only 7 spot sprays with B.t. were required in the hand picking/B.t. spot spray treatment. Thus, the profitability of hand picking eggs and larval clusters plus spot spraying with B.t. may be a viable approach in areas where cabbage fields are small and not much time is required to search the field for egg masses and larval clusters. Thus, this approach could result in considerable build-up of natural enemy communities of both DBM and CHC, and reduce or eliminate the usual practice of farmers who make weekly applications (12) of chemicals.

6.3.4 Shallots/Onions

Of all the vegetable crops, shallots are most heavily sprayed with chemical pesticides. In large shallot-producing areas of Brebes, in Central Java, it is not uncommon for farmers to apply chemical insecticides every other day. This has resulted in high levels of resistance in the target pest, the beet armyworm (BAW), *Spodoptera exigua* (Hübner) (Lepidoptera: Noctuidae). The only viable control tactic was "hand picking" larvae from the plants. Health impact studies carried out in these areas showed that fully one in five (21%) of all spray operations resulted in clinical poisoning events (Kishi et al. 1995). Heavy damage by *S. exigua* also was prevalent in West Sumatra (Alahan Panjang), East Java (Batu and Proboling.) and West Java (Cisantana and Pangalengan).

BAW is more serious during the dry season. During the rainy season, fungi are most important, notably *Alternaria, Colletotrichum* and *Peronospora destructor* (Meity Sinaga, personal communication). Weeding is normally carried out on an "as needed" basis, most often simultaneously with "hand picking" *S. exigua* larvae. Aphids, *Neotoxoptera formosana* (Essig) (Homoptera: Aphididae), can be locally important in highlands but we have not observed them in high numbers in most major production areas.

Heavy infestations of a leaf-mining agromyzid, *Liriomyza huidobrensis* (Blanchard) (Diptera: Agromyzidae), were found on shallots in Alahan Panjang, West Sumatra in the mid-1990s (Shepard et al. 1996) and this pest has since been found in several other areas of Indonesia. The extent to which these infestations affected yields has not been determined but judging from the severity of infestations, yield losses were substantial. More recently, heavy infestations of another exotic leafminer species, *Liriomyza chinensis* Kato (Diptera: Agromyzidae), were observed in Brebes, Central Java in 2000.

In the Philippines, the most important soil-borne diseases are *Sclerotium cepivorum, Fusarium oxysporum* and *Phoma terrestris* and the use of fungicides for control of these pathogens has been unsuccessful (Gapasin et al. 1998). *Anthracnose* is one of the most important diseases of onions in the Philippines. At present, the only effective means of control is intensive fungicide applications. Purple nutsedge and horse perslane are the most important weed pests of onion (Miller et al. 2005).

6.3.4.1 Farmer Participatory Research to Test IPM Strategies in Shallots/Onion

A microbial control agent – a Nucleopolyhedrovirus (SeNPV) – was discovered in populations of *S. exigua* in Cimacan, in the Puncak region of West Java, through routine field surveys of shallots (Shepard et al. 1996). Results from preliminary tests in the Puncak revealed that damage to leaf onion was significantly lower when the SeNPV was applied in farmers' fields. The virus was then tested in the Brebes area with our collaborator, Pak Karsum, a shallot farmer in Ciledug, Central Java. Results were so impressive that Karsum asked for the SeNPV from USAID-supported laboratories in Bogor. Project scientists worked with him closely to develop production techniques and soon after he was able to mass-produce the material and carried out tests in his own fields. A unique feature of the biological control system is that the microbe is easily mass produced because of a ready supply of *S. exigua* larvae that are collected daily by women. This hand picking is carried out as part of an effort, along with chemical insecticides, to control the pest.

Field applications of the SeNPV against *S. exigua* have been highly successful. As a result of these tests, the farmer collaborator changed his pest control strategy to SeNPV, instead of chemical insecticides for control. He has shared this technology with farmers from six other villages. The FAO Action Research Facility in Brebes also worked closely with other farmers in the area to help them understand how the microbial agent works and how to best utilize it in a program that helps restore other natural enemies – parasites and predators – for long-term stability of the system.

Additional field tests were conducted with farmers using randomized, replicated plots, but with farmer-level production and application techniques using a crude preparation of SeNPV. Six experiments were carried out from July through September 1996, to assess the SeNPV's control potential at different *S. exigua* population levels.

Average yields were compared among the six treatments: (1.) SeNPV plus hand-picking larvae, (2.) Chemical insecticide + hand-picking, (3.) SeNPV alone, (4.) Hand-picking larvae, (5.) insecticides alone and (6.) untreated controls. Yields for these treatments are shown in Fig. 6.3. Clearly, SeNPV and SeNPV along with hand picking larvae provided the best control of *S. exigua*. During the late season planting, with heavy pressure from *S. exigua*, yields from the untreated control plots were nearly zero. Plots with hand picking alone significantly improved yields, but highest yields were obtained when SeNPV was applied along with hand picking. The SeNPV treatment alone was as good as insecticides plus hand-picking which was common farmer practice before the IPM system was introduced (Fig. 6.3).

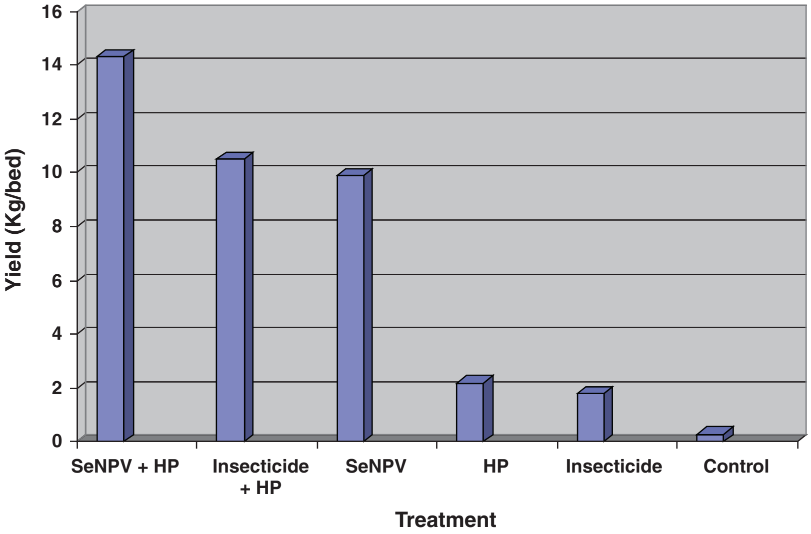

Fig. 6.3 Yields of shallots treated with combinations of SeNPV, insecticides, and hand picking – Ciledug, West Java, September 1996
Source: (Shepard et al. 2001).

A program for farmer production and use of SeNPV has been developed and is being carried out in Alahan Panjang, West Sumatra (Zamzami and Djoni, personal communication). West Sumatra Plant Protection Agency staff from laboratories at Padang and Bukittinggi were supplied the inoculum and training in propagation techniques. They, in turn, have trained 150 shallot farmers. These farmers are currently using the SeNPV in their own fields. A Farmer Field Seminar for Biological Control was conducted in Alahan Panjang to bring together farmers, trainers and researchers from all of the major shallot-growing areas of Indonesia, to share experiences and design plans to expand the understanding and use of SeNPV. Over 10,000 farmers currently use the SeNPV as part of their control program on shallots in West Sumatra (Zamzami, personal communication). The IPM system, based on the use of the SeNPV virus together with hand-picking, provides a dramatic opportunity for economic benefits to farmers. Insecticide costs are eliminated and hand-picking requirements are reduced. These factors alone imply that production costs can be reduced by $1,100 per hectare. In addition to these cost savings, evidence from the field studies implies that crops produced under the IPM system have higher yields and improved quality over the common farmer practice. The combination of the yield boost and the price premium paid for high quality product results in an additional $2,800 per hectare gain from IPM. Thus, the net benefit is about $4,000 per hectare. In addition, health benefits from development of IPM should be substantial because pesticide poisoning continues to be a major, and poorly diagnosed, public health problem in rural agricultural communities (Kishi et al. 1995).

In summary, the use of SeNPV has excellent potential for providing long term control of *S. exigua* while stabilizing the shallot ecosystem by allowing natural enemies to re-colonize the areas. Farmer training in IPM is the key to the success of the program.

The fundamental comparison of common farmer practice to the IPM alternative, based on the use of SeNPV virus, is shown in Table 6.2. The data were obtained from field studies conducted in the Ciledug sub-district of Cirebon District, Central Java. This area is typical of the major shallot growing area of Indonesia that includes Tegal and Brebes Districts, as well as Cirebon. The irrigated production system used also is common in Probolinggo, East Java, another important shallot area. Combined, these areas account for about one-third of all shallot production in Indonesia.

The use of fungicides is largely unsuccessful for control of soil-borne pathogens of onions. However, *Trichoderma* spp. are known for their antagonistic effects against these fungal pathogens. In the Philippines, *Trichoderma* isolates were as effective as chemical fungicides in reducing the incidence of these soil-borne diseases. VAM (vesicular arbuscular mycorrhizae) has been found to be an economically and environmentally friendly supplement that can help reduce fertilizer input and helps onion plants tolerate infection from soil-borne pathogens and nematodes (Gergon et al. 2003). For control of Anthracnose, the combination of cultural and chemical control reduced the number of fungicide applications (Alberto et al. 2003).

For weed control, IPM CRSP on-farm studies showed that one application of the correct herbicide followed by timely hand-weeding controlled weeds as well as the farmer practice of two herbicide treatments followed by three hand weedings. Weed

Table 6.2 Comparison of shallot growers who use the microbial agent (SeNPV) to control insect pests to growers wo follow conventional chemical-based practice. Cirebon, West Java and Brebes, Central Java, September 1998

Item	SeNPV users ($n = 17$)	Conventional growers ($n = 52$)
Area and yield		
Area harvested (m^2)	1847.1**	1473.1
Yield (kg/1000 m^2)	678.4	597.0
Pest control		
Pesticide applications per season	11.9***	17.4
SeNPV applications per week	2.4	
Production costs (US$/1000 m^2)		
Land rent	6.10	6.75
Irrigation fee	.42	.33
Total fertilizer cost	10.27	12.26
Insecticide	2.05***	9.88
Fungicide	3.43***	7.27
Herbicide	.50***	.97
Seed	115.00**	88.82
Land preparation labor	11.58	10.68
Planting labor	.66	.70
Cultivation labor	1.82	1.61
Hand picking labor	6.90	5.87
Pesticide application labor	4.23***	7.68
Fertilizer application labor	1.35***	2.03
Watering labor	10.88	10.94
Weeding labor	2.61	3.33
Irrigation maintenance labor	1.54	1.53
Harvesting labor	1.06	.83
Transportation	1.02	.75
Night guard	3.47	2.05
Tying labor & materials	.37	.40
Returns		
Price received (US$/kg)	.62	.57
Gross return (US$/1000$m^2$)	393.48**	309.26
Profit (US$/1000$m^2$)	205.80*	134.58

Note: * = significantly different at 90% confidence, ** = significantly different at 95% confidence, *** = significantly different at 99% confidence.

control costs were reduced by 15–70% without reducing weed control efficacy. Rice straw mulching was shown to be an effective weed management technique in on-farm research trials with farmers. Weed growth was reduced by 60%, yields were increased by 70%, and weed control costs were reduced by 50% (Miller et al. 2005).

6.3.5 Chilies

This crop is by far the most important of all the vegetable crops in Indonesia, with production of nearly 900,000 metric tons in 2005 (FAO 2007). However, development of a sound IPM program for chilies is the most challenging of all vegetable crops. The crop is attacked by numerous pests including insects, mites and plant pathogens (Vos and Frinking 1998). In addition, inappropriate agronomic practices, e.g., planting in low, wet areas which hinders healthy growth due to poor soil drainage often are major constraints to achieving maximum production. Major arthropod pests include mites, *Polyphagotarsonemus latus* (Banks) (Acarina: Tarsonemidae), and the CEW. Thrips and aphids may be important locally as vectors of plant viruses. Occasionally, farmers spray to control *S. litura*, but this insect feeds mostly on leaves and probably causes little damage in most cases. CEW, on the other hand, selectively feeds on the pods as does the gall fly, *Asphondylia* sp. (Diptera: Cecidomyidae), and these can cause significant pod loss. However, populations of these two pests are highly variable between seasons and locations. Recent information from West Sumatra suggests that parasites build up during the growing season and fruits that mature early are most affected. The fruit fly, *Bactrocera* (= *Dacus*) *dorsalis* (Hendel) (Diptera: Tephritidae), seems to be ubiquitous but the incidence of pod attack is usually not high in the major chili growing areas of Indonesia. Details of the agronomic factors and pests of chilies on Java were reported by Vos (1994). *Colletotrichum, Phytophthora, Alternaria, Cercospora*, *Pseudomonas* and viruses are usually among the most important groups of pathogens.

6.3.5.1 Farmer Participatory Research to Test IPM Strategies in Chilies

Field tests conducted in W. Sumatra demonstrated that seedbed height and control of soil pH with lime were effective in reducing the incidence of bacterial wilt. Insecticide sprays were not effective in increasing yields. This study was carried out in an area where CEW was not an important pest. In other areas, the use of the CEW virus (HaNPV) might be a viable tactic to replace chemical pesticides. Plant viruses, prevalent in many parts of S.E. Asia, may be managed using resistant varieties currently under development at the Asian Vegetable Research and Development Center (The World Vegetable Center) in Taiwan. Field tests are planned for 2008 to test these in Indonesia through support by USAID through the IPM Collaborative Research Support (CRSP) program administered by Virginia Tech University.

6.3.6 Yardlong Beans

Yardlong beans are second only to chilies in terms of area planted among vegetables and are an important part of the Indonesian diet. Major insect pests are the pod borer, *Maruca vitrata* (= *testulalis*) (Geyer) (Lepidoptera: Pyralidae), and aphids (usually *Aphis craccivora* Koch) (Homoptera: Aphididae). The extent to which *M. vitrata* causes economic losses is not understood and varies widely according to location and market supply and demand. This pod-borer damaged an average of only about 3 cm along the length of maturing pods but caused much more severe damage in younger ones. Economic losses from *M. vitrata* damage in yardlong beans in West Sumatra were estimated at about 25% (Zamzami, personal communication). Aphids are important both as a direct feeders on blooms and pods and also as virus vectors. Sucking bugs are almost always present in the crop but their importance may be over emphasized. *Ophiomyia phaseoli* also can cause yield reductions locally.

6.3.6.1 Farmer Participatory Research to Test IPM Strategies in Yardlong Beans

A field study, carried out by the USAID-Funded Clemson University Palawija IPM Project, FAO and the Provincial Plant Protection laboratory in Padang, West Sumatra, compared: (1.) farmers' usual practice (2.) no treatment but with good cultural practices and, (3.) designated "action windows" that we generated: for aphids, based on the literature (>100/hill), pod borer (>10% of pods damaged), Anthracnose (>10% infected leaves), and leaf spot (>10% infected leaves).

Yield from the farmers' practice treatment and the IPM "action windows" treatment were about the same, although the farmers' treatment called for eight sprays compared to two in the IPM treatment. The major difference was in the "untreated" control where *O. phaseoli* and aphids seriously reduced yields.

Another field study carried out with personnel from the University of Lampung revealed that late-planted yardlong beans were more severely attacked by CEW than those planted early. This difference was not as obvious for *M. vitrata*. In tests at the Muara field station in Bogor, mosaic virus reduced the plant population by 50%. IPM strategies must include tactics for dealing with aphid-borne viruses. Untreated longbean plots near Ciloto, W. Java resulted in over 50% losses due to the direct feeding by aphids (*A. craccivora*). Recent results indicate that "spot" treatments with aphicides versus treatment of the entire plot, may conserve natural enemies, but this approach requires that the crop be monitored at least twice weekly.

6.3.7 Eggplant

The major insect pest of eggplant is the fruit and shoot borer (FSB), *Leucinodes orbonalis* Guenee (Lepidoptera: Pyralidae). In some areas, this insect is the limiting factor to eggplant production. Farmers may apply insecticides 50 times or more in a single growing season (Miller et al. 2005). In spite of frequent pesticide applications, yields are reduced by more than one third due to this pest. Also, leafhoppers may be important locally. Of the plant diseases, bacterial wilt is most common. Losses to bacterial wilt in Central Luzon consistently reached 30–80%.

6.3.7.1 Farmer Participatory Research to Test IPM Strategies in Eggplant

Data from on farm research in the Philippines showed that simply removing damaged fruits and shoots reduced infestations by FSB and if carried out at harvest time, labor costs are reduced. This resulted in a net incremental benefit of $2,500 per hectare when conducted weekly and $1,000 per hectare for bi-weekly removal (Miller et al. 2005). The second approach is the identification of eggplant resistant varieties.

Bacterial wilt susceptible eggplant grafted onto resistant rootstock (EG 203) increased resistance to the disease by 30% and yields were higher. The stale seedbed technique which includes sequential harrowing or harrowing followed by a non-selective herbicide at bi-weekly intervals carried out during the fallow period between the rice and onion crops, was effective in reducing purple nutsedge tuber populations by 80–90% (Miller et al. 2005).

6.3.8 Tomato

Diseases such as early and late blight, powdery mildew, bacterial wilt, *Alternaria* and viruses are the major constraints to tomato production. Insects that vector viruses include thrips, aphids, and whiteflies. CEW and, sometimes, *S. litura* often feed directly on the fruit.

6.3.8.1 Farmer Participatory Research to Test IPM Strategies in Tomato

In North Sulawesi, Indonesia staking of tomatoes is not a common cultural practice and incidence of fungal diseases is high due to contact of plants with soil. Field tests in farmers' fields have demonstrated that staking decreases disease incidence and increases yield. This cultural practice has been readily accepted by many farmers and is now standard practice for the area.

In the Philippines, tomato plants did not survive well under the constant high moisture conditions during the rainy season. Farmer participatory field tests have shown that grafting tomato onto resistant eggplant rootstock greatly increases crop survival and improves yields.

6.3.9 Citrus

Surveys were carried out in a large citrus growing in the Karo District of N. Sumatra. Heavy infestations of fruit flies (20% of the fruit was infested) were observed. The fruit fly was identified as the papaya fruit fly, *Bactrocera papayae* Drew & Hancock (Diptera: Tephritidae). All growers in the area were reporting high levels of fruit loss from this pest. In addition to fruit flies, we observed lepidopteran larvae, *Citripestis sagittiferella* (Moore) (Lepidoptera: Pyralidae), in about 3% of the fruit.

6.3.9.1 Farmer Participatory Research to Test IPM Strategies in Citrus

Due to the intensity of citrus growing in North Sumatra, the only effective fruit fly management strategy would be an area-wide approach with all citrus growers participating. Without this, re-infestations of fruit flies would continue to occur in IPM managed areas. Tactics to be included in this management plan should include sanitation activities, spot spraying of protein baits mixed with insecticides, traps to monitor adult fruit fly populations, and early harvesting of fruit. If farmers can be organized in area-wide programs, there is great potential developing an effective IPM system for fruit fly in citrus-growing areas of Indonesia. Results from recent Farmer Field Schools emphasizing the use of compost and organic fertilizer along with reduced chemical pesticide applications in citrus in this area have shown that farmers can drastically reduce their input costs for fertilizer and pesticides (over 50%), allowing them to make a profit even when commodity prices are at their lowest point (Cahyana, personal communication).

6.3.10 Cotton

Cotton in these six countries of an IPM program for cotton sponsored by FAO and the European Union was implemented in six developing countries of Asia represented about 51% of the land area under cotton production world-wide and contributed to ca. 48% of the cotton produced. In India and Pakistan, more than 50% of all pesticides used were applied on cotton (Ooi et al. 2004). In the Philippines, pesticide costs on cotton account for nearly 65% of the costs of production. This has led to unsustainable production and resulted in a decline in areas under cotton. The entry point for IPM in cotton is the excessive use of insecticides. Using this entry point, Farmer Field Schools focused on a more ecological approach and the benefits of this change included a 34% decline in use of insecticides by farmers who participated in FFS (Ooi et al. 2005).

Cotton cultivation was first developed in Asia and this partly contributed to the large area of land devoted to cotton production. However, the relative small size of farms in Asia is challenging and indeed, demands an alternative approach to bringing IPM to cotton farmers (Fig. 6.4).

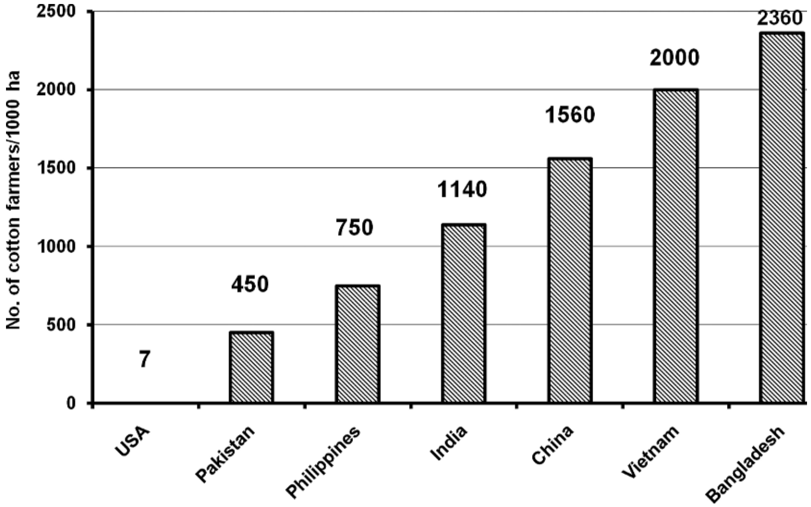

Fig. 6.4 Estimates of number of cotton farmers per 1000 hectares based on data compiled from various sources for year 2000 by the FAO-EU IPM Program for Cotton in Asia

6.3.10.1 Outcomes from a Participatory Approach to Cotton IPM

Ooi et al. (2004) illustrated the process of a participatory approach to educating farmers in cotton IPM in the six participating countries. Besides enhancing skills in better production techniques, the project also focused on farmer-to-farmer education to bring about sustainable IPM to a whole community, not just a few farmers. In addition, empowered farmers were better positioned as partners to researchers as shown in a study using genetically modified cotton – B.t. cotton. When B.t. cotton was introduced into Asia, there should have been a warning about the danger of relying on a single tactic for insect control. Farmers thought that B.t. cotton would solve all their insect problems which, of course, it did not. This was because B.t Cotton was developed only for bollworms and not for aphids, red spider mites, jassids and other sucking bugs. Hence, with farmers as research partners, studies leading to an understanding of the synergy of B.t. cotton and IPM were conducted with very promising results (Fig. 6.5).

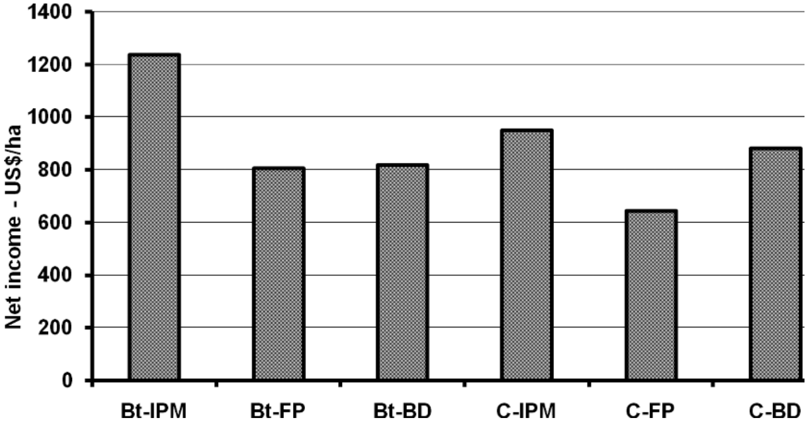

Fig. 6.5 Net incomes from farmer research in Xiantao, Hubei, China in the year 2001 under three conditions with both B.t. cotton (B.t.) and non-B.t. cotton (C). The three conditions were: fields where decisions for pest management were made after conducting cotton eco-system analysis (IPM); farmers spray in response to actual or perceived pest damage (FP) and no chemical insecticide sprays used (BD)

6.3.11 Summary and Future Directions

Field research and demonstration projects for most of the crops listed above have shown that substantial reductions of pesticide applications are possible without jeopardizing yields. Figure 6.6 summarizes results from field tests conducted in the mid 1990s in West Java, Central Java, and Sumatra, applying IPM principles with specific recommendations for each crop, and with broad applicability throughout S.E. Asia (Hammig et al. 2008). Given the potential reductions in pesticide

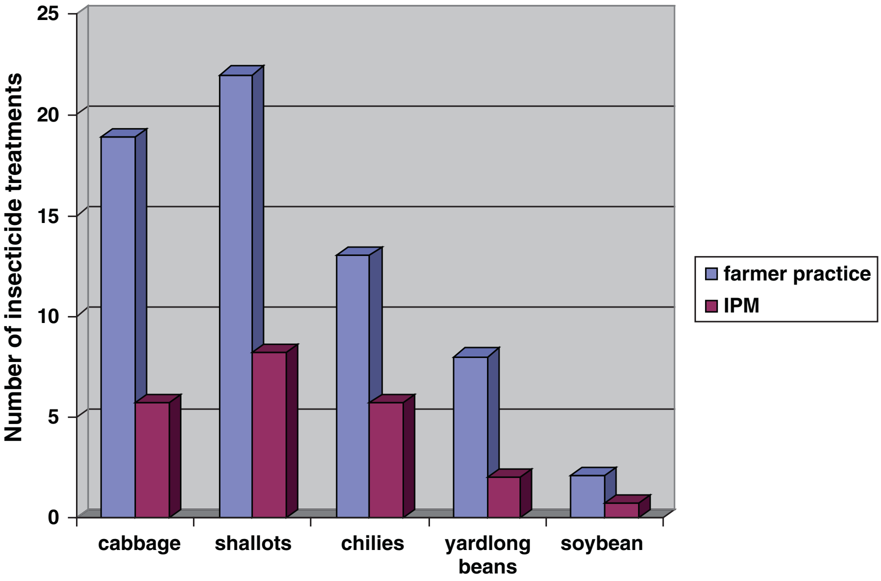

Fig. 6.6 Numbers of pesticide applications per crop per season made by vegetable farmers using their normal practice compared to IPM practices
Source: (Shepard et al. 2001).

applications, associated environmental and human health benefits justify a policy commitment to expand IPM to other areas.

Some of the IPM tactics that could have a major impact if adopted on a wide area are listed in Table 6.1. One constraint is that information about strategies and tactics found useful in one area is often not transferred to another. A mechanism to transfer information through FFS and farmer participatory research from one area to another would greatly expedite adoption on a wider scale. The information technology component of the IPM CRSP also will be helpful in this regard. We have found that workshops, which allow participants from different countries and regions within countries, to come together and exchange information, is a good way of exchanging information among researchers. Thus, researcher/farmer workshops should be an integral part of developing an IPM program. At another level, farmer participatory field studies and FFS is the most appropriate way to determine if the various tactics are applicable for specific locations and socio-economic settings.

6.4 Socioeconomic and Environmental Impacts

The impact on crop yields of IPM systems that reduce use of chemical inputs is positive in most cases, translating into higher gross economic returns. Evidence from field sites where developing country farmer groups employ the IPM approach shows that costs of inputs, because of dramatically reduced outlays for pesticides, decrease.

Thus, IPM farmers may enjoy higher profits than their traditional counterparts (Hammig and Rauf 1998, Hammig et al. 2008). Much of the economic evidence is anecdotal, but results from Indonesia consistently show improved returns by IPM farmers. A report by van den Berg (2004) analyzed 25 IPM impact evaluations. Although most of the examples were rice, they also included vegetables. The conclusion was that farmers who had participated in FFSs reported substantial and consistent reductions in pesticides attributable to the effects of the IPM training. Further, more pesticide reductions and higher farm-level revenues were realized in vegetables than in rice. Clearly, the anticipated economic bottom line is a key determinant of farmers' adoption of alternative production practices. Therefore it is important that analysts address long-term adoption patterns and the persistence of the benefits of IPM training. A survey of West Java vegetable farmers, some with IPM training and others without training, showed that the farmers with IPM training employed more sustainable farming practices compared to untrained farmers, even years after the training had occurred (Norvell and Hammig 1999).

The IPM training routine includes comparisons of fields employing IPM and traditional farmer practice. These comparisons are not just of what is happening to pests and crop yields, but also the impact on market returns. Farmer groups keep careful accounts of their expenses and the comparison of IPM and non-IPM results are the focus of group discussions during the training process. There is no doubt that area-wide adoption of IPM is contingent on positive results in the marketplace. If adequate returns are not assured, then the traditional practice will dominate, even after training. Fortunately, sound application of IPM principles invariably results in better bottom lines for farmers.

Health benefits from IPM must be considered along with higher market returns. Farmers relying on chemical pesticides pose a significant danger to themselves, their families and their neighbors, not to mention the environment of rural areas. Sustainable IPM systems reduce human health and ecological risks by reducing the volumes of many of the most toxic chemicals applied to crops. In a study from Vietnam, Murphy (2002) showed a direct correlation between frequency of pesticide applications and farmer illnesses. Kishi et al. (1995) found that IPM-trained farmers in Indonesia make fewer pesticide applications to their crops and when they do apply pesticides, they use less toxic chemicals than comparable farmers who have not participated in IPM training.

Impacts beyond the farm gate are meaningful components of comprehensive impact assessments. The highland vegetable areas of Indonesia, in almost all cases, are situated upstream from major population centers. USAID/Jakarta has recognized the critical importance of upland water catchment areas and agricultural practices on urban water systems by funding an Environmental Services Project (ESP). In cooperation with the Government of Indonesia, USAID is mounting a comprehensive effort to improve water quality in selected urban centers through improved land and agricultural management.

IPM programs are integral components of the ESP effort. Examples of this linkage include IPM training in West Java focused in the watershed feeding Jakarta and surrounding communities. Jakarta fresh vegetable markets are served from the mountainous region immediately to the south of the city. Local governments, Bogor Agricultural University, and international collaborators have been working with farmers in that region to reduce the runoff of harmful chemicals through IPM training for selected vegetable crops. Unfortunately, meaningful changes are constrained by the relatively slow process of farmer education. Local government budgets for IPM training are limited, so reaching large numbers is a slow process (Hammig et al. 2008).

In North Sumatra, the headwaters of the Deli River that provides water to Medan, the provincial capital is another area of concentrated vegetable production. The *Lembah Gulen* (Vegetable Valley) at the foot of Sibayak Volcano is a relatively small area composed of two villages, where the population is almost entirely dependent on vegetable production for its livelihood. Traditional production systems are similar to those observed elsewhere. Tomatoes, cabbage, shallots, chilies, and other vegetables are grown in continuous rotations. Prior to the ESP project, production systems were chemical-intensive, and farmers were frustrated by poor response to their control efforts. IPM training was first introduced in 2006, and farmers are eagerly adopting different approaches (Hammig et al. 2006). At the time of this writing, budget cuts to the ESP have reduced resources available for IPM in *Lembah Gulen*; however, farmers themselves are carrying on the program with some continuing support from the NGO, Farmer Initiatives for Ecological Literacy and Democracy (FIELD) (Weinarto, personal communication).

In North Sulawesi, the Lake Tondano watershed provides another example of the link between upland vegetable production systems and urban centers. The lake is located in a mountain valley, and the Tondano River flows from the lake to Manado, another provincial capital. It drains into the Molucca Sea at Bunakan, an Indonesian National Marine Park. The mountain slopes surrounding Lake Tondano are covered by vegetable fields with the usual mix of crops growing year around. An earlier USAID/Jakarta natural resource management program focused on environmental stewardship by local communities, spearheaded an effort to motivate local groups to seek better ways to improve the conditions of their environment. IPM training formed a part of this effort, and with assistance from scientists at Sam Ratulangi University, training programs were initiated for onion, cabbage, and tomato growers in the area in 1997 (Sembel, personal communication, 1998). Vegetable IPM continues to be a high priority activity for farmers and university scientists working in the area.

When farmers experience training for one of the selected crops, they recognize the need for training on the other crops they plant as well. This presents a challenge to IPM farmers and IPM trainers. Each crop has different pest management problems, and proposed alternatives for one crop may not be applicable to another. Therefore, the key to obtaining significant widespread impact is to establish a continuous process of field monitoring, research, and experimentation with the farmer as the central figure. Farmers can be introduced to IPM principles through training, and they can access technical support in critical times of need, but the greatest impact occurs when farmers themselves do their own experiments, and learn with experience how an ecological balance can be maintained in their fields while they continue to obtain positive economic returns.

Gender roles are important in determining socioeconomic impacts of IPM. In Southeast Asia, gender roles in agriculture vary from region to region. In some areas, field work activities are differentiated by gender. For example, planting, weeding, harvesting, and/or pest management tasks such as spraying or hand picking of pests may be jobs for which gender is the first order of selection.[2] Within the household, women are responsible for child rearing and common household tasks. Men do most of the heavy lifting, but by no means all. Data from the Philippines indicates that in Nueva Ecija province, women manage the household and farm budgets in the majority of cases (Hamilton et al. 2005). Therefore, IPM training, if it is to be effective, must be sensitive to gender roles in the production and management of the crops. Decision-making is the essential foundation of IPM, so it is essential that the key decision-makers are informed of the ramifications of their choices. In Southeast Asia, trainers include both men and women, and they are sensitive to the need to ensure that there is no gender bias in selection of training groups. However, recognizing the need does not mean that overcoming obstacles to attaining the ideal gender mix in IPM training is easily accomplished.

In the Philippines, Tanzo (2006) found that the following key gender-related issues must be considered for effective IPM training. Domestic tasks overlap with field activities. In the field, women are frequently found weeding, handling pesticides and hand picking pests. Household tasks include clothes washing, food preparation, and family health care. Women are more involved in vegetable pest management than with rice because of their frequent roles in field monitoring and hand picking. They are exposed to pesticides both in the field and while washing pesticide-soaked clothing. Daily schedules often conflict with IPM training programs, so few women, relative to their importance in the decision-making process, can take advantage of IPM training opportunities.

Impacts of area-wide pest control efforts in Indonesia, implemented over the nearly 20 year history of IPM training, have yielded important benefits to farmers, the environment, and consumers of farm products. Evidence of these benefits is apparent from many studies addressing a range of issues. However, in Indonesia and other countries in S.E. Asia with similar demographics, where over 40% of the population is involved in production agriculture, the process of spreading the IPM message is slow. The best sign suggesting that there is significant momentum to the IPM paradigm comes from farmers who have embraced IPM and who are the primary motivators for engaging their peers.

The effect of educating farmers in FFS in an attempt to empower poor cotton farmers to make better production management decisions and thus take greater control of their lives in six developing countries in Asia was reported in Ooi et al. (2004, 2005). Using a double delta model enabled the FAO-EU IPM Program for Cotton in Asia to use impact assessment both as a tool for strategic planning as well

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[2] In Central Java shallot fields the traditional pest control practice is for women to handpick pest egg masses from shallot plants at the same time that men apply chemical pesticide sprays.

as quantifying the benefits of change brought about by IPM. That cotton farmers averaged 23% increase in gross margin relative to the control group (USD$175/-per ha), suggests that the project was on target to improving farmer livelihoods and reducing poverty.

A similar effort to study the impact of FFS in sustainable vegetable production in the Mekong region was reported by Ooi et al. (2007). This project has a large component of IPM to ensure safe vegetable production.

6.5 Conclusions

This chapter discusses IPM strategies for developing country situations as they contrast with strategies for developed countries. At their most basic, IPM strategies everywhere are designed to provide acceptable pest control at some optimal level of intervention. With IPM, pests are controlled in effective, environmentally friendly ways. To be effective, farmers must obtain pest control suitable for their crops in a cost effective manner. To be environmentally friendly, the negative secondary effects of pest control – water pollution, human exposure, harm to biodiversity, etc. – must be taken into account. Achieving these ends requires an astute decision-making process that is based on solid understanding of the consequences of actions taken. Thus, the farmer must have the critical information necessary to judge when to act and when not. Systems for providing and utilizing this information differ significantly between developed and developing country situations.

In developed countries, farms tend to be larger and farmers are, in general, better educated and better equipped to access information from outside the farmstead. Therefore, considerable success has been achieved by professional extension services that focus specifically on pest control issues, and private firms that provide farm-specific input to aid the decision process. In the end, the farmer determines the actions appropriate for his situation, but he is operating in a well-informed environment for making those decisions.

In developing countries, large numbers of small farms operated by farmers having very limited resources – financial as well as knowledge-based – provide a very different environment for IPM implementation. Farmer Field School training programs, begun in Indonesia and expanded to developing countries worldwide, take a very different approach to farmer education with respect to pest control from IPM education in developed country situations. Farmers learn to closely monitor the ecology of their fields and to identify beneficial organisms as distinct from pests. IPM principles are simple, but field ecologies can be very complex. Thus, it is imperative that strategies for developing countries are backed by a strong research infrastructure as well as a commitment by national and local governments, NGOs, and international institutions to invest heavily in continuing training and research programs to convey the lessons of IPM to small-scale, limited-resource farmers so that, in the end, farmers, rural communities, and the vast numbers of urban consumers all share in the benefits of IPM.

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Chapter 7
Moving On: Farmer Education in Integrated Insect Pest and Disease Management

Janice Jiggins and Francesca Mancini

Abstract This chapter explores intensive hands-on occupational education for farmers in selected European, African, Latin American countries and in south India. An Indian case study of Farmer Field Schools for Integrated Pest and Production Management (IPPM) to ensure food security and livelihood improvement is presented, to introduce discussion of the role of IPPM beyond improving agriculture productivity. Does it enable farmers to adopt practices that move food and farming systems toward a low carbon economy? Does it help mitigate the effects of climate change? Does it help small farmers reach the combined goals of sustainability and development?

India is experiencing unprecedented economic growth, based primarily on service sector development, yet income inequalities are widening and the number of poor – 300–400 million living mainly in rural areas – is not decreasing as a consequence of a deepening agrarian crisis. Agriculture for marginal farmers provides the major part of their family's nutritional requirements; however, it is no longer the primary source of income, neither does it ensure food security. Climatic change effects, with higher temperatures and less rainfall, have reduced further the viability of farming in drought-prone areas. The tendency is for millions of poor farmers to leave agriculture, aspiring to join the service sector but more commonly ending up among the urban destitute.

The prospect for agriculture in India is thought to lie in a mix of high science applied in favourable areas to sustain the grain, legume, and oil seed output needed for basic food security; for high value crops for the rising domestic consumer and export markets; expanded investment in market-led enterprise development and skills training in rural areas; and renewed attention to farm-based livelihoods and agro-ecosystem functioning, especially in rainfed farming. This chapter addresses livelihoods and agro-ecosystem functioning, and specifically the role of IPPM as a means for strengthening agro-ecosystem resilience in the face of environmental changes.

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7.1 Introduction

Agricultural development effort over the last half century has focussed on the introduction of new technology and practices for increasing yield, and on the strengthening of agricultural services and markets. At the same time, governments in developing countries have struggled to provide to all citizens a general school-based education, focussing on primary-level numeracy and literacy, even in remote rural locations. But there has been a big gap in provision that is in itself hard to understand: the lack of serious effort to provide and sustain occupational education that addresses the core tasks of the majority of rural people, that is, their farming and post-harvest enterprises. This chapter addresses recent efforts to develop farmer-centred occupational education, in particular in relation to the management of insect pests and diseases.

Our principal concern is to explore by means of a case study from India the contribution of Farmer Field Schools (FFSs) to the provision of occupational education in Integrated Pest and Production Management (IPPM). However, we begin by briefly presenting examples of innovation in the way that opportunities to learn about integrated management of insect pests and diseases are being brought to farmers in other parts of the world. We do this in order to provide a frame of reference for discussing in the third section the potential of combining different ways of providing occupational education to farmers in India.

Although we take IPPM as our theme we believe the lessons we draw may have much wider application. Recent scientific assessments provide strong evidence that agriculture is substantially implicated in the exhaustion and degradation of natural resources (Comprehensive Assessment of Water Management in Agriculture, 2007), negatively impacts biodiversity and ecological function (MEA, 2005), is a large emitter of the gases forcing climate change (IPCC, 2007), and that the costs are unequally distributed among income classes (Srinivasan et al., 2007). Many efforts are ongoing throughout the world to reduce these impacts on the one hand and on the other to move toward creating agricultures that absorb carbon and sustain ecological functioning. The two outstanding characteristics that these efforts share is that they (i) require farmers to make informed, site-dependent decisions based on a thorough understanding of the principles of what tends toward sustainability; and (ii), depend on the millions of small farmers becoming organised to take the lead or enter into effective partnerships with other organisational actors to defend their ‘freedom to operate’ in a highly unequal competitive marketplace. Obviously, simple ‘transfer of technology’, extension campaigns and mass media messages will continue to play their part in bringing about change. Yet the key message is that resilient, sustainable agro-ecologies require confident farmers, well-educated in their occupation, who have the skills to learn and who are able to network and organise for self-directed change. We return to these points in Part III.

7.2 Part 1: Innovations in IPM Education from Around the World

We present here initiatives in six European countries, the push-pull program in East Africa and mobile plant health clinics in various countries in Latin America. Together they represent 'cutting edge' practices that seek to extend farmers' access to knowledge and knowledge products and to offer new means for farmers to generate their own reliable site-specific knowledge. They also represent new pathways for closing institutional gaps. Institutional failures, under development trajectories led either by Green Revolution actors or more recently by private industry, so far has prevented the placement of science in society in ways that are effective for the combined goals of sustainability and development for the mass of the rural poor.

7.2.1 Assorted European Initiatives

A new Directive for the Sustainable Use of Pesticides[1] and a new Regulation[2] for the placing of pesticides in the European Union (EU) market were adopted by the European Commission in July 2007 and completed the approval process by the European Parliament and Council of Ministers in January 2008[3]. The provisions in the Directive include training activities to raise public awareness, compulsory checks on spraying equipment, a ban with restrictions on aerial crop-spraying, establishment of 'reduced' or 'pesticide-free' areas, measures to protect water resources and the compulsory implementation in all Member States (MS) of Integrated Pest Management (IPM) from 2014 onwards. IPM is defined as:

> Careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep plant protection products and other forms of intervention to levels that are economically justified and reduce or minimise risks to human health and the environment. Integrated pest management emphasises the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural control mechanisms

This definition is in line with the definition in the FAO Code of Conduct that already has been agreed by FAO Member States, CropLife International (the umbrella organisation of the crop protection industry) and non-government organisations. However, the Directive leaves open to MS how far they want to go in pushing reduction of use of crop protection chemicals and in risk avoidance, providing funding to support farmers to take up IPM, and introducing alternative options as standard practice. There are no specific measures for collecting and dealing with stocks of obsolete pesticides.

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[1] http://ec.europa.eu/environment/ppps/home.htm

[2] http://ec.europa.eu/dgs/health_consumer/dyna/press_room_en.cfm

[3] Directive 2008/17/EC; Regulation No149/2008

The Regulation maintains the current dual system of approval of substances by the EU and approval of products by MS. However, it introduces a positive obligation to replace riskier pesticides with safer alternatives and requires the adoption of hazard-based criteria for the approval of substances. Very hazardous substances are no longer accepted[4]. Substances defined as very hazardous include Carcinogenic, Reprotoxic or Mutagenic (CRM) categories I and II as defined by Directive 67/548/EEC; Persistent, Bio-accumulative, and Toxic (PBT) substances; very persistent, very bio-accumulative (vPvB) substances; Persistent Organic Pollutants (POPs), as defined by the Stockholm Convention; and those listed under EU Community or internationally agreed test guidelines that consider substances with endocrine disrupting properties. However, the approval criteria in effect remove very few of the currently used substances from the market altogether.

A new element in the registration and approval procedure is that protection of children and vulnerable groups is specifically mentioned as an obligatory criterion in the assessment procedure but a methodology to assess safety factors in setting Maximum Residue Limits (MRLs) and Acute Reference Doses is missing, as are criteria for defining Low Risk Substances (which enjoy a simplified registration process). Further, the Regulation appears to give more weight to market efficiency criteria than to health and environment considerations. For instance, the designation of zones, within which products authorised for sale in one country are automatically authorised for all countries in that zone, has been revised on market efficiency grounds. The new ‘zonal authorisation’ boundaries bizarrely couple unlike agro-ecosystems and unlike climates[5]. The zonal designations may threaten countries such as the Netherlands, Sweden and Denmark with the re-introduction to their markets of a number of products they have successfully removed from sale. However, some authorities think, to the contrary, that the designation will push standards within the zones toward IPM best practices and clear the more toxic products from markets where regulation has been weakest.

The EC estimates the agreed measures will lead overall to a 13 per cent reduction in pesticide use. Some MS already are forging ahead regardless, aiming to achieve use reduction levels considerably above this level. The urgent necessity of doing so has been unequivocally demonstrated by the EC’s own monitoring report, that covered 60,450 food samples (European Commission, 2006). It showed that 40% contained pesticide residues with an additional 3% containing levels in excess of

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[4] The hazardous substances covered are given in Annex I of Regulation No149/2008 of 29 January 2008; they include acephate, acetamiprid, acibenzolar-S-methyl, aldrin, benalaxyl, benomyl, carbendazim, chlormequat, chlorothalonil, chlorpyrifos, clofentezine, cyfluthrin, cypermethrin, cyromazine, dieldrin, dimethoate, dithiocarbamates, esfenvalerate, famoxadone, fenhexamid, fenitrothion, fenvalerate, glyphosate, indoxacarb, lambda-cyhalothrin, mepanipyrim, metalaxyl-M, methidathion, methoxyfenozide, pymetrozine, pyraclostrobin pyrimethanil, spiroxamine, thiacloprid, thiophanate-methyl and trifloxystrobin.. The MRLs are given in Annexes II, III, IV.

[5] North – Denmark, Estonia, Latvia, Lithuania, Finland, Sweden; Centre - Belgium, Czech Republic, Germany, Ireland, Luxembourg, Hungary, Netherlands, Austria, Poland, Slovenia, Slovakia, United Kingdom; South – Greece, Spain, France, Italy, Cyprus, Malta, Portugal.

EC MRLs. An analysis of pesticide residues in eight fruit samples on sale in the GB Express Supermarket (owned by Carrefour, Belgium, one of the world's leading supermarket chains) that is located in the European Parliament building, Brussels, revealed the presence of 28 toxic pesticides, averaging almost five residues per fruit; none were uncontaminated (PAN Europe, 2007a). Three of the samples contained pesticide residues in excess of EC MRLs (in the case of oranges from Spain, the level of imazalil, a known carcinogen, was 40% above the Acceptable Daily Intake for a 5 year old, who would also eat 70% of the Acute Reference Dose by eating just one orange).

A six-country case study (PAN Europe, 2007b) showcases successful strategies that farmers are adopting ahead of the new Directive and Regulation. They demonstrate that competitive and effective alternatives to harmful pesticides exist that can be brought into widespread practice when supported by creative institutional changes. The cases[6] are briefly highlighted in turn. It is not possible to give comparative data for these countries on trends in pesticide use, active ingredients or sales because of differences in the ways that data have been collected between countries and over time. The new European Directive will considerably aid the effort to collect and register uniform data in future years.

7.2.1.1 Belgium

A not-for-profit fruit farmers' association in Wallonia, Belgium, supports IPM in fruit production in approximately two-thirds of the fruit growing area in the region. It has developed standards for Integrated Production (IP) based on guidelines issued by the International Organisation for Biological and Integrated Control of Noxious Animals and Plants (IOBC). The guidelines include, for instance, requirements to plant or preserve natural hiding places for beneficial insects, placement of nest boxes and perches for birds, planting or enrichment of mixed hedges around the orchards, and specification of permitted weed management and of the alleys between rows. Soil fumigation and bare soil between trees are not permitted.

Permitted pesticides are confined to those listed in the guidelines. All pesticides are classified as either 'green' – may be used when use is justified; or 'yellow' – may be used only when no 'green' product is suitable; or 'orange' – may be used only if necessity is established and permission granted by the association. Pesticides on a 'red' list are prohibited; growers cannot use more than two products on the orange list per year per hectare. The association provides training to its member farmers based on group meetings through the year, typically held in a grower's orchard, organises field visits and study trips, provides a warning service for major pests and a telephone advisory service. A members' marketing cooperative, operating under the label, FRUITNET, has captured 12% of the Belgian pome fruit market, through a supermarket chain (Delhaize-Le-Lion), selling through 120 national outlets.

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[6] The full report can be read on www.pan-europe.info

7.2.1.2 Denmark

Here the initiative was taken at the political level, with the launch of the first Pesticide Action Plans (PAPs) in 1986, as politicians became alarmed at the evidence of contamination of food and water resources by pesticides. Wild plant diversity in farmland for instance decreased by 60% from 1970 to 1990. The aim from the start has been to use the PAPs to reduce pesticide use. The 1985–1997 PAP targeted a 25% reduction in total pesticide consumption by 1992 and 50% by 1997. The 1997–2003 PAP introduced a new monitoring and control instrument, the 'indicator treatment frequency index'[7]; farmers were required to register data on their 'treatment frequency' per crop/season, with the aim of reducing this to 2.0 by 2003. The PAP also established 20,000 hectares of pesticide-free zones along the margins of waterways and lakes. The current PAP, 2003–2009, aims to reduce the treatment frequency to below 1.7, to promote pesticide-free cultivation, establish an additional 25,000 ha pesticide free margins along waterways and lakes. While the first and second PAPs impacted mainly arable and grassland, the current PAP includes also fruit and vegetable production.

The farmers' organisations, that in Denmark provide by far the majority of advisory activities, responded by developing information materials and services to help farmers make the transitions required. A key to changing farmers' decision-making and behavior have been the plant protection groups, established from 2001 onwards, that meet in the field several times during a season, to observe, measure and discuss the options. Changes also were introduced in the pesticide approval scheme. Some 209 pesticide active ingredients were reassessed at the beginning of the 1990s and only 78 were given renewed approval. The government also used the 'stick' of changes in taxation, replacing the former 3% charge on wholesale turnover by an *ad valorem* tax (value added tax) on pesticides, herbicides and fungicides. Currently the tax amounts to 34% of the wholesale price of herbicides and fungicides and 54% for pesticides. Thirteen per cent of the revenue from the tax is retained by the government to cover the costs of the approval and regulatory authorities and research; 83.5% is returned to farmers through funds targeted to maintain the resilience of the farm sector. Danish farmers indeed now use more than 50% less pesticides (by active ingredient) than they did twenty years' ago; a drop from some 7000 tonnes of solid active pesticide ingredient to 3000 tonnes. Water quality has improved twofold, the number of domestically produced food samples with detectable residues has markedly decreased – and the economic consequences for farmers has been neutral or positive.

Robust analyses pinpoint as decisive factors in this success as: decisive political leadership (sustained through three cycles of PAPs), clear targets and indicators, a revision of all substances permitted for sale on the Danish market, introduction of buffer zones to protect water resources and mandatory record keeping by farmers.

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[7] The treatment frequency index expresses the average number of times an agricultural plot can be treated with the recommended dose, based on the quantities sold.

The PAPs in addition have provided comprehensive and independent training, implemented largely through Denmark's network of strong farmers' organisations.

7.2.1.3 Switzerland

Switzerland has achieved a 40% reduction in insecticide (including acaricide) sales over the five years 2000–2005, and from just under 16,000 tons active ingredient to 14,000 tons active ingredient for all agro-chemicals[8], an overall decrease of 11.6%. It has done so in part by directing the subsidy program (that almost all farmers are eligible for) toward regulations that require farmers to adopt minimum ecological standards. These include limiting the use of pre-emergence pesticides, using pest warning services and prognosis models when taking pest management decisions and testing spray equipment at least once every four years. Farmers can access further subsidies if they demonstrate additional substantial decreases in pesticide use: in 2004, 11,000 cereal farmers, 13,000 animal fodder producers, and 2000 rape seed producers enjoyed these additional payments. The second main pillar of Swiss efforts to reduce pesticide use is the development and wide application of Integrated Production (IP) protocols. Over 18,000 farmers have joined IP Suisse, a farmers' association that works to support its members in adopting strict measures. Together they have grown 110,000 tonnes of wheat, 30,000 tonnes of potatoes and 2000 tonnes of rapeseed. Over 3000 of Switzerland's 4000 professional fruit growers grow IP certified fruit and account for the main output of apples, strawberries and raspberries. All major retailers and food processors in Switzerland sell IP Suisse products, including Migros, Switzerland's largest supermarket chain. Further, in Switzerland all McDonald's buns are baked from IP Suisse certified wheat and 63% of its meat and 30% of its rapeseed oil are from IP Suisse farms.

7.2.1.4 Netherlands

The Netherlands is the second largest exporter of agricultural products, by value, in the world (at 40.9 billion Euros, compared to USA's 57.2 billion Euros, 2003 data). Dense human settlement, highly intensive production in the presence of three large river systems, numerous waterways and drainage canals and mounting evidence of the harmful effects of agricultural pollution, coupled with increasing public pressure to move toward safe, productive and profitable management of the 'green space' commanded by agriculture, meant that by the mid 1980s the government had to act to restrain pesticide use. It forced through a new policy requiring within a specified time period major reductions in the amount of active ingredients reaching the soils, water and air but it left it up to the agricultural industry how to achieve these targets. By the turn of the century the easy gains had been made: over-use had been eliminated, less toxic products were brought into use, glasshouses made greater use of

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[8] Rodenticides, insecticides, aracnicides, fungicides, bactericides, seed treatments, plant growth regulators, herbicides.

biological controls and closed water management systems and competitive pressures had encouraged wider adoption of less wasteful precision application equipment and methods. In 2003 the government together with the national farmers' organisations launched a new national Agreement on Crop Protection, supported by a fund of Euro 14 million, to promote Integrated Crop Management (ICM) throughout the sector in the context of a highly intensive farm industry and a legal obligation under European law to reduce the impacts of agriculture on water resources. An advisory service for the implementation of low pesticide farming methods has been established, working both with individual farmers and with farmer study clubs. Environmental Impact Cards to provide guidance to farmers have been introduced, as well as an Environmental Indicator to track performance and progress at the national level. The targets of the Agreement, taking 1998 as the reference year, are to reduce:

- overall environmental impact of pesticides by 75% by 2005, and by 95% by 2010;
- the impact of pesticides on surface water by 50% by 2005 and by 95% by 2010; and
- reduce the percentage of food samples exceeding MRLs by 50% by 2010, in comparison to 2003; as well as
- achieve usage of uniformly labelled and certified pesticide products by 100% of farmers by 2010.

Best Practice ICM protocols have been developed for all the major crops. The crop-specific protocols are generally two pages long, containing on the first page a table listing the recommended individual measures. The second page gives more detailed explanations, followed by a list of references and resources. The measures are categorised according to a 'scientific hierarchy' and a 'hierarchy according to the Agreement on Crop Protection' (Table 7.1). The reason for this was to provide flexibility in farmers' practice, to accommodate the needs of the range of highly specialised sub-sectors that comprise Dutch farming. The protocols are further developed, so that each measure is weighted (Table 7.2).

Growers' associations reviewed all the draft Best Practice materials and their views were taken into consideration in the final versions. The Environmental Impact Cards are similarly designed for practitioners. They provide a quantified guide of the impacts of specific practices. For instance, the card used by apple and pear growers

Table 7.1 Scientific hierarchy and hierarchy according to agreement on crop protection

Scientific hierarchy	Hierarchy according to Agreement on Crop Protection
Prevention	Prevention
	Cultivation technique
Determining control necessary	Warning and advice systems
	Non-chemical crop protection
Control	Chemical crop protection
	Emission restriction

Source: Table 7.2, Pan (2007b), p.11.

Table 7.2 Weighting of 'best practice' measures

Degree of implementation	1 = generally in practice 2 = only at trendsetter farms 3 = only at experimental farms 4 = strategy still being developed
Restrictions/limitations	1 = cost 2 = labor 3 = risk 4 = perception of risk and unfamiliarity 5 = not registered
Contribution to the reduction of environmental impact	1 = reduced dependence on the chemicals 2 = big 3 = moderate 4 = small 5 = none
Application in Organic Farming	1 = measure applicable in organic agriculture 2 = measure not applicable in organic agriculture

Source: Table 7.3, Pan (2007b), p.11.

registered with the Farming with Future (Telen met Toekomst) network, can see 'at a glance' that 'for the pesticide product 'Apollo' (active ingredient clofentenzine), the time of usage is March-August, the recommended dose is 0.45 litre/ha (0.23 kg active ingredients/ha), and the Environmental Impact Points for groundwater is zero' (PAN Europe, 2007b, 13). However, the card also shows that Apollo's environmental impact on aquatic organisms is highly variable according the season of use and the percentage drift (17–1%).

The policy objective was clear, it had received wide support, and the scientific underpinning of all recommended measures was robust. However, the weakness of the Agreement was that it relied in effect on voluntary compliance and lacked a strong economic driver. However, in 2005 a Dutch supermarket, Laurus, offered farmers who had adopted the ICM Rest Practices a premium, initially covering apples, pears, strawberries, parsley, cabbage and lettuce, and since extended to glasshouse produce such as tomatoes, cucumbers and peppers. Discussions are underway between the farmers' organisations, consumer organisations, Laurus and other supermarket chains to establish a consumer certification scheme for Best Practice ICM produce.

7.2.1.5 Italy

In 2001 Legambiente, Italy's largest environmental NGO (with some 20 regional committees and more than 1000 regional groups), launched a campaign to support farmers to produce fruit and vegetables free of pesticide residues. Over 230 farms, including Italy's largest food cooperatives, have joined the project. A LAIQ logo (Legambiente per l'Agricultura Italiana di Qualità) has been introduced for products certified pesticide free and protocols have been introduced for low pesticide agriculture for potatoes, peaches, apricots, onions, kiwi fruits, tomatoes, apples, carrots, lettuce and figs. The scheme promotes the use of IPM, the use of pesticides with low persistence and the extension of the period between the time of final spray and harvest. Legambiente every year carries out, without prior notification, pesticide analysis for 5–10% of the participating farms and checks farmers' spray records and their plant protection methods. In the few cases where residues are detected, the food is withdrawn from the scheme and the farmers receive special advisory services to help them improve their performance. Recent results of the random testing show that the goal of supporting pesticide-free produce (i.e. in compliance with MRLs) has been achieved almost completely, though not all co-operatives managed to reach zero residues.

7.2.1.6 United Kingdom

UK has one of the largest co-operative retailers in the world, the Co-operative Group (known simply as 'the Co-op'). Its food retail operations generate sales of over Euro 4.4 billion a year. Its agricultural division, Farmcare, is the largest farmer in the UK, managing some 10,000 ha of Co-op owned land and 20,000 ha of farm land owned by other landowners. In 1999 the Co-op brought in an international Code of Practice on pesticide use. The Code prohibited 23 pesticides from use on all farmland managed by itself and in all farms worldwide supplying the Co-op's retail outlets (Table 7.3). It thereby raised standards within the UK (seven of the pesticides on the banned list were authorised for use in the UK) and it used its purchasing power to raise standards beyond the reach of its own agricultural operations. A further 32 pesticides were placed on a restricted list that farmers could use only with written permission.

Recent analysis shows that the Co-op receives only 3–4 such monthly requests, signalling major impact in overall use reduction. The Co-op at the same time provides guidance on Integrated Farm Management (IFM) and farmer advisory sheets explaining the IFM protocols for a range of crops. In addition, Farmcare at certain sites in its own landholding portfolio conducts research into low pesticide production. An independent ten-year assessment showed that the Co-op's IFM methods, which prioritise biological and mechanical strategies, can halve pesticide use without compromising profitability.

These examples from six European countries show that there is no single route to achieving pesticide use reduction. Some have been led by government policy, others by civil society initiatives or by food retailers. Some have used the 'carrot' of subsidies and others have relied more or in addition on the 'stick' of regulation. But in all cases farmer organisations have played a central role; focussed scientific research has been essential; and the provision of high quality support materials, opportunities for learning along the entire food chain, and targeted advisory services have been a necessary ingredient in the successes achieved. It is worth stressing that in all six cases substantial and widespread reduction in use has been achieved without loss of yield or profitability in highly competitive markets. When pesticide use reduction is associated with new branding of farm products and development of

Table 7.3 List of prohibited and restricted pesticide by the Co-operative group (July 2006)

Prohibited	Restricted: usage with permission by Co-op only
Dieldrin+	Aldicarb
Endrin+	Benomyl
Aldrin+	Captan
Chlordane+	Carbenazim
Hexachlorobenzene+	Chlordimiform+
Heptachlor+	Chlorothalonil
Lindane	Daminozide
DDT+	Dicofal
Cadusaphos+	Dienochlor+
Chlorfenvinphos	Disulfoton
Demeton-S-methyl+	Endosulfan
Ethoprophos	Fentin
Fenamiphos+	Ferbarn+
Omethote+	Lead
Phorate	Linuron
Phosphamidon+	Mancopper+
Prothiophos+	Mancozeb
Tebupirimiphos+	Maneb
Terbufos+	Mercury
Haloxyfop+	Methoxychlor+
Triazoxide	Metiram+
Captfol	Nabam
Chlordecone	Nickel Bis (dimethyldithiocarbamate)+
	Propineb
	Thiophanate Methyl
	Thiram
	Toxaphene+
	Tributly tin+
	Vinclozolin
	Zineb
	Ziram
	Other thylene thiourea and propylene thiourea generators

+ = not authorised in Great Britain.
Source: Table 8 in PAN Europe 2007b, p. 34.

new market outlets, it can generate additional profits for farmers and others along the food chain.

7.2.2 Push-Pull in East Africa

So-called push-pull strategies are based on the manipulation of insect pests and their natural enemies by means of stimuli that act to make the protected crop resource unattractive or unsuitable to the pests (push) while attracting them toward another source (pull) where the pests can be removed. In general the push and pull components are non-toxic and are integrated in methods for reducing the population of the target pests by measures such as biological controls.

The efficacy of the strategy relies on careful orchestration of the additive and synergistic effects of the stimuli, with the aim to reduce pesticide use (Cook et al., 2006). There is thus no specific 'recipe'. The strategy requires adequate scientific resources to develop clear understanding of a pest's biology and on the behavioural and chemical ecology of its interactions with its hosts, other insects of the same species and natural enemies, at the level both of principle and in any given set of local conditions.

Potential components for push stimuli include visual cues, synthetic repellents, non-host volatiles, host-derived semiochemicals, anti-aggregation pheromones, alarm pheromones, antifeedants, oviposition deterrents and oviposition-deterring pheromones. Potential components for pull stimuli include visual stimulants, host stimulants, host volatiles, sex and aggregation pheromones, gustatory and oviposition pheromones.

Practitioners can build the appropriate components into a viable crop protection practice by a variety of means. These could include, for instance, the introduction of natural products (such as plant extracts) or nature-identical analogues (usually through synthetic production and release in formulations such as slow release dispensers that may add robustness to the strategy). The use of plant extracts may provide opportunities for local production and new income opportunities for rural communities. Vegetative diversification by means of intercropping and trap cropping are common traditional practices that often can be improved in collaboration with scientists. Further modification of the vegetation mix, for instance by the introduction of cultivars with antixenotic properties i.e traits that modify herbivore behavior by conferring nonpreference, that typically are exploited in non-host intercrops but that also may deliver push stimuli in the main crop. Plant hormones such as salycilic acid or jasmonic acid may be used as chemical elicitors that induce the mobilisation of plant defences in a crop; since the same chemical may induce susceptibility in other plants, and different elicitors can elicit different responses in the same crop, this competent requires informed choices to be made. The use of mass-trapping and attractor traps, when appropriately designed and positioned, may prove more robust in general farm practice, especially among poor farmers who have few opportunities for learning.

Although this brief review of some of the potential components of push-pull strategies may give the impression that the strategy is too complicated to be introduced to small farmers in developing countries, it is the fact that the most successful documented application of the strategy was developed in eastern Africa for subsistence farmers, based on trials in Kenya (Khan and Pickett, 2004). Over 160,000 small farmers are now (2006) using push-pull strategies to protect their maize and sorghum against stem borer *(Chilo partellus)*, based on the combined use of intercrops such as molasses grass (*Melinis minutiflora*) and silverleaf desmodium (*Desmodium unicinatum*), and trap crops (such as for instance Napier grass (*Pennisteum purpureum*) or Sudan grass (*Sorghum vulgare sudanense*) that are locally available and exploit natural enemies (Khan et al., 2006). The rapid spread of Farmer Field Schools and Junior Life Schools (for school age children) throughout eastern and southern Africa is helping to carry the strategy to an increasing number of farmers[9]. The adoption of the push-pull strategy for stem borer has led to increased crop yields and livestock production (animals commonly are fed on the stover), with significant impact on food security throughout the region.

Moreover, an increasing number of public extension agents who used to promote chemical methods of control that small farmers could not afford and that are hazardous in the actual conditions of use, have also begun to throw their weight behind push-pull as the preferred strategic option. Some agrochemical companies, such as Syngenta, after initially seeing the strategy as a threat to their chemical sales, have begun to show interest, for instance in promoting semiotic signalling products as components of effective push-pull crop protection in small farm practice.

7.2.3 Mobile Plant Health Clinics[10]

We have chosen to include plant health in our examples partly because some plant diseases are transmitted by insect vectors and partly because it is an idea that could be further developed to include pest management. The Global Plant Clinic (GPC)'s development of mobile plant health clinics was initiated to answer for as many farmers as possible their question: What do I do? While scientists are good at asking questions and probing causes, farmers have problems of plant health defined by *symptoms* and an implicit or explicit demand for speedy advice on practical methods that solve these problems in the specific context of their own farm.

The GPC is an alliance established in 2005 between three UK-based science centres, Commonwealth Agriculture Bureaux International (CABI), Rothamstead Research and the Central Science Laboratory, as a worldwide diagnostic and advisory service, primarily for scientists. The spread of email and internet services expanded the demand as physical samples began to be supplemented by photos. Yet little of the benefits seemed to be reaching farmers nor the agronomists and extension workers who work regularly with farmers. On reflection, those concerned chose to re-think their diagnostic role, using the metaphor of plant doctors (rather than merely plant scientists) with social and clinical skills. Uganda, Bangladesh and Bolivia were the first three countries to experiment with mobile plant health clinics with GPC support.

In the preparatory training courses in field diagnosis, participants realised through hands-on practice and peer evaluation of their own performance, the necessity of first carrying out a careful inventory and recognition of the 'symptoms' and the context in which they arose, before rushing to premature diagnosis or proposing

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[9] Information available on <global-ffs-l@farmerfieldschool.net>; bibliography on <info@farmerfieldschool.net> (accessed January 2008).

[10] This section is based in part on discussion with Eric Boa, CABI, U.K., and Boa, E. 2007. Plant Healthcare for Poor Farmers: An Introduction to the Work of the Global Plant Clinic. An APSnet Feature Story. (The American PhytoSanitary service is the largest in the world). Accessed on line January 16, 2008, at: http://www.apsnet.org/online/feature/clinic/

remedies. In Bolivia, the first exercise in ‘going public’ was held in a crowded market place from the back of a pick-up truck. The agronomist from the national research and extension service, PROINPA, quickly attracted a crowd with his demonstration of a simple test to detect the presence of nematode cysts in the soil. CIAT, an international agricultural research organisation, at around the same time began to support community plant health clinics focussing on the integrated management of potato pests and diseases. The clinics are open most days of the week and located in small rural towns in key potato-growing areas.

In addition to the training another key to the early impact of the clinics has been their success in creating and sustaining routine links between those staffing the clinics, networks of specialists to whom samples and photos can be sent and laboratories able to help with ‘hard to diagnose’ cases.

By October 2007 eight countries had begun experimenting with the concept of plant health clinics, operating on a regular basis some 60 facilities. The biggest schemes currently are those operating in Bangladesh and in Nicaragua (Danielsen et al., 2006). In both countries effective links have been built among science facilities, non-government organisations (NGOs) and farmers’ organisations, including in Bangladesh the Grameen Bank’s women’s groups. There are numerous experiments taking place, as yet insufficiently evaluated, that explore the potential synergies between plant clinics and Farmer Field Schools (for instance in Sierra Leone), community-based technical colleges, NGOs and farmers’ organisations, and the use of modern media (such as farmer-generated short videos or DVDs) to support and spread information and skills in diagnosis and treatment options.

7.3 Part II: An Indian Case study

7.3.1 The Agrarian Crisis

Indian agriculture has undergone a major transformation from the time of independence, primarily as a result of the private and public investments made in a broad spectrum of technology (including plant breeding and cropping, irrigation, agricultural engineering and animal traction, food processing). After the production jump achieved in the 1980s, which enabled the country to become self-sufficient in its major foodstuffs, farmers by the turn of the millennium were reporting a decline in factor productivity caused by the overexploitation of natural resources, especially of water and land (Hanumathan Rao, 2004). The average annual growth rate of agriculture output in the years 2002–2006 has been the lowest since independence (1.87%). Annual grain production per capita has declined from 207 kg in 1995 to 186 kg in 2006 (National Planning Commission, 2007). Moreover, income inequalities are widening and the number of poor – 300–400 million living mainly in rural areas is not decreasing (World Bank, 2006, IFAD, 2006) as a consequence of what is now recognised as a renewed agrarian crisis that threatens the huge development gains of the recent past (Patil, 2007).

The policy and research strategies adopted to achieve rapid advances in agriculture productivity targeted mainly the favourable resource areas. However, two-thirds of the cultivated land of the country falls within semi-arid zones where large numbers of India's poorest people live (Vaidyanathan, 2004). State-level consolidated statistics on productivity have hidden the financial distress faced by marginal producers. For instance, a sharp rise in the proportion of indebted rural households, and in the amount of debt, was recorded in the same areas where high production levels were achieved. Forty percent of the credit requirements of farmers was, and still is, met by unofficial sources at high interest rates (Hanumathan Rao, 2004).

Public investments in agriculture are now down to 1.7% of Gross Domestic Product. The expansion of cultivated land is fast approaching its saturation point, as indicated by the decrease in the per annum growth rate of net area sown recorded since 1962 (Bhalla and Singh, 2001). An estimated 750,000 hectares of cultivated land are yearly diverted to industrial and infrastructure development purposes.

7.3.2 The First National Policy for Farmers

The Government of India has acknowledged the urgency of addressing the crisis in the agrarian sector by focusing policies on educating farmers and developing new eco-technologies. The National Policy for Farmers, approved in 2007, brings for the first time farmers' livelihoods, rather than agriculture, to the centre of government thinking. Its primary objective is to improve the economic viability of farming while protecting the natural resources that ensure the food and nutritional security of the country. The policy acknowledges that achievement of the policy entails retaining educated youth in agriculture. Creating 'science literacy' at the grass roots is thus seen as an essential investment that underpins the development of farmers' skills, practices and understanding of technical advances and, notably, signals that farming can become a dynamic pathway to a sustainable modern lifestyle in the countryside.

Integrated Pest Management (IPM) was introduced first in rice and cotton in 1974–1975 under the Operational Research Project led by the Indian Council for Agricultural Research (ICAR), that sought to develop area-specific IPM. In 1985 IPM was adopted nationally as the main plant protection strategy and implementation effort was intensified. The IPM strategy represents the earliest effort by the Government of India to promote agricultural growth based on a sustainable practice. The lessons learned from attempts to apply IPM principles in farmers' field conditions, and from a range of IPM extension approaches, over time have moved practice toward a higher involvement of farmers in the development and implementation of plant protection strategies.

At the onset, IPM was brought into practice through the use of the Economic Threshold Level (ETL). The ETL is an equation for calculating the level of plant infestation at which the economic returns resulting from pest control compensate for the cost of applying pest control (Thompson and White, 1979, Stern et al., 1959). The ETL's parameters include management cost, price of the farm produce and the expected damage or yield losses. These values are calculated in research stations and then extrapolated for national and state level application. In practice, the variability of the parameters used for the computation of ETL values proved to be a limitation to the reliable generalisation of ETLs over large geographical scales. Moreover, national recommendations were set at conservative levels with the benign intent of reducing the risk associated with late interventions. In practice, this was found to have the unintended counter effect of encouraging an unnecessarily high use of chemicals. Today, the reported adoption of ETLs at farmers' level is low (for Punjab, see Peshin, 2005).

The ETL concept is in principle functional if all factors influencing yield loss are considered and if it is applied in the specific situation used in the computation. But the requirement for specificity and precision to make pest control decisions that are effective in a specific time and place has led to the introduction of a more flexible tool called Agro-Ecosystem Analysis (AESA). AESAs enable farmers to calculate their own local thresholds for intervention on the basis of the actual field situation, by taking into account observations and measurements of the presence of natural enemies, plant health, weather factors, social aspects etc. (Berg and Jiggins, 2007). As a result of AESA, decisions on the overall plant management including nutrient and weed management are implemented to prevent or control pest problems (Table 7.4). Trained farmers tend to intervene at a higher pest incidence, if the environmental conditions are not conducive for pest build up, as compared to the officially recommended ETLs (Table 7.5). Farmers learn to perform this ecological analysis in a season-long educational intervention, the Farmer Field School (FFS). Farmers also learn good agronomic practices aimed to prevent the insurgence of pest problems.

7.3.3 The New Agenda: Meeting Current and Future Concerns

There are several advantages associated with the practice of IPM based on ecological analysis that are of particular relevance to current and future environmental concerns.

First, at the international level, all countries are urged to develop adequate agricultural research, extension and policy tools to respond to the requirements of the emerging global environmental and trade regimes. Numerous authors point to the resultant conflicts and tensions in deciding what is 'good practice' because the global policy drivers for 'sustainability' and 'profit' today are pulling in different directions (Tansey and Rajotte, 2008). Commercial biotechnology, seed and agro-chemical companies have sought to preserve their own freedom to operate by developing global quasi-monopolies and by centralisation (through mergers, acquisitions and cross-licensing agreements) (Graff et al., 2003; ETC Group, 2005). The resultant pattern of Research and Development (R&D) indicates a severe under-investment from the point of view of the social good (millions of poor farmers' livelihoods) and of environmental sustainability, because these commercial interests will not work on

Table 7.4 Cotton ecosystem analysis summary (Village: Aloor, Ranga Reddy district, Andhra Pradesh, India 2003)

Subject	IPM decisions	Reasons
Insect pest management	NSKE 5% spray at 51 DAS	Sucking pests Thrips 8.7/leaf, Aphids 5.1/leaf, Helicoverpa eggs 2/plant. Defender population low. Plants look unhealthy
	Chlorpyriphos spray at 58 DAS	Helicoverpa eggs and larvae 4.0/plant, Chrysoperla eggs 2.7/plant. Cloudy weather persists, crop stage vulnerable
	Do nothing at 65 DAS	Thrips 25/leaf, Helicoverpa eggs 0.2/plant, Lady Beetles 1.0/plant and Spiders 2/plant. Dry weather. Plants look healthy
	NPV spray and installation of Yellow Sticky Traps at 79 DAS	Helicoverpa eggs 1/plant and larvae 2/plant, White flies 3/leaf and Spiders 2/plant
Fertilizer management	Apply DAP 125kgs/ha at 30 DAS	Sufficient moisture in the soil and good root development is required since the crop is in early vegetative stage
	Apply Urea 62.5kgs/ha and DAP 62.5kgs/ha at 60 DAS	Sufficient moisture in the soil and the crop is entering into reproductive stage
	Apply Urea 62.5kgs/ha and Potash 62.5kgs/ha at 100 DAS	Sufficient moisture in the soil and good nutrition is required for retention and enlargement of bolls
Weed management	Do weeding at 30 DAS	More weeds around the cotton plants
	Do weeding at 60 DAS	More weeds around the cotton plants competing for space and nutrition
Disease management	Do nothing	Diseases are not severe
Irrigation	Irrigate at 90 DAS	Crop is in flowering stage and the soil is too dry

Source: FAO Training of Facilitators Report, Warangal District, Andrha Pradesh, Annex-3 FFS report.

Table 7.5 Reccomended Economic Threshold Levels (ETL) for major cotton pests by the Government of India, 2003

Insect pest	ETL
1. American and Spotted bollworm	5% damaged fruiting bodies or 1 larva per plant or total 3 damaged square/plant taken from 20 plants selected at random for counting
2. Pink bollworm	8 moths/trap per day for 3 consecutive days or 10% infested flowers or bolls with live larvae
3. *Spodoptera*	1 egg mass or skeletinized leaf/10 plant
4. Jassids*	2 jassids or nymphs per leaf or appearance of second grade jassid injury (yellowing in the margins of the leaves)
5. Whitefly*	5–10 nymphs or adults per leaf before 9 AM
6. Aphids	10% affected plants counted randomly
7. Thrips*	5–10 thrips/leaf
8. Nematode	1–2 larvae per gm of soil

*3 leaves (top, middle, bottom) per plants from 10 plants

Source: Integrated Pest Management Package for cotton, IPM package N.25, Directorate of Plant Protection, Quarantine and Storage, Government of India, 2003.

pest management for poor farmers who have no money to spend on their products, nor on pest management approaches and products that can be freely copied or given away, nor on approaches that are very context-dependent.

Under increasingly probable climate change scenarios, agricultural systems are likely to be transformed at an accelerated pace and new plant protection concerns will emerge. Centralised, formal science is not well-placed to monitor locally significant emergent problems, and centrally-derived technological management practices and products will take time to reach the millions of small producers, even those who already are growing industrial crops such as cotton or food crops for sale. Farmers trained in the practice of adaptive ecological management, and with enhanced skills for learning based on observation, measurement and experimentation, are more resilient. They are better prepared to develop and evaluate technological options for dealing with problems caused by the ‘surprises’ of climate change and the fast depletion of natural resources under competitive pressure from very large corporations and industries, infrastructure developments and rapidly expanding urban areas.

Secondly, the community approach to IPM used in FFS programs supports collective action, group management and leadership development. The learning exercises used to support pest monitoring, interpretation of measurements, joint analysis of experimental results and peer review, and in planning have spin-off effects beyond only IPM, that are critical to the advancement of farming communities and the farming sector (Pontius et al., 2002, Braun et al., 2006). The same skills are also critical elements in actions to reduce area-wide pest infestation, in community-wide and landscape scale risk estimation, and to prevent pest diffusion.

The current performance of the genetically engineered Bt cotton in north India is reinforcing the evidence that the introduction of new technologies does not dispense with the need to provide end users, farmers, with an ecological education. Bt cotton was introduced to control the heavy application of pesticides against the bollworm complex and it has performed as expected in this respect. However, the continuous expression of the Bt control has induced the insurgence of secondary pests – also as predicted by the entomological and ecological sciences. For instance, economically damaging infestations of mealy bugs have appeared in the last two seasons in some regions of north India, especially in Punjab. The primary causes of these infestations are yet unclear to researchers but farmers, according to press reports, have responded with an increase in the use of chemical controls.

A large cadre of trained FFS farmers and facilitators has been created in the country through State departments of agriculture and horticulture, universities, international and national research centres, NGOs, Foundations and the private sector (e.g. by IKEA through the Better Cotton Initiative). In Andhra Pradesh alone, 35,000 farmers were directly trained by the FAO in Farmer Field Schools between 2000 and 2004. In subsequent years the State Department has made provision for the funding of IPM FFSs at the rate of 3-4000 schools per year. Non-profit organisations like AME Foundation and its partner NGOs, that have embraced the FFS methodology, have reached about 10,000 farmers.

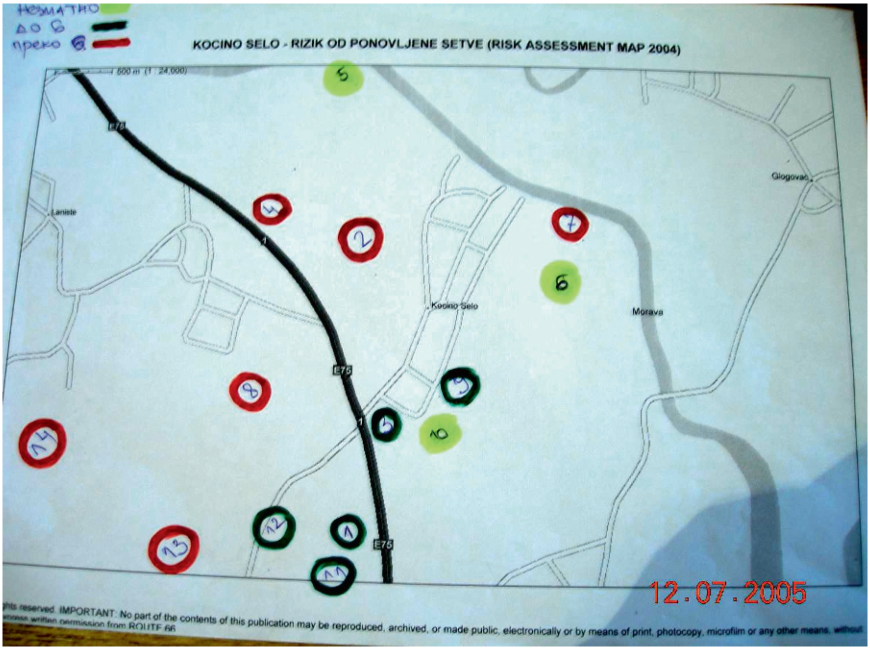

Fig. 7.1 Example of risk estimation map prepared by FFS in Pozarevac (Jiggins et al., 2005)

The National Plan to upgrade the Plant Protection System, which is currently being implemented with technical assistance from FAO, foresees a key role for the IPM trained farmers in pest surveillance and risk estimation. This initiative parallels that of IPM farmers in Eastern and Central Europe, who are working with phytosanitation authorities and pest surveillance experts to control a pest introduced from America during the Yugoslav conflict, the Western Corn Rootworm (Kiss, et al., 2007). Figure 7.1 is an example of a risk estimation map developed by FFS graduates for a maize-growing community in Serbia. The red, black and yellow circles indicate the number of years under continuous maize succession. The red circles indicate the maize fields under continuous succession for three years that are at high risk of economically damaging loss if farmers chose not to break the biological cycle of the WCR by growing a different crop but to go for a fourth year of maize in the same fields.

7.3.4 IPM Farmers' Potential Role in Risk Estimation in India[11]

The Indian Department of Agriculture and Cooperation has recently (2007–2008) sponsored a project to upgrade the pest surveillance system in India. This includes

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[11] Information in this section has been provided by Mike Robson, FAO (March, 2008); his contribution is gratefully acknowledged.

the creation of small, specialised organisational units with national, state and district responsibilities for surveillance, and the introduction of hand-held digital technology for field data recording. Field data recording efforts previously tended to be fragmented – different parties have used very different methodologies, data were not geo-referenced; data have often been obtained late (at end of season) or in a form where the detail has been 'lost' in aggregation. The tool is intended to overcome these problems, providing timely and accurate detailed data to a new national surveillance database. The equipment itself consists of a personal digital assistant (PDA) adapted for use in field conditions, with a simple bespoke software application for geo-referenced data collection. Data collected includes field conditions at the time of observation, and quantification of observed pests and defenders present in the field, following a pre-agreed crop-specific sampling protocol. Data is uploaded at the end of the working day to a national database, which is available over the web for users at national, state and district level. Indicators designed by crop specialist groups – combining crop stage and weather parameters as well as insect populations (and disease incidence/severity) – have been derived in order to generate a simple 3 or 5 point scale to show the level of threat to the crop. The system has been trialled in four districts of Andhra Pradesh and was launched nationally in February 2008. The development and implementation of a new tool for data recording is useful in itself, but also because it provides a focus around which broader efforts can converge. It is expected that the tool will improve significantly the quality of data available, to both policy makers and, at district level, to farmers, and will become a key element in revitalising the national pest surveillance network in India. It is envisaged that IPM – trained farmers will play an active role in the monitoring of domestic and exotic pests in the field and in providing data to update pest database and maps and in farmer-to-farmer communication of alerts on enhanced risks.

7.3.5 Case Study from South India: the Contribution of IPPM to Food Security

In South India, FFSs on IPM and sustainable agriculture practices are now organised largely to strengthen the agricultural knowledge and skills of poor farmers as a strategy for reducing the hardship and vulnerability of poor households with respect to food and financial security. In 2007 the authors collaborated in a survey conducted by the AME Foundation, Bangalore, to understand the role of agricultural services, including IPM, to the betterment of farmers' livelihoods. The Sustainable Livelihood framework, which is constructed around the identification of five capitals' assets: natural, human, social, physical and financial, was used to investigate changes attributable to attending FFSs. Nearly five hundred marginal farmers were interviewed in the drought-prone areas of the states of Tamil Nadu, Karnataka and Andhra Pradesh; half of the sample was FFS graduates. The variability of rainfall had led the majority of small farmers into debt under the conventional recommended practices (including agro-chemical input purchases). The contribution of agriculture to the overall house income has become minimal in the case of marginal households. One hectare of rainfed land in the area generates Rs. 8250 (US $ 183), which can be as low as 5% of the total cash income, in addition to food for self consumption. Marginal farmers with access to groundwater through bore wells have achieved a better financial status, diversifying cropping patterns with crops of commercial value, the most effective farms generates up to 50% of the total household income in cash. However their economic growth is based on an unsustainable use of water (Fig. 7.2).

The study showed that the FFS graduates were practising improved agricultural management embracing the principles of integrated pest and production management. The practices included: seed germination test, seed treatment, intercropping, use of biopesticides and biofertiliser; cultural practices to conserve moisture in the soil and to restore soil fertility. Farmers using these practices reported to have obtained higher, more stabile yield levels. The stability of yield, and not just the fact that yield levels were higher, was perceived to be an important contribution to the food security by marginal farmers who were meeting their needs primarily from their small-holdings. FFS farmers reported a higher level of satisfaction with their livelihood than the control group (Table 7.6). The average income from agriculture reported by the FFS graduates (12,822 Rs, about 320 US $ at the exchange rate of 1$ = 40 Rupees) was 3-fold higher than the control group. Nevertheless, the income difference was too small to allow FFS graduates to make a financial breakthrough and free themselves from their historic debt burden. The Government of India has responded to data such as these by proposing in the budget for financial year 2008–2009 to write off all farm loans taken from banks (i.e. not including debts incurred with moneylenders), for all farmers with landholdings up to 2 ha. Full implementation of this measure would cost the government exchequer Rs.600 billion (US $15billion US) (Union Budget, 2008, presented on 29 February, 2008).

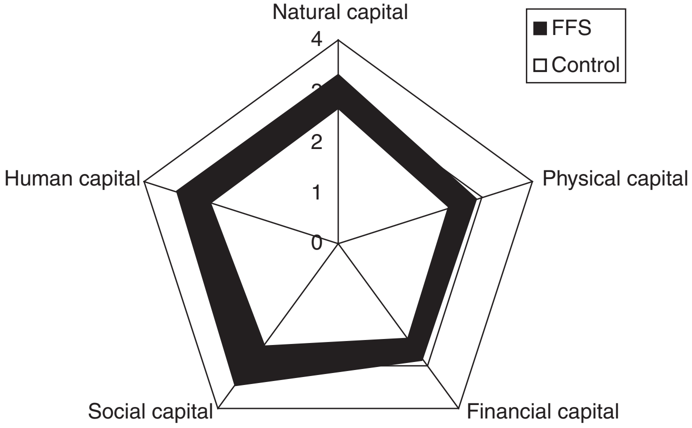

Fig. 7.2 Visualisation of the score assigned to the five capitals with reference to the year 2006 using a 0–5 scale by FFS and control farmers
Source: modified from ‘One acre (1 acre = 0.4 hectare) of land’, survey conducted in 2007 by AME Foundation.

Table 7.6 Sources of income (Rupees) of two types of marginal 1.1 acres (0.44 ha) rural households (HH)

Source of income	Dry land, (27 farms)	50% access to water, (9 farms)
Agriculture (average)	3.300	9.700
Range	(0–7.800)	(0–35.000)
Agri-labor	2.820	4.000
Dairy/poultry	6.250	12.700
Off-farm labor	23.200	32.800
Loan/saving	35.570	26.750
Total	71.140	85.950

1 American $ = 40 rupees.

Source: this study.

Without investments such as the FFSs the push out of agriculture, under increasingly variable rainfall and temperature conditions, will increase for millions of poor farmers. The Government is committed to moderating the exodus by adopting policy drivers to increase the profitability of small-scale farming. These will include the abandonment of ‘one-size fits all’ approaches and adoption of State-specific strategies based on local agro-climatic conditions and constraints, adoption of precision farming’ techniques adapted to small scale management, investment in Agri-clinics to provide services such as integrated soil health, nutrient management and integrated insect pest and disease management diagnoses and advice, and Knowledge Centres located at Gram Panchayats (the lowest level of local government) (Patil, 2007).

However, improving agriculture productivity and resilience, even in the most sustainable fashion, might not offer a way out of a subsistence livelihood for the majority of the poorest farmers unless attention is also given to the design of funding flows that can reward farmers for their role in the management of agro-ecosystem functioning. This implies that the central and State governments would need to reconsider their embrace of ‘free trade’ policies and of global Intellectual Property Rights regimes that have been designed to meet the interests of industrial farming and global corporations. It seems certain that the world has entered an era of structural change in food prices, driven by increased demand for feedstock for poultry and animals as incomes rise, higher oil prices, increasing climate instability in the major cereal exporting regions of the world, diversion of food crops into biofuels and the rapidly increasing limits to production from irrigation as the competition for water increases. Higher market prices will negatively impact poor consumers everywhere; they may offer opportunities for some small producers to get out of poverty. However, the extent to which small farmers may benefit depends critically on their capacity rapidly to organise to meet market demand, and the procurement policies of the dominant actors in the wholesale and retail sector (Berdegue and Reardon, 2008)

In the case considered here, low farm-gate prices and competition from large-scale producers threaten to keep the dryland farmers trapped in poverty. The value of output per hectare in 1992–1995 was Rs 9390 (about 235 US $) in Andhra Pradesh, Rs. 5176 (about 129 US $) in Maharastra (Bhalla and Singh, 2001); small and marginal farmers will remain below the poverty line in the future if they continue to depend solely on agriculture. There is evidence that FFS education can contribute to the development of personal and social capital (Mancini et al., 2007), i.e. FFSs assist farmers to develop the self-confidence, awareness and learning capacities to organise themselves and their communities in a search for and investment in resilient livelihood options.

7.4 Part III: Discussion: Moving On in India

The information and case materials presented so far begin to build a picture of how a much wider and deeper impact might be gained by combining approaches. The ones we consider most salient are the following.

1. Linking second and third generation IPPM FFSs to development of market opportunities. Pro-poor marketing approaches to add value to agri-products for local markets, to link farmers' organisations to big retail chains, and in some limited areas and specialised crops also to export opportunity, offer real opportunities for farmers' financial uplift. However, it is worth noting that the development of such opportunities has required policy action by the government to encourage preferential procurement (or at the least, equalisation of opportunity to supply) from the small farm sector and an appropriate degree of protection for India's own wholesale and retail entrepreneurs as they develop a market presence strong enough to compete globally with the dominant actors. While limited financial investment has been made so far to upgrade storage, processing and marketing activities for high value addition at farm level, the relaxation of the post-independence political instruments regulating domestic trade of national commodities (Essentials Commodities Act, Agricultural Produce Marketing Act and Small Scale Industry reservation) has facilitated the entrance of larger private companies into agri-businesses, which have rapidly established vegetable and cereal retail chains across the nation. Diversification of agriculture and allied activities in turn requires that greater effort is made to develop rural-urban linkages and integration. Post-harvest technologies and small agro-processing industry, particularly of perishable produce such as fruits, have the potential to further increase producers' returns without affecting negatively the stocks of natural resources. The increasing domestic demand for 'pesticide-free produce' and nation-wide concern for the state of India's natural resources opens a potentially wide market for IPM-labelled produce and for FFS graduates to develop niche products and micro-enterprises.
2. In a number of instances, federations of small farmers' organisations, in which FFS graduates are beginning to play important leadership roles, are becoming involved in the creation of entire value chains. Intermediary organisations – specifically, NGOs, development organisations and community institutions – are playing a vital role in developing value chains that benefit small-scale farmers, for instance in certified organic produce and Fair Trade products, and

in cotton/textile chains (through to links with the international fashion industry). Successful examples are reported also from Africa, where small producers have improved their competitiveness by achieving economies of scale through collective action. The actions include the collective organisation of inputs, production practices, marketing or diversification into higher-value crops or livestock products, linked to identified market demands (spices, medicinal herbs) using FFSs as a platform for learning business and technical skills (KIT, 2006).

3. There is robust evidence that high social capital underpins the development of added value and the effective coordination and management of small farmers' organisations as they move into competitive markets. Collective action and willingness to collaborate in turn facilitate the diffusion of new agricultural technologies and management practices. Villages with higher levels of social capital when paired with the agency of capable, educated young leaders, achieve better development outcomes (Krishna, 2003)
4. IPM/IPPM Farmer Field Schools cannot alone achieve the agenda sketched under 1–3 above. As the opening sections of this chapter indicate, there are complementary investments in agro-technology services that India could be considering. There would seem to be both opportunity and urgent need for experimentation in how, in the specific conditions of diverse agro-ecosystems, market opportunity, and State histories, a mix of IPPM interventions would complement what FFSs are able to deliver.

7.5 Conclusion

We have sought in this chapter to illustrate how investment in Integrated Pest Management, applied in the context of an appropriately designed mix of policy, regulatory and market drivers, can contribute to the resilience of food security and livelihoods in the face of climate change effects and market shocks. We suggest, with evidence that India stands at the threshold of decisive choices that can stabilise the sustainability of its production base without sacrificing yields or profits. We further indicate that IPPM Farmer Field Schools have an important though by no means exclusive role to play in moving the small farm sector toward achievement of combined sustainability and development goals. Finally, we argue that the time is ripe for experimentation in delivering a mix of investments in farmer education that can equip farmers for the demands of the 21st century.

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Chapter 8
Impact of IPM Extension for Smallholder Farmers in the Tropics

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Abstract In recent years, IPM extension came to mean FFS (farmer field school). Most studies of FFS pilot projects suggest that IPM helps farmers to lower costs or to increase yields, although the farmers pass on little of their new knowledge to their neighbours, which limits the cost-effectiveness of FFS. Some quantitative studies of FFS suggest that there is actually little overall impact of FFS programs. FFS may be better suited to stimulating collaborative research with farmers than for extension itself. In other words, FFS may help to perfect the extension message (the technology) which can then be communicated with other methods. There are many alternative extension methods available, although their impact needs further study. The challenge is to find methods that deliver quality and quantity messages (reaching a large audience with an appropriate, understandable message).

Keywords IPM · extension · FFS · smallholder farming

8.1 Introduction

The impact of extension depends on an appropriate message, delivered with an understandable extension method, although it is not always that simple. In the scramble to adopt Bt cotton in Warangal District, Andhra Pradesh, India, farmers may be led to plant genetically modified cotton because of clever marketing. Some farmers planted a new cotton seed after being taken to the field of an influential farmer, and given lunch (Stone 2007). In another experience, a group of Bolivian farmers expressed an increased demand for growing quinoa after being given a piece of quinoa cake at a technology fair (Bentley et al. 2007).

However, adoption fuelled only by convincing extension messages may be short lived. In the cotton example above, farmers often abandon the new variety after a single planting (Stone 2007). In the 1990s in Colombia, researchers insisted that extensionists teach coffee farmers to culture the fungus *Beauveria bassiana* (Bb)

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to control the coffee berry borer. A nation-wide network of dedicated extensionists taught the farmers to boil rice, to place it in used rum bottles, and then inoculate it with Bb, with which they would later prepare a solution to spray on their groves. The farmers adopted, and then abandoned the technology because they could not get enough rum bottles, and could not keep the rice medium sterile in their kitchens, plus the whole operation was too much work, and took up too much space (Bentley and Baker 2002).

In 2003 I saw some excellent extensionists in Nicaragua, trying to teach farmers to calculate the percentages of pest incidences, using a complex pest sampling chart divided into about 625 squares of data (personal observation). The chart had rows of sampling sites and columns for different pests. It arguably offered a complete picture of all the pests and diseases in coffee, but it took 20 people two hours (i.e. 40 person-hours) to gather the data. Even the agronomists had to use a calculator to figure out all the percentages. The sampling scheme “worked” but it demanded too much time, and math skills. The sampling method was never adopted, even after persistent extension efforts.

While there is not a direct, mechanical relationship between extension method, message and impact of a program, method and message still have to be taken into account. In recent years the IPM message has been linked with one particular extension style: farmer field schools, even though IPM can be taught with other methods, and FFS can be used for other messages.

8.2 Evaluation of Farmer Field Schools

Farmer field schools (FFS) became a kind of standard in IPM extension after the late 1980s, even though they are now being questioned. In spite of the great interest they enjoyed, the evaluation of their impact is hardly straightforward. FFSs were created by the FAO IPM in Asia program in the 1980s to teach Indonesian farmers to avoid needless insecticide applications on rice, especially for white rice stem borer and brown plant hopper. An FFS teaches about 25 farmers at a time. They meet once a week for half a day during the whole cropping cycle. In theory, the FFS do not involve lectures (Gallagher 2003), although field observations show that the facilitators do actually give talks (Winarto 2004, Palis 2006). This is not a criticism; talking is a legitimate way of conveying ideas, but it does suggest that the designers of FFS over-packed the method with unhelpful rhetorical baggage.

The first attempts to measure impact were qualitative. This was a useful first step. Anthropologists Vayda and Setyawati (1995) found that while taking a field school, farmers in a village in Indonesia learned much about insect natural enemies, and began to use pesticides less often.

During an intensive, two-year study of a village on Java, Winarto (2004) found that FFS graduates experimented with the new ideas, e.g. inventing early ploughing, and hand collecting egg masses to control white rice stem borers. Ooi (1998) also found that farmers experimented after taking an FFS. Winarto learned that farmers who took the training were flattered to be involved, and took it seriously. They once organized a trip to a research station to ask researchers questions which had arisen during training. The farmers enjoyed the FFS, but it was difficult for them to teach the messages to their neighbours, because the messages were complex, because the farmers did not have a convenient time and place to convey the information and because the untrained villagers were sceptical. Farmers were also disappointed that researchers did not visit them to learn about the farmer inventions (Winarto 2004).

Various studies show that farmers adopt the principles taught in FFS. For example, a study in the Philippines found that FFS farmers had learned enough from the field school to adopt organic rice growing (Carpenter 2003). A study in Peru found that potato farmers who had attended FFS had higher yields than their neighbours (Ortiz et al. 2004, see also Godtland et al. 2004). In the Central Philippines, a long-term village study showed that farmers learned to observe insects in the field school, and that each year fewer of them used insecticides, until some six years after training, when all or nearly all of them had stopped spraying for insects in rice (Palis 2006). A study of cotton farmers in Southern India showed that IPM adoption (following FFS) reduced pesticide use by 78% without affecting crop yields, suggesting that IPM is profitable and that much of the current use of pesticides is unnecessary (Mancini 2006).

However, quantitative studies of some of the original FFS cohorts by Feder and colleagues raise doubts. They found that the most prosperous farmers had been preferentially chosen for the field schools, biasing the results. There was little difference between FFS graduates and their neighbours; i.e. the FFS graduates were not getting better rice harvests, and were not using less pesticide. Trained farmers were not teaching their new IPM knowledge to their neighbours (Feder et al. 2004a, 2004b). This is a problem because only about 25 people can take an FFS at one time. Small class sizes help ensure a quality experience. However, if the 25 people who take a field school do not teach the information to their neighbours, a message that reached more people might be more effective. Rola et al. (2002) also found that FFS graduates do not teach new information to friends and neighbours. van den Berg and Jiggins (2007) critique Feder et al.'s methods, e.g. arguing that information might have spread from IPM farmers to the non-trained ones, and that the study gave insufficient attention to savings in insecticide by IPM farmers. There is clearly a partisan flavour to this debate, and various other studies do suggest that the results of FFS are often modest. For example, Ricker-Gilbert (2005) in Bangladesh concluded that a visit from an extension agent was a more cost-effective method than FFS for teaching IPM technology.

Rice farmers in Bangladesh who had taken FFS could not identify planthopper nymphs; most thought the nymphs were related to stem borers (which are lepidopterans, i.e. entirely different insects). After IPM training by various NGOs, few if any farmers practiced new techniques that they were taught, because the technologies were perceived as being labor intensive or risky. Over time, farmers tended to forget much of what they were taught (Robinson et al. 2007).

Two reviews of African field schools suggest that FFS do lower pesticide use and raise yield, but that these benefits do not spread beyond the FFS graduates, in part because farmers are not rewarded for taking time to teach others. Also, field schools are not integrated into local extension programs, churches or other grassroots organizations. Field schools are expensive and dependent on foreign donors. Their impact has not been sufficiently evaluated, but FFS are probably not a feasible model for national extension programs, at least not in Africa (Davis 2006, Anandajayasekeram et al. 2007).

One rather sobering review of insecticide use suggests that despite the popularity of IPM, insecticide use is increasing around the world, even in areas that favour IPM, like California and the UK. Perhaps insecticide use would have been even more widespread if not for IPM, but it will be unlikely to do away with insecticides, in part because new compounds are being invented which cause lower environmental impacts. The major new pest management technology that is making an impact on the way that insecticides are targeted is genetically modified (GM) crops (Devine and Furlong 2007).

FFS has been a popular IPM extension method in tropical countries for several years, and yet its full impacts and cost-benefit are only partially understood. FFS was already being promoted outside of its pilot areas before its impact was well known.

Most studies of the impact of FFS report reduced expenses for inputs, increased yields, and higher income for farmers. However, most of these studies are of pilot programs, and there is less information on the cost-effectiveness of large-scale IPM Programs (Sorby et al. 2003 cited in Kelly 2005).

A study of FFS graduates, their neighbours and “control” farmers from non-FFS villages in Sri Lanka concluded that FFS graduates do make fewer applications of insecticide than others, and that the field school did teach them about natural enemies and the importance of not making early sprays. However the FFS farmers do not teach what they learn to their neighbours (after all, what people learn through discovery learning may be difficult to transmit by talking). There is little or no impact of FFS at the national level, because so few farmers actually attend an FFS, less than 2% of Sri Lanka’s farmers (similar to figures from Indonesia, the Philippines and elsewhere). In other words, FFS does teach valuable ideas to individual farmers, but the new ideas do not spread to others, and national programs are not able to teach enough field schools to directly reach most farmers in the country (Tripp et al. 2005).

8.3 The Message

The first FFS (Rice in Asia) had an appropriate message: natural pest control, with native, natural enemies of insect pests. The message was well suited to the FFS method: talking about natural enemies of pests, observing them in the field. Farmers experimented by leaving a small part of their field untreated with insecticides. Then they observed the counter-intuitive results: there were fewer pests without insecticide. The new technology (no insecticide) was cheaper and easier to use than the technology it replaced (insecticide abuse). This fortunate match of message and method helped to make FFS appealing, but when FFS began to be applied more widely, pesticides were occasionally added to the curriculum.

For example, when FFS came to South America in 1999, it was forced to include fungicides, for late blight in potatoes (Nelson et al. 2001). In Bangladesh a large, international NGO received training from some of the best experts in FFS, and conducted a widely-publicized FFS program. After the project ended, some of the staff formed their own NGO. By the early 2000s, the problem in Bangladesh was labor shortage, as young people took jobs in the garment factories. Farmers could not hand weed all their own rice. In 2005 I interviewed extensionists and farmers in Bangladesh, who were excited about having conducted an FFS to teach herbicides. The extensionists taught the farmers to apply herbicides to the water in the flooded field, and to count days of labor, keep costs, and to observe fish and frogs, to ensure that wild animals were not killed by the chemicals. Farmers had been reluctant to try herbicides, fearing they would damage their land, but were pleased with the results. FFS is versatile enough to teach many messages, including chemicals.

There are many versatile extension methods available, but choosing the message is often more difficult. When the coffee berry borer entered Colombia in the early 1990s, researchers were keen to find an alternative to chemicals. They tried Bb, which failed. They invented sampling methods which took six hours to conduct, so no one would adopt them. They brought parasitic wasps from Africa, which did become established, but which parasitized only 5% of the berry borer population. Five percent fewer pests is a significant savings in a crop as valuable as Colombian coffee, but farmers still demanded more control (Baker 1999, Bentley and Baker 2002).

Through rigorous entomological studies, researchers knew that the borer only lived in coffee berries. It had no alternative host. So by gathering up all berries from the ground and by gleaning over-ripe fruit from the trees, the growers could eliminate the pest's habitat. Researchers called the gleaning-plus-clean harvest "Re-Re." Extension agents taught Re-Re, but farmers would not pick fallen fruit from the ground. The hillsides were usually so steep that bending over was uncomfortable and could lead a person to slip or fall; the fallen fruit was often hidden by leaves. The berries on the ground were often rotten and could not be sold. But farmers adapted Re-Re, and began to make more of an effort to harvest all the coffee berries from the trees (clean harvest), because the good berries could be sold, which usually paid for the labor to pick them. At first researchers and extensionists were displeased that farmers were modifying Re-Re, but they eventually realized that the farmer modifications made the technology more acceptable, that clean harvest was being adopted, and it was controlling the pest (Aristizábal et al. 2002).

Clean harvest is also being used by farmers to control the coffee berry borer in other parts of Latin America and in India. Even though Re-Re is a low, unglamorous technology, farmer modifications made it simple and functional enough so that others would use it.

FFS may be more useful for research than for extension, because it gives scientists a chance to see how farmers react to scientific ideas, and because the FFS permits farmers to understand the reasons behind a new technology, and to suggest improvements (Paul Van Mele, personal communication). In the 1990s, a Swiss-funded project by Zamorano in Nicaragua and El Salvador taught farmers using various FFS (some farmers learned about maize and beans, some learned about vegetables, etc.). Farmers combined the new ideas creatively with their own knowledge, even though the program did not actively encourage them to do so. Some of the changes were especially useful. For example, twenty years earlier, in the 1980s, researchers had tried to develop "trash trap" (piles of leaves, where slugs would hide; farmers could turn the piles over and kill the slugs by hand). The original traps did not work very well, but over the years the farmer experiments improved them in several ways (e.g. combining the traps with commercial pellets, using old sacks as the traps), which made them more practical (Bentley 2006).

Field schools are starting to be combined with CIALs (the Spanish acronym for "local agricultural research committees"), to fine tune technologies (Van Mele and Braun 2005, Braun et al. 2000). Researchers in Peru used FFS and CIALs to invent cultural controls for bacterial wilt in potatoes. The farmers who had studied in FFS liked the experience, and readily agreed to stay organized, but as a CIAL. Many technologies came from the experience. One of the most interesting was a set of rotational crops for reducing the bacteria in the soil. This was investigated in formal trials, under the leadership of the researchers, with collaboration from the farmers. Some of the technologies emerged serendipitously. For example, researchers taught farmers to clean their sandals with lime before entering a field, so as not to track in bacteria. CIP plant pathologist Sylvie Priou noticed that when farmers ran out of lime, they used wood ash instead. She tested the ash in her laboratory and found that it effectively killed the Ralstonia bacteria (Bentley et al. 2006).

FFS experts are now arguing that field schools "are not meant for technology transfer" and there is a need to experiment with how to combine FFS with mass media, extension etc. (Braun et al. 2006).

8.4 Reaching the Largest Audience Possible

Once the IPM message is right, the challenge is to take it to as many people as possible. There are basically two types of extension methods: face-to-face (i.e. people teaching other people), and mass media.

Face-to-face methods are not necessarily limited to small audiences. Promoters are a kind of farmer extension agent, which are popular in Central America, due to World Neighbours and other institutions. They are a low cost, personal way of reaching many people, which allows the technology to be adapted by the people who will use it. In Central America, farmers burned crop stubble from fallow lands every year before planting. This killed pests, and released nutrients as ash for the crops, but it also increased soil erosion. Burning was common until the 1980s, but has now stopped almost entirely in Central America, thanks to efforts by promoters linked with Elías Sánchez, World Neighbours and other.

Morales et al. (2002) found that the promoters were a kind of filter for technologies, simplifying them and passing them on. For example, in 2001, when the Nicaraguan Ministry of Health insisted that coffee growers keep coffee pulp out of streams, NGOs responded by inventing a kind of cess pool for coffee. It was made of two pits, with a wooden sluice between them and a gravel filter in a bucket. Farmer promoters saw the technique, and adapted it, by making just one pit. This saved on expenses (no wooden sluice, no plastic bucket), but it also kept coffee pulp out of streams. The promoters had grasped the essential concepts of the technology, but redesigned it to be much more affordable.

Picture songs in Bangladesh: singing and dancing about IPM, while showing large illustrations

In Bangladesh, one innovative NGO, Shushilan, used "picture songs" (song and a very large painting on a scroll) as a kind of moving picture, to teach appropriate rice technology to thousands of people, especially about natural enemies and using organic fertilizer. As a performer sings out the message (and dances), the rest of the troupe accompanies her with music, and rolls out the illustrations on the scroll. Hundreds of people can see each memorable performance at one sitting, and as of 2005, some 25,000 people had seen and heard the message (Bentley et al. 2005).

Videos have been used in Bangladesh, combined with farmer participatory research, and community meetings. Researchers at RDA (Rural Development Academy) developed appropriate rice seed technology with farmers (e.g. drying rice seed on a bamboo table, keeping seed dry in a painted pot). Then they made videos where farmers spoke on camera. Their honest words were convincing to other farmers, who could identify with them. Extension agents showed the videos in communities, and then answered questions from the audience, which allowed many people to be trained at once, in a relatively short time (Van Mele et al. 2005, Van Mele in press).

An evaluation in Bangladesh in eight villages (in four districts, around the country) show that one year after villagers watched the videos mentioned above, they had improved their seed storage practices, and had adopted various technologies recommended in the videos, and abandoned other practices which the videos discouraged.

Adoption of seed health technology in Bangladesh one year after seeing videos

Seed storage method	Before (%)	1 year later (%)
Not recommended		
Gunny bag	27	13
Motka (large earthen jar)	28	11
Earthen pot	9	6
Recommended		
Poly bag	24	56
Metalic drum	7	7
Painted earthen pot	0	3

Source: adapted from Harun-Ar-Rashid (2007)

Plant health clinic in Bolivia: farmers consult the weekly clinic at a farmers' market

Plant health clinics are a new extension method being implemented in Nicaragua, Bolivia, Uganda, Bangladesh and elsewhere, pioneered by the Global Plant Clinic. They started in Bolivia in the 1990s, so farmers from distant areas could bring plant samples and get advice about plant health problems. Most of the clinics are "mobile" (only open one morning a week, e.g. on fair day, when the small town fills with farmers from many kilometres around). The plant clinics provide a place for personalized consultations between farmers and agronomists. The plant clinics can be easily combined with other methods like fact sheets, radio, short courses (Danielsen et al. 2006).

Going Public is another face-to-face method for a mass audience. An extensionist goes to a market or another crowded place, and delivers a short message, and then repeats it. The audience comes and goes, but if the message is kept to five minutes, several hundred people can hear it in a few hours. It is especially well suited to rather simple messages that must show something (e.g. a disease symptom, a new tool). Going Public has been used in Bolivia, Bangladesh, Uganda and elsewhere (Bentley et al. 2003).

Going Public in Kenya: Nelson Wekulo tells a crowd how to vaccinate hens for Newcastle disease. IPM topics work equally well with this soap-box style of extension

Written material in Bolivia: Gonzalo Sandoval (*left*) hands out fact sheets on onion diseases, and discusses them with farmers

Written material, including fact sheets, journals and newspapers are also useful, especially when written for farmers and validated by farmers before distribution. In India, coffee farmers in Karnataka have journals and magazines in their homes. *Adike Pathrike* is a magazine that started as a newsletter in the 1980s and rapidly expanded. It is published entirely in the Kannada language. It has a color cover and additional black and white photos inside. Almost all of the material is based on farmer experiences. Although the title literally means "areca magazine" only 10% of the material is on areca. But whatever the topic, the new technology described has to be validated by farmers, even though agricultural scientists write most of the material. The readers are solid commercial growers, family farmers who are literate and who can afford a magazine. The strong local tradition of publishing and reading also helps. Advertisers help keep the costs down, and a good postal system helps to move it. Journals would not be effective everywhere, but in this situation they are (Padre and Tripp 2003).

Radio is a promising method, and has been used recently in Vietnam to teach people to avoid insecticide abuse in rice. A project using radio, leaflets and other media led to a 53% reduction in insecticide use and no loss in production in project sites, and the change eventually spread to more than a million rice farmers three years later (Escalada and Heong 2004). Vietnam recently experienced an outbreak of a virus disease in rice. Researchers helped to adjust an environmental radio soap opera to communicate essential information to farmers. This together with leaflets, TV broadcasts reached two million farmers in three months and spread the use of the "Escape Strategy" (light traps to detect peak immigrations of the brown plant hoppers that transmit the virus, to make group decisions as to when to plant in order to escape virus infection though synchronized rice planting). The "escape strategy" helps farmers to avoid virus transmission without pesticides and is now widespread in the Mekong Delta (KL Heong, personal communication).

A study in Bolivia compared FFS to radio and community workshops, which are like FFS, but more people attend, as many as 80. Community workshops only meet three times instead of a dozen, saving time and expense. The community workshops were nearly as effective as FFS at getting a message across, and the radio made a respectable showing, but at a fraction of the cost (Bentley et al. in press).

8.5 Impact of IPM Extension

Studies of other IPM extension methods are even harder to find than evaluations of FFS. But there are a few.

Like the brown plant hopper in rice, the fall armyworm in Central America is a pest of maize which is usually controlled by its natural enemies, as long as people do not spray insecticides. IPM training in Honduras in the 1980s used short courses, but like FFS the courses emphasized learning by observation. Honduran farmers who had taken IPM training could name more natural enemies, and were less likely to use insecticide than neighbouring farmers who had not taken IPM courses. However, the

IPM farmers were not likely to practice other technologies they had learned on courses (like using sugar-water to attract natural enemies) and over time some farmers came to doubt that social wasps (Vespids) were effective predators of army worms, because farmers observed that the wasps were abundant when there were also high levels of armyworms in their maize (Wyckhuys 2005, Wyckhuys and O'Neil 2007). Local knowledge, behavior, and training interact in non-obvious ways.

In Bangladesh there is now runaway pesticide abuse, especially as farmers grow more vegetables for the ever more sophisticated internal market. In a study sponsored by the Global Plant Clinic, based on in-depth interviews and multiple community meetings in 30 communities, researchers found that farmers used common as well as some unauthorized pesticides, making frequent use of chemicals to control the bean aphid, bean pod borer, cabbage butterfly, brinjal shoot and fruit borer, cucurbit fruit fly, cutworm, banana leaf and fruit beetle etc. In Natore district, farmers made 40–50 pesticide applications to protect a single bean crop from bean pod borer. To protect the brinjal shoot and fruit borer, farmers used the pesticides almost every day and in some cases, 150–200 times in a single crop season. Farmers of Norsingdi district applied pesticides at least 1–3 times in a week on vegetable crops. Some farmers in Natore and Norsingdi district spray high amounts of chemicals to their market crops, but avoid spraying the part they intend to eat at home (Harun-Ar-Rashid et al. 2006).

Part of the problem is that in many countries, there is no longer a formal extension service, or there is a highly fragmented, donor-driven service, which has poor links to research. There are some exceptions. Researchers in Uganda report success with banana Xanthomonas wilt (BBW), which was new to Uganda and was devastating the staple food crop, banana, in the early 2000s. Researchers developed cultural controls, especially twisting off the fleshy, red male flower, because insects visited it, and transmitted the bacteria. BBW control required a simple message, delivered to millions of people, and urgently. The Ministry of Agriculture and various donor-funded programs used a mix of posters, radio programs, newspaper ads, conventional extension and Going Public to get the message out. Cultural control of BBW is catching on in Uganda, not unlike the way cultural control was adopted in Colombia for the coffee berry borer.

A well-funded, well-organized agency can make a difference. For example, in Bolivia after public extension collapsed in the early 1990s, one of the few programs left was IBTA-Chapare (Bolivian Institute of Agricultural Technology), funded by USAID to provide alternatives to coca-growing. One of the alternative crops was banana, which was attacked by the Sigatoka disease. IBTA-Chapare responded with fungicides and also by cutting off diseased leaves. Although slicing off the leaves (with a blade attached to a pole) was tedious, commercial farmers adopted it more or less en masse, in part because the technology worked, and in part because of a well-funded, well-coordinated effort by extension agencies to convey the message to farmers.

Money is not always the answer. Certain well-funded agencies continue to teach dysfunctional technologies after many years. For example sticky, yellow traps were promoted to capture whitefly in tomato as early as 1991 in Nicaragua. They are still being promoted, from Guatemala to Bolivia, 16 years later, even though they do not work. The traps are big sheets of yellow plastic, tacked between two sticks and set out in the field, coated with sticky oil. Insects are attracted to them, stick to them and die. Even a cursory look at one of the sheets shows that many beneficial insects are killed, and many pest insects escape. After a season or so, farmers realize that the traps are ineffective and abandon them. That does not stop extension agents from teaching yellow traps to a new set of farmers. So the traps have been tried, abandoned, and tried again for nearly a generation, all over the American tropics. Extension agents teach them because they are non-chemical, colourful, visual and easy to teach.

8.6 Conclusion

There is still a great deal of work to be done in order to understand the impact of IPM extension in the developing world. There is some cause for optimism; regardless of the method used, most farmers who have received IPM training seem to have either lowered costs, raised their yields, or both. In order to get sound IPM information to as many farmers as possible, at an affordable cost, more extension needs to be done with mass media, especially videos, TV and radio. More work also needs to be done with face-to-face methods that can reach large audiences, but which are not mass media, strictly speaking. Face-to-face extension methods may not be cost-effective in many cases, unless they are used to do more than simply teach farmers. For example, extension can be a way for researchers to learn about farmers' conditions and to conduct adaptive research with farmers, who can then speak on radio or video programs and reach a much larger audience.

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Chapter 9
Impact of IPM Programs in Asian Agriculture

Kevin D. Gallagher, Peter A.C. Ooi and Peter E. Kenmore

Abstract IPM Programs in Asia, including on rice, cotton and vegetables, have been broadly based on three dimensions. First is a solid IPM science basis including ecological interaction, plant physiology and soil-plant interactions. Second is policy for IPM, especially elimination of pesticide subsidies which cause over-use of pesticides and disrupt natural enemies leading to secondary pest outbreaks particularly on rice and cotton. Finally, the third dimension is farmer education through hands-on practical training. Lessons are drawn from the FAO Inter-Country Program for Rice IPM in Asia, the FAO-EU for Cotton in Asia and FAO Regional Vegetable IPM Program in South and Southeast Asia. A case study on cotton highlights broadened aspects of IPM activities through farmer empowerment.

Keywords Integrated Pest Management (IPM) · farmer empowerment · Farmer Field School (FFS) · IPM policy · environmental education

9.1 Introduction

This chapter will draw heavily from the experience of the authors working directly within a few large-scale IPM Programs, especially on the FAO Inter-Country Program for Rice IPM in Asia, the FAO-EU for Cotton in Asia and FAO Regional Vegetable IPM Program in South and Southeast Asia. These long running programs, supported by national and international funds, provided the basis to develop the science, policy and mass education for development of IPM programs in the region. The objectives of these IPM programs were to promote an environmentally sound system of plant protection through better science, better policy and mass implementation.

This chapter will attempt to provide background on the role of a program approach to achieve the objectives from the viewpoints of the authors. It will

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also present a case study on cotton programs to illustrate how a program approach enriched the key IPM program dimensions of science, policy and mass implementation.

9.2 Impact Studies

Most readers of this chapter will be looking for impact studies on IPM, although the focus of the chapter is on IPM programs overall. Nonetheless, a number of impact studies on IPM outcomes in Asia have been undertaken. Waibel et al. (1998) provided specific protocols to measure changes in pesticide usage with before/after project surveys including control villages outside the project area. Social-economic analysis (Praneetvatakul and Waibel 2002) have been rigorously conducted under academic conditions. An extensive literature review of peer reviewed journals by Davis (2006) attempted to draw conclusions from the body of academic studies alone. Her paper provided a much needed electronic debate over the FFSnet[1] on the role of peer reviewed papers while the literature on IPM programs is largely "grey literature" consisting of reports prepared by practitioners and farmers (Gallagher et al. 2006). For example, Pontius (2003) provided methods for farmers to express their viewpoints through an illustrative and narrative method. Other impact studies (for example, Tripp et al. 2005, Ooi et al. 2005 and van den Berg et al. 2006) focused on specific countries or topics within IPM programs and provided critical feedback for narrowly defined specific situations. A number of thesis have also been published following the Waibel et al. (1998) protocol, testing specific hypothesis related to pesticide use and yields. Other recent research focused on the social dimensions (Mancini et al. 2007 and Ogawa 2007) and examined the social aspects of IPM programs especially livelihood improvements and social relationships.

On program level impact assessments, Pontius et al. (2002) prepared a thorough review of the FAO Inter-Country Program on Rice IPM, including its evolution towards a wider Community IPM approach in which the science of IPM provided an essential entry point within farmer communities but extended to touch on the social, economic and political basis of crop production in those communities. An extensive review (van den Berg 2004) of twenty five impact evaluations in Asia concluded that none of the reviewed evaluations were able to cover the entire range of science, policy and mass education objectives of IPM program approaches. He also concluded that there is a great need for better designed impact evaluation starting with better baseline information, clearer indicators and long term commitment to impact assessment. Ooi et al. (2005) review of cotton IPM program is discussed in the case study below.

9.2.1 Science Within IPM Programs

A key first step of the FAO IPM Programs has been to ensure a firm scientific foundation. To take the example of the FAO Inter-Country Program for Rice IPM,

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[1] Global FFS Network and Resource Centre: www.farmerfieldschool.info

the science of IPM began with the plant resistance and new variety approaches of the International Rice Research Institute (IRRI) of the 1970s and 1980s. However, IPM programs expanded IPM to the importance of maintaining natural enemies which were being disrupted by pesticide applications: pesticides that were heavily subsidized during the early years of the Asian Green Revolution. The rice brown planthopper (*Nilaparvata lugens* Stål) was a particular problem threatening rice production in Asia in the 1970s (Sogawa and Cheng 1979) and was linked to early-season insecticide sprays for leaf folders (*Cnaphalocrocis medinalis* Guenee) and stemborers that were thought to cause high yield losses in rice. Kenmore (1980) and Kenmore et al. (1984) working at IRRI provided a clear basis for a broadened IPM system which protected the integrity of natural enemy communities from disruptive pesticide applications. It is now known that not just insecticides but also certain herbicides and fungicides (for example Kitazin® is a fungicide in the organophosphorous group and popular for rice disease control) also disrupt natural enemy populations leading to resurgence of primary pests and severe secondary pest outbreaks. Ooi (1986 and 1988) confirmed these findings and provided a good general review (Ooi and Shepard 1994). Settle's Indonesian team (Settle et al. 1996) working under the Inter-Country Rice Program, further elaborated the key role of non-pest species such as Chironomidae in the rice ecosystem to maintain general predators, even in the absence of pest species. Settle also provided a key link to the role of organic matter in the soil to higher populations of detritivores and ultimately to lower pest populations. Finally linkages between plant compensation to stemborer and leaf folder damage (Rubia et al. 1996) showed that yield losses were much less than expected, when plants were able to recover, thus reducing pressure to apply disrupting early-season sprays.

Thus the scientific basis for an IPM rice program was eventually well established. These scientific results became the basis for the "rice IPM principles" which when translated into lay-language, were to first "grow a healthy soil and crop" using resistant varieties and ensuring adequate plant compensation capacity (classically "cultural controls"); "conserve natural enemies" through avoidance of disruptive sprays and active maintenance of natural enemy habitat in the off season ("biological controls"); "observe fields regularly" for good water, weed, plant, rat, bird, pest and natural enemy management; and, "farmers become experts" to be able to understand and implement these principles of rice IPM (Matteson et al. 1994).

The IPM programs in vegetables and cotton have followed similar first steps to build a foundation of the underlying science of IPM from an ecological and economic point of view far beyond more classical economic threshold and sampling based IPM systems developed in the 1970s and 1980s. IPM Program support has been essential to maintain focused research both on and off research stations. Indeed, off-station research has been as important as on-station research (van de Fliert et al. 2002). Most of the work of Settle et al. (1996) was conducted in farmers' fields near the Indonesian Ministry of Agriculture's Pest Surveillance Laboratories, but with the backstopping by experts at the University of Gadjah Mada, Bogor Institute of Agriculture and other national experts. In another off-farm approach, van den Berg et al. (2004) showed the effectiveness of farmers carrying out common robust research protocols in multi-location trials to gain area wide data on key IPM issues.

9.2.2 Policy Within IPM Programs

As noted above, high pesticide inputs during the early stages of the Asian Green Revolution, especially during the 1970s were one of the underlying causes for secondary outbreaks of brown planthopper that widely threatened rice production in Asia (IRRI 1979). IRRI, national research and the FAO Inter-Country Rice IPM Program (see Section 9.2 above) scientific basis showed that this pest was actually caused by pesticide applications. For policy makers across the region, the notion that a pest could actually be caused by the pesticides they were subsidizing to get rid of pests was difficult to accept (and still is through out the world today among non-entomologists). Pesticide subsidies in Indonesia for example "were a financial burden to the government: for example, in 1986 subsidies amounted to 179 million 1995 U.S. dollars (about 0.17 percent of GDP and 0.8 percent of the total government expenditure) and in the period of 1976–87 nearly $1.5 billion 1995 U.S. dollars (World Bank data[2])".

Indeed, the role of natural enemies was not widely known by decision makers who even came up against some simplistic IPM notions of economic thresholds that many policy level decision makers had been exposed to in their university courses. Secondary pests and pest resurgence had to be demonstrated in the field to decision makers (Kenmore 1991, 1997). This was one of the major roles of the IPM Programs: that is setting up field demonstrations with farmers in a relatively small number of sites so that policy makers could see for themselves the effect of over spraying which resulted from the low cost of subsidized insecticides. Policy makers were exposed to side-by-side fields, with unsprayed fields having very low populations of brown planthoppers and good yields while sprayed fields had extremely high "hopper-burnt" fields with low yields. In retrospect, it is not surprising that this should be the case as IRRI scientists testing resistant varieties had developed a method of building up brown planthopper populations by applying pesticides. Although undocumented, it is important to realize the subsidies also mean kick backs to decision makers granting large contracts to supplies of pesticides and thus there is a strong reluctance to remove subsidies once started, no matter how much science and field evidence.

In the case of Indonesia, to cite the World Bank[4] again "in 1986 many pesticides on rice were banned and direct subsidies for pesticides were phased out in 1986–89. The policy shift not only saved more than $100 million per year in government expenditure but also made the country economically and environmentally better off. Pesticide production dropped to 22,100 metric tons in 1990 and meanwhile pesticide imports fell to a third of mid-1980s levels. Although no data exist to quantify the environmental impact of the subsidy elimination, the significant drop in pesticide use is thought to have alleviated damage to the environment—particularly to public health and to biological diversity. The reduction in pesticide use has been

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[2] wbln0018.worldbank.org/essd/eeipm.nsf/c0219bb8ef063b4c8525663b00657a5d/0ac89ed75640c61785256642004e6077

accomplished without adverse effects on rice production. Total milled rice production rose from 27 million metric tons in 1986 to 30 million metric tons in 1990."

Bangladesh, India, Philippines and other Asian countries also reduced or eliminated pesticide subsidies for rice and also reduced brown planthopper problems. Unfortunately, lessons are lost over time with changes in policy makers such that there is again a push to encourage subsidies for rice production with the notion that yields and pesticide applications are positively correlated in all cases.

The results of policy change for pesticide subsidies were thus an important part of IPM programs and integrated policy with policy maker education for better decision making (McClelland 2002). It is likely that policy changes in themselves had the largest impact on pesticide reductions as the cost of pesticides increased and use declined. However, policy changes also led to changes in extension for crop production as seen in the next section.

9.2.3 Empowering Farmers Within IPM Programs

One of the fundamental truths of nature is its diversity and variation. For IPM management, each field will have its own dynamic and each farmer will have their own capacity to manage the situation. Blanket recommendations for crop production may provide good guidelines but in general are just guidelines that must be assessed for each case differently. Within IPM programs, specific education should be undertaken for farmers to have basic information for better decision making, recognizing that farmers also have their own valid knowledge and experiences that must be tested alongside outside knowledge.

IPM programs have frequently developed as hands-on programs in many parts of the world. RiceCheck seminars in Australia, for example, help farmers to recognize stemborers and know their ecology in order to improve decision making. The FAO Inter-Country Rice IPM Program in Indonesia was also able to develop a hands-on practical system for rice IPM building on various experiences in the region as well as building on models developed for functional literacy and primary health care (Matteson et al. 1994). Dilts (1985), as FAO officer in charge of the Indonesia IPM project with others from World Education, provided the strong basis for adult based experiential learning while IPM practitioners provided practical management tools. Thus for rice IPM farmer education in Indonesia, the successful Farmer Field School (FFS), indeed "schools without walls", evolved from the Training and Visit methods of the extension service of the Government of Indonesia to provide a place for farmers to test IPM methods and improve on their own methods. The main thrust was to implement the principles of rice IPM cited above – while learning why heavy inputs of spraying only caused more problems with brown planthoppers (van de Fliert et al. 2002). The FFS model allowed local learning and decision making in ways that created local ownership leading to demand driven programs and farmer led actions (Dilts and Pontius 2000, Pontius et al. 2002).

The FFS model proved to be very flexible and easily adapted to other crops and topics (Mangan and Mangan 2003, Kjetil Øyna 2006, Stigter 2007, Braun et al.

2006) on IPM. However, FFS groups themselves were able to use FFS skills in organizing to move past education programs to research groups (van de Fliert et al. 2002, van den Berg et al. 2004) and advocacy (Rahadi and Widagdo 2003). As FFS groups expanded their confidence and organization, the notions of Community IPM emerged with local communities engaging policy makers on issues such as crop credit forcibly linked to pesticides, local environmental regulations and pesticides, health impact of pesticides, and other IPM related issues while also developing local initiatives for marketing IPM products and building alumi associations (Pontius et al. 2002).

IPM Programs have encouraged development of FFS to empower farmers to be able to make their own individual decisions as well as to develop community level approaches to dealing with community level pest management (e.g. rats) and policy issues such as pesticide impact on the environment and health of the community. Science-based understanding combined with advocacy and organizational skills to influence policy therefore come together at community levels, but influence overall IPM policy.

9.3 Cotton Case Study

9.3.1 Genesis of Cotton IPM Project Headed by FAO

The IPM program promoted by the Food and Agriculture Organisation (FAO) of the United Nations, focused on farmer education that helped made farmers experts in shifting from dependence on chemical insecticides to a higher appreciation of existing natural biological control. By 1990, the FAO initiated a program that brought farmers to IPM field schools (Pontius et al. 2002). The lessons learned in rice benefited in the development of cotton IPM and a major focus of implementing the Cotton IPM project in Asia is based on the IPM Farmer Field Schools model.

The IPM Farmer Field School (FFS) is the primary learning approach used within the context of farmer education (Dilts and Pontius 2000). Irrespective of the crop the IPM Field School is a season long learning experience. The important aspect of FFS is that the resulting process is learner-centred, participatory and relies on an experiential learning approach (Pontius et al. 2002).

9.3.2 The Farmer Field School in Cotton IPM

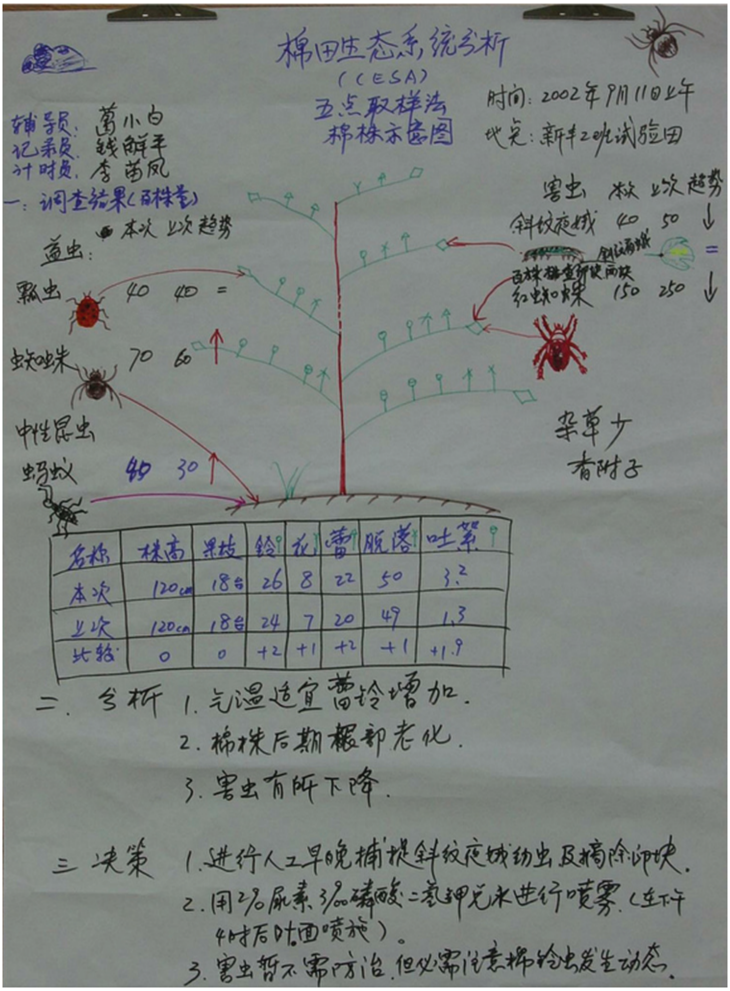
The FAO-EU Integrated Pest Management (IPM) Program for Cotton in Asia had six member countries, namely Bangladesh, China, India, Pakistan, the Philippines and Vietnam. Approved in 1999, the project activities started in 2000 in China, India and Vietnam, and in the remaining countries in 2001. It had the development objective of “sustainable, profitable and environmentally sound production of cotton in the participating countries, through the development, promotion and practice of IPM by farmers and extension staff". The immediate objectives included:

- developing a cadre of IPM cotton trainers from existing extension or field plant protection staff to train farmers in Farmer Field Schools (FFS)
- promoting co-operation for cotton IPM among governments, research institutions, development agencies, extension services and farmers' and other NGOs and to improve access for all interested parties to information from within and outside of the Program area
- enhancing national policies on plant protection in cotton to support IPM development in the six Program countries

To facilitate farmer education in FFS, there is a need to invest in training of IPM Facilitators. This is achieved in Training of Facilitators (ToF) programs initiated in each participating country. A ToF, like FFS, is a season long education experience where potential educators are trained in leadership, facilitation, and ecology.

The Program piloted a way towards skill development to overcome inefficiency in cotton production resulting from over-reliance on the use of chemical insecticides to control perceived pest problems. FFS are schools without walls, organized next to the cotton fields. About 25–30 farmers meet in the morning for a half day each week for one whole season. At each FFS meeting, participating farmers broke into small groups to make detailed observations of the cotton crop in the study field (Fig. 9.1), comparing the field situation between an IPM plot and a "farmer practice" plot.

Fig. 9.1 Farmers from an FFS in Vietnam examining cotton plants in their study plot, in southern Vietnam in 2000



棉田生态系统分析

（CESA）

五点取样法

棉株示意图

时间：2002年9月11日上午

地点：新丰2晚试验田

辅导员：葛小白

记录员：钱解平

计时员：李苗凤

一：调查结果（百株量）

益虫：	本次	上次	趋势
瓢虫	40	40	=
蜘蛛	70	60	↑
中性昆虫 蚂蚁	40	30	↑

害虫	本次	上次	趋势
斜纹夜蛾	40	50	↓
斜纹夜蛾 百株棉查卵块两块			=
红蜘蛛	150	250	↓

杂草少

香附子

名称	株高	果枝	铃	花	蕾	脱落	吐絮
本次	120cm	18台	26	8	22	50	3.2
上次	120cm	18台	24	7	20	49	1.3
比较	0	0	+2	+1	+2	+1	+1.9

二、分析 1. 气温适宜蕾铃增加.
2. 棉株后期根部老化.
3. 害虫有所下降.

三 决策 1. 进行人工早晚捕捉斜纹夜蛾幼虫及摘除卵块.
2. 用2%尿素3‰磷酸二氢钾兑水进行喷雾（在下午4时后叶面喷施）。
3. 害虫暂不需防治，但必需注意棉铃虫发生动态.

Fig. 9.2 A cotton ecosystem drawing by cotton farmers in an FFS from Anhui Province, China, 2000

Observations were recorded, discussed, and interpreted by the group and collated, resulting in an agro-ecosystem drawing (Fig. 9.2) summarizing the data collected from the respective plots. Farmers would share their findings with other farmers (Fig. 9.3)

9.3.3 Impact of Educating Farmers in Cotton IPM

The benefits of farmer education in FFS can be gauged by the results from selected FFSs in six participating countries of the FAO-EU IPM Program for Cotton in Asia (Fig. 9.4). Usually, fields with IPM practices that encompass an understanding of

Fig. 9.3 IPM facilitators learning techniques to encourage farmers to share cotton ecosystem analysis to fellow farmers in an Sukkur, Pakistan in 2003

the cotton agro-ecosystem in making agronomic decisions have a higher net profit as compared with that of a similar field that followed normal practices (Ooi 2004). This may be attributed to a better knowledge of beneficial insects that exist in the field as noted by Thai rice farmers (Praneetvatakul and Waibel 2002). Often this is

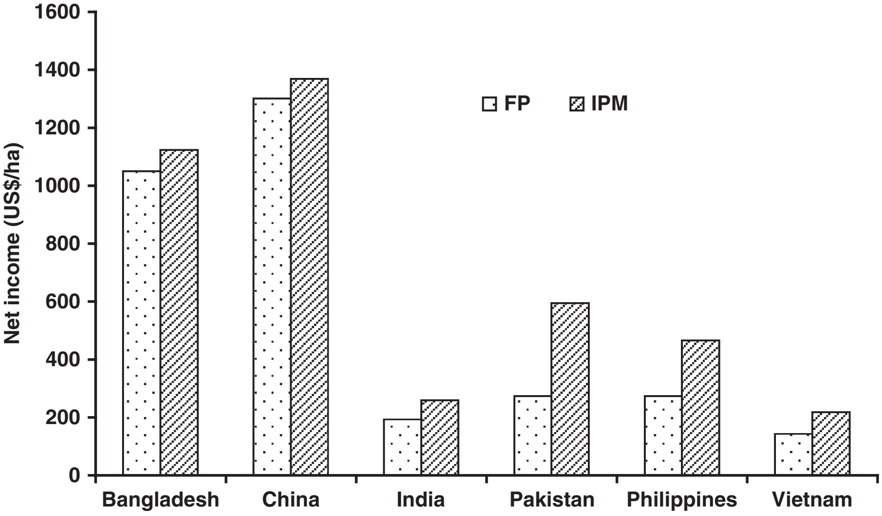


Fig. 9.4 Net income (US$/ha) obtained at selected Farmer Field Schools in six participating countries of the FAO-EU IPM Program for Cotton in Asia (see Ooi, 2004)

translated into reduced use of chemical insecticides and greater attention to agronomic practices that are directly related to plant growth and productivity (Ooi et al. 2004). Impacts of the FFS in cotton in other related fields are provided in the publications on the Impact of the FAO-EU IPM Program for Cotton in Asia (Ooi et al. 2005).

9.4 Conclusions

Asian IPM Programs, especially the FFS aspects, have fostered programs in Africa (Anandajayasekeram et al. 2007), Latin America (for example: Schut 2006), Eastern Europe and Central Asia. Many examples are found on FFSnet mentioned above. These programs not cover more than 70 countries and 30 topics (Braun et al. 2006) and thus one may claim a massive impact of the Asian programs.

There is a growing concern, however, that the wider aspects of scientific basis and policy are left behind while FFS and other mass education programs proceed as strong demand driven extension programs. The authors feel that while it is extremely important that farmer education is mainstreamed in extension programs of government, non-government and private sector activities, there is a corresponding need to promote a solid IPM scientific foundation and ensure each new generation of policy makers are on target for budget and legislative decisions which build on past lessons of solid IPM management and not yield to yet another cycle of pesticide subsidies, especially in the face of high food and fuel costs.

Acknowledgments The authors would first like to recognize the large number of scientists, facilitators and farmers that provide the foundation of IPM programs. Many senior mentors in all the Asian countries provided the fabric within which these programs were able to be implemented. The authors specifically lay no claim to the innovations achieved in the programs but do acknowledge their deep appreciation to have been a part of this IPM community. For literature cited, much of it grey literature prepared by colleagues without the access or funding to publish in peer-reviewed journals, we would like to thank Arnoud Braun for establishing and maintaining the Global FFS Network and Resource Centre where most of the articles cited my be found. Finally, last but not least, the authors would like to thank Dr R. Peshin for his leadership to prepare this monumental book and his extremely kind patience with us in preparation of this chapter.

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Chapter 10
Evolutionary Revolution: Implementing and Disseminating IPM in Indonesia

Edhi Martono

Abstract Integrated Pest Management (IPM) program in Indonesia was implemented after the government's rice self-sufficiency program failed, in most part, due to brown planthopper attack during the 1970s and 1980s. The IPM program implementation, modeled after some pioneer projects, introduced a new plant protection approach, mainly by involving farmers as early as possible in decision making, and reducing their use of pesticides. Since farmers had already been accustomed to chemical-based approach, at the beginning many farmers got confused, lost their confidence in extension sevices, and were hard to convince that the new approach is more feasible. The Indonesian experts then created a training-cum-extension program called Farmer Field School (FFS) on rice, and for about five years (1988–1993) trained about one million rice farmers. The training was later extended for other crops such as dry-land, vegetables and estates' commodities. A considerable number of farmers became familiar with IPM, but the change expected in their attitudes did not really emanate, especially when they were faced with problems other than plant insect pests and diseases.

This chapter details the development of IPM program in Indonesia, the way of its dissemination and the result among Indonesian farmers. The complexity of the problems shows that technology transfer and program dissemination cannot depend on single approach. A multidisciplinary study should follow the development of a technology introducing program, and monitor it until it is assured that the program works as expected.

Keywords Indonesia · IPM national program · FFS

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10.1 Indonesia's Rice Cultivation: A Problem from the Start

Rice self-sufficiency has long been an obsession with the Indonesian government ever since Indonesian people proclaimed their independence in 1945. There were also political challenges concerning Indonesian government policy on economic development. By the end of 1950s, a clear and well-rounded agricultural policy had yet to be formulated. President Dr. Soekarno tried to foster self-sufficient plans, including programs on food crops such as rice and corn (maize), with only meager results, as incompetence and the disadvantages of the newly formed state haunted those programs. He rejected western help, but the agricultural policy applied by Indonesian government reflected more of the western approach to increase production. Quietly the Green Revolution was applied to Indonesian agriculture. There was "Pancha Usaha", five agricultural principal practices to be adopted by farmers, which included seed technology, irrigation improvement, pesticides usage as plant protection measures, use of synthetic inorganic fertilizers, and improved marketing techniques. The use of synthetic chemicals in many of Indonesian rice paddies started in late 1950s.

IR 5 and IR 8 rice varieties were introduced to boost production by International Rice Research Institute (IRRI). Rice intensification through program called BIMAS (*Bimbingan Massal*, Mass Guidance) was intensified in 1966. The results, however, seemed slow and uncertain, and was not been able to provide Indonesia with staple food. Some of the introduced rice varieties were not popular among Indonesian farmers, due to their unacceptable taste and too low plant habitus. Meanwhile, in regional level, FAO/UNEP (United Nation Environmental Program) Panel of Experts on Integrated Control advised on the initiation of cooperative Regional Program on the integrated control of rice pests in Asia (Oudejans, 1999). During those times, major rice insect pests were various stemborers—white and yellow stem borers (*Scirpophaga innotata* and *S. incertulas*), striped borer (*Chilo suppresalis*); leafhoppers not only the one vectoring tungro diseases i.e. green leafhopper *Nephotettix impicticeps*, but also whitebacked and zigzag leafhoppers (*Sogatella furcifera* and *Inazuma/Recilia dorsalis*); rice gall midge (*Orseolia oryzae*); and rice seed bug (*Leptocorisa oratorius*). The field rats (*Rattus argentiventer, R. brevicaudatus*) inflicted major damage in some regions (De Datta, 1981; Van de Fliert et al., 1994). The solution to these pest problems was that pesticides—insecticides, rodenticides—were always included in Bimas' technology package, either in kind or in credit loans. Therefore, farmers in Bimas program would always use pesticides in scheduled treatment, because "we have the chemicals and were urged to use them" as recalled by a farmer (Winarto et al., 1999). This resulted in imbalance in rice ecosystem. The outbreak of brown planthopper (BPH), *Nilaparvata lugens* hit Indonesian rice farming very hard. Many rice producing regions were left with no harvest, and rice production was threatened as hundred thousand hectares of rice planting suffered from BPH attack and only a small number of agronomists and experts realized that BPH attack was the result of indiscriminate use of pesticides (Untung, 2006). Kenmore et al. (1985) had reported that pesticides could resurge BPH population but his work had no immediate effect in terms of policy or implementation of improved pest control measures to prevent BPH.

Some Indonesian entomologists from government offices and universities recognized the need of a more holistic and comprehensive approach to control BPH. They started the IPC (Integrated Pest Control) Pioneering Project on Rice in 1980, although efforts to introduce IPC on rice had started since 1975, when the Directorate of Food Crops Protection in Pasar Minggu, Jakarta adopted IPC concept in their policy and was responsible for its implementation (Oka, 1990; Partoatmodjo, 1981). The IPC Pioneering Project was implemented in six rice producing provinces, i.e. West Java, Central Java, East Java, Yogyakarta, South Sulawesi and North Sumatera. The result of this project was a confirmation on IPC practices, since rice fields with IPC produced as much as those without IPC practices, but with lower pesticide inputs. The policy and decision making impacts, however, were a little bit delayed as the government was still obsessed with the self-sufficiency program, and pesticide packages in the intensification program were still considered beneficial to maintain the sufficiency (Untung, 2006).

The rice self-sufficiency for Indonesia was eventually achieved in 1984. Once again BPH threat loomed in 1985/1986, caused by local BPH population explosion in Java. Research showed that insecticides use affected the BPH population to become explosive as resurgences followed insecticides treatments (Untung and Mahrub, 1988). With scientific evidence being available, President Suharto in 1986 issued a presidential decree banning 57 insecticides formulations used in rice farming. This is an important step of IPC (by then was known as IPM, Integrated Pest Management) on rice, as the decree also stated the importance of IPM approach in rice pest control. The decree was also followed up by the gradual cut back of pesticide subsidy, and by 1989 pesticides were no longer supported by government subsidy. The establishment of IPM policy was completely ensured, when in 1992, the Indonesian House of Representatives amended the Crops Husbandry System Bill, which explicitly states that IPM is the only system recognized as legal plant protection measure in Indonesia.

10.2 Disseminating Farming Technology to Farmers

The development of IPM program on rice in Indonesia happened in about the same time with the advance of similar programs in other rice producing countries. The Inter-country Program for the Development and Application of Integrated Pest Control in Rice in South and South East Asia was established in 1977 after repeated advices by FAO/UNEP Panel of Experts on Integrated Control and Host Plant. The program was finalized with a plan of operation between seven governments (Bangladesh, India, Indonesia, Malaysia, Philippines, Sri Lanka and Thailand), was drafted in a technical consultation meeting held in Bangkok in 1978 (Waterhouse, 1983). The funds for this program came from several donor countries, namely Australia, the Netherlands, United States and Arab Gulf countries. The objective of this program was to encourage applied research mainly for farmers' rice fields, foster traditional extension approaches, and strengthen national IPM policies and capacity building.

The first step in applying IPM practice at farmers' level is to instill a new pest control paradigm, which would mostly oppose current practice of heavily relying on pesticides. As by the time it is proven that pesticides induced the BPH outbreaks, insecticides usage should be limited under the guidance of economic injury threshold (Kenmore, 1987). Local and national findings further confirmed the benefit of IPM program. These and other research findings developed at IRRI provided National IPM programs to formulate and implement strategies for BPH control. National leaders and policy makers were duly impressed by these evidences, but implementing policies into action by farmers and growers needed different approach as it would be they who would suffer if the IPM action and practices failed to bring about sufficient rice production free from BPH and any other pests' attack. In short, IPM program had to assure economic gains and prevent any pest-induced losses.

The challenge was a formidable task. In most extension sessions for rice intensification programs, farmers were advised to practice crop protection technologies which permit the use of toxic chemicals (with euphemistic term "crop/pest medicines"). Treatments were done according to calendars and schedules, regardless of the pests' existence and it was believed that pesticides were indispensable. The use of agrochemicals was thought as an obligatory input in their farming. With IPM strategies, the relatively new, acquired belief had to be drastically changed. Pesticides could worsen their farming, and change of attitude was needed to practice IPM. The thinking was not only dominant among farmers, even extension workers and agronomists were deeply convinced by the important role of pesticides usage.

With these background conditions, conventional extension technique such as T&V (Training and Visit) would not be effective. This technique commonly used to spread the Green Revolution technology and to relay the messages of intensification down to farmers' level, would not be able to instill the paradigm of change necessary for the farmers and farming practitioners. Integrated Pest Management is not just a new technology; it is a new way of looking into farming and farming system. A T&V session, however, would provide farmers with materials coming from extension workers and "contact farmers", a "second-hand" (even "third-hand") material with little experiencing involved, because the farmers were not the direct subject of the training.

The designation and underlying concept of T&V extension is actually acceptable and might work well in a hierarchical, top down structure of the Ministries of Agriculture in most South and South East Asian countries along with their extension services. Under this system, schedules, duties and responsibilities are clearly defined, and their practices are closely supervised at all levels. A "transfer of technology" implementing concept, T&V extension emphasizes regular training for extension field workers and contact farmers, with better linkage between research and extension. The responsibility of providing administrative control and technical material to the extension workers is in the hand of a directorate in the Ministry of Agriculture (Oudejans, 1999). The training for extension workers is given once a week, while on the other days during the week the workers are supposed to extend the messages from the training to the contact farmers. The contact farmers is a member of a farmer group, which in Indonesia consists of about 70–150 farm families. The member of this group is farmers operating in certain tract of rice fields. One contact farmer from the group receives recommendation for the forthcoming one or two weeks of the planting season from extension worker and then spreads the messages to the other group members.

Van de Fliert (1993) observed that the system often did not work out as expected. The visits did not happen as scheduled, or simply did not happen. When it happened, the information conveyed by the extension workers did not relate to the condition of the planting schedules. The low social status and salary of the extension workers did little to their motivation and most of them spent some of their time looking for additional income opportunities. However, the more fundamental failure of the T&V system is in developing the farmers' capacity to deeply involved in the farming system, mainly in term of accessing external information anytime they need it, doing experimental works to be concluded and applied on their plantings, and enhancing their ability, both individual and collective, to take right and feasible decisions (Roling & van der Fliert, 1994).

One of the Training and Visit methods of extension's legacy is in the availability of farmers groups formed for its purposes, which could be useful for the IPM extension as well. The T&V extension also gave rise to broadcast material and networks. The so-called "Siaran Pedesaan" (Rural Programs) on radio, and later on TV, became popular with most farmers that many formed their groups based on their collective schedule of listening or watching the programs. By considering these and similar farmer groups, extension for IPM would then be designated. The extension model was what is called Farmer Field School or FFS. This development was partly the result of the IPC Pioneering Projects in six provinces in the early 1980s. In later years it spread to other countries and was approved by FAO and many NGOs as the more preferable extension model for IPM dissemination and implementation.

10.3 IPM Extension: Disseminating Concept and Practices

The traumatic experience of BPH outbreak which recurred in 1985, approximately a decade after the first one, convinced policy makers that a working concept of IPM should be developed, introduced and implemented. The concept must be based on real condition but must have strong scientific justifications. The basic principles of IPM to be disseminated in Indonesia were formulated by experts from the Ministry of Agriculture, working together with academicians from various universities. These principles compiled by Oka (1994) and Untung (2006) are:

10.3.1 Understand the Agroecosystem

Agricultural production process, ecologically speaking, is a set of activities in managing agricultural- or agro-ecosystem. The process' goal is to achieve optimal yield and production, both quantitatively and qualitatively, so they fulfill the need of the farmers or the ecosystem “managers”. Therefore an implementing IPM program should be placed as an integral part of a comprehensive agroecosystem. The ecosystem managers, i.e. farmers or growers, have to understand the character and dynamics of the ecosystem they manage in order to be able to control pest and diseases problems by practicing IPM.

Although the general rules of agroecosystem dynamics are widely known, some are locally specific, and have to be honored as such. Agroecosystem is an artificial ecosystem, as it is defined by humans to fulfill humans needs. Its biological and genetic diversity are usually low and tend to become uniform, which make it unstable and vulnerable to insect pest or disease population domination. It develops over time and varies between spaces, with a unique yet dynamics changes. Changes may alter an agroecosystem drastically, since its sensitivity to any kinds of change is commonly high. By understanding agro-ecosystem structures such as plants and crops, pests, natural enemies and other biotic factors compositions, the dynamics interaction among them, and the influence of abiotic factors, the right and proper strategy will prevent pests to inflict economic damages.

10.3.2 Benefit and Cost of Crop Protection

Farming or planting system, economically speaking, is an enterprise to gain profit. This profit is the difference between income generated by agricultural product sale and the cost to produce. To adequately protect the crops, farmers have to spend their money to purchase materials such as pesticides, resistant variety seeds, take on rent chemical treatment euipments and to hire farm-workers. The gain of these spending is the prevention of economic damage, which can be quantified. Thence, the difference between this economic loss prevented and the cost of protecting the crops is the (economic) benefit of the crop protection measure.

In the long term this benefit will increase the profit, since a rightly practiced IPM ensure the sustainability of the agroecosystem. The benefit would also extend to other ecosystems and increase farmers’ welfare since they would tend their farms in an eco-friendly condition. The price of their produce as well as the environment where they live, would be better under more organized and carefully executed plant protection schemes.

10.3.3 Plant Tolerance to Damage

All plants have tolerance level to pest damage, and at this level damage actually does not cause economic loss. Low pest population, slow development of plant diseases or tough and resistant crops may result in affordable losses, which can be compensated by recuperating crops and unaffected produces. Therefore, pest management is not aimed to decimate pest population, but to lower the pest population up to a tolerable level. Plant protection measure, specifically pesticides treatment, is done only when the pest population has risen over that tolerable level referred as economic threshold level.

10.3.4 Letting Small Numbers of Individual Pest to Survive on the Field

IPM concept recognizes the role of population balance between pests and their natural enemies. Without any pests, natural enemies might not survive and will decrease, probably into extinction. It is fortunate if they are able to move out of the area and find some kinds of refuge where their survival may be ensured. The field that they leave, however, is in danger of being devoid of any natural enemies, and pest population outbreaks may happen. Managing pest population in such a way that a small number of individual pests still exist proves very important to sustain natural enemies' role.

10.3.5 Sustain and Maintain Natural Enemies

Natural enemies must be managed to ensure their ecological functions in an agroecosystem. The important role of natural enemies to control pests is already common knowledge. People have already used parasitoids, predators and pathogens to control pests. If local species is insufficient, exploration and introduction are sought, either to provide the non-existent or to enhance the low potential natural enemies. In essence, sustaining and maintaining natural enemies meant for tending and caring more for the agroecosystem, would only be possible with adequate knowledge about its characters and behavior. It is now understood that maintaining an ecological balance using available components is more preferable than importing alien species, be it useful or otherwise.

10.3.6 Healthy Plant Culture

Plant health is now recognized more as an important factor in ensuring potential yield and production. With healthy plant culture, pests and pathogens are kept away from invading the farm or plantation. The efforts to keep the pests away from the plants are not necessarily coming from pests control practices, but there are cultural practices which are effective in preventing the pests and protecting the crops. Some of the practices were actually followed by growers, and were handed down as traditional practices that once too often were thought as ineffective or having no beneficial effect. A lot of those traditional practices came from long experiences of many diligent and industrious farmers. There were proofs that traditional practice of choosing the right planting time by observing natural phenomena (the rising and setting of certain star constellations, the emergence of some insects or wild animals around the fields) often helps farmers in avoiding one or two kinds of key pests.

On the other hand, lack of knowledge, limited education and difficult access to funding sources seem to hinder the proper care of farmers' fields and plantations, make them prone to pest and diseases threats. Dissemination of IPM knowledge helps farmers to understand more of their farming, and how to take care of their crops from land preparation up to marketing. IPM is introduced as an overall practice, in which every step is ensured to prevent economic loss by emphasizing the importance of plant health. Planting practices that enhance plant resistance to insect pests and diseases are implemented.

10.3.7 Field Monitoring

The dynamics character of agroecosystem needs close observations from time to time. A lot of its components interact in interrelated patterns, resulting in a cause-effect condition which may or may not support living organism population life therein. Both crops and herbivores benefit from this condition, therefore, regular monitoring of the field has to be done to provide information needed for decision making in handling the farm. To predict accurately when an outbreak will happen is not easy, since the pest population dynamics is very specific for different times and places. Monitoring should be done by farmers, which is an important tool in decision support system for pest management. The ability of farmers to compose the right schedule of monitoring activities for each planting season is as important as possessing a comprehensive working knowledge on the pest population and management.

10.3.8 Farmers Empowerment

For Indonesia, farmers are the biggest producers of agricultural goods. The small farmland ownership, non-existent capital, and low educational level contribute to the substandard performance. The need of farmers' empowerment becomes more important with the introduction of IPM. For the farmers to effectively understand and implement IPM principles and technology, empowerment is a prerequisite: they need that basic knowledge given to them in their own language. This is where Farmer Field School plays its crucial role, and serves as an agent of farmers attitude reforms.

10.3.9 IPM Concept Socialization

It is not only farmers who need to know more about IPM. The bureaucracy, the lawmakers, the technical officers must also understand the basic idea behind IPM concept. Extension, education, training and publication both formal and informal are ways to disseminate IPM to all members of the society. Changing farmers' attitudes that had been nurtured under conventional view of plant protection, e.g. emphasizing chemical control, into those under more holistic concept such as IPM need time, energy and commitment from all stakeholders of agriculture. The socialization will determine the success of an IPM program implemented on any crop planting system.

IPM basic elements and the IPM components, as defined by Watson et al. (1975), are the core knowledge and information of IPM which have to be recognized before planning and composing an IPM working concept. When implemented, knowledge on ecosystem and social-economic system must be fully understood so that the optimal combination of technical and tactical pest control measures is achieved. These basic elements and components are:

i. Basic elements:
   a. *Natural control*
   b. *Sampling technique*
   c. *Economic threshold*
   d. *Biology and ecology*

ii. IPM components:
   a. *Cultural control*
   b. *Biological control*
   c. *Resistant varieties*
   d. *Physical control*
   e. *Mechanical control*
   f. *Legislative control, mainly through quarantine measures*
   g. *Chemical control*

10.4 Farmer Field School as Extension and Training Process

IPM National Project in Indonesia had its milestone point in 1989 when Farmer Field School training method was adopted for the implementation of IPM. The decision was taken following the 1986 presidential decree banning a number of insecticides, and it was a very timely one. With the withdrawal of those insecticides, not only people need to be assured that farming with fewer chemicals is possible, but also there must be information on how ecologically correct farming should be done. The IPM Pioneering Project in early 1980s, provided the base for training and extension model, which was developed together by experts from FAO IPC and major Indonesian universities such as Gadjah Mada University in Yogyakarta, Bogor Agriculture Institute in West Java, and Hasanuddin University in South Sulawesi. The training was first planned for rice farmers, but later was extended to cover also soybean, corn, potato, cabbage, chili and shallot farmers. In 1997, the same FFS model was further adopted for estate crops smallholders i.e. coffee, tea, pepper, cacao, cotton and cashew (Untung, 2006).

Intensive training on rice for the first time was aimed at obtaining a sufficient number of trainers, the very first ones or the master trainers. This was carried out in some kind of community college level course in selected universities. Afterwards, these master trainers would train Field Scout 1 (FS1) and FS2 personnel in 12 Field Training Facilities (FTFs) around Indonesia. The personnel trained were Pest Observers who were Ministry of Agriculture employees, especially those stationed in rice producer provinces. They underwent a four planting seasons (15 months) rigorous learning on rice and dry-land crops, followed by one season (four months) in-campus training at a designated university. The trainees learned how to do the basics of IPM by themselves. They observed, analyzed, made decisions and practised those directly in the fields. Activities such as field experiments and studies were also part of the curriculum, under the guidance and support of master trainers and college lecturers (Martono, 1996).

FFS relies on these trained pest observers as the training guides who lead and organize the school for one planting season. The school itself is actually an extension *cum* training activity, with the goal of IPM implementation on one crop in the same tract of land, representing a definite agroecosystem. What these guides obtained in the FTFs was applied on the FFSs, step by step. A typical schedule is presented in Table 10.1. The experience-based training helps participants to adopt knowledge and technology in rapid yet sustainable manners. The FFS for rice and food crops' farmers were started in 1989 and ended after ten years in 1998. The number of farmers participated in FFS was estimated to be around 1,500,000 to 2,000,000, with more than 10,000 officers served as their guides. In 2005, when the FFS on estate crops smallholders was terminated, another 160,000 smallholder planters were trained in several provinces, under a similar system based on the model developed on food and horticultural crops (Oka, 1994; Untung, 1993; 2006).

To make IPM concept easily understood by the farmers, the IPM basic principles are developed into four IPM working principles, which are simpler, easy to understand and applicable in field condition. These four principles also represent a new paradigm approach, as described by Untung (2006).

10.4.1 Healthy Plant Culture Maintenance

Farmers need to be assured that the first important step toward successful planting is maintaining plant health. The plants must be healthy and strong so that they are qualitative and quantitatively productive. This will lead to better value, and eventually good price. Healthy and strong plants will also improve their resistance to pest and diseases. This principle is emphasized to FFS participants, and should motivate them as long as the participants find out by themselves what healthy plants mean in their farming. "Finding by themselves" become the main theme of FFS's materials transfer.

Table 10.1 The Composition and Structure of an FFS Curriculum

No.	Activities	Goal	Time	Involved People
1.	Preparing material for general overview on the FFS activities	A ready-made material on IPM including defining IPM and FFS, map of the location, FFS activities renumeration, learning contract	One hour allocation	Scouting farmers
2.	Preparatory meeting with local administrators	Same as above, added with request for supports	Any time before the FFS start, preferably about two weeks	District head, Contact/scouting farmers, Pest Observer and Extension Officers
3.	Preparatory meeting with village administrators	Same as above, with request for supports	One hour allocated, supposedly 2–3 weeks before planting time	Contact/scouting farmers, Village head, Village officers, Pest Observer and Extension Officers, Representative of farmers' group
4.	Preparatory meeting in farmers' group level	Information and description on FFS activities as above plus requirement for participants, the process of FFS activities, and signed learning contract.	3–4 hours First week before seedbed preparation	Same as above
5.	Week 1 of FFS	1. Training described 2. Ballot box: Pretest 3. Group dynamics (introducing participants) 4. Sampling and land estimates 5. Break 6. Raising questions 7. Agroecosystem observed	Week when the farmers start planting	Scouting farmer and FFS participants (25 people, 70% males and 30% females)

Table 10.1 (continued)

No.	Activities	Goal	Time	Involved People
6.	Week 2–11 of FFS	1. Agroecosystem observation 2. Drawing and discussing observed ecosystem 3. Presenting the analysis and deciding the action 4. Break 5. Group dynamics 6. Special Topic	07.30–08.30 a.m. 08.30–09.45 a.m. 09.45–10.00 a.m. 10.00–10.15 a.m. 10.15–10.30 a.m. 10.30 a.m.–12.00 noon	Same as above
7.	Week 12 of FFS, the last	1. Agroecosystem observation 2. Drawing and discussing observed ecosystem 3. Presenting the analysis and deciding the action 4. Break 5. Group dynamics 6. Yield/harvest measuring 7. Closing and plan for the next season	Unscheduled	Village head, Village officers, Contact/scouting farmers, Pest Observer and Extension Officers, FFS participants

Source: IPM Field Guide, 2001.

10.4.2 Natural Enemies' Manipulation and Conservation

Most farmers actually know that there are "bad" and "good" organisms in their fields. This principle helps farmers to confirm and also to deliberately recognize those organisms, to learn how they function in the ecosystem, and to propose how to get the best out of them. In some FFS, there are also special topics on "insect garden", by which participants observe the life cycle and behavior of several organisms found in the fields. The old concept of "learning by doing" is implemented true to its meaning.

10.4.3 Weekly Field Monitoring

Since population dynamics fluctuates over time, climatic change occurance and cultural practices applied according to crop's growth and development, and ever-changing condition of the field should be well observed and documented with regularly executed monitoring. A weekly monitoring is about enough to record what happens in the field. The information is then analyzed and the decision making is based on the result of the analysis. Actions which follow after the decision should be evaluated, and the following weekly field monitoring should be able to yield the evaluation needed.

10.5 Farmers as IPM Experts in Their Fields

Farmer is the manager, the person in charge, the person responsible, and the sole decision maker for the field. Officers such as Pest Observers, Extension Workers are resources giving information, should the need arise. IPM put farmers in their right place, as in this concept the farmers must know anything that happen in the field, and be accountable to themselves. FFS tries to train farmers to be "IPM Experts" at least on their own fields. Farmers' confidence and their independence are expected to encourage farmers to apply IPM principles and technology for their own benefits. As experts, farmers should be able to monitor the ecosystem, to analyze the information obtained, to make decision and to apply the right control technology.

Farmer Field School is distinctly different from classical extension pattern mentioned in the previous part of this article. The FFS training is much more participatory, with a bottom up approach implementing an androgogy method of learning. Farmers are encouraged to learn from their experiences on IPM principles and technology by observing what happens in their fields.

Technically, the implementations of IPM concept into basic practical guidelines are composed together by FFS participants and their scout. They consist of following points:

10.5.1 Land/Field as Main Learning Site

All learning and discussion are conducted in the field/plantation patch/farming site, not indoors. The land sites provide references, learning materials and a place where group members interact.

10.5.2 Learning from Experiences

All activities of FFS, starting on the first meeting day up to the last, are done by monitoring, calculating, measuring, and directly observing the events which take place in the field. Expressing group members' experiences, analyzing the observation results, and formulating the decisions to achieve the right measures become part of the training, since participative method makes farmers to find out by themselves field's concept and technology, both individually and in groups.

10.5.3 Agroecosystem Study

The training process motivates farmers to actively analyze agroecosystem in order to sharpen their ability in managing pest and other planting problems based on ecological dynamics. Every week farmers analyze information and data gathered from the field so that they can make appropriate decisions. The weekly frequency will prepare farmers to get used to monitoring and ecosystem analysis on their own field before applying control measures.

10.5.4 Practical and Functional Materials and Methods

FFS participants, with the help of their scouts, are urged to use local resources and materials, such as manure, compost, botanicals, and other eco-friendly complements in their fields.

10.5.5 Skill-Based Curriculum

The FFS curriculum develops flexibly, in accord with local agroecosystem problems development but without ignoring IPMs four basic principles. Parts of the curriculum are prepared by field scouts who have been participants in training of trainers program. Every meeting starts with ecosystem monitoring, followed by information analysis, decision making, group dynamics and special study. The curriculum is also tailored to farmers' need i.e. improve their special skills, such as biological control agents rearing, botanicals mixing etc.

10.5.6 Train Farmers to be Trainers

FFS does not only train farmers but also equips them with knowledge and skills on scouting and carrying out an FFS. FFS lets farmers to find out by themselves anything about ecosystem as they observe pests and natural enemies, recognize ecosystem dynamics, make decisions and take actions in the fields based on IPM principles. Group dynamics helps them to improve their activity, creativity and ensures their confidence in expressing themselves, individually or in groups. By the time they finish the training, participants are able to lead their peers in similar training.

10.5.7 Bottom Up Planning

To ensure that the training and its curriculum coincide with local needs, a TNA (Training Need Assessment) is done before carrying out the FFS. The TNA for instance will decide which field site is used as trial site, what topics will be the main theme of the training etc. The farmers scout and trainer should be responsible for the TNA.

10.5.8 Select Participants

The optimum number of participants in FFS training is 25, therefore, there must be certain criteria for a farmer to be a participant, since often the number of farmers in a certain land tract wanting to join the FFS exceed the optimum. If there are more than 25 participants in a training group, the schooling is just ineffective. Also, these participants must have very high commitment to the activities, otherwise they won't be able to completely understand and practice IPM on their field. The commitment is also important since food and vegetable crops planters have to attend at least 11 weekly meetings, while estate smallholders must attend at least 15 such meetings. A participant should also be, no more than 45 years old, literate and a farm owner, not just a farm worker. A kind of "learning contract" has to be signed by farmers at the beginning of the training to make sure that they stay through the program to the end.

10.5.9 Participant Evaluation Test

The effectiveness of knowledge and skill transfer of the participants are checked through "before" and "after" tests device called the ballot box. The first test is to measure the participants' knowledge and perception on IPM before they undergo training, while the second is to evaluate the FFS through the skill, knowledge and attitude changes, acquired and shown by the trainees.

10.5.10 FFS Structure

Every FFS participants' group of 25 farmers is divided into 4–5 subgroups, of which each group is facilitated by two field scouts who have previously been trained under similar program. There are Field Scouts 1 (FS1) who train FS2, and these FS2s are the ones who train farmers in an FFS. These farmers, who are called Scouting Farmers, are also known as FS3, and responsible for the training of their fellow farmers. The routine schedule of an FFS during any meeting day from 7 a.m. to 1 p.m. is agro-ecosystem monitoring by observation, drawing and analysis of the ecosystem, group presentation and discussion, conclusion and decision making, group dynamics and special topics considered urgent and specific for the area (Table 1 presents a detailed list).

10.5.11 FFS Follow-Ups

The ultimate goals of an FFS program, i.e. change farmers' behavior and establish farmers' self-reliability in managing their lands, will not be easily gained only after a season or two. FFS alumnae should continue the activities they have learned from the school, and use all the experience and knowledge from the group-based work to solve their planting problems. Follow up activities will mostly rely on the conscience and self-activity of former FFS trainees, and each season they have to adapt themselves to different problems and challenges. FFS-trained farmers often discuss problems on group's plan scheduling, post-harvest work, product marketing, market institutionalization, organic and sustainable farming practices etc. Field Scouts and other government officers play their role as facilitators, partners and motivators for farmers' groups with FFS experiences.

10.6 Experiences as the Best Learning Motivation

What was the real achievement of this almost three decades of IPM implementation? There were claims on the success of the program, but the definition of success varied according to those who made the claims. During the program implementation under government-backed funding (with loan from foreign donors), survey and research were also undertaken to evaluate the technological, policy and socio-economic impacts of the practices. Most of these surveys showed the superiority of IPM program to the conventional approach. They recorded that more environmental-friendly practices were not only possible, but in some cases also profitable. These "first phase" results, however, still viewed IPM as technological transfer and change program, and only a limited number of researches were aimed at describing the social and cultural acceptance by the farmers. Within the "second phase", socio-economic baseline studies were emphasized, although technological and farming practices observations were also carried out. The latter studies were aimed more to confirm IPM practices rather than to justify IPM concept. The success of IPM was later measured in the terms of the farmers' benefits and not only from technical indicators which stated that IPM program was running well.

The major result of the first phase of implementation (1983–1993), aside from controlled population of brown planthopper, was the establishment of IPM Farmers Field School, FFS, which proved crucial to the dissemination of the program. From the point of introducing and establishing a national IPM program, especially on rice, this is an undeniable success. Furthermore, the program success including the rice self-sufficiency were achieved in 1984, albeit for a very brief period, and the bold and unconventional government policy of banning 57 pesticides from being used on rice in 1986 through a presidential decree. In the second phase (1993–1998), IPM national program was implemented not only on more commodities (corn, soybean, cabbage and potato), but also with better methods as FFS was built after recognizing constraints, threats and failures of the preceding phase. The political gain of this phase is the ratification of Bill no. 12/1994 on Crop Husbandry System, in which IPM is recognized as "the only plant protection system to be practiced"; followed by governmental regulation no. 6/1995 on crop protection as a technical guidance of IPM implementation. But the most important gain was that, since farmers knowledge was significantly improved, they became more empowered. Not only was their technical knowledge and ability upgraded, they also began to recognize their rights, and to express their opinions. IPM-FFS alumni organized themselves, and established a network system among them to exchange thoughts, ideas and information. With Indonesian farmers, these were beneficial steps toward accommodating them in a more democratic setting.

The typical examples of those phases' evaluation research are discussed here. The impact studies reported decrease of insecticide use (frequency/planting season) and increase in rice yield (tons/hectare) (Anonymous, 1988, Fig. 10.1), while Fig. 10.2 depicts how in 8 years the use of pesticides increased, only to be cut down by IPM-based policy in 1986 (Anonymous, 1990). In the beginning, convincing farmers to be critical to conventional control measures, which mostly consisted of the use of pesticides, was the main concern. Soejitno (1990) confirmed the overuse

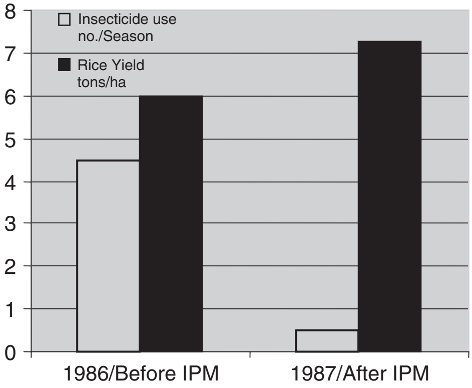

Fig. 10.1 Frequency of pesticides used before and after IPM in Indonesia

Fig. 10.2 Pesticides production in Indonesia, 1972–1991

of pesticides in Indonesia since many pesticides were recommended under rice intensification programs carried out since 1960s. But until early 1990s, studies on pesticides were emphasized in testing different types of pesticides, for finding the optimal dose, timing and methods of applications (Panudju et al., 1974; Sama et al., 1977; Mochida, 1985). No resistance study, for instance, was ever done until 1993 although field reports and IPM preliminary survey found out that insecticides' resistance was prevalent (Soejitno et al., 1994). About that time a comprehensive study on carbofuran insecticides showed that faunal diversity was lower and pest attack was higher in carbofuran-intensive areas along Java north shore due to lower ratio of natural enemies/pests (Martono et al., 1994). Other technological components studies such as measuring the effect of Fluid Supplemental Fertilizers on soybean (Adisarwanto, 1996), crop rotation patterns on different fields (Hendarsih, 1996), or potato seed selection for more vigorous crops (Suryadi, 1996), uniformly pointed out their positive contribution to IPM program on vegetables. But farmer-oriented research was still rare, and the few researches that were done used to employ observer-object attitude, and were conducted as partial studies, which often exposed farmers' weaknesses without trying to fully understand their overall background (Cholil et al., 1996; Maman, 1996). These weaknesses were frequently blamed as to be counter-productive to IPM program, yet the solution by which problems could be holistically, comprehensively and realistically solved almost never emerged.

More interesting observation arose when social and cultural aspects were examined thoroughly by specially trained scientists such as sociologists and anthropologists. Most of the studies took place by the end of the loan-backed IPM programs on food crops and vegetables (1998); followed by those on estate crops (2003). Although the success of those programs was imminent, few farmers were convinced to continue practice of the programs, while local and regional governments were also reluctant to put the programs in their annual budget. The latter became important as government administration in Indonesia started to move toward more autonomous system, in which the national government budget no longer provided for many technical programs. Meanwhile, several farmers who became empowered found a break from the repressive, highly centralized and paternalistic government of Suharto after his fall. The so-called "reformation" period provided them with opportunity to coordinate themselves, and to build networks to share information and new technologies among them. Many farmers who graduated from the FFS were so well motivated that they learned a lot, and started to develop their kind of farming techniques based on IPM. The techniques they developed are close to LEISA (Low External Input Sustainable Agriculture) and organic farming techniques, which greatly enhance farmers' self-reliance, since they select crops' seed, make organic fertilizers, and prepare botanical pesticides all by themselves. This progress was the least expected by the government, as it cut farmers' dependency on bureaucracy, something that have not been anticipated properly by many national and regional administrators.

The farmers' achievement reflects the changing atmosphere in farming community after the introduction of IPM. As Winarto (2002) stated, IPM sowed the seeds of empowerment which grew into self-governance and freedom. This is an important aspect of agricultural development in most developing countries, including Indonesia. The development through the so-called Green Revolution movement imposed internal intervention by the authorities in individual farmers' decision situation. The government intervention has also heavily affected the environment, agricultural practices and methods, and the structure of farmers' organizations (Winarto, 1996; Winarto et al., 1999). This was the condition under which Indonesian farmers worked and made their living since technology-based agriculture development started in early 1960s, mainly in the form of rice intensification programs. After about thirty years, IPM, more specifically IPM-FFS, provided farmers with alternative condition: that they may act from, for and by themselves. The shift from "doing what have been told" to "doing what they consider right according to field data" was not merely a change of technique. It represented bigger change: the way farmers think, the way they observe their farms, the way they make decision. The change was much more basic, it was a change of paradigm (Untung, 2001; Winarto, 2002).

The empowerment can be graphically illustrated with farmers' new understanding on the role of fauna in their fields. IPM farmers became more familiar with natural enemies, and recognize their important role in agroecosystem, after they were briefed by IPM facilitators (Martono et al., 1998; Mahrub et al., 1998; Wagiman et al., 1998; Winarto, 1995; Winarto, 1998). With this knowledge, farmers started to tend their fields differently (= according to IPM principles). The existence of natural enemies was used then to justify pest control measures applied during the planting season. This fact shows that farmers' improved knowledge also improved the farming system, but further it also indicates that farmers were willing to change, and that given the opportunity, they were able to make their own decision to do whatever they thought beneficial for their farming. These thoughts were then consolidated through meetings, talks, negotiations and agreements. This led to new perspective in viewing their farmings. Farmers also became more outspoken, and they began to understand what they could and could not (or need not) do. The new experiences gained by the farmers were effectively utilized not only as additional or new knowledges, but more importantly as motivational drives toward better agricultural practices.

The empowered farmers also realized that the right information would help them to maintain the sustainability of their land; therefore they started to use different media for that purpose. Alumni of IPM-FFS presently publish bulletin and newsletters, have their own websites, use cell phones to exchange information, even with some professional help launched short films. There are currently two films on preparing rice farming “the farmers’ way”. One, entitled “Bisa Dewek” (2006, Javanese for “We can do it by ourselves”) tells how farmers breed rice seeds by themselves, and how they are able to select seeds which suit their lands and are less demanding in chemical inputs. This film (which is also available in English) illustrates the somewhat “deviant” attitudes of farmers, a change which was completely unimaginable before IPM. The other film (which was called SRI, System of Rice Intensification, 2007), relays a similar message. It shows how farmers are able to manage their own rice farming, apply their own brand of technology, and produce better yields than the average “guided” farming. These films confirm the meaningful change in thinking and attitude of farmers after they were introduced to IPM-based farmings.

Other surprising finding is the one stated by Untung (2004). He has pointed out that despite all the efforts to limit pesticides, even up to the issuance of the 1986 presidential decree banning several pesticides, in larger scale the IPM policy has not been able to put pesticides business under control. As shown by his compiled figures (Fig. 10.3), pesticides use which had dipped after the 1986 decree, started to climb up and matched the previous amount used before the ban. Untung (2004) suggested that this condition indicates an imbalance between increasing pesticides distribution and use, and the existing rules and regulations. A regular and thorough evaluation

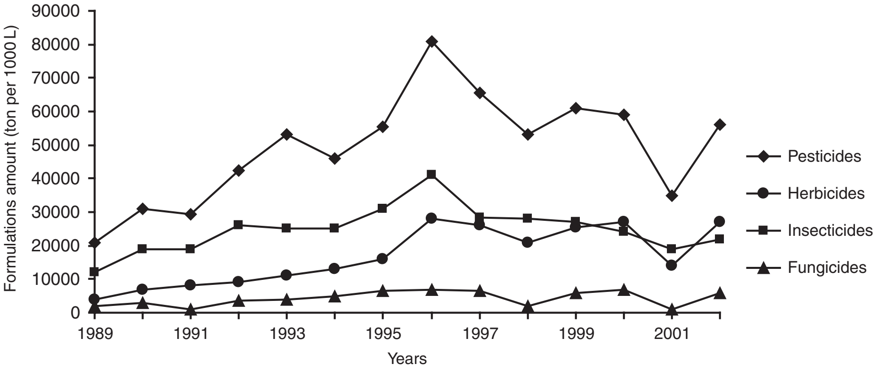

Fig. 10.3 Formulated pesticides produced in Indonesia, 1989–2002

should be done comprehensively, not only for the pesticides component, but for IPM as a program and policy, since technically IPM will always depend on ever-changing inputs, which in most part constitute the "after-effect" of implementing IPM principles to the ecosystem.

10.7 Afterthought

The development of IPM programs in Indonesia reflects evolutionary changes of conventional agricultural practices based on Green Revolution which were once relayed by the government through intensifications programs. The changes were of such magnitude that it opened up farmers perspectives and provided them with new attitudes to cope with the problems in their farmings. Many of these changes happened under accomodative conditions, some were deliberately prepared, while others were not. The ability to observe the process of changes, and the condition underlying the changes, proved to be very important in implementing IPM in any farming community.

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Chapter 11
Principles and Methods of Rice Lepidopteroid Pest and its Enemy Management (PEM) Program in North Vietnam

Eugeny S. Sugonyaev

Abstract The principle technological scheme of lepidopteroid rice pest and its natural enemy management (PEM) on an ecosystem basis is elucidated. The elaborated algorithm of rice agro-ecosystem management includes; (a) well grounded economic thresholds (ET) both for rice leaffolder and yellow stem-borer; (b) monitoring of number dynamics of lepidopteroid pests and their natural enemies; (c) decision making with employment of the standard survey forms; (d) registration of quantitative index – the zoophage efficiency level as an indicator of ecological resistance of paddy agro-ecosystem on rice pest injury, and its usage for lepidopteriod pest ET correction; (e) environment friendly tool set and tactics of lepidopteroid pest population management.The tactics of PEM program implementation allows to control of lepidopteroid pest populations (and secondary pests) and cutting down of the quantity of chemical insecticide treatments six times under the condition of the Red River Delta.

Keywords Lepidopteroid rice pest · economic threshold · paddy agro-ecosystem · generalist predator · monitoring · decision making

11.1 Introduction

At the end of 20th century a dependency of rice production on pesticide application in South-East Asia was one of the main factors which, side by side with population growth, degradation of soil fertility and water resources, created constant tension in food security and pesticide pollution of the environment (Bull, 1982; Kenmore, 1991; Lampe, 1994). Pesticides are significant inputs to rice production: in 1988 alone, insecticides costing US$ 910 000000 were used in rice world wide, more than for any other crop (Lampe, 1994). At the same time it is a known fact that an overuse of pesticides has negative impact on natural enemies of rice pests which is the cause of outbreaks of some secondary pests, for example, brown planthopper

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(*Nilaparvata lugens*). Brown planthopper was a minor pest of tropical rice in the past but increased dramatically in the early 1970s when pesticides used against lepidopteroid rice pests eliminated its natural enemies. It is obvious that development of environment-friendly rice pest and its enemy management is essential for sustainable productivity of rice.

In 1993, the Russian-Vietnamese Tropical Centre, Hanoi, Vietnam, began ecological studies on lepidopteroid pest and its enemy management (PEM) program in the Red River Delta which produced 20 per cent of the country's rice. The study was carried out at of Hanoi Agriculture University, Hanoi and in the Quoc Oai District, Ha Tay Province, during six rice seasons.

IPM principles and methods used in the Philippines (Reissig et al., 1986) and Indonesia (Kenmore, 1991) provided the basis for development and implementation of rice IPM in some areas of South-East Asia. However, the peculiarity of approach in Vietnam was the specific environment, pest and beneficial arthropod fauna, and local traditions on rice growing which helped to best address PEM tools and methods.

The choice of rice lepidopteroid pests as target species was conditioned by the potential hazard of its injury activity, and the visibility of plant damage which was used by farmers as a signal for insecticide treatment early in the season. This practice abolished natural enemies and disturbed the natural control of the pest, which resulted in resurgence of some secondary pests such as brown planthopper. The key rice pests in North Vietnam are: the leaf folder, *Cnaphalocrocis medinalis* (LF), the yellow stem-borer, *Scirpophaga incertulas* (YSB) (Pyralidae). Vu Quang Con (1992) brought out data on these species and other lepidopteroid rice pests and their parasites in Vietnam.

The feature of our approach was an elaboration of pest and its enemy management strategy assuming conservation of biodiversity at different trophic levels (zoophages mainly) in the rice agro-ecosystem and strengthening of an ecological stability in this ecosystem in order to turn events in the life of the rice arthropod community into a desirable direction. Hence, the main objectives were: a) Development of well-grounded economic threshold (ET) for main lepidopteroid pest species with obligatory consideration of associated circumstances; b) Rice plant ability to compensate for pest damage at different stages of plant growth; c) Pest population dynamics pattern during the spring and summer rice seasons; d) Share of natural enemies activity in the formation of resistance of the rice agro-ecosystem to pest injurious activity; e) Analysis of the pattern of pest population dispersion and elaborations of the method of monitoring of pest and its enemy populations for improvement of decision making; f) Use of bacteria compounds as the most environment-friendly insecticides; and g) Elaboration of the principle technological scheme (program) of PEM under the condition of the Red River Delta.

11.2 Paddy Agro-Ecosystem

The basic feature of the paddy agro-ecosystem is a combination of two life environments – aquatic and terrestrial ones that determine trophical relations of organisms connected with both kinds of environments (Settle, 1991). The detritophages and screeners build up the first level of substance and energy circulation which is not reserved because of many detritophagous arthropods and screeners are prey of generalist predators, e.g. spider-wolf, *Pardosa pseudoannulata*, during 20 days after transplanting (DAT) of rice sprouts particulary in the beginning of rice season (Table 11.1).

Thus, in a paddy agro-ecosystem, long before rice plant begins to play an important role in the environment formation in a given paddy field, significant stock of natural enemy populations are formed that will later determine an ecological situation in paddy agro-ecosystem. Overall, more than 220 species of predators and parasites are regular for the paddy agro-ecosystem in south China (Pu Zhelong and Zhou Changqing, 1986). During our investigation about 20 species of predators and parasitic Hymenoptera were most visible and important in natural biological control of rice pests (Table 11.2) (Sugonyaev et al., 1995).

The natural enemies are very convenient for identification from practical point of view as indicative zoophagous species the farmers recognize most of them in a field easily (after some training). It is believed that the number of indicative zoophagous species counted in a given paddy field reflects a general species diversity of zoophages. Besides there are four species of microhymenopteroid egg parasites of LF – *Trichogramma chilonis*, and YSB – *T. japonicum, Tetrastichus schoenobii* (Chalcidoidea) and *Telenomus dignus* (Scelionidae).

In general, an increase of zoophage numbers in paddy field without the use of insecticide treatment displays some correlation with rice growth. Although the

Table 11.1 Main functional groups of the paddy agro-ecosystem (sweep samplings with standard entomological net, 50 beats) in rice summer season

Date	DAT	Functional groups (%)		
		Zoophage	Phytophage	Detritophage and Screener
1993				
5.07	9	3.8	0.61	95.6
22.07	15	15.2	5.1	79.7
05.08	29	20.7	5.3	74.0
12.08	35	50.9	14.4	34.7
19.08	42	41.1	12.08	46.9
24.08	48	30.7	16.0	52.5
31.08	54	51.1	23.2	25.7
09.09	63	32.5	7.3	60.1
16.09	70	38.4	12.1	49.5
21.09	75	43.8	10.7	46.7
1994				
25.07	14	10.7	0.0	89.3
01.08	21	12.0	0.0	88.0
08.08	28	8.2	1.4	90.4
15.08	35	12.0	1.0	87.0
24.08	44	37.3	22.6	31.1
12.09	65	19.6	25.0	55.4
19.09	72	12.6	12.5	58.9

Table 11.2 The main zoophagous species in the paddy arthropod community

Type of zoophage, species and species group	Prey, host			
1	LF 2	YSB 3	Other moth-species 4	Plant hopper 5
Predator				
Aranei				
Pardosa pseudoannulata	+	+	+	+
Oxyopes javanus	+	+	+	
Tetragnatha maxillosa	+		+	
Araneus spp.	+		+	+
Clubionia japonicola	+		+	+
Phidippus sp.				+
Coleoptera				
Micraspis spp.	+		+	+
Ophionea nigrofasciata	+		+	
Pederus fuscipes	+		+	+
Carabidae, gen., sp.	+		+	+
Odonata				
Agriocnemis spp.				+
Heteroptera				
Microvelia sp.				+
Cyrtorhinus lividipennis Reut.				+
Tettigoniidae				
Conocephalus spp.		+		
Parasitic Hymenoptera				
Cardiochiles philippinensis	+			
Temilucha philippinensis	+	+		
Xanthopimpla flavilineata		+		
Apanteles ruficrus, inc. coccon group			+	
A. cypris, inc. single coccon	+			
Charops bicolor, inc.coccon suspended at leaf			+	

numbers of any single species of entomophage may change. Nevertheless, their mean number is relatively high and constant during the season, forming a so called biological barrier. Which put together are hundreds of specimens indicative zoophagous species registered during 30 minutes of walk through the plot, in the peak for the mid-season (40–60 DAT) (Sugonyaev and Monastyrskii, 1997, 2008). In the first half of both rice seasons spider-wolf, *P. pseudoannulata*, is the main dominating species – the curve of its numbers correlates best with that of the total numbers of all registered predators. In the spring rice season small beetles (Staphylinidae, Carabidae) also reach significant numbers in the middle of cropping season whereas lady beetles, *Micraspis* spp., reach the most numbers in the middle – end of the season. In the middle of the summer rice season spiders (*Oxyopes javanus, Araneus* spp., etc), dragon-fly (*Agriocnemis* spp.) and predaceous grasshopper (*Conocephalus* sp.) have significant contribution to the total number of predators. Thus, the probable importance of zoophages rises until the numbers of detritophages and screeners decline while pest populations grow uniformly. The change of the zoophagous species numbers is almost similar, both in optimal and late-planted paddy fields in contrast to cotton, for instance (Sugonyaev, 1994).

11.2.1 Economic Threshold (ET)

For solution of ET issues, data of experimental research in laboratory and field surveys was critically analyzed. The main variety of rice was CR203, and in special cases other varieties were also used. Concept of ET accepted fixed quantity of both 5 per cent and 7 per cent yield loss admissible levels (YLAL) which form the economic basis of ET.

11.2.1.1 ET of Leaf Folder (LF)

From the studies, it was found that if the average rate of leaffolder damaged leaves increased by 1% then the loss of grain increased by 0.3% approximately. Since plant ability for damage compensation decreases with growth of a plant, the equations have been developed for both vegetative (1) and reproductive (2) periods of the plant cycle (Monastyrskii and Sugonyaev, 1995; Sugonyaev and Monastyrskii, 1997, 2008).

$$a(\%) = \left[\frac{(0.088 + 0.844N) \times e^{(0.204-0.0085N)T}}{-53.95 + 30.021\ln(t_0 + T)}\right] \times 100 \tag{11.1}$$

where: a (%) – level of damage leaves in %;

N – density of pest population;
T – duration of pest activity;
t_0 – days after transplanting (DAT);
e – basis of natural logarithm.

$$a(\%) = \left[\frac{(0.088 + 0.844N) \times e^{(0.204-0.0085N)T}}{485 - 106.91\ln(t_0 + T)}\right] \times 100 \tag{11.2}$$

The equations allow calculating ET of leaf folder at any time during the crop growing season. But as a guide, some data would be useful. For instance, for plant aged 20–30 DAT the ET is 20 (lower level) – 25 (upper level) per cent of damaged leafs; for 50–70 DAT – 6–8 per cent of damaged leafs. Of course, the information will be more useful if lower and upper levels of larvae number are also used. Thus, till 25 DAT, the ET is 1.5–2 larvae per hill, for 70 DAT – 0.15–0.25 larvae per hill (Sugonyaev and Monastyrskii, 1997, 2008).

11.2.1.2 ET of Yellow Stem-Borer (YSB)

"White head" damage appears because of yellow stem borer activity during the reproductive period, i.e. 50–80 DAT, and it has provocative effect on the farmer to treat his paddy field with chemical insecticide. Of course, knowledge of the real YSB, ET is urgently needed (Monastyrskii and Sugonyaev, 2001).

There is a negative correlation between pest damage activity and quantity of stems per hill, a count of stem average for at least 20 hills need to be done. For example, the mean number of stems per hill is 7.0. If the unit is a hill, make use of the counted diagram (Fig. 11.1). The equation for calculation is:

$$D^{st}(\%) = \left(\frac{n}{N \times x}\right) \times 100 \tag{11.3}$$

where: n – quantity of damaged hills;

N – quantity of hills in the sample;
x – a mean of stems per hill.

For example, there are 100 damaged hills in the sample out of 500 total hills while the mean number of stems per hill is 7.0.

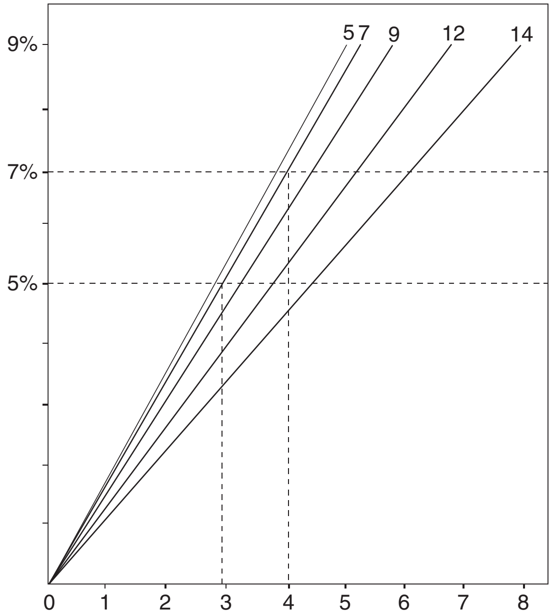

Fig. 11.1 The diagram showing on dependence of grain loss as a result of damaged stems by yellow stem-borer, *Scirpophaga incertulas*, into hills with different quantity of stems per 1 hill – 5, 7, 9, 12 and 14 ones. On ordinate axis – grain loss in %; on absciss axis – stem in %

Table 11.3 The probable threshold meanings of YSB damages for 5 and 7% YLAL

Plant age, DAT	YLAL	Maximal quantity of damaged stems per hill
20–35	5%	0,9
	7%	1,7
36–55	5%	0,4
	7%	0,8
56–75	5%	0,7
	7%	1,1

$$D^{st}(\%) = \left(\frac{100}{500 \times 7.0}\right) \times 100 = 2.86\%$$

In order to know the weight of this value use diagram (Fig. 11.1), and draw the perpendicular from the found point 2.86% to the intersection with the inclined line giving the mean of stems per hill. In our case, the point of the intersection will be on the horizontal line giving 5% YLAL, i.e. no serious injury. Next 7% YLAL would be about 4% of damaged stems.

The relation between the growth stage of plant, the quantity of damaged stems and YLAL for preliminary decision making can be determined by Table 11.3.

The recommended ET is characterized by two levels – a lower and upper one. In other words, ET is not one fixed line but a sort of strip. The notion of ET levels is useful for improving decision making because it allows in evaluating a change in pest population density not only at one moment of time but over a period of time also. Really, if ET is just a line then any crossing of the line will mean a need for immediate managing action – often treatment with insecticide. However, if two-leveled ET is used then the process of population density change can be watched because the crossing of the lower level by pest number curve does not mean a need of immediate managing action. In fact, the curve perhaps will not reach the upper level of the ET, and consequently no measure is required. Thus, two-leveled ET informs and improves the decision making process. In terms of this concept, the lower and upper levels of ET are threatening and operative ones, respectively.

11.2.2 Zoophage Efficiency Level (ZEL)

Zoophage Efficiency Level is a definite summed up population density of indicative zoophagous species, which is typical for field study state in ecological science, and used for cotton field monitoring (Sugonyaev, 1994). From our studies of several years it is clear that the higher the indicative zoophagous species number, the lower the number of leaves damaged by LF, (Sugonyaev and Monastyrskii, 1997).

A pattern of indicative zoophagous species appearance during the season shows that its number reaches the peak mostly during the mid-season. Based on empirical data we consider that the zoophage numbers in the range of 70–100 specimens per survey in mid-season (about 50 DAT) is the minimal zoophage efficiency level (ZEL). It shows a probable steady type of a given paddy agro-ecosystem which is most resistant to lepidopteroid pest injury. On the contrary, a number of 30–50 specimens of indicative zoophagous species imply an unsteady type of paddy agro-ecosystem that is more prone to lepidopteroid pest problems. The advantage of this method is an opportunity to estimate both a probable injury level of pest and an ecological situation in paddy that is important for decision making process.

The next important point for decision making is to take into consideration the parasitization of egg masses of yellow stem borer by hymenopteroid parasitic species collected during examination of 100 hills. Each single egg mass is put into a separate small test tube for rearing, either yellow stem borer larvae or minute parasitic wasps, or the former and the latter together. If the parasitization of egg masses is about 70 per cent, then approximately 50 per cent of host eggs will be eliminated, i.e. probability of pest damage reduces by two times. The parasitization of egg masses by about 90 per cent indicates insignificant damage in the coming week.

11.3 Monitoring for Decision Making

Decision making based on the sequential method of sampling and analysis, and a weekly ZEL field survey is the operative ground of rice pest and its enemy management (PEM) program. Of course, a standardization of survey methods is a prerequisite of PEM implementation. Standard survey forms (SSF) for definite age period of rice plant based on biometrical interpretation of an insect dispersion pattern are offered. SSF are used for quick field survey and preliminary decision making by summing up of both pest infested and non infested rice hills till the drawn curve will cross either lower or upper inclined lines of the figure, meaning lower and upper levels of the ET. Accordingly, the lower intersection means there is no necessity for managing action while the higher intersection implies the need for such action.

Besides the SSF include definite predictable information because the size of the first, "harmless" zone lying under lower level gives objective guidance on the general susceptibility of paddy field to lepidopteroid pest problems. Actually, the declining of the 1st zone and an increase of the 2nd "harmful" zone show how a lepidopteroid pest problem probability grows from early to mid-season. The above described method is used directly for the counting of leaffolder larvae and stems damaged by yellow stem borer in rice hills (Sugonyaev and Monastyrskii, 1997, 2008; Sugonyaev et al. 1997; Monastyrskii and Sugonyaev, 2005).

In any case, the calculation of indicative zoophagous species needs thirty-minutes walking on ridge along the edges of the paddy fields. During final decision making there is a necessity to follow next directions. For example, the density of indicative zoophages reaches the ZEL, and at the same time the summed up curve of leaffolder number crosses the upper level of the ET after examination of at least 40 hills then a managing action is not needed. If the upper level of the ET is crossed after examination of less than 40 hills, for instance 20–30 hills, a managing action is needed. The density of 20–50 indicative zoophages in a given paddy field in any case shows a necessity of a managing action.

In case of yellow stem borer, counting of egg masses parasitization by parasite wasps is essential for taking any management action. This way of identification of ecological situation in a given paddy field seems complicated but there is a need to get improved information because every chemical insecticide application is undesirable from ecological point of view and it must be rejected even if there is some risk.

11.4 IPM Tools

11.4.1 Application of Bacteria Compound

From our studies, it was clear that one application of 1% solution of Bitoxibacillin™ (BTB-202) decreases a leaf folder population by about 60% within 5 days of treatment. In PEM program, such effectiveness is satisfactory because the remaining part of the pest population will be devoted by entomophages owing to a change of entomophage: pest ratio in favor of the former. On the other hand, BTB-202 made in Russia showed itself to be a effective compound under the tropical condition. But BTB-202 is not recommended for suppression of yellow stem borer population because of protective mode of life of the latter.

11.4.2 Manipulation of Transplanting Time

Time of rice transplanting largely determines the feature of a relationship between rice plant and pest. There is a link between plant growth studies and probability of yellow stem borer injury. The critical point is the time of panicle initiation: the rice crop with early panicle initiation is much less susceptible to the pest injury activity. So, the variety with the early panicle initiation (∼56 DAT) is not damaged by yellow stem borer or damage is upto 1–1.5% only. Yellow stem borer to the extent of 8–10% may damage v.v., variety with comparatively late panicle initiation (∼77 DAT) because in this case plant growth stage coincides with the peak of yellow stem borer moths flying stage (Sugonyaev and Monastyrskii, 2007).

In general, under the condition of the Red River Delta, (a) In the spring rice season if the plant ripening stage in a given paddy begins in the middle of May then the crop will be less prone to lepidopteroid pest problems; (b) In case of summer rice season a ripening stage begins first, partly in second ten-day period of September then a given paddy will have more tolerance to lepidopteroid pest injury.

11.4.3 Monitoring and Decision Making

The SSF for revealing of lepidopteroid pest density and damage level are good ground for PEM program implementation. However, PEM will run the risk if principle of ET is used as a sort of a trigger for chemical insecticide application. That is why an incorporation of the ZEL and YSB egg masses parasitization (70%) in the decision making process is a necessity.

11.4.4 Application of Broad-Spectrum Chemical Insecticides

From the PEM strategic point of view, less is always better when it comes to insecticide application in rice. The regulation of insecticide application are: (a) when pest number curve crosses the upper level of the ET and when the density of indicative zoophages is low (20–50 specimens per survey); (b) unavailability of bacterial compounds and other biological means of control; (c) local use of insecticide at damaged plot or spot application only; (d) rejection of so called "prophylactic" application; (e) screening of most safe insecticides for zoophages, its dosage and application methods.

11.4.5 Tactics of the PEM Program Implementations

There is a definite pattern of population density dynamics of lepidopteroid pest in each rice growing season. In the spring (1st) season the increase of lepidopteroid pest abundance has a low rate, and as a rule it does not reach ET. On the contrary, the summer (2nd) season is characterized by fast increase in their population density, and a strong probability of crossing the upper (operative) level of ET (Vu Quang Con, 1992; Sugonyaev and Monastyrskii, 1997, 2007). Almost every year, the critical situation necessitating rice protection appears during rice flowering at the end of August and in the first ten days of September when the peak of 6th generation of leaf folder and 5th generation of yellow stem borer take place. Thus, perennial data allows us to distinguish the period of natural history for both leaf folder and yellow stem borer when their damage activity is high, and at the same time, the opportunity for suppression of pest populations is also good. During this period one treatment by bacterial compound, for instance BTB-202, will take care of lepidopteroid pest problem in rice and address two main tasks: a) rice protection and b) particularly conservation of paddy agro-ecosystem biodiversity and natural enemy populations. It is assumed that suppression of leaf folder population and preservation of zoophage number in a given paddy creates the ground for natural control of yellow stem borer, brown planthopper and other insect pests by maintaining their population below their economic thresholds (Sugonyaev and Monastyrskii, 1997, 2008).

11.5 Effectiveness of Rice Pest and Its Enemy Management Program

The principle technological scheme of rice pest management on ecological basis is the creation of the optimized ET for both leaf folder and yellow stem borer, ascertaining the ZEL, and formalization of survey through SSF for improveing to a great extent the decision making process and rice protection on the whole under the conditions of the Red River Delta.

The tactics of PEM program implementation allows six times decrease in the of quantity of chemical insecticide treatments which are conventionally in use here. As it has been discussed above, one per year and time fixed treatment with bacterial compounds would be more effective and cheaper than two-three treatments with chemical insecticides during the same period. Simultaneously, the former removes the problem of pest resurgence, for example, brown planthopper, the cost of which may be much higher. This feature of the paddy agro-ecosystem is the direct consequence of high activity of natural enemies there by maintaining most of the rice pest species below their economic threshold level. The similar conclusion has been drawn by our Vietnamese colleagues as a result of organization of farmers' IPM demonstration schools in the south and north parts of the country. Almost everywhere, both in rice crop treated with chemical insecticides and untreated ones, the rice harvests have been similar (Tran Quy Hung and Pham Thi Nhat, 1994).

The worth of the suggested PEM program is its relative simplicity for rice farmer after training, e.g. in farmer's school. The result of our research have proved that it is not necessary to spend about $1 billion (Lampe, 1994) on chemical pesticide treatments under the tropical condition in South-East Asia because a mobilization of natural control resources on an ecological basis, and the definite investment into production and distribution of bacteria compounds, e.g. Bitoxibacillin™, ensure success in productive rice growing, removal of the danger of both outbreaks of secondary rice pest and pesticide pollution of the environment.

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Chapter 12
Challenges of Integrated Pest Management in Sub-Saharan Africa

Arnold van Huis

Abstract As a response to the negative side effects of chemical control in the developed world, Integrated Pest Management (IPM) developed with an emphasis on reducing the role of pesticides. Later the role of natural enemies was recognized as being the cornerstone for sustainable pest management strategies. The IPM concept initially stressed the combination of control tactics while afterwards the empowerment of farmers in managing their own agro-ecosystems became the focus. Reasons are given why integrated pest management has been instrumental in making the Farmer Field School (FFS) prominent in sectors such as nutrient management, animal husbandry and health. FAO started with an IPM project in subsistence crops in Africa, but because of its low impact on farmers' livelihoods changed to crops with a higher consumption of pesticides such as cotton and rice. Some pests like locusts require the attention of the central government. The multiple dimensions of desert locust problems are highlighted, and the realization that its solution is more operational than technical. Invasive pests are a continuous threat, and classical biological attempts have been highly successful. Some examples of technical IPM components such as varietal resistance, the judicious use of chemicals, agronomic practices, and biological control are given. However, it appeared that the adoption rate by farmers of proposed technologies is low. It is argued that farmers face very small windows of opportunities. Therefore, institutional development needs as much attention as technological improvement. A number of examples are given to illustrate this point.

Keywords Integrated pest management · Sub-Saharan Africa · institutional development · locust · invasive insect species

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12.1 Introduction

The rapid population increase in Africa (expected to double from about 1 billion in 2007 to 2 billion in 2050 (UN, 2007) will bring about an intensification of agriculture. The demand for agricultural products will also increase because standards of living are expected to rise and because of the recent developments in biofuel. Shortening of fallow periods, adoption of high yielding varieties, use of synthetic fertilizers, the increased use of monocultures, and more intensive use of pesticides will create favourable conditions for pest outbreaks (Abate et al., 2000).

The Integrated Pest Management (IPM) approach emerged in the 1970s in cotton in the USA, mainly because of the problems associated with the use of pesticides, in particular those concerning human health and the environment (Perkins, 1982). The effect on the population of pest insects was often contrary to what was intended. This was due to pesticides not only causing the development of resistance in arthropods, but also its negative effect on natural enemies leading to resurgence and secondary pest outbreaks.

Natural enemies are usually more susceptible to insecticides than their prey or host because of differential mortality. This is caused by a number of factors: differences in intrinsic toxicity (Theiling and Croft, 1989), the level of exposure (Waage, 1989), disruption of synchronization between the pest and its natural enemy (Waage, 1991), differential resistance development (Croft and Strickler, 1983), disruption of food chains (Reynolds et al., 1982), and agrochemicals affecting entomopathogens (Ignoffo et al., 1975). Concerning the level of exposure a search of literature revealed that most research on resurgence relate to three pest groups: Homoptera (44%), Lepidoptera (24%), and mites (26%) (Waage, 1989). This can be expected as relatively sessile pests, such as scale insects and mealybugs, are protected from contact insecticides by a waxy covering, lepidopterous leaf miners or stemborers by plant tissue, and mites by a web at the underside of the leaf. These pests are poorer targets for contact insecticides than their natural enemies which must forage over the plant to find them.

Integrated pest management often focuses on the best technical means to keep herbivores under damaging thresholds. This is achieved by integrating different control components. Resistance or tolerance of plants to herbivores is increased by varietal resistance or making the cropping environment less favourable for pests (cultural control methods) or more favourable for natural enemies (conservation biological control). Pesticides less harmful to natural enemies are introduced like the use of entomopathogens, and botanicals. Against invasive pests classical biological control is attempted.

However, integrated pest management has often not been very successful. Likely because the human dimension was underestimated, and this was realized from 1990 onwards. As a response the Farmer Field School (FFS) approach was introduced in rice in Asia. The FFS approach was different from the conventional integrated pest management approach in the sense that empowerment of farmers became the focus and not the management of pests and diseases. Farmers when having a better understanding of their own agro-ecosystem, become better practitioners in pest management. Ghana was the first country in Africa where the Farmer Field School concept was implemented.

The FFS approach is currently used for a variety of disciplines such as animal husbandry, integrated nutrient management, conservation agriculture HIV/AIDS (Life Schools), and nutrition (Bunyatta et al., 2006). So, pest management was the starting point for the FFS approach? Why? Likely because a number of effective pest management decisions are counter-intuitive, and requires a learning environment to be understood. For example, a considerable amount of injury by a defoliating insect does not necessarily lead to economic loss. Completely defoliated young maize plants are able to recover completely without any reduction in yield (Brown and Mohamed, 1972; Hicks et al., 1977) The same is true for rice plants which can tolerate up to 50% leaf loss without affecting the yield (Matteson, 2000). Farmers themselves can observe that yields do not diminish after they defoliate plants with scissors. Another counter intuitive phenomenon is that spraying with insecticides often leads to a higher pest incidence. Farmers are often unaware of the concept of a beneficial fauna. They learn that natural enemy do exist in their own agro-ecosystem, and that they play a very important role in maintaining pests at low incidence levels. The insect zoo exercise during FFS is an eye opener for many farmers. By bringing together natural enemies and pests, they can observe for example that earwigs eat young caterpillars. This is a clear example of how understanding of natural control by beneficials may guide farmers' decision to refrain from pesticide use.

In this article a short history of integrated pest management programs will be given, migratory pests and invasive pest species are discussed as well as institutional issues which are a constraint for application and therefore a challenge to many integrated pest management programs. Framework conditions are often conditional to the success of IPM projects. Small farmers in Africa have small windows of opportunities. The question is whether to work within those windows of opportunities or to stretch those (van Huis et al., 2007a). Therefore, we focus on institutional conditions under which integrated pest management will be possible.

12.2 History IPM Programs in Africa

Without trying to give a complete overview of all past pest management activities in Africa some major historical developments will be highlighted.

The first large scale integrated pest management program was executed in eight Sahelian countries in the 1980s. It was financed for about US$ 30 million by USAID and implemented by FAO in cooperation with the Permanent Inter-State Committee on Drought Control in the Sahel (French acronym CILSS). The project entitled "*Research and development of IPM for basic food crops in Sahelian countries*" started in 1979 and terminated after the first of three planned phases (Zethner, 1995). The effect of the project on the improvement on the livelihoods of farmers proved to be very limited. The perception of the scientists at that time was that a farmer cannot be approached without having full proof technology. Participatory technology development was considered irresponsible. Another factor was that pests and diseases were not the main problems in subsistence farming in crops like millet, sorghum, and maize, certainly not when compared to the erratic rainfall and low soil fertility. Unlike cotton, there was no problem with injudicious use of pesticides, because the low revenues in those subsistence crops did not justify use of chemical control measures (Jago et al., 1993). Another question was whether integrated pest management would work for resource-poor farmers with low-value staple food, low yields, no or low pesticide use, mixed cropping systems and unreliable markets (van Huis and Meerman, 1997; Orr, 2003).

After the Sahel IPM experience in subsistence crops, FAO concentrated on crops with a high intake of pesticides, such as rice in Asia, where insecticide-triggered outbreaks of the brown plant hopper (*Nilaparvata lugens* (Stål)) created problems (Heinrichs and Mochida, 1984), and of the whitefly (*Bemisia tabaci* (Gennadius)) in cotton in the Gezira in Sudan (Bashir et al., 2003). Cotton alone consumes 11% of world's pesticides, while for insecticides this figure is 25% (FAOSTAT, 2007). In developing countries it is estimated that roughly 50% of all pesticides are applied on cotton (Caldas, 1997). In 2005/06, cotton production in Africa was 1.7 million tons of lint, equal to 7% of world production and worth approximately $2 billion to African economies (Anonymous, 2006). African cotton exports account for 17% of world exports. Employment in the cotton sector of Africa is estimated at about 20 million. Cotton is the largest employer (estimated at 3 million) in countries such as Burkina Faso, Chad, Mali, and Togo. Equally in Mali, Sudan, and Zambia many families depend on cotton for their livelihoods. Eveleens (1983), giving the history of pest management in cotton in the Gezira in Sudan, indicated that the average number of sprays increased from one in 1960–61 to eight in 1980–81. Before 1965, the whitefly *B. tabaci* (Gennadius) was an occasional, early to mid-season pest contained at insignificant levels by natural mortality. With the increase of the non-selective use of broad spectrum insecticides the whitefly population increased and persisted at sustained high levels into picking time. The impact on cotton production was considerable, not only in yield but also in quality of lint because of honeydew contamination. The FAO project "*Development and application of integrated pest control in cotton and rotational food crops in the Sudan*", initiated in 1979, recommended judicious use of pesticides, varietal resistance, conservation biological control and cultural control methods (Eveleens, 1983). Similarly, in South Africa, insecticide applications in cotton seemed to be correlated with decreasing yields, because of their negative impact on beneficial arthropods (Hamburg and Guest, 1997).

The FAO Global IPM Facility introduced the FFS approach in West Africa through a season-long training and three associated FFS held in 1995 in rice Ghana (Simpson and Owens, 2002). Following the efforts in Ghana, a major FFS effort on irrigated rice was launched in the Office du Niger in Mali. Similar efforts were launched in Kenya and Zimbabwe. To date the FAO Global IPM Facility (GIF) has helped to start, or is currently working with pilot FFS programs in over a dozen countries, from Senegal to South Africa. For example, in Kenya FFS was first introduced on a small scale in 1995 by the FAO's Special Program for Food Security to promote maize based IPM in western Kenya (Bunyatta et al., 2006). Since 1995, 1500 FFS has been conducted in issues such as the production of dairy cattle and poultry, soil fertility management, water harvesting, and HIV/AIDS. The national program (Kenya Agricultural Research Institute) is taking over and is involved in FFS implementation.

The CGIAR Systemwide Program on Integrated Pest Management (SP-IPM) was initiated in 1995 with as main aims to achieve synergies and greater impact in IPM research and implementation, and to ensure that these activities are fully responsive to the needs of IPM practitioners (Lenné and Chancellor, 2007). One of the major achievements of this program has been the establishment of a large multi-stakeholder Tropical Whitefly Project, initiated in 1995 and now in Phase III. It deals with the sustainable integrated management of whiteflies as pests and vectors of plant viruses in the tropics, and with exchanging information and to achieve a collaborative research agenda.

12.3 Invasive Pests

Unintentional introduction of pests and diseases of agriculture as contaminants in crops and animals has led to severe problems, because alien species thrive in new ecosystems where their hosts are abundant and their own natural controlling factors may be absent. In Africa, the classical biological control approach (the use of introduced natural enemies to control an exotic, invasive pest species) has shown impressive results, in particular in Africa. Neuenschwander (2001) reviewed the biological control of the cassava mealybug in Africa, and estimated that the project saved 8 tot 20 billion US$ (Neuenschwander, 2004). Similarly, the control of the cassava green mite saved 2 billion US$, and the control of invasive weeds like the water hyacinth and the red water fern each half a billion US$. These savings were obtained against costs lower than one percent of the benefits. The stemborer, *Chilo partellus* (Swinhoe) was accidentally introduced from Asia before the 1930s and became the predominant stemborer in the 1990s in eastern and southern Africa with more than 70% yield loss in lowland and mid-altitude areas. The parasitoid *Cotesia flavipes* (Cameron) was introduced from Asia in 1991 and released in coastal Kenya in 1993 (Overholt et al., 1997). It established in nine countries in eastern and southern Africa. It is estimated that the parasitoid will accumulate a net present value of US$ 183 million 20 years since its release (Kipkoech et al., 2006). The advantage of classical biological control is that it can be done without farmer involvement. Scientists from international research organizations carry out such programs almost entirely relying on funding by donor organizations.

However, challenges remain such as the larger grain borer, *Prostephanus truncates* (Horn) (Coleoptera: Bostrichidae) introduced in the 1980s and a serious pest in farm-stored maize and cassava (Schneider et al., 2004). The histerid predatory beetle *Teretrius nigrescens* Lewis (Col.: Histeridae) was introduced from Central America in several countries. Although in West Africa, the predator was effective in humid-hot zones, it did not have an impact in the hot-dry and cool zones of eastern and southern Africa. Some other introduced pests are: the Spiralling Whitefly, *Aleurodicus dispersus* (Russell), first reported in West Africa in 1993 (D'Almeida et al., 1998) and now reported in East Africa; the Mango Fruit Fly, *Bactrocera invadens*, from the Asian subcontinent and since its detection in Kenya in 2003 has spread to over at least ten countries in central Africa attacking a wide range of host plants, including important food crops (Drew et al., 2005); the Red Spider Mite *Tetranychus evansi* Baker & Pritchard is an important pest of Solanaceae (e.g. tomatoes, egg plant), accidentally introduced probably from South America into Africa in the 1980s, and presently occurring as a key pest in many African countries (Furtado et al., 2006).

Continuing globalisation, with increasing trade, travel, and transport of goods across borders, will facilitate the spread of invasive alien species with increasing negative impacts. Studies in the United States and India show that the economic costs in these countries amount to approximately US$130 billion per year. Emergency food aid is also a pathway of agricultural invasives. The neotropical weed *Parthenium hysterophorum* recently arrived in Africa through grain shipments for famine relief to Ethiopia, where it has earned a local indigenous name which translates to "no crop" (McNeely et al., 2001).

12.4 Migratory Pests (Emphasis on Desert Locust)

The desert locust, *Schistocerca gregaria* (Forskål), inhabits the central, arid, and semi-arid parts in Africa, the Middle East, and South-West Asia. The species recession is estimated at 14.6 million km^2. This is about half that liable to be invaded by swarms, with an area estimated at 29.3 million km^2. In the recession area there are 25 countries involved, and large scattered populations are potential sources for outbreaks (van Huis et al., 2007b). These countries have different capabilities of dealing with recession populations of locusts. This has to do with the size of the area to be surveyed, with the Gross National Income of the country (e.g. Morocco, Sudan and Niger relate to each other as 17 : 6 : 1 - Atlas method – World Bank data 2003), with the value of agricultural produce to be protected, and with their level of priority for locust control. A number of the more poor countries have difficulties in maintaining an effective functioning locust unit. Commitment of governments and donors is strongly correlated to the occurrence of upsurges and plagues.

Pests like locusts and armyworms occur occasionally in large numbers destroying whole crops of some farmers. Because of their localized heavy impact on livelihoods, they get more attention from national authorities then less conspicuous pests like stemborers which may inflict the same level of damage or even more when calculated at a national scale. The spectacular occurrence of locusts is quickly taken up by the public media, and therefore the motives for locust control become political. For donors contributing to campaigns it is rewarding in terms of contributing to international solidarity, peace and good relationships. Locusts are an international event, and therefore political. Uvarov (1953) already indicated "*Locusts recognize no frontiers*" and he added "*in many cases, the ability of locust swarms to cross frontiers is more readily admitted when they are entering a country than when they are leaving it for the neighbouring one*." Recrimination from neighbours may occur if they are invaded by large number of locusts, although swarms may have already crossed several frontiers before.

The interdisciplinary character of the event requires the involvement of many stakeholders: farmers, plant protection departments, different ministries, local authorities, private enterprise (e.g. pesticide, vehicles, aircraft, and equipment), donors, international organizations, etc. locust control requires the coordination at the national level from a number of Ministries such as Agriculture, Defence, Health and Environment, Planning, Interior Affairs, Finance). That is why Head of States become involved. The military are often asked to assist in surveys and control operations in insecure areas, or the military run campaigns because of their often excellent organizational and logistic capabilities (e.g. Morocco), or they put their vehicles at the disposal of locust units (e.g. in Algeria).

The economic dimensions of the desert locust problem have national implications. For example do control investments justify potentially prevented losses? (FAO, 1998; Herok and Krall, 1995) or would it be better to invest in insurance schemes (van Huis, 2007). Is locust control sustainable? Can we prevent plagues from happening? What is the effect of control measures in terms of containing the problem? How is the problem perceived, in particular by donors? The victims are either the farmers (appeal to national governments) or the locust affected countries (appeal to donors). Donors often classify migrating pests under "Disasters" and as such can respond quicker to emergencies. Investments in emergency assistance are often obtained easier and faster than structural assistance. Unfortunately, the funds allocated for the first are often much larger than for the last. Misappropriation and misallocation of funds and resources often occur (Lockwood et al., 2001), as narrated in the novel "Locusts" of 1927 by Sergei Budantsev. Desert Locust outbreaks and upsurges are considered by some as opportunities. This in particular taken into account the large amounts of money involved in locust operations: an estimated US$ 315 million during the plague of 1986–1889 (Gruys, 1991) and US$ 260 million used during the latest upsurge of 2003–2004 (van Huis et al., 2007b). A large portion of those funds are allocated by donors.

Desert locust control relies on synthetic insecticides, and for emergency situations this is unlikely to change. However, effective oil formulations of *Metarhizium anisopliae* spores have been developed in Africa and Australia. The *Metarhizium* biopesticide kills 70%–90% of treated locusts within 14–20 days (Lomer et al., 2001). In Madagascar the effect of this biopesticide on the biodiversity was investigated using 225 species of Coleoptera. It showed that from the two native isolates of the biopesticide one had minimal detrimental effects (Ivie et al., 2002). In Australia, an incentive to use the biopesticide to control the Australian Plague Locust, *Chortoicetes terminifera*, was the requirement of pesticide residue free export of beef production (Milner and Hunter, 2001). Such an incentive is currently lacking in Africa, although donors could opt for such a strategy. However, although donors financed the development of the product, even during the upsurge of 2002–2003, it was not tested or used.

Political and technical issues get mixed up in emergency situations making it extremely difficult to separate those in managing outbreaks, upsurges or plagues (see also Lockwood et al., 2001). As LeCoq (2001) concluded in his overview of locust control in Africa: "*Locust control seems now more to depend on political and institutional choices than on scientific and technological innovations*." How do we separate the political from the scientific and technical domains? Can we create the social space necessary for scientific and technical people to deal with locusts rationally?

12.5 IPM Components

Kogan (1998) reviewed 64 definitions for integrated pest management and proposed "*IPM is a decision support system for the selection and use of pest control tactics, singly or harmoniously coordinated into a management strategy, based on cost/benefit analyses that take into account the interests of and impacts on producers, society, and the environment*." This definition takes into account technical, societal, environmental and economic considerations. Most definitions stress the combination of tactics: chemical, cultural, biological and varietal control.

12.5.1 Chemical Control

Pesticide use in sub-Saharan Africa was 0.16 kg per ha of arable land, while this figure for developing and developed countries was 1.02 and 1.55 kg respectively, meaning that it is still very low (FAOSTAT, 2007). Most pesticides in Africa are spent on cash crops like cotton, oil palm, coffee and vegetables, and migratory pests. Williamson (2005) reported on the percentage of production costs spent on pesticides for several countries in Africa: 22–31% in cotton and 40% on cucumber in Senegal, 16 tot 20% in pineapple and 32–61% in cowpea in Ghana and 10–54% in mixed cropping in Ethiopia.

The negative side effects are well-known. In particular for resource-poor farmers the health risks are high as they often lack the means to buy and maintain application equipment. Besides they lack proper storage facilities, are often not instructed to use it safely. When pesticides are bought on credit, farmers take a risk becoming indebted when the crop fails. There is further the danger of falling into the trap of the pesticide treadmill, caused by the build-up of pesticide resistance and resurgence and secondary pest outbreaks. The danger is largest in a crop like cotton. In West Africa pyrethroid resistance to *Helicoverpa armigera* in cotton was reported in West Africa (Martin et al., 2002), and the resurgence of whitefly in the Sudan (Abdelrahman and Munir, 1989; Eveleens, 1983).

In subsistence crops Jago et al. (1993) concluded that in millet the use of pesticides was not economically justified. Nevertheless in some Sahelian countries, like Niger, village crop protection brigades were set up (de Groot, 1995). They applied pesticides donated by donors for their fellow farmers on millet. The uniforms of the brigade members and the sophisticated equipment gave the erroneous impression of modernity and prosperity to the farmers. Apart from introducing unsustainable methods by donors, in the process traditional pest management practices are getting lost (Atteh, 1984).

Migratory pests, like locust plagues, armyworm outbreaks and quelea birds are controlled by the government through the Plant Protection Divisions that apply pesticides free of charge. This also strengthens the impression to farmers that pest control is not their responsibility, but that of the government.

The unused pesticides donated for locust control may eventually be spent for other pests. It happens also with pesticides of which the procurement is facilitated by the government in crops like cotton. It eventually may be applied on food crops, in particular when producer prices for cotton are low. For example in Benin, farmers indicated that they grew cotton in order to obtain sufficient pesticides to treat their cowpea plots (Prudent et al., 2006). Locust upsurges often results in donated pesticides which often become obsolete stocks that effects the environment. FAO (2004) estimated the amount of obsolete stocks in 53 African countries to be 50,000 tonnes. FAO is participating in the Africa Stockpiles Program (ASP), a multi-partner initiative, which aims to clear obsolete pesticide stocks from African countries and put in place measures to prevent the problem from recurring.

Farmers often use natural products to control insect pests. Nkunika (2002) indicated that in the Muswishi area in Zambia maize farmers hardly use pesticides, but they do use plant products, wood ash and cow dung to control pests.

Fruits and vegetables are one of the fastest growing agricultural markets in developing countries, with production increasing by 3.6 percent a year for fruits and 5.5 percent for vegetables over 1980–2004 (McCulloch et al., 2007). A variety of these management-intensive crops are grown with a heavy use of chemicals, viz. horticulture crops account for 28 percent of global pesticide consumption (Foster and Rosenzweig, 2004). For example, farmers in Benin increased their applications on cabbage from three per season to 12–20 by 2001 (PAN, 2001).

12.5.2 Varietal Control (GMOs)

The International Board for Plant Genetic Resources and CGIAR institutes collect landraces and wild relatives of crops, conserve germplasm and use this to develop resistant and tolerant crop varieties. It is an appealing strategy for resource-poor farmers as just planting a crop variety provides control. However, Zannou et al. (2007) showed that for yam and cowpea in Benin that the diversity of rituals, food habits, technological traits, food security strategies, and market demands contributes to the maintenance of varietal diversity by farmers. It is not possible for one or even a few varieties to meet all needs. The management of on-farm genetic resources is a socially and culturally constructed system. Any external strategy to improve varieties should take into account these social and cultural aims. It is probably for the above mentioned reasons that sub-Saharan Africa has seen very incomplete adoption of improved varieties (World Bank, 2007).

In 2006, farmers in 22 countries worldwide planted transgenic seeds on about 100 million ha, which is about 8% of the global crop area (World Bank, 2007). South Africa is currently the only country in sub-Saharan Africa, where Bt cotton is grown commercially. Toenniessen et al. (2003) mentioned that small farmers in the Makhathini Flats the Northern Kwa-Zulu Natal received a 77% higher return from Bt cotton than from conventional varieties and also benefited through a significant reduction in the number of necessary insecticide applications. However, Hofsa et al. (2006) found in the same area that cropping Bt cotton did not generate a tangible and sustainable socio-economic improvement. The problem they mentioned was that these farming systems are characterized by recurrent low crop yields and broad variations due to climatic and environmental factors. In this setting, the adoption of Bt cotton increases the financial risk for farmers. Focussing on Bt cotton without considering other factors was considered misguided. Hillocks (2005) also concluded that Bt cotton cannot deliver yield increases if crop management is poor. Therefore, it should be used in an integrated crop management system, and to have the full benefits spraying against non-lepidopterous pests would be necessary. Another problem is that incentives are provided to smallholders to grow cotton, such as fertilizers which are often diverted to food crops and seed. Therefore, farmers are reluctant to pay for Bt cotton seed which is about 50 US$ per ha (Hillocks, 2005).

Toenniessen et al. (2003) mentioned a method to control Striga in maize. Resistance to the herbicide imazapyr was bred into maize varieties that were adapted to East African conditions. The seed coating of these varieties with a magnesium salt of imazapyr against a cost of 4 US$ per ha before planting prevented the development of Striga parasitized plants.

12.5.3 Biological Control

The classical biological approach has been treated in the paragraph on invasive pests. The inundation type of approach is not very important in Africa. It would only be beneficial for large plantation crops in Africa, and not for small farmers, as it requires the rearing of natural enemies.

Conservation biological control involves the enhancement of naturally occurring natural enemies. Van Mele et al. (2007) showed in Benin that at high ant abundance levels, *Oecophylla longinoda* (Latreille) (Hymenoptera: Formicidae) significantly reduced fruit fly (*Ceratitis* spp. and *Bactrocera invadens*) infestation in mango (*Mangifera indica* L.). Ayenor et al. (2007a) also showed in Ghana that this ant species was able to control the capsids, *Sahlbergella singularis* Hagl. and *Distantiella theobroma* (Dist) (both Hemiptera: Miridae) in cocoa (*Theobroma* *cacao* L.) as effectively as applying crude aqueous neem *Azadirachta indica* A. Juss. (Meliaceae) seed extract. When ant abundance was high, capsid incidence was low. One of the most important issues to conserve natural enemies is to refrain from using insecticides, especially in agro-ecosystems where no pesticides are used. This provides a challenge with the intensification of agriculture. Although adoption rates to conserve predatory ants are still low, emerging markets for organic and sustainably-managed fruit, nut and timber products are likely to boost investment in weaver ants (Van Mele, 2008).

12.5.4 Cultural and Mechanical Control Practices

Traditional pest management practices are often cultural or physical, and of special interest for farmers that cannot afford expensive inputs. Cultural control is making the cropping environment less suitable for insect pests and more suitable for their natural enemies.

An interesting example is the push-pull strategies, which is a behavioural manipulation of insect pests and their natural enemies. The crop is protected by associating it with stimuli that makes it unsuitable of unattractive (push), while luring them to an attractive source (pull) where the pest is subsequently removed (Cook et al., 2007). An example is the control of stemborers in maize and sorghum in eastern and southern Africa. Stemborers are repelled by non host intercrops (*Molasses minutiflora, Desmodium uncinatum* and *D. introtum* (push) and concentrated on attractive trap plants (*Pennisetum purpureum* and *Sorghum vulgare sudanense*) (pull). *Molasses minutiflora* at the same time increases parasitism by *Cotesia flavipes* and *Desmodium* suppress the parasitic weed *Striga hermonthica*.

Melon production in the north of Kordofan in the Sudan was in the 1990s severely affected by the melon bug, *Aspongopus viduatus*. This bug congregate and aestivate in large numbers from May to June. Due to a hand picking campaign in which in particular women and children participated more than 200 tons of bugs were collected and burned (Bashir et al., 2003). Brader (1979) also mentioned that *Spodoptera littoralis* egg masses in cotton has been hand picked in Sudan since 1905. He also mentioned the picking and burning of bolls infested with the pink bollworm *Pectinophora gossypiella*, at the end of the growing season, to reduce its carry-over. Heat treatment of seeds was also applied.

12.6 Institutional Constraints and Challenges

Thompson (2006) stated: '*Much of the failure of agriculture to achieve its potential is institutional and political. Support by the state has been unresponsive to the needs of the poor and inefficient in marketing producers' output, sometimes preventing the natural development of market for producers. Public institutions need to be strengthened in their capacity to develop an appropriate blend of policies, regulatory*

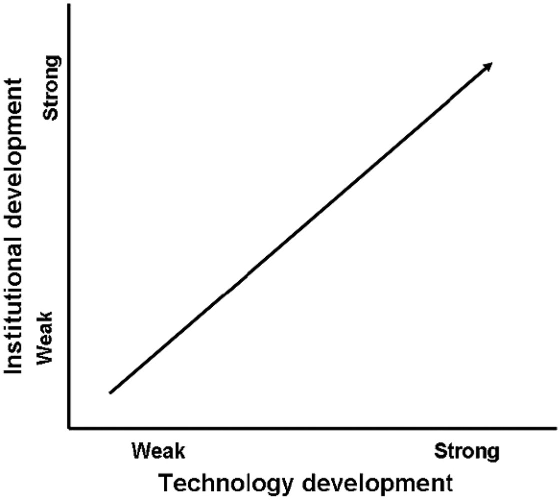

Fig. 12.1 Innovation as a function of institutional and technical change (Giller, 2001; based on Dorward et al., 1998)

frameworks and investments to re-launch the agricultural sector'. Figure 12.1 shows institutions and technology as two dimensions of innovation.

The dominant narrative in agricultural research is, after all, that science-based technologies for raising farm productivity can, in principle, raise incomes the rural poor earn from the food they sell. In this view, innovation is seen as change along the horizontal axis. Cultivating a resilient, bountiful crop and managing pests may be easier than cultivating an equally thriving market, with access to credit and distribution channels. In other words, one could argue that markets, access to inputs, farmers' political influence, etc. are the factors in the minimum. In this view, technology development is hampered by institutional innovations, such as better prices which motivate farmers to invest in innovation on their farms, or strengthening farmer organizations in order to increase their political clout such that needs and opportunities of farmers are better addressed (Altieri 1989).

12.6.1 Markets

Ghana was on the way to becoming self-sufficient in rice production in the 1970s and 1980s. It was the first country where FAO started with the Farmer Field School approach (Afreh-Nuamah, 2003). However, rice growing is close to being not longer profitable as the farmers cannot compete against the rice imported from the U.S.A. Ghana now produces a mere 150,000 tonnes of rice, or 35 percent of its domestic need. Ghana is the largest importer of high quality American long grained rice in Sub-Saharan Africa and typically the only major commercial market for USA rice in the region (Childs and Livezey, 2006). However, the USA farmers producing the rice imported in Ghana has been subsidized for more than 50%, while the IMF structural adjustment program halted farm subsidies to Ghanaian rice farmers. According to Oxfam (2005), 110.000 tonnes were imported from the USA in 2003, the imported rice displacing local Ghanaian rice. The question is whether under these conditions it is still worthwhile to set up FFS in rice in Ghana.

With an increase in producer's price, it may become interesting to protect the potential yield loss by pests or diseases. For example, from 2001 to 2004 producer price of cocoa increased in Ghana, and production increased by 80 percent during the same period (Dormon, 2006). This can only have been achieved by farmers paying more attention to production issues. For example, in this period of price increase, Dormon et al. (2007a) was able with farmers to come to an arrangement of reciprocal and communal labor arrangement in order to clear one farmer's field in one day of black pods, diseased by *Phytophtora palmivora* and this increased yields threefold. Many farmer practices are resilient and adaptable to changing conditions (Stoop and Hart, 2005).

Ayenor (2006) studying integrated pest management in cocoa in Ghana in order to produce organic cocoa, used neem to control capsids (Myridae). However, the American company that wanted to buy organic cocoa withdrew when the Ghana Cocoa Board proved reluctant to cooperate in organizing certification.

12.6.2 Government Interference

In Zanzibar rainfed rice is produced on 15,000 ha on the southern island of Unguja. Rice farmers form a stable electorate for the ruling party, reason that rice growing benefits from many types of subsidy (Bruin and Meerman, 2001, p. 95). Dependency on these subsidies erodes initiatives for more efficient production methods. On Pemba the northern island of Zanzibar on 600 ha irrigated rice, farmers are assigned seasonally to 0.1 ha plots. They need to obey the directions of the Ministry otherwise they will loose the plot. They are also not allowed to switch to vegetables, which according to them is much more profitable. These government policies of dependence do not make farmers very motivated, and hampers the FFS approach (Bruin and Meerman, 2001, p. 91).

African countries have programs to provide direct or indirect subsidized inputs, among which pesticides, as Fleischer and Waibel (2003) showed for Benin, Ghana and Mali. It not only drains financial resources of the country but also contributes to farm inefficiency, and to a lower chance of IPM implementation. A general problem is that pesticide externalities are often not monitored and not economically assessed.

Dormon (2006) reports from Ghana that mass spraying of all cocoa farms is organized by the government as a way of reducing pest incidence. These campaigns are "free of charge", although the costs are indirectly paid by farmers through the cocoa revenues received by the government. He disputes the effectiveness of such programs as the spraying is calendar based and not need based. Besides, spraying gangs are used being area-based paid, causing them to rush through the farms.

Another danger is that it discourages farmers' innovation, because they become over-dependent on the government for pest and disease control. Besides, these campaigns will reduce the abundance of predatory ant species which have shown to be effective in controlling capsids (Ayenor et al., 2007a). Applying neem would be a better combination as it does not seem to affect ant abundance.

From 1982 to 1985 the author was leading a pest management training program for eight Sahelian countries. The focus of the training was on integrated pest management options. Most of the trainees were employees of Plant Protection Divisions (PPDs) of the countries involved. However, the main task of the PPDs was not in IPM issues but in the application of pesticides. Many applications by PPDs are politically motivated, in particular when it concerns migratory pests. Therefore, decisions based on pest management rationality are often not followed. This shows that unless IPM becomes a national strategy, the usefulness of training in IPM is questionable.

12.6.3 Pest Management in Relation to Other Constraints

In subsistence crops, yields are often so low that saving the percentage loss by pests, does not pay, not in labor and not in costs for pesticides. As Orr (2003) states: "*the main production problem facing smallholders is not crop losses from pests but low average yields*." The marginal benefits from crop protection are often less than those from improved water management or increased soil fertility. In the absence of pesticides, pests may be adequately controlled by natural mortality factors. A disciplinary entry point when dealing with subsistence farmers without a proper identification of their needs and opportunities is a wrong approach. For example in Zanzibar cassava farmers confronted the Plant Protection Service of Pemba who conducted FFS that their main problem was not pests but marketing, which in this case was addressed.

12.6.4 FFS Abused

Nederlof and Odonkor (2006) studied a cowpea FFS project in Ghana. They showed that farmers had predetermined ideas about the objectives of the FFS. Instead of grounding the curriculum in the needs and opportunities of farmers, the scientists involved in the program pushed their ideas about improved varieties and pesticide use. The curriculum was adapted by the researchers and used as a blueprint to transfer technologies 'that work'. FFS is often wrongly considered as an extension methodology to push technology.

This misconception is widespread, e.g. Bunyatta et al. (2006) stating "KARI has adopted the methodology as an up-scaling approach for its promising technologies". Isubilalu (2007) analyzed the functioning of five FFS in Uganda, dealing with IPM in cowpea and groundnut, safe pesticide use and handling in vegetables, soil productivity improvement in maize and groundnut, and IPM and post harvest management in sweet potato. It was concluded that farmers had no negotiating power to influence the curriculum and the decisions were made top down by donors and researchers. She stated: "*FFS is turned into a platform where researchers promote their mandates and interests rather than addressing farmers' interests*." Scientists for FFS focussed on low yields and pest management while farmers considered health and income generating activities as more important priorities.

12.6.5 Impact FFS Questioned

FFS has been criticised for having little impact on farmers others than the direct participants (Feder et al., 2004a,2004b). Complex pest management information however does not readily diffuse among farmers as it requires experiential learning (van den Berg and Jiggins, 2007; Ayenor et al., 2007b). van den Berg and Jiggins (2007) also argue that impact cannot only be measured in yield increase. Technical impact should also consider externalities of pesticide use (health costs through poisoning and resistance build up of malaria vectors, environmental costs by loss of beneficial insects). Besides there are also a number of development impacts such as experimentation, collective action, leadership, planning and organization.

12.6.6 Insects and Diseases Not Considered a Pest

Some insect species assumed to be pests may in fact be considered a benefit. For example, in 1995 in Niger many grasshopper species are collected by women early in the morning in millet fields after which they are sold as food on the local market (van Huis, 2003). Apparently they earn more by selling edible grasshoppers then by marketing their millet crop. Also, in Malawi we were informed that women may prefer cassava leaves infected by Cassava Mosaic Virus because the infected leaves taste sweeter than healthy leaves (Dr.Nzola M. Mahungu, personal communication).

12.6.7 Land Tenure

Cassava grown on fertile soils suffers less from Cassava Mosaic Virus. Agroforestry is often an attractive option. Spittel and van Huis (2000) demonstrated from Zanzibar that application of *Gliricidia sepium* leaves increased yields most in plants having highest CMD scores, and that increasing organic matter content in the soil lowers CMD severity. However, the land tenure system in Zanzibar often prohibits farmers to grow trees as it is a covert claim to landownership (Bruin and Meerman, 2001).

12.6.8 Exploitive Networks

Sinzogan et al. (2007) reported how a large enterprise with stakes in the cotton chain and a licensed provider failed to provide the inputs necessary for a pest management strategy, called Lutte Etagéé Ciblé, (targeted staggered control). This method uses economic thresholds and reduces the amount of pesticides considerably compared to the conventional recommendations. The non provision of the inputs forced the farmers to resort to the conventional crop protection products. This and other methods entrapped the producers in formal institutional linkages.

Dormon et al. (2007b) tackled complaints by cocoa farmers in Ghana that purchasing officials of the Cocoa Licensed Buying Companies were cheating them by adjusting their weighing scales. They set up a task force of relevant stakeholders and solved the problem. Increasing their revenues in this way may also motivate farmers to invest in IPM.

12.6.9 HIV/AIDS

The ‘new variant famine’ hypothesis argues that HIV/AIDS pandemic is one major contributing factor for the current food insecurity in southern Africa, particularly due to four new factors: labor shortages, asset and skill loss, increasing burden of care for the sick and orphans, and malnutrition (de Waal and Whiteside 2003). It also argues that the reduced farm labor is likely to be directed towards less labor-intensive root crops such as sweet potatoes and cassava, but compromising nutritional value. That is because cassava is easy to grow, resilient to droughts and other harsh environments, and commands little farm inputs such as fertilisers and labor. With HIV/AIDS as the leading cause of death in the age group 15–49 years in Malawi, cassava is for those reasons in high demand inducing widespread theft of the standing cassava crop. This also lead to loss of viable planting stems. Farmers then have to resort to other means and sources of obtaining planting stems, often infected by Cassava Mosaic Virus (CMV). Thus, the loss of clean planting stems by theft aggravates the already prevalent damage by CMV in the area (Chiwona-Karltun et al., 2005)., which can compromise the yield up to 70%.

In addition, Charleston et al. (2003) indicated that many IPM practices are labor intensive and or for that reason would comprise such an approach.

12.7 Conclusions

Demand for food production in sub-Saharan Africa is expected to reach 100 US$ billion by 2015, double its level of 2000 (World Bank, 2007). The question how this can be done in a sustainable manner? In the 1990s public spending on R&D fell in nearly half of the countries in the region and as stated by the World Bank this is a risk, as Africa's agroclimatic conditions and crops are rather unique. The question is of course where to put scarce resources in the case of pest and disease development.

Improved varieties are one of the most effective components of IPM. However, new challenges in pest and diseases will come up. For example, in 1999, high susceptibility of CIMMYT germplasm to stem or black rust (*Puccinia graminis tritici* UG99) was noted in Uganda and an increase in stem rust incidence and severity was seen in Kenya, although in the past 30 years genetic resistance in semidwarf wheat cultivars (*Triticum aestivum tritici*) was a remarkable success story (Singh et al., 2007). Progress in resistance breeding has been mostly in pest and disease resistance, but developing varieties that perform well under drought, heat, flood and salinity are new challenges in the adaption to climate change.

Morse and Buhler (1997) talk about an IPM paradigm, an ideal way to deal with pests but it is very knowledge and expertise intensive. They consider IPM a creation of scientists, with the emphasis on technical excellence, reason for poor adoption by farmers. In particular they question whether pests or diseases are a concern of the farmer. Although the FFS approach is supposed to be demand driven, the question is whether the choice for the issues to be tackles, e.g. soil fertility or pest management, is negotiable. Choices may have been made before, without having properly identified the real needs and opportunities of the farmers. This could be due to the priorities of the funding or the executing agency, the national authorities or the experts involved (see Schut and Sherwood, 2007). An a priori choice may affect the success of any IPM approach.

When IPM specialists talk about constraints of IPM, they mention of course inadequate funding for research, but also issues as lack of collaboration between research and extension (meaning that research results are not taken on by the farmers), low income of farmers who cannot afford costly inputs and the use of traditional varieties which result in low yields (e.g. Dakoua et al., 2003; Nyambo et al., 2003). It shows the paradigm problem in which the conditions of the farmer are not taken as the starting point but as a constraint. It should be realized that the farmers ultimately have veto power over the recommendations proposed by scientists.

The examples of institutional constraints given above suggest that scientific and farmers' knowledge needs to converge and that innovations comprise a mix of technical, economical, social and institutional elements requiring an effective encounter between social and biological science (Nederlof et al., 2007). The bottleneck in agriculture is often not so much innovativeness and productivity at the farm level, within the existing very small windows of opportunity. The challenge is to stretch those windows in this way enlarging the space for innovations. Efforts to foster agricultural development through technology push in absence of institutional support structures will most probably fail. Institutional development arises out of coalitions, networks, or configurations of multiple stakeholders in agricultural innovation across multiple scales. Institutional development allows them to act in concert with respect to fostering conditions for growth. This requires investment in experimentation with, learning in, and capacity building of innovation systems at the international, national and local levels, involving agricultural research organisations, universities, farmers' organisations, parastatals, private companies, NGOs and donors. This concept of enhancing agricultural innovation systems is largely unexplored (World Bank, 2007). FFS emphasized farmer empowerment, but the above examples show that the range of stakeholders need to be broadened along production chains and institutions involved.

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Chapter 13
Evaluating Dissemination and Impact of IPM: Lessons from Case Studies of Potato and Sweetpotato IPM in Peru and Other Latin American Countries

Oscar Ortiz, Jürgen Kroschel, Jesús Alcázar, Ricardo Orrego and Willy Pradel

Abstract Integrated Pest Management (IPM) programs have been implemented in Latin American for several decades. Examples in the case of Peru include the successful IPM programs for cotton, citrus, olives, sugar cane and potatoes. However, impact assessment of such programs has not been common. Most of the IPM programs, except the potato case, did not include formal impact assessments neither efforts to document lessons about program implementation and methods used. This paper presents a historical analysis of potato IPM implementation in Peru in which the International Potato Center took part. The analysis is complemented with IPM cases on potato and sweetpotato from other Latin American countries, which enabled the extraction of factors that influence implementation and impact of IPM. The analysis indicates that IPM to become a reality at field level needs the coexistence of sound technical knowledge and solutions, inter-institutional cooperation mechanisms, collective action of farming communities and an enabling political environment, which is not common in most Latin American countries.

Keywords IPM · impact · potatoes · sweetpotatoes · Peru

13.1 Introduction

Integrated Pest Management (IPM) programs have been implemented in Latin America for several decades. Examples in the case of Peru include the successful IPM programs for cotton, citrus, olives, sugar cane and potatoes (Palacios et al.,

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2003). The content of these programs was based on results of IPM research activities mainly conducted on the entomology and agronomy disciplines, which were disseminated to farmers through the public extension systems that existed until the 1980s. Although, publications describe successful implementation of IPM, there have not been specific studies for assessing the impact of this technology prior to the 1980s. It was in the 1980s that other disciplines such as anthropology, economics and extension sciences began to look at IPM from a different angle, particularly at the International Potato Center (CIP). Since the mid 1980s, different socioeconomic studies have been conducted to assess, for example, farmers perceptions about pest control, cost-benefit analysis of pest control methods, and more recently the impact of IPM, which focused mainly on the economic benefits of this technology, but later focusing on impacts on other aspects of the farmer livelihood systems, such as human, social, and natural capitals.

This paper aims at analyzing IPM implementation with a human dimension, by extracting lessons from the socioeconomic and impact oriented studies of IPM, taking Peru, and particularly the potato crop, as a case study, but also using examples of other crops in other Latin American countries.

13.2 Potato IPM in Peru and Examples from Other Latin American Countries

The evolution of pest control in Peru, taking the example of the potato crop, is described by Ortiz (2006), who identifies some clear stages in the historical evolution of pest control; for example, prior to 1532, during the Inca Empire, a well organized agricultural system existed and pest populations were regulated mainly by crop rotation using the "sectorial fallowing system" which consisted of rotating crops on a communal basis, meaning that all farmers in a community agreed to plant one single crop (i.e. potatoes) in a sector of the community, and then all moved to another sector, in which potatoes had a 7-year rotation period (Hastorf, 1993; Zimmerer, 1991). However, during the Colonial era, between 1532 and 1821, the whole agricultural system began to be disrupted; particularly rotational periods were reduced, which did not allow the fields in the high Andes to recover in terms of fertility and soil health. During the first century of the Republican era, between 1821 and 1930s, the disruption of the systems continued and potato pests increased. It was in the 1950s when pesticides were introduced to the potato systems, and their use has been growing ever since. As a response, potato IPM programs, particularly to control the Andean potato weevil (*Premnotrypes* spp.) and the potato tuber moths (*Symmetrischema tangolias* and *Phthorimaea operculella*) began to be tested in farmer fields in the late 1980s, and these programs have been growing through inter-institutional collaboration. Potato IPM was promoted by the International Potato Center (CIP) and the National Agricultural Research Institute (INIA) of Peru (CIP, 1995). CIP also launched sweetpotato IPM programs in Central America. Alvarez et al. (1996) described the impact of IPM for controlling the sweetpotato weevil (*Cylas formicarius*) in Dominican Republic, which was based on the use of sex pheromones as attractants and the appropriate use of pesticides. Maza et al. (2000) and Cisneros and Alcázar (2001) described another interesting case of sweetpotato IPM in Cuba, where the program was based on a combination of pheromone use, biological control with the fungus *Beauveria bassiana* and the predatory ants (*Pheidole megacephala* and *Tetramorium guineense*) as well as different cultural practices.

Potato IPM programs were also implemented in Bolivia and Ecuador through collaborative agreements between CIP and the National Agricultural Research Institute (INIAP) in Ecuador and with the Potato Research Program (PROINPA) in Bolivia. In both cases, the national research institutes adapted IPM practices to control the Andean potato weevil and the potato tuber moths developed by CIP in Peru to their local conditions.

Potato IPM has not been the first example of using this technology in the Peruvian agricultural systems. Palacios et al. (2003) presented a comprehensive description of the IPM evolution in Peru indicating that it was in the 1937 when a program of classic biological control in olives was implemented to control the black scale (*Saissetia oleae*), which lasted about 17 years. Valdiviezo (1998) even reported earlier attempts to introduce beneficial insects in 1904 to Peru. Later, in the 1940s, a successful biocontrol program for the sugar cane borer (*Diatraea saccharalis*) was implemented. The introduction of an exotic parasitoid failed but inundative releases of *Paratheresia claripalpis* reduced damage by 83% due to high parasitism (88%). This program was significantly impaired because of new policies during the Agrarian Reform in the 1970s. In the 1950s, and in response to problems caused by the indiscriminate use of pesticides in cotton, which according to Daily (1997) reached up to 21 sprays per season, a private farmer organization (Farmers' Association of the Cañete Valley, located in the Peruvian Central Coast) organized an IPM program to reduce the use of highly toxic pesticides through the implementation of improved cultural practices, pheromone, biological control applying inundative releases of the egg parasitoid *Trichogrammatoidae bactrae* to control the Indian pink bollworm (*Pectinophora gossypiella*), one of the major cotton pests and others. The number of sprays dropped to about 2 per season. The control measures have continued since then with some variations, but in general following the same principles. The applied control measures against the Indian pink bollworm reduced by 70% the use of pesticides (Castro et al., 1997), or when focusing on organic production reduced production costs by 50% (Van Elzakker, 1999). There was also the case of IPM for citrus, which was implemented in the 1960s, basically focusing on the successful introduction of biological control agents.

As indicated, biological control agents to control insect pests in several crops, particularly in citrus, cotton, and sugar cane, were introduced to Peru since 1904. Valdiviezo (1998) lists the introduction of a total of 98 beneficial species during the period of 1904–1998. Studies indicated that 29 species have established, and 13 species controlled completely 11 pests. The economic benefit of 10 beneficial species for controlling 9 pests was calculated to amount to US$ 39 millions annually for pesticide savings. Some examples of successful introductions include the species *Aphelinus mali* to control aphids in apple (*Eriosoma lanigerum*), *Rodolia cardinals* to control cottony cushion scale *Icerya purchasi* in fruit trees, wasp species (*Scutellista cyanea, Metaphycus lounsburyi* and *Lecaniobius utilis*) that were efficient to control black scale *Saissetia oleae* in olive trees, and wasps of the genus *Trichogramma* to control the sugar cane borer *Diatraea sacharalis*.

The common feature of these IPM programs was that they were implemented in relatively high value industrial or export crops. In the early 1990s, IPM for potato pest management was introduced to Andean communities through inter-institutional cooperation. Fano et al. (1996) describe the collaborative activities between the CIP and extension organizations as an alternative way to facilitate farmers' access to information and technologies. Since 1992, CIP has established several contacts with NGOs in order to disseminate its research results to resource-poor farmers in the Peruvian Andes. For example, a collaborative project was implemented between CARE-Peru and CIP in order to train farmers in IPM (Chiri et al., 1996; Ortiz, 1997). However, this effort gave priority to the technical aspects of IPM, and paid little attention to the use of participatory methods for training farmers.

Between 1995 and 2000, an inter-institutional potato IPM program took place with the participation of CARE-Peru, Ministry of Agriculture, CIP and the financial support of the United States Agency for International Development (USAID). This program aimed at the dissemination of potato IPM to Andean communities in large scale, taking advantage of the decentralized extension network of the National Program for Soil Conservation (PRONAMACHS) from the Ministry. Several courses, manuals and farmer training activities were conducted, focusing on a conventional extension approach. However, there is no evidence about the number of farmers that were reached through this program.

In 1998, CIP began to implement integrated disease management against potato late blight (*Phytophthora infestans*) using participatory research and training methods, such as the farmer field school (FFS) approach (Nelson et al., 2001; Ortiz et al., 2004). This experience showed that working with knowledge-intensive technologies such as IPM required methods that facilitated farmers' learning process. In 1997, CARE-Peru and CIP initiated the testing and dissemination of participatory research and training approaches based on the FFS experience (Nelson et al., 2001), which put emphasis on adapting a participatory method to help farmers understanding complex biophysical principles involved in pest control, moving beyond technology or information transfer to promoting hands-on learning for improving decision-making. FFS was shown to be an effective way to enhance information exchange, learning, and the adoption of IPM. Farmers learned complex concepts more efficiently than with alternative extension approaches, and new knowledge was associated with increase in productivity (Godtland et al., 2004; Ortiz et al., 2004).

In recent years, institutions such as NGOs have been promoting an approach called ecological pest management (EPM), which derives from IPM, and emphasizes the use of botanical insecticides, beneficial insects and entomopathogens in crops such as potato, beans, onions, cotton and vegetables (Arning and Lizárraga, 1999). This approach has been promoted actively by the "Red de Acción en Aternativas al uso de Agroquímicos – Raaa" (Action Network for Alternatives to the Use of Pesticides) through training, research, promotion and the formation of micro enterprises for the production and marketing of IPM-related inputs. A combination of different means for information delivery, such as courses, seminars, demonstration plots, publications and radio programs was used reaching about 6,000 beneficiaries between 1991 and 1995 (Hollands and Lizárraga, 1998). However, there is no evidence in the literature about the impact of these programs.

Chavez-Tafur et al. (2003) indicated that there has been a movement towards ecological organic agriculture in Peru, resulting in the formation of a national association of ecological producers, which included farmer organizations and institutions, providing certifications for this type of agriculture. This factor has resulted in a renewed interest in IPM, particularly when associated to crops for specific organic markets.

More recently, FAO coordinated an inter-institutional IPM program using the FFS approach building upon CIP and CARE previous experience (Nelson et al., 2001; Ortiz et al., 2004). This project was implemented between 2001 and 2003 with the participation of governmental institutions such as the National Institute of Agricultural Research (INIA), the National Agricultural Sanitation Service (SENASA), La Molina University, and several NGOs. In an initial phase, the project included potato IPM in the Peruvian Highlands, and cotton IPM in the coastal region. Later, other crops such as coffee, citrus, peanuts, maize, bean, banana, aromatic herbs, vegetables, and also some cases of integrated management of livestock pests were included. A total of 200 FFS were implemented in 2002 and 2003 generating benefits for farmers in terms of accessing information and knowledge about pest biology and ecology and control methods. In addition, farmers learned to experiment with pest control methods on their farms. Some lessons learned indicate that IPM implementation is not only about the technical content, but also the appropriate way of delivering information. This requires adequate participatory research and training methods that supports farmer understanding of complex concepts related to pest control (Groeneweg et al., 2004).

The participation of farmers in adapting IPM has been essential because of the high variability of agro-ecosystems existing in the Peruvian territory, particularly in the Andean region. This is particularly important when dealing with pests, which are highly influenced by the environment, such as potato late blight that is influenced by relative humidity and temperature. Therefore, technologies that work for a farmer in one location may be different for other farmers located at higher or lower altitude, and that is why farmer opinion and contribution with their local knowledge about their conditions is essential to adapt IPM.

13.3 Potato and Sweetpotato IPM Implementation and Dissemination. Cases from Latin America

13.3.1 Technology Transfer Phase: The Pilot Area Approach

CIP in collaboration with INIA initiated the implementation of potato IPM programs in the late 1980s. The approach used by researchers and extension workers in the early 1990s was called IPM pilot units, which were implemented at community level (Cisneros, 1999). The first pilot unit was located in the Peruvian Southern highlands, in a community called Chincheros. The idea was to evaluate the effect of different control practices against the Andean potato weevil. About 60 farmers were involved during 3 years and the records indicated a decrease of the weevil damage to harvested tubers from originally 31% to 11% (Ortiz et al., 1996). There were other pilot units within Peru in the Central and Northern highlands, where farmers had access to information directly from researchers (Ortiz, 1997). Other cases of pilot units were built up in Ecuador, Bolivia, Dominican Republic and Cuba. The main characteristics of the pilot units were that an agronomist trained on pest control was permanently presented in the communities, who was in charge of assessing farmer practices, IPM training and gathering farmers' opinions about the new IPM technologies. Researchers frequently visited pilot units to conduct pest-related research. Extension workers received IPM training too, but were not trained on how to teach IPM to farmers. As a result, extension workers were very active trying to develop training approaches using their own creativity (Ortiz, 1997, 2006), which included visits to fields to see over wintering places for insects, visual aids to explain insect life cycles, dramas and games to explain insect behavior, which took considerable time. The experience demonstrated that prioritizing the technical IPM component was not sufficient. The technology required appropriate methods to facilitate learning and dissemination, so that farmers could acquire timely information and knowledge; finally these were essential elements for the adoption of IPM. At that time a clear demand for IPM-related training methods began to be expressed among participating institutions (Ortiz et al., 1997; Ortiz, 2001).

Impact assessment of the pilot unit approach was conducted using an economic approach consisting on estimating the net benefit of IPM at field level, taking samples of farmers fields and assessing insect damage at harvest time, the rate of adoption and comparing costs and benefits of the program using the internal rate of return and the net present value estimates. At that time, economic impact was the focus of the analysis and results showed that farmers could achieve an average benefit of about US$ 100/ha because of the adoption of IPM, which compared favorably with other investments in agricultural research and development. Although the pilot unit approach was replicated in several places of Peru, for example, with the support of the Inter-American Development Bank (BID), a potato IPM program was implemented to control potato insect pests in the Central Highlands and also Central Coast in Peru, basically to control the Andean potato weevil and the leaf miner fly

Liriomyza huidobrensis, respectively. The program was successful in bringing scientific information to farmers about innovative pest control methods, using mostly conventional extension methods such as field days, demonstration plots and individual or group training.

In general terms, there is not an up-dated assessment of the level of adoption that potato IPM reached. The review of files indicates that information about potato IPM reached about 5% of Peruvian potato growers, but there has not been a formal assessment so there is no evidence to estimate real adoption. Because of the lack of a functional extension service and difficulties for farmer-to-farmer dissemination of complex technologies such as IPM, there is no strong reason to believe that the adoption moved beyond that point. An additional aspect in the assessment was related to the number of IPM practices disseminated, and the difficulty to estimate how many were needed to consider the technology adopted. Hence, the question at that time was if IPM adoption consisted in the adoption of a number of pest control practices, or of the decision-making process to select appropriate pest control practices. The emphasis was on the former.

13.3.2 Participatory Research and Training for IPM: The FFS Experience

The lessons learned during the pilot unit phase have led to start looking at other experiences related to IPM training and implementation. Practitioners were interested in methodological innovations that could facilitate farmers' uptake of IPM beyond the pilot units. The idea of the FFS approach was introduced to Peru by a CIP scientist who previously gathered experiences in Asia on rice FFS (Nelson et al., 2001). This method was the best bet for teaching IPM at that time, and a process of adaptation began through a collaborative project between CIP and the NGO CARE-Peru. Between 1998 and 2001, the FFS method was adapted to potato related IPM, giving emphasis to late blight control. Although, the idea was to develop a method that could facilitate farmers' understanding of complex concepts on the biology, reproduction and dissemination of the microorganism that causes late blight, the experience soon revealed that there was also the need to evaluate the efficacy of control technologies in specific locations of different agro-ecologies. Late blight occurrence and incidence depends on the susceptibility of the cultivars, the climate (humidity, rain and temperature) and on farmers' management practices. Therefore, the FFS that were at the beginning initiated as a learning method for farmers were used for participatory research, being called participatory research through FFS (PR-FFS). This allowed farmers to assess technologies and scientists to collect information about the performance of the technologies in a range of socioeconomic and agro-ecological situations. The combination of learning and technology assessment seemed to be the right approach to tackle a complex problem such as late blight. In this way, new resistant cultivars and clones were introduced and jointly evaluated with farmers and, at the same time, farmers learned about how to control this disease. Although, this project was initiated focusing on late blight, farmers demanded also information on control methods for other pests, such as the Andean potato weevil and potato tuber moths, resulting in a more integral potato pest control program. Additionally, potato agronomic cultivation practices were included[1].

The adapted version of the FFS, which combined participatory research and training, generated impact in terms of changes in farmers' knowledge about potato management, influencing positively the productivity of potatoes. Godtland et al. (2004) reported that knowledge increase significantly because of the participation in FFS and that the input-output rate for potato could be increased by 32% as a result of additional knowledge. In addition, Zuger (2004) indicated that additional knowledge gained through FFS and the introduction of resistant cultivars generated productivity gains of US$ 236/ha and US$ 350/ha respectively, which showed the profitability of investing in training combined with participatory research. However, the amount of additional income from potato depended on the size of the potato plots, which tended to be less than 0.5 ha, which suggested that the impact of IPM, or of any other technology, should be assessed in terms of the contribution to the total income of the farm to see the real benefit for farmers.

The adaptation of the FFS method by CIP and CARE initiated the scaling-out of the methodology to other contexts and crops. In Ecuador and Bolivia, the national agricultural research institutions, the Agrarian National Research Institute (INIAP) and the private research foundation for potato and Andean crops (PROINPA) respectively, also adapted the approach to their local conditions. Groeneweg et al. (2004) indicated that with the support of FAO the method was replicated in cotton, tomato, maize, coffee, vegetables as well as in potato. CARE-Peru adapted the method to work on pest control and market aspects of native fruit trees. Anecdotic evidence indicates that at least ten other institutions have tried the FFS method, and that there is continued interest to adapt it to new problems and topics, for example, for pest control on livestock.

The FFS experience showed the need to provide training to farmers using appropriate methods, and to introduce suitable technologies that could complement farmers' knowledge to make appropriate decisions. However, implementing FFS requires skilled staff, organizational response on the part of communities and farmers, and adequate financial support to run the method properly, which still remains a challenge. The FFS method was introduced to Peru in 1998 and there is evidence that it has been replicated in more than 10 institutions. However, the spread and reach of this method has not been studied yet.

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[1] Alternatives to control the Andean potato weevil include elimination of volunteer plants, nocturnal hand-picking of adult weevils, turn-over of soil in infestation sources, use of sheets to pile potatoes during harvesting and sorting, harvest on time, use of chickens as larva predators, use of diffused light stores, trenches around stores or fields, biological control agents, and vegetative or chemical barriers (Alcázar et al., 1994).

13.4 Retrospects and Prospects of IPM: Some Lessons from Impact Assessment of Potato and Sweetpotato IPM

In the last 15 years, CIP has been engaged in the promotion of potato and sweetpotato IPM in some Latin American countries. For potato, IPM programs were implemented in Peru and subsequently in Bolivia, Ecuador, Colombia and Dominican Republic. For sweetpotato, the work was focused in Dominican Republic and Cuba. These IPM cases allow for a comparative analysis by describing the main characteristics of factors that enabled or hindered the adoption of technologies and finally the impact achieved of the different IPM interventions (Table 13.1).

Formal assessments were carried out during and immediately after the programs ended, using as indicators the rate of adoption, the net benefit of IPM adoption expressed in US$ per ha, and the cost of IPM development and implementation in each program, but no formal follow-ups of adoption were performed further, only anecdotic information could be used for this analysis.

In terms of economic impact, in all cases the internal rates of return (IRR) to investment for IPM development and dissemination were between 27% and 49% and compared very favorable with other types of investments in agricultural research. The IPM adoption at the pilot sites was encouraging, and the achieved additional net benefits on potato or sweetpotato ranged from US$ 100 and US$ 536 per ha. Very exceptional in the case of Cuba, the adoption for managing the sweetpotato weevil (*Cylas formicarius*) occurred beyond the pilot sites and reached about 50% of the total sweetpotato production area. There is no evidence that something similar happened in potato IPM in the Andean region. In all IPM programs, there was the need of a substantial investment for the introduction, adaptation, development and dissemination of IPM practices. Compared to classical biocontrol programs, however, the profitability of these IPM projects is relatively low. Valdiviezo (1998) reports that the naturalization of 10 exotic beneficial insects to control pests in different crops in Peru has generated annual pesticide savings of about US$ 39 million. The difference is that classic biocontrol has been introduced to relatively high value crops in most cases, which is different to the potato that still tends to be a food security crop.

The lack of follow-up studies in the IPM cases presented before indicates that there has been limited learning from the cases in terms of successes and failures. When learning and documentation do not happen, new IPM projects do not built on the lessons learned but tend to duplicate efforts or make similar mistakes than in the past.

The comparative analysis suggests that the main enabling factor for the success of a program and IPM adoption was the strong collaboration between research and development-oriented institutions, and in the case of Dominican Republic, the participation of the private sector, which facilitated the participatory adaptation of IPM strategies according to each location. Synergies can be clearly achieved when an international agricultural research center, national agricultural research institutes, non-governmental organizations, private sector and farming

Table 13.1 Main features of potato and sweetpotato IPM programs in Peru, Ecuador, Dominican Republic and Cuba

IPM program Feature	APW Peru (1990–1996)[1]	LB Peru (1998–2005)[2]	APW Ecuador (1994–1998)[3]	APW Bolivia (1995–1998)[4]	SPW, Dominican Republic (1992–1994)[5]	SPW, Cuba (1994–1998)[6]
Benefit/ha and internal rate of return (IRR)	US$ 100/ha IRR: 30%	US$ 536/ha IRR: 31%	US$ 270/ha IRR: 33%	US$ 101.8 IRR: 18%	US$ 100/ha IRR: 27%	US$ 126/ha IRR: 49%
Intervention method	Pilot sites (conventional group training)	FFS (hands-on learning activities).	Pilot sites (conventional group training)	Pilot site (conventional group training).	Pilot site (conventional group training).	Pilot sites as part of government interventions.
Status of adoption	Limited beyond the pilot sites.	Limited beyond the FFS intervention area.	Limited beyond the pilot sites.	Unknown	Limited beyond the pilot sites.	Exceeded expectations, went beyond pilot sites.
Enabling factors	Collaborative project between CARE and CIP.	Collaborative project. Participatory method facilitated farmers' learning and adoption.	Collaborative project between CIP and INIAP enabled local adaptation of IPM.	Collaborative project between PROINPA and CIP enabled the adaptation of IPM to local conditions	Collaborative effort facilitated the work. Support of the private sector (JAD).	Collaborative project. Political commitment, functional extension service and collective action. No competition from agrochemical companies

Table 13.1 (continued)

IPM program Feature	APW Peru (1990–1996)[1]	LB Peru (1998–2005)[2]	APW Ecuador (1994–1998)[3]	APW Bolivia (1995–1998)[4]	SPW, Dominican Republic (1992–1994)[5]	SPW, Cuba (1994–1998)[6]
Hindering factors	Lack of functional extension service for scaling-out. Strong competition of agrochemical companies.	Lack of functional extension service for scaling-out. Strong competition of agrochemical companies.	Limited extension services for scaling-out. Strong competition of agrochemical companies.	Inexistence of a government extension service. Strong competition of agrochemical companies.	Limited availability of pheromones after project cycle, and limited support of the government for scaling-up.	Limited availability of pheromones after project cycle.
Main lessons	Working at community level is essential for developing IPM.	IPM requires participatory methods to facilitate learning and adoption, but that increases the cost.	Adaptation of IPM principles developed in other context is essential.	IPM options do not reduce the need for insecticides. The pilot site approach is too specific for IPM and farmers face a number of problems.	Availability of IPM inputs needs to be taken into consideration from the beginning.	Commitment of policy-makers, and collective action facilitated implementation.

Key: APW: Andean potato weevil (*Premnotrypes spp.*), SPW: Sweetpotato weevil (*Cylas formicarius*), LB: late blight (*Phytophthora infestans*).
[1] Ortiz et al. (1996), [2] Zuger 2004, [3] Barrera and Crissman (1999), [4] Esprella et al. (2001), [5] Alvarez et al. (1996), [6] Maza et al. (2000).

communities work together towards common objectives. In Peru, the partnership between CIP and CARE-Peru was initiated with an IPM program in 1993 and has lasted 15 years. Initially working with the pilot site approach and the collaborative effort resulted in the adaptation of FFS as a participatory research and training method for IPM (Ortiz et al., 2008a). A similar partnership has happened between PROINPA foundation and CIP in Bolivia. In Ecuador, CIP and the National Agricultural Research Institute (INIAP) collaborated with local organizations and farming communities for the adaptation of IPM, first through the pilot site approach and later through the FFS method. In Dominican Republic, there was the participation of the "Junta Agroempresarial Dominicana – JAD" (Agro-entrepreneurial Dominican Association). In Cuba, favorable for the program was the political (by law) and institutional commitment towards IPM development and implementation, and had its main cause in the limited access of Cuban agricultural sector to agro-chemicals after the end of the Soviet Union. As a result, the government sector (research and extension) and the state cooperatives were organized to facilitate IPM implementation. Cooperatives built and maintained units for the mass production of the entomopathogen (*Beauveria bassiana*) to control the sweetpotato weevil. The coexistence of political will, institutional support and collective action made the large-scale implementation of the IPM program possible and a full success. In contrast, in all other countries, a lack of political support for IPM implementation was one of the main hindering factors for a large scale adoption. The weak government extension services prevalent in most countries prevented the scaling-out of the IPM experiences beyond the pilot sites although some special projects that tried to promote the spread of the technology. Köli (2003) concluded that adoption of IPM for the Andean potato weevil depends on a relatively well-organized extension or education service with a stable presence in the communities, which is in line with the experiences made at IPM pilot units or FFS. Further this author pointed out that the coordination of a large number of GO and NGO would be needed for scaling-out IPM experiences; the great variability of agro-ecological and economic conditions, farmer perceptions including availability of time and personal attitudes calls for a better "IPM product differentiation", meaning fine tuning IPM strategies according to different types of farmers. One additional hindering factor has been the strong competition of agrochemical companies, which have aggressive selling strategies and well-established selling networks, so that farmers have access to pesticides with relative facility, compared to IPM-related advice or inputs.

Limited availability of some IPM inputs has turned out being often another important factor for IPM adoption. In the Dominican Republic and Cuba, the availability of pheromones was reduced substantially after the project cycle. Local production could not build up and the importation from the Netherlands was too costly; recently it was shown that pheromones produced in China are used. In IPM leaflets and brochures produced by national programs it can be often observed that IPM items like pheromones are mentioned but which are not available on local markets. In Peru, there were some government and non-governmental organizations that attempted to produce biological control agents such as the fungus *Beauveria bassiana* to control the Andean potato weevil and the potato tuber moth granulovirus (*Po*GV) to control potato tuber moths, but results were not encouraging, and the private sector has not been part of the efforts so far.

Collective action was clearly present in Cuba but not in the other countries, where farmer organizations are weak and no mechanism for promoting collective action exists. According to the experiences and the lessons learned at the pilot units and FFS, the commitment of farmer organization to IPM is utmost important; where it does not exist, the chances of adoption are very low.

IPM is clearly a type of technology that depends on an enabling innovation system, meaning the existence of relatively strong research and development organizations and also strong farmer organizations, which can make collective action for IPM a reality. The technology also requires inter-organizational coordinated efforts, which are not easy to initiate or to sustain over time (Ortiz et al. 2008b)

13.5 Concluding Remarks: Some Lessons for the Future

IPM to become a reality at field level needs the coexistence of sound technical knowledge and solutions, inter-institutional cooperation mechanisms, collective action of farming communities and an enabling political environment. The relatively appropriate combination of these factors existed for the successful implementation of an IPM program only in Cuba. The lack of some or all of these factors has negatively influenced the IPM adoption in the other examples presented in this paper.

Unless the availability of IPM-related inputs (i.e. pheromones) is ensured, also after the end of the projects, these IPM inputs should not be promoted as part of an IPM program, because it creates expectations that cannot be fulfilled. Otherwise the reliability of the project and the IPM technology will be negatively affected and the IPM adoption could drop sharply after the project.

Working at the community level is essential for IPM development and implementation, which was the main contribution of the pilot unit approach. Prior, IPM practices were tested in individual plots only, where no real understanding could be achieved for all those factors which might influence IPM implementation. IPM assessment at community level with the participation of many farmers and institutional actors is more meaningful and accurate, because it involves different points of view. Appropriate participatory research and training methods are important to facilitate the understanding of IPM by farmers, which was the main contribution of FFS to the pilot unit approach.

The economic impact of IPM at pilot sites of FFS communities has been encouraging and is an important parameter to take into consideration. However, also impact on human capital like changes in stakeholder knowledge and skills is important, which could last even beyond the IPM program or the crop in hand. Impact in social capital can also be achieved when working with IPM programs, which requires inter-institutional and collective action. Again, strengthened social capital would have benefits beyond the specific IPM programs. However, most of the IPM programs analyzed in the paper did not assess the importance and changes of social capital and its influence on IPM scaling-up and implementation. Some indicators of impact at the level of human capital include, for example, proportion of farmers recognizing stages of pest life cycles, infestation sources, and ways the insect reaches fields or stores. Also, proportion of farmers who are able to explain how, why and when IPM practices should be used. Examples of indicators of changes in social capital include the existence of farmer organizations, the formalization of them, number of sources of information and access to credit related to pest control.

Farmers' characteristics are changing rapidly in response to market development, globalization, urbanization and threats to human health. In general farmers are diversifying their sources of income, meaning that they are engaged in more and different on and off-farm activities. IPM strategies and program need to take those new conditions into consideration by developing strategies and products more target oriented. Product differentiation is a well-known concept in the private sector, which should also be considered in public IPM research and intervention.

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Chapter 14
Integrated Pest Management in Europe – History, Policy, Achievements and Implementation

Bernd Freier and Ernst F. Boller

Abstract Inspired by the pioneering work in Canada and California in the early 1950s, the first European IPM task force – the "Working Group for Integrated Plant Protection in Fruit Orchards" – was established by the International Organisation for Biological and Integrated Control of Noxious Animals and Plants (IOBC) in 1959. From the beginning, the implementation of IPM proved to be a problem because of its complicated and non-uniform requirements and insufficient economic benefits. In spite of these obstacles, IPM has become an accepted model for plant protection in all European countries and in the European Union. More than 30 working groups of the West and East Palaearctic Regional Sections of the IOBC (IOBC/wprs and eprs) organise research programs and information exchanges and actively promote the implementation of IPM into practice. IPM can be well implemented within the scope of Integrated Production (IP). Respective IP guidelines developed by IOBC/wprs working groups and local production organisations are currently being used, particularly in pome fruits and grapes. Studies have shown that IPM systems yield greater biodiversity and reduce pesticide use by at least 20% compared to conventional farming, as assessed using the treatment index. Some countries, such as Denmark, Germany and Switzerland, have developed national pesticide reduction programs. The European Union also supports IPM by issuing regulations and directives and by funding research programs. National action plans shall help to achieve faster and more consistent implementation of IPM in the Member States.

Keywords IPM · Europe · IOBCwprs · biological control · integrated production

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14.1 Introduction

This chapter describes the specific pattern of development of IPM in Europe. Plant protection has always been a key component of sustainable agricultural production systems. Prevention and control of important pests, diseases, weeds and physiological disorders followed different patterns in organic and integrated production systems. In both schools of thought, however, plant protection was considered part of and was ultimately integrated in the entire range of production processes at the farm level. Outside organic farming plant protection in Europe evolved from chemical pest control in the 1940s and 1950s via integrated pest control, integrated pest management (IPM) and integrated plant protection (IPP) to the holistic concept of integrated production (IP). The first investigations, particularly those in fruit-growing in Western Europe, showed that IPM could be used as a model for practical plant protection in all crops. Based on positive long-term research results and practical experience, the IPM concept is now widely accepted as a plant protection strategy for sustainable farming in all of Europe.

Since its introduction the IPM concept has received political and financial support from the European Union and the governments of all European countries aiming to minimise the noxious effects of chemical pesticide usage and to ensure sustainable crop production. From the late 1970s on, more and more research and implementation programs have been established, not only in Western Europe but also in Eastern Europe. Even before the more recent political changes, the IPM concept was also welcome in European socialist countries. In these states, chemical pesticides were scarce and had to be bought on the international market. The "Integrated Production" (IP) concept and corresponding guidelines were developed as an important result of IPM research in Europe. Anyone wishing to produce crops under the "Integrated Production" label had to comply with the requirements specified in these guidelines. European Union Directive 91/2092/EEC (which adopts the private IFOAM regulations) defines the requirements of organic agriculture, but no equivalent EU-directive exists for IP although international standards for IP are in place. Therefore, most governmental regulations in Europe concerning plant protection still address IPM issues only.

European studies have shown that IPM systems increase biodiversity and reduce pesticide use by at least approximately 20% compared to conventional farming, as assessed using the treatment index. Nonetheless, overall implementation levels are still low. In Europe, IPM is considered to be a standard procedure in perennial crops (fruits, grapes etc.), but not in annual/rotational cropping systems. However, unlike organic farming, integrated production systems have not yet achieved significant added value for the products at the farm level. This is one of the main problems slowing down the implementation of IPM and IP in practice.

It is another particularity in Europe that principles of Good Plant Protection Practice (GPP) were introduced as "basic standards", the requirements of which are not as strict as the IPM standards, but should ensure proper use of pesticides by farmers (see Section 14.3.1). National programs for the promotion of IPM, e.g. Pesticide Reduction Programs, and indicators used to estimate the status quo of IPM and the progress made in pesticide use and risk reduction will also be outlined in this chapter.

14.2 History of IPM and IP in Europe

14.2.1 Corner-Stones

The history of IPM and IP in Europe is well-documented (e.g. Boller et al. 1998, 2006; Minks et al. 1998). Not surprisingly, IPM and IP were developed primarily by orchard entomologists. As soon as the first synthetic insecticides became commercially available in the 1940s, they were readily introduced in apple orchards – a perennial agro-ecosystem rich in fauna but highly susceptible to pests. The first cases of resistance to pesticides (DDT and organo-phosphorous compounds) were observed around 1949. Particularly spider mites and pear psylla exhibited a great ability to develop resistance.

The IOBC (**I**nternational **O**rganization for **B**iological **C**ontrol of Noxious Animals and Plants), established in 1956, is closely linked with the development of biological and integrated control strategies for major insect pests in Europe. This organisation celebrated its 50th anniversary in 2006 (Boller et al. 2006). Inspired by the pioneering practical work of Picket and his team in Nova Scotia, Canada (Picket et al. 1958) and by the conceptual ideas published in California (Stern et al. 1959), the IOBC established a "Commission on Integrated Control" already in 1958 and a Working Group on "Integrated Pest Control in Fruit Orchards" in 1959. At the beginning this group operated mainly in the Netherlands (e.g. de Fluiter, de Wilde), Germany (e.g. Steiner), Switzerland (e.g. Baggiolini, Mathys) and certain parts of France (Milaire). In many respects, entomologists involved in apple production can be considered the pioneers of IPM and leaders of the later development of IP in Europe (Steiner 1977; Boller et al. 1998). They were the first to address serious resistance problems in arthropod pests, a phenomenon encountered 10 years later by plant pathologists and 20 years later by weed people. IOBC Working Groups developed IPM in all major crops of Europe (see Section 14.5.1.). Based on the Californian term "Integrated Control", an FAO expert panel elaborated in 1967 a first definition of "Integrated Pest Control" (F.A.O 1968). However, many IOBC members felt that the broader term "IPM" was more appropriate. To emphasise the interdisciplinary dimension and systems approach in plant protection, the IOBC Orchard Group adopted the term of "Integrated Plant Protection" in 1974, and all other IOBC Working Groups followed suite in 2001.

14.2.2 Integrated Production (IP) Born in Europe

July 11, 1976, is the historic landmark date on which, after reviewing current developments, five IOBC specialists coined the term "Integrated Production" (IP). This important evolutionary step became known as the "Message of Ovronnaz" (Steiner 1977; Boller et al. 1998), widened the dimension of IPM into a holistic approach.

The new concept postulated that plant protection had to be removed from isolation and integrated into the entire range of production processes at the farm level. Instead of focusing on linear pest, disease or weed control, emphasis was placed on management of agro-ecosystems and of the entire farm as basic holistic unit. The IOBC established an IP Commission in 1977, but initial acceptance of IP in fruit and grape crops was slow. Conventional production procedures and sectorial IPM programs remained the backbone of agricultural policy and market pattern in most European countries in the late 1970s.

14.2.2.1 New Standards in Plant Protection and Agricultural Production in the 1990s

After reviewing the general direction of its activities and the recent developments in plant protection concepts in 1989, the IOBC gave its Commission on "IP Guidelines and Endorsement" the mandate to define a conceptual frame for IP to describe the underlying strategy, to provide technical assistance and services for regional IP organisations, and to operate on behalf of the IOBC an international endorsement service. The first basic document "Integrated Production: Principles and Technical Guidelines", which was finalised in 1992, summarised the most recent conceptual and technical developments in Europe (El Titi et al. 1993). It opened the door for the establishment of crop-specific IP Guidelines and for an international endorsement service for IP organisations operating according to IOBC standards (see Section 14.5).

14.2.2.2 Food Scandals Generate New Standards for Food Quality

The 1990s and early 2000s were marked by international and local food scandals and increased consumer criticism of the food sector. Important market players and international institutions reacted by discussing and defining international standards for food safety and social/ethical aspects of food production and distribution, which became increasingly effective as of 2005. Already in 2001, the IOBC made a first major step forward by postulating a total quality approach in the pre-harvest sector of agricultural production. The new "IOBC Standard 2004 for IP" (Boller et al. 2004a) was the first standard to incorporate elements of product, production, ethical and social quality; it became an international benchmark for excellence (see Chapter 3.4). This standard was field-tested with adequate analytical tools in 2005–2006 and is now being implemented by IOBC-endorsed farmers' organisations in France, Spain and Oregon/USA (www.iobc.ch).

14.3 Policy

Increasing revelations about the effects of pesticides and pesticide residues in the environment and in foodstuffs for humans and animals, and the publication of "Silent Spring", the challenging book by Rachel Carson (1962), strongly influenced the

IPM movement in all European countries and the European Union. European policymakers aimed to minimise the noxious effects of chemical pesticides while, at the same time, ensuring sustainable crop production. The governments supported projects related to international IPM research and implementation and encouraged inter-European political and scientific collaboration on the subject. However, the socialist countries of Eastern Europe initially cooperated mainly among themselves in relative isolation until the political situation changed in 1989.

14.3.1 European and Mediterranean Plant Protection Organization (EPPO)

The European and Mediterranean Plant Protection Organization (EPPO) (www.eppo.org) was founded by 15 European countries in 1951. EPPO now has 48 member states, representing almost all countries of the European and Mediterranean region. Its objectives are to protect plants, to develop international strategies to prevent the introduction and spread of dangerous pests, and to promote safe and effective pest control methods. One of the EPPO's main activities is to publish Standards on Good Plant Protection Practice (GPP). Twenty-six standards for different crops or crop groups have already been published (Anonymous 2002). The GPP standards document rules for good handling and diversity of action in plant protection within the framework of existing regulations; however, they do not comprise binding requirements. The "Principles of good plant protection practice" define GPP as a basic strategy for everyone to ensure the proper use of pesticides and explicitly state that GPP is not the same as IPM, which is a more complex sophisticated concept. It is very important to distinguish between the two policies because some people believe that GPP includes the elements of IPM and is synonymous with IPM. This misconception dilutes the general high standards of IPM.

14.3.2 European Union

The European Union currently consists of 27 Member States. EU Directive 91/414/EEC, which regulates pesticide registration and usage, came into force in 1991. The Directive, which has 6 annexes, defines IPM as:

> "*The rational application of a combination of biological, biotechnical, chemical, cultural or plant-breeding measures whereby the use of plant protection products is limited to the strict minimum necessary to maintain the pest population at levels below those causing economically unacceptable damage or loss.*"

The system approach and necessary minimum levels of pesticide usage are central points. Directive 91/414/EEC encourages Member States to take the principles of IPM into account. However, generally binding IPM principles and rules on how IPM should be implemented still do not exist at the European Union level. The EU authorities recently published a "Thematic Strategy on the Sustainable Use of

Pesticides" (Anonymous 2006a) and put forward new draft documents for discussion. These include:

a) A new "Regulation Concerning the Placing of Plant Protection Products on the Market" which shall ultimately replace the Directive 91/414/EEC (Anonymous 2006b) and
b) A "Directive Establishing a Framework for Community Action to Achieve a Sustainable Use of Pesticides" (Anonymous 2006b). An essential element of this directive is the idea that the Member States should develop "National action plans" during the next years (Article 4). These national action plans should include targets, measures and timetables to reduce pesticide risks and hazards and dependence on pesticides. It also specifies that Member States shall ensure by 1 January 2014 at the latest that all professional users implement the principles of IPM (Article 13). Consequently, it strongly demands that Member States not only consider, but also implement the IPM principles. The directive also provides that, based on these principles, the Member States shall be encouraged to develop "crop-specific guidelines for IPM", the practical implementation of which shall be voluntary. Besides establishing a legal framework, the European Union supports IPM research and implementation of integrated methods or IPM concepts and organises platforms for information exchange (see above).

The European Union supports agriculture by providing the following types of subsidies:

a) Direct payments contingent upon compliance with the Principles of Good Plant Protection Practice and
b) Subsidies for participating in Rural Development Policy Program 2007–2013 which includes incentives for reducing pesticide usage and implementing IPM techniques. In Germany, for example, farmers can receive approx. €60 per ha for using *Trichogramma* parasitoids against *Ostrinia nubilalis* in maize.

Since 1993, the non-EU country Switzerland has also pursued a comprehensive direct payments scheme involving some 97% of all Swiss farms (see Section 14.3.3.3).

14.3.3 IPM in National Legislation and Action Plans

Most national plant protection acts incorporate IPM as a general model and aim. The policymakers generally use IPM as an orientation mark and consider it a strategy that should be supported, but not necessarily as a mandatory plant protection standard for everyone who uses pesticides. The implementation of IPM is therefore voluntary in European countries. IPM guidelines and relevant requirements are generally used by regional organisations interested in certified labels (such as IP). Figure 14.1 demonstrates the relationship between regulations, GPP and IPM.

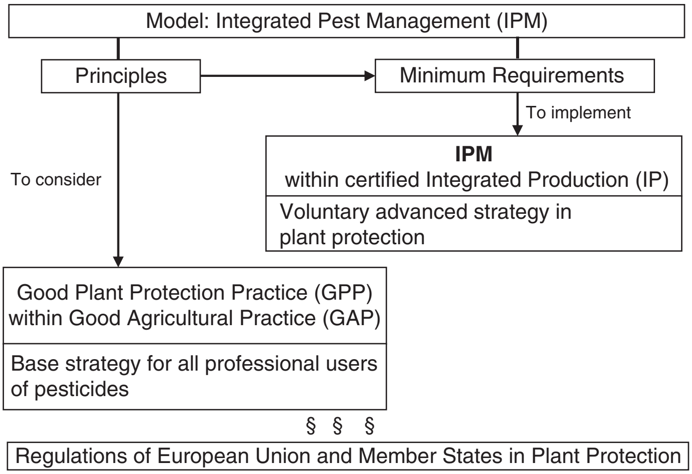

Fig. 14.1 Relationship between regulations, good plant protection practice (GPP) and integrated pest management (IPM)

The German Plant Protection Act takes into account the IPM concept since 1987 (Anonymous 1998). It defines IPM as:

> “*A combination of methods in which primary attention is paid to biological, biotechnical, plant-breeding and cultivation techniques, and in which the use of chemical pesticides is limited to necessary amount.*”(Article 2).

Article 2a states that: “*GPP implies that principles of IPM have to be considered.*”

To “consider” is an unspecific term meaning that IPM is not obligatory.

In Germany, IPM Principles have been published (Burth et al. 2002). Similar documents were also developed in other European countries. They are integral parts of General Guidelines for IP in most of the countries, e.g. Italy, Germany, Spain and Switzerland (Boller et al. 1998, Cadahía Bielza 2003, Wiegand et al. 2004, BLW 2005).

Environmental and consumer organisations and political stakeholders criticise the high level of pesticide use in European agriculture. Figure 14.2 shows the rate of pesticide use per ha in crops (arable crops, fruits and vegetables). The statistical method used by Eurostat (2007) does not present a realistic picture. The collected data probably underestimate the actual level of pesticide usage. In addition to legal regulations at the national and EU level, some European countries have therefore passed action plans to promote the development of IPM and to reduce the risk of pesticides and pesticide dependency. Almost all European countries presented their programs at an EU meeting held in Berlin in 2007 (Anonymous 2007a). The Danish Pesticide Plan is an interesting example.

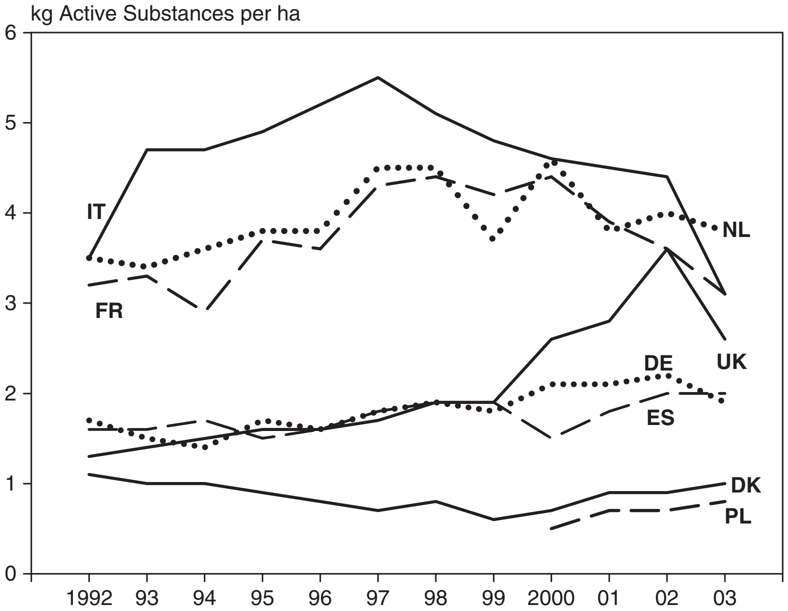

Fig. 14.2 Usage of pesticides in crops (arable crops, fruits and vegetables) in eight European countries (Eurostat 2007) DE: Germany, DK: Denmark, ES: Spain, FR: France, IT: Italy, NL: Netherland, PL: Poland, UK: Great Britain

14.3.3.1 The Danish Pesticide Action Plan

Denmark began its pesticide reduction program over 20 years ago, in 1986. The Danish government aimed to achieve a more stringent authorisation system and to reduce total pesticide consumption, as assessed using a newly developed indicator called the "Treatment Intensity Index" (TI) (Kudsk 1989). The TI (=Treatment Frequency Index, Treatment Index or Frequency of Application) represents the number of pesticide applications in a defined area per year, provided that a fixed standard dose is used. The average TI value remained at 2.67 from 1981 to 1985 and decreased to 2.5 within 10 years. When corrected for differences in crop composition compared with the reference period, the reduction was 25% in 1997 (Nistrup Jorgensen 2003). The sales of active ingredients for pesticides were also reduced by 40% in Denmark. The established "Bichel Committee", which participated in the Pesticide Action Plan, concluded that the TI could be reduced to 1.4–1.7 without significant losses to farmers and society if all available technologies, particularly IPM, were implemented. However, although the TI decreased until 2002, it subsequently rose to 2.32 by 2005. The introduction of incremental pesticide taxation failed to reduce the actual pesticide use. The subsequent tax levels were:

1986–3%,
1996–13% (herbicides and fungicides) and 27% (insecticides) and
1999–33% (herbicides and fungicides) and 54% (insecticides).

14.3.3.2 The German Reduction Program Chemical Plant Protection

The German Federal Ministry of Food, Agriculture and Consumer Protection launched the "Reduction Program Chemical Plant Protection" in 2004. Its aims were:

(1) To reduce the risks associated with pesticide use,
(2) To reduce the intensity of plant protection product use to the necessary minimum and
(3) To reduce the percentage of domestic products exceeding the existing maximum residue limits to less than 1%.

A total of 19 actions were proposed, including the introduction of the Treatment Index (TI) similar to the Danish Treatment Intensity Index as an indicator of intensity of pesticide use. The German TI is defined as the number of pesticide applications at the authorised dosage on a defined area. Surveys started in 2000 have shown remarkable differences in the intensity of pesticide use between crops, landscapes and farms in different German regions (Table 14.1). A second action was the establishment of a network of reference farms for determination of minimal necessary pesticide use levels. A third action was to support the development and implementation of innovations for integrated plant protection. Other actions are aimed towards improving compliance with Maximum Residue Limits (MRLs), management of "hot spots", improvement of professional knowledge, keeping records of pesticide use, improvement of plant protection inspections, provision of more and better professional information, development and introduction of modern plant protection equipment, use of national and regional support programs for IPM and organic farming, co-operation with trade organisations and the food processing industry, and improvement of consumer information. Risk indicators were established using models such as SYNOPS (Gutsche and Strassemeyer 2007). Simulations indicate that the relative risk has decreased since 1987 (baseline), particularly in the case of insecticides.

Table 14.1 Intensity of pesticide use (treatment index) in field crops in Germany (2000) [Means (S.D.)] (Rossberg et al. 2002)

Crop (Number of farms)	Herbicides	Fungicides	Insecticides	Growth regulators
Winter wheat (790)	1.37 (0.67)	1.39 (0.78)	0.36 (0.59)	0.62 (0.50)
Winter barley (724)	1.07 (0.53)	1.10 (0.60)	0.10 (0.35)	0.49 (0.50)
Rape (644)	1.18 (0.54)	0.68 (0.61)	1.44 (0.91)	0.12 (0.24)
Maize (489)	1.22 (0.48)	0	0.03 (0.17)	0
Potatoes (130)	1.55 (0.85)	6.08 (3.26)	0.94 (1.14)	0
Sugar beet (382)	2.59 (0.95)	0.15 (0.35)	0.19 (0.55)	0

14.3.3.3 IPM and Sustainable Agriculture in Switzerland, a Non-EU Country

In 1993 the Swiss government introduced a new system of direct payments based on defined achievements obtained by individual farms, as measured using target environmental and animal welfare parameters. Today, over 97% of all Swiss farms participate in this voluntary program. Some 10% follow organic guidelines and the others follow IP or production schemes with near-IP standards. The federal program endeavours to achieve significant nationwide improvement concerning the reduction of pesticide, nitrogen and phosphorous inputs, the conservation of soil fertility, the increase of biodiversity and the implementation of animal production schemes respecting animal welfare. Most of the target parameters have an important impact on the effectiveness of IPM in the context of sustainable production systems, as was shown by a federal monitoring program (BLW 2005).

14.4 IPM/IP Research and Implementation

IPM and IP research is supported by special projects or research programs sponsored by European countries and the European Union. These research activities focus on the development and implementation of single-method and holistic concepts. The IOBCwprs (West Palaearctic Regional Section) and IOBCeprs (East Palaearctic Regional Section) Working Groups have proved to be the most important platforms for communication and coordination of IPM research in Europe (see Section 14.4.3.1).

14.4.1 European Union

Besides existing national projects, the European Union supports joint IPM research projects within the 6th Framework Program (2002–2006), the theme of which was "Food Quality and Safety Priority". This priority program for research into food quality and safety creates a scientific basis for development of environmentally friendly production and distribution chains for safer, healthier and more diverse foods for European consumers. The Integrated Projects and Networks of Excellence are useful instruments for developing large, multi-partner research projects that cover entire food production chains relating to agriculture and fisheries. Details on the 6th and new developed 7th Framework Program (2007–2014) can be found on the EU homepage (Anonymous, 2007b). Selected projects are described below.

- MASTER (Integrated pest *M*anagement *S*trategies incorporating biocontrol for *E*uropean oilseed *R*ape pests, 2000–2005).

Crop protection in oilseed rape, a major European crop, currently relies on pesticides and lags behind recent scientific advances. As a trans-European collaborative experiment, MASTER developed and evaluated economically viable and environmentally less harmful IPM strategies for oilseed rape. These strategies should maximise biological control of pests and minimise pesticide use by enhancing naturally occurring natural enemies of the pests. Indicators of crop performance, pest and damage incidence and cost-benefit assessments were used in the evaluation. Guidelines for end-users and a phenological model for decision-making were produced. New information on the pest/natural enemy community in the crop ecosystem and new insight into the socio-economic processes affecting new technology adoption by farmers were acquired.

- ENDURE (Diversifying crop protection, *E*uropean *N*etwork for the *DUR*able *E*xploitation of Crop Protection Strategies, 2007–2010).

This project was founded to develop international communication for establishing sustainable plant protection strategies in Europe, with a particular focus on IPM. ENDURE was launched by the European Union with a budget of over €11.2 million for a term of four years (2007–2010). Seventeen institutions from 12 European countries are involved into this joint project, which covers the following three fields of activities:

(a) Network-building
ENDURE identifies the areas of competence covered by each institution and elaborates scenarios regarding the future of crop protection. Scientific infrastructure is provided by networking the best facilities and know-how available among partners. Information and knowledge are compiled in a database.
(b) Joint research program
ENDURE aims to optimise plant protection towards more integrated strategies and to reduce pesticide use. Case studies were used to assess how existing and new practices, tools and evaluation methods can be better adapted by growers.
(c) Dissemination of results and knowledge.
Activities include the organisation of pilot training sessions with farmers, extension services and facilitators involved in crop management and promotion of the transfer of technologies. The project provides doctoral programs in crop protection research and organises summer school courses for young scientists. Finally, ENDURE aims to promote the dialogue with stakeholder and end-users.

- COST (European *CO*operation in *S*cience and *T*echnology) projects are low-budget projects aimed at promoting co-operation and communication between European research groups. Furthermore the European Union also promotes policy support actions which are also low-budget projects for financing joint expert meetings. The following project is such an example.
- REBECA (*RE*gulation of *B*iological *C*ontrol *A*gents, 2004–2008).

Invertebrate biological control agents, including nematodes, mites and insects, are safe for users, consumers and the environment. However, since the spread of the coccinellid *Harmonia axyridis* in Central Europe environmentalists have been concerned about possible hazards related to the use of exotic beneficials, although no evidence exists about a replacement of indigenous coccinellid populations and no major damage due to the use of exotics in Europe has been observed. Out of 17 European countries, eight already regulate the use of invertebrate biocontrol agents, four are preparing a regulatory system and five have no regulation in place. Biocontrol agents have become an important part of plant protection in European horticulture with an annual turnover of approx. €150 million. Thus, exaggerated regulatory requirements could significantly impact the future of biological control. The REBECA Action proposes alternative, less bureaucratic and more efficient regulatory procedures that maintain the same level of safety for human health and the environment but accelerate market access and lowering registration costs. Stakeholders presented results on how to regulate biocontrol agents according to a hierarchical system taking into account establishment, dispersal, direct effects and indirect effects of biocontrol agents. The methodological and financial problems concerning the assessment of environmental risks were also discussed. For further information on the progress of this Action, see Anonymous (2007c) and the recent European book by Bigler et al. (2006).

14.4.2 National Projects

The first Europe-wide, national projects on the implementation of IPM were launched in the 1970s and 1980s. They were first and most frequently performed in pome fruit and grape growing, but also in vegetable growing, glasshouse horticulture and arable cropping. Examples include the Lautenbacher Hof project in Germany (El Titi and Landes 1992) and the Nagele farm experiment in the Netherlands (Wijnands 1997).

In Great Britain, the "Integrated Farming Systems" project was conducted from 1992–1997 on six farms situated in the main arable farming areas of the UK. The work was incorporated in the LINK Program entitled "Technologies for sustainable farming systems" (Tzilivakis et al., 2004). The aim of the project was to develop an arable integrated system of production that included IPM while maintaining profitability by using a different balance of lower inputs and reduced environmental impact than conventional systems. The overall results show that profitability can be maintained in an integrated system. Savings on pesticide costs averaged £ 32/ha. The greatest percentage savings were achieved with plant growth regulators, followed by fungicides, herbicides and insecticides. The number of pesticide treatments was also reduced by 26% (1.2 treatments). Compared with conventional methods, 32% fewer pesticide units with 18% less active ingredient by weight were used. Populations of earthworms, carabids and spiders hardly ever benefited from integrated systems; their densities were more strongly influenced by site, season and crop (Holland et al., 1998).

The LEAF (*L*inking *E*nvironment *A*nd *F*arming) initiative supports the implementation of IPM in Great Britain. Participants demonstrate integrated farming principles in a nationwide network of volunteer demonstration farms on which they carry out integrated farming and show other farmers how to adopt it.

INTEX (*INT*egrated Arable Farming Systems in *EX*periment and Practical Experience, 1990–2002). Summarizing the 13-year data from field experiments at two sites near Goettingen (Germany) and from model farms in Central Germany, integrated farming reduced the frequency of pesticide use relative to the frequencies in conventional farming (GPP). With respect to differences in pesticide costs in wheat, the integrated system achieved potential savings of 40–55%, but did not result in a difference in the gross margin for the whole crop rotation. The results from demonstration farms even showed that the farmers who implemented the complete package of integrated farming package suffered financial losses (Steinmann, 2003).

Past and current projects show that IPM can be adapted within IP systems in vegetable, fruit and grape growing. If "premium quality" product labels are thereby established, the market will reward these efforts. In arable cropping, however, there is still no comprehensive IPM concept being implemented in practice. The current standard of plant protection in arable crops is GPP, which does still not completely meet the requirements of IPM. However, certain IPM methods are widely used. These include the use of different action thresholds, modern computer-based decision support, disease-resistant cereal varieties, and situation-related timing and dosage of pesticides. Important obstacles to IPM implementation must still be overcome, particularly in arable cropping. These include:

- The lack of official, uniform Europe-wide general IPM standards (minimal requirements) and a uniform label for products produced in accordance with these standards,
- The lack of additional profits for using IPM standards,
- The difficulty of implementing (handling) IPM in practice, which needs special user support. But the capacity of national plant protection advisory services is reduced in most European countries.

14.4.3 Non-governmental Organisations (NGO's)

Non-governmental environmental and consumer protection organisations are also interested in the theory and practice of IPM for reduction of pesticide dependency and minimisation of risks associated with pesticide use. We present here IOBC, IPM Europe and PAN as representatives of NGO's that act Europe-wide and world-wide.

14.4.3.1 IOBCwprs and eprs Working Units

The IOBC was originally established in Europe in 1956. In 1971, the name was changed to IOBC Global with six regional sections operating in Western Europe (WPRS), Eastern Europe (EPRS), North America (NRS), South America (NTRS), Pacific and Asian region (APRS) and Africa (ATRS) (www.iobc-global.org). IOBC Global has nine working groups that cover various aspects of specific pests and weeds.

The Western European section WPRS (West Palaearctic Regional Section; www.iobc-wprs.org) is not only the oldest, but also has the largest number of working units, which are listed below. Those in bold-face are crop oriented "Working Groups", and those in regular type are "service units" providing specific information.

IOBCwprs working units as of 2005, including year of establishment (in brackets):

Four IOBCwprs Commissions:

- Commission for determination and identification of entomophagous insects and insect pathogens (1956),
- Commission for Publications (1956),
- Commission for Integrated production guidelines and endorsement (1974/1990),
- Commission for harmonized regulation of biological control agents (2003).

Twenty IOBCwprs Working Groups:

- Integrated protection of fruit crops (1959),
- Integrated protection of citrus crops (1962),
- Integrated protection of olive crops (1965),
- Integrated control in protected crops: temperate climate (1968),
- Integrated control in protected crops: Mediterranean climate (1968),
- Integrated protection in oak forests (1968),
- Integrated protection in field vegetables (1970),
- Integrated protection in viticulture (1974),
- Integrated protection in oilseed crops (1979),
- Integrated protection of stored products (1991),
- Multitrophic interactions in soil and integrated control (1970),
- Pesticides and beneficial organism (1975),
- Pheromones and other semio-chemicals in integrated production (1975),
- Breeding for plant resistance to pests and diseases (1976),
- Insect pathogens and entomoparasitic nematodes (1985),
- Integrated control of plant pathogens (1989),
- Induced resistance in plants against insects and diseases (1999),
- GMOs in integrated plant production (2001),
- Landscape management for functional biodiversity (2001),
- Integrated control of spider-mites (2005).

Some Eastern European countries are traditionally involved in IOBCeprs (Eastern Palaearctic Regional Section), which was established in 1977. To date, six Commissions and 16 working groups have actively worked within the framework of IOBCeprs (Sosnowska et al. 2006).

14.4.3.2 IPM Europe

IPM Europe was established in 1993 to promote the implementation of IPM in Europe. Its first Secretariat was located at the University of Greenwich, Kent, UK. The Secretariat has been hosted by the GTZ (*Deutsche Gesellschaft für Technische Zusammenarbeit*) in Eschborn, Germany, since 2002. Activities, results and obstacles to IPM implementation were discussed by IPM Europe in a publication entitled "Concerted European Policy on IPM in International Co-operation, a Framework towards a Strategy" (1998). Its main focal points for changes in European plant protection policy were:

- Establishing common European IPM guidelines based on a set of agreed principles,
- Strengthening partnerships with key stakeholders,
- Promoting effective utilisation of European resources and
- Establishing of national IPM development committees.

However, this publication has not had much influence on European policy so far.

In 2000 the IPM Europe Secretariat published "Guidelines for IPM Planning: Donors – Harmonisation of European Support to Developing Countries in the Use of IPM to Improve Agricultural Sustainability." Apart from the European Union, this key document addressed European development agencies concerned with research and development activities with an IPM component. These guidelines are also very helpful for preparing, monitoring and evaluating IPM activities in developing countries (Dreyer et al. 2005).

14.4.3.3 PAN

PAN (Pesticide Action Network) is a worldwide network established to replace the use of hazardous pesticides with ecologically sound alternatives. The very active PAN-Europe group organised a meeting in 2006 to analyse the status quo of IPM in Europe, the effects of reducing pesticide use and obstacles to adapting IPM (Anonymous 2007d).

14.5 Standards and Guidelines for Food Safety and Integrated Production (IP) in Europe

As outlined in Section 14.2.2, new international standards for food safety emerged in the late 1990s. Most of them (e.g. the internationally applied EUREP-GAP/GLOBAL-GAP standard) focus on food safety but also contain rather general recommendations concerning Good Agricultural Practice and IPM. Currently, IP guidelines seem to be the best way to implement IPM in practice. In Germany, Italy, Spain, Switzerland and other countries guidelines for IP label programs inspired by the IOBC standards, particularly in fruit and vegetable growing, have been used for many years (Wiegand et al. 2004).

14.5.1 The IOBC Guidelines for Integrated Production (IP)

The basic IOBC document for the establishment of crop-specific IP guidelines is the 3rd edition 2004 of "Guidelines for Integrated Production: Principles and Technical Guidelines" – referred to as "IOBC Standard 2004 for Integrated Production" (Boller et al. 2004a, www.iobc.ch). The first edition in 1993 attempted to provide a conceptual umbrella for IP considering the concepts established by the historic "Message of Ovronnaz" (Steiner, 1977) and the developments in Europe during the 1980s. IP standard 2004 introduces a total quality approach. Aspects covered include product quality, production quality, ethical quality and social impact, consumer perceptions, food safety, environment, animal welfare and workers' health, safety and welfare. Hence, the IOBC standard 2004 incorporates elements of other international standards addressing food safety issues (e.g. GLOBAL-GAP) and social aspects (ILO charter) in order to make it compatible with these standards. However, the field of competence of the IOBC is and remains biological pest control, IPM and its incorporation into holistic IP-programs. This basic document includes Technical Guidelines I (requirements for organisations and their members) and Technical Guideline II (general agronomic requirements valid for all crops). Crop-specific guidelines (Technical Guidelines III) are established by the IOBC Commission on "IP Guidelines and Endorsement" in close collaboration with the respective crop-oriented IOBC working groups and *ad hoc* expert panels. They are updated every 5 years and cover the most important crops of the temperate zones: Pome fruits (1991, 1994, 2002), arable crops (1997), stone fruits (1997, 2003), grapes (1999, 2008), soft fruits (2000), olives (2002), citrus (2004), and field grown vegetables (2005). The guidelines published before 2004 are now being revised and adapted to the new IOBC Standard 2004. All of these documents serve to provide a framework for the formulation of regional or national guidelines according to IOBC standards and to facilitate their harmonisation.

The chapters of crop-specific guidelines follow the same pattern and cover the following topics: 1. General aspects (e.g. definition and objectives of IP; traceability; self-evaluation by farmers); 2. Biological diversity and landscape (ecological infrastructures; buffer zones); 3. Site selection; 4. Site management (e.g. crop rotation; soil management, soil protection); 5. Cultivars, seeds, and cultivation systems; 6. Nutrition; 7. Irrigation; 8. Integrated plant protection (the principles; the choice of direct control measures; the green and yellow lists of plant protection measures; storage and handling of pesticides); 9. Harvest; 10. Post-harvest procedures; 11. Animal production on mixed farms; 12. Workers' health, safety and welfare. All of these documents can be downloaded in full text from the website of the Commission (www.iobc.ch).

14.5.2 Endorsement Service

The Commission on "IP Guidelines and Endorsement" operates on behalf of the IOBC an international endorsement service for regional IP organisations working according to IOBC standards. Given the worldwide interest in these activities, IOBC Global has given the Commission the mandate to extend its endorsement system to temperate zones outside Europe. In 2001, LIVE, the grape growers' organisation in Oregon (USA), was the first extra-European group endorsed by the IOBC. All IOBC check-lists for the endorsement process are available in full text on the website www.iobc.ch.

14.6 Tools for Implementation of IPM and IP

14.6.1 Tools Developed by EU Research and Development Programs

IPM, which aims to minimise pesticide usage to the necessary minimum, contributes to reducing the dependency on chemical pesticides and risks associated with pesticide usage.

14.6.1.1 Indicators of Pesticide Use Intensity

The intensity of pesticide use can be characterised in different ways:

- kg pesticides (or active substances) sold per country or farm,
- kg pesticides (or active substances) per hectare farmland, crop or field,
- Treatment frequency in a defined area (region, farm, crop in a farm or field),

Treatment index (= Treatment Intensity Index, Treatment Frequency Index or Frequency of Application) in a defined area (region, farm, crop in farm or field).

The treatment index appears to be a suitable indicator of pesticide use intensity.

Definition

The treatment index represents the number of pesticide treatments in an area considering reduced dosages and treatments in partial areas. Each pesticide in tank mixtures is calculated separately.

Sample calculations:

- One treatment with the authorised dosage in the total area: 1.0,
- One treatment with the half dosage in the total area: 0.5,
- One treatment with the half dosage in half the total area: 0.25.

Examples for use of treatment index were presented in Section 14.3.5.2 (Table 14.1).

14.6.1.2 Environmental Risk Indicators

Environmental risk indicators are useful for demonstrating potential ecological effects of plant protection strategies or for evaluating possible advantages of IPM. In Europe, experts from different countries co-operate to find suitable approaches to estimate the ecological risk of practical pesticide use on a regional, farm and field scale (Reus et al. 2002). Most of the experts are organised within HAIR (*HA*rmonised environmental *I*ndicators for pesticide *R*isk, 2004–2007), a project of the European Union. HAIR will deliver a set of indicators to assess pesticide impacts on agro-ecosystems and human health. As such, the project will:

- Establish a consistent database structure for parameters affecting pesticide risk (e.g. land use, toxicological properties, soil type, climate, etc.),
- Provide a standardised set of indicators for predicting pesticide risk in the expanded European Union,
- Validate indicators of risk using existing datasets,
- Utilise GIS-based information to provide outputs on different regional and European scales and
- Deliver an integrated and user-friendly software tool for predicting overall pesticide risk.

Outputs of risk model calculations are relative values, not data describing an absolute risk.

Other risk indicators were used for consumer risk calculations, e.g. the number (rate) of samples with residues and the number (rate) of cases exceeding maximal residue levels.

14.6.2 The IOBC Toolbox

In 2001, the Commission established an “IOBC-Toolbox” designed to assist IP organisations establish their own IP concepts and programs (www.iobc.ch). These tools include the IOBC database on the selectivity of pesticides, examples of the green and yellow lists of plant protection measures, the IOBC software program SESAME used for inspecting and analysing IP farms of IOBC-endorsed organisations, and an Ideabook on ecological infrastructures at the farm level (Boller et al. 2004b).

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Chapter 15
IPM Programs in Commonwealth of Independent States and Russia

Eugeny S. Sugonyaev

Abstract Main principles of ecological approach to pest and its enemy management both in annual and perennial agro-ecosystem are discussed. The author's approach to cotton protection is orientated towards an elaboration of pest and its natural enemy management strategy. It is based on the usage of environment friendly means for cotton pest management, conservation and augmentation of natural enemy populations in a cotton agro-ecosystem. Correlation between arthropod species diversity, numbers of generalist predators, resistance of plant, and cotton pest population fluctuations laid the foundation of two main parameters for decision making: (a) the minimal zoophage efficiency level, and (b) the dynamic threshold of main pest species, particularly bollworm. The full or partial replacement of broad-spectrum chemical pesticides by bacteria compound and other environment friendly means is a basic demand of the elaborated cotton pest and its enemy programs in Turkmenistan and Tadjikistan. The significant achievements of its implementation in both the countries during 1970s–1980s demonstrate an effectiveness and benefits of an ecological approach to cotton protection.

At present in the southern Russia the typical feature of conventional programs of insecticide treatment in apple orchards is an arbitrary combination of chemical compounds of different characteristics in ecological sense, i.e. use of environment hazardous chemicals after environment friendly one and vice versa. Such alternation of insecticides of opposite vector will never stabilize an apple orchard agro-ecosystem. In the experimental apple pest and its natural enemy program the alternation of only environment friendly compounds have been used, namely, bioinsecticides: Lepidocide$^{\text{TM}}$, Phytoverm$^{\text{TM}}$, and bioregulators: Insegar, Match, Dimmilin which all work in the same direction – stabilization of an orchard agro-ecosystem, i.e. they have equal vector. Under a trial of the suggested program apple fruit damaged by codling moth has been 1.2% in the harvest (ET is 5% of damaged fruit).Thus the possibility of codling moth management without the use of broad-spectrum chemical pesticides in practically possible.

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15.1 Introduction

In 1970s–1980s of the last century in the Union of Soviet Socialist Republics (USSR) a classical biological control occupied a considerable sector in plant protection system in the country covering an area of 20–25 million hectares annually. The bio-plants network has provided cooperative farms and other agricultural enterprises with living natural enemies (*Trichogramma* spp. mainly) and bacteria compounds in very large quantities.

However, integrated pest management (IPM) program based on mass rearing and release of natural enemies and microbiological insecticide application only has been used in some large–scale greenhouses. As an exception, in the same period of time, the significant progress in development of cotton pest management program was achieved in some Central Asian republics – the process in which the author was involved for a long time. I suppose my own experiences will be useful for the further interpretation of attained results.

Data obtained in an apple orchard in North-West Caucasus recently will be interesting for an understanding of pest and its natural enemy management problems under the condition of perennial agro-ecosystem.

15.2 Part I: Cotton pest and Its Natural Enemy Management

Evolution of integrated pest management concept and its derivative ecological versions (Tshernyshev 2001; Sugonyaev and Monastyrskii 1997, and suggested in this chapter) is closely aligned with cotton insect pest problems and the widespread use of pesticides on the crop. Cotton is a real model for development of ecological approach to a solution of crop pest and its natural enemy management tasks in annual crops.

The Cotton Belt in the Commonwealth Independent States (CIS) occupies an arid territory stretching along the border of Iran in Transcaucasica in the west and Afghanistan in Central Asia in the east.Climatic condition for a cotton growing determines both the production system and the spectrum of arthropod pests. Spring frosts often destroy cotton seedlings, necessitating resowing. Late-sown cotton fields (in half of May) are common in many areas. In general, the growing season begins in early April and ends in late August. Severe winters and short season influence the range of insect pests. Some subtropical specialized cotton pests [*Pectinophora gossypiella, Earias insulana* (Lepidoptera), etc] are absent while generalists are common. The dominant and regular pests are: sucking species – *Tetranichus telarius* (Tetranichidae), *Thrips tabaci* (Thripidae), *Bemisia tabaci* (Aleyrodidae), *Aphis craccivora, A. gossypii, Acyrthosiphon gossypii* (Aphididae), *Lygus gemellatus*

(Miridae), gnawing species – *Agrotis segetum, Spodoptera exigua, Helicoverpa armigera* (Noctuidae). The last species is a key pest, which causes highest losses. The dynamic of population density of cotton bollworm is characteristic of two peaks: the first one is in the middle – late June (the 1st generation), the second is in the middle of July and the beginning of August (the 2nd generation). The 3rd generation takes place in August – September. Moreover, it is known that caterpillars of the 2nd generation are most injurious (see below) while caterpillars of the 3rd generation do not cause any injury. The numbers of cotton aphids complex and spider mite are most in the beginning – middle of July and in August – September while other sucking species (tarnished plant bugs, cicadellids) reach the maximum in middle of August and in the beginning of September, i.e. in the end of the growing season.

15.2.1 The History of the Cotton Pest and Its Enemy Management Conception Development

From the 1950s to the 1980s cotton pest management in the USSR passed through a series of phases (Sugonyaev 1977; 1994). During late 1950s and 1960s chemical control was a single method of the crop protection. A combination of artificially low economic threshold (ET) of cotton bollworm – 2 to 3 caterpillars per 100 cotton plants–provoked frequent, universal, broad-spectrum insecticide treatments, gradual selection of resistant strains of the bollworm and other cotton pests, and suppression of natural enemies activity. This created a system of increasing dependence on pesticides that resulted in up to 10–12 applications per season (Sugonyaev 1977; Kovalenkov and Aleshev 1977). As a result, the pesticide load per hectare in cotton-growing areas was 10 times higher (about 30 kg/ha) than the mean index throughout the country (Sugonyaev, 1994). But the heavy usage of pesticides did not prevent harvest losses caused by pests (Narzikulov and Kovalenkov, 1977). General harvest losses were estimated at about 30%. In addition, pesticide pollution seriously threatened the environment and health of the people.

An unfavourable situation in cotton production prompted Agricultural Ministry of USSR to find causes of such development of events. In 1966 on the initiative of Mr. L.S. Drozdov, Head Department of Outward Plant Quarantine, Dr. M. V. Stolyarov, entomologist of All-Union Institute of Plant Protection, Leningrad, and the author investigated the situation in cotton production in Afghanistan. The objective was to find an answer to the question – why cotton bollworm does not damage cotton seriously at the left bank of Amu-Dariya River, in Afghanistan, as it does at the right bank, in the USSR?

The study of the cotton arthropod community in North Afghanistan (The National Agriculture Station in Baglan-city, Baglan Province) in 1966–1968, where no treatments with pesticides were done, revealed a great share of insect zoophagous species in the cotton field (Sugonyaev et al., 1968, 1971; Sugonyaev, 1969, 1979; Stolyarov et al. 1974a). From approximately 120 dominant and common regular arthropod species inhabiting in cotton field in North Afghanistan, 20% of species fall into plant–feeding category (including 2% of injurious species), 49.1% of species are predators and parasites, and 30.9% of species are so called «indifferent» ones. Species of natural enemies form a specific complex characteristic for the given agro-ecosystem during the whole season. Field surveys showed that initial situation information of the cotton arthropod community in a given field during a definite period of time determines a pattern of species population fluctuation. Total abundance of arthropods is higher in the early-sown cotton field (middle April) (left part of dotted curve in Fig. 15.1) than the same in the field with a late sowing time (middle May) (left part of unbroken curve). As a result, the total number of species (mostly cotton aphid, *Aphis gossypii*) in the late-sown field was 12 times higher than the same in the early-sown one i.e. the former may be characterized as an unsteady field while the latter is a steady one (Fig. 15.1). More detailed analysis has revealed the higher population density of potential aphidophagous species in the early-sown cotton fields with their mild microclimate towards middle half of June (Fig. 15.2A) after their migration from the withering wild landscape. The opposite picture is observed in the late-sown cotton field (Fig. 15.2B). The ratio of natural enemies to that of aphids in an initial period of growing season in fields of both types determines the aphid population fluctuations and absence or presence of injury (Fig. 15.2A, B, the aphid numbers in relation of ET).

Similar course of events was observed regarding the population fluctuations of the spider mite (*Tetranicus telarius*) and the big cotton aphid (*Acyrthosiphon gossypii*). Eventually the important role of aphidophages and general predator's

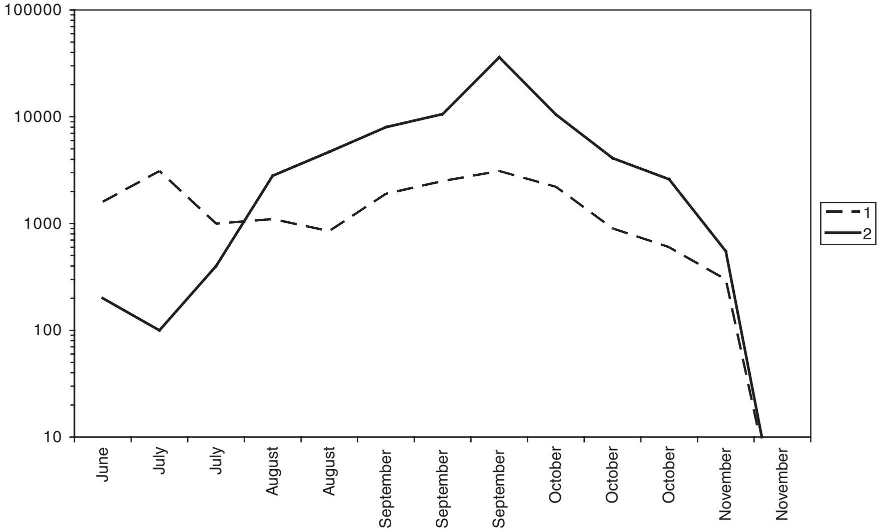

Fig. 15.1 The dynamics of total numbers of harmful and beneficial insects both in early (1) and late sown (2) cotton fields (see in text also). On ordinate axis – numbers, logarithm scale; on abscissa axis – date

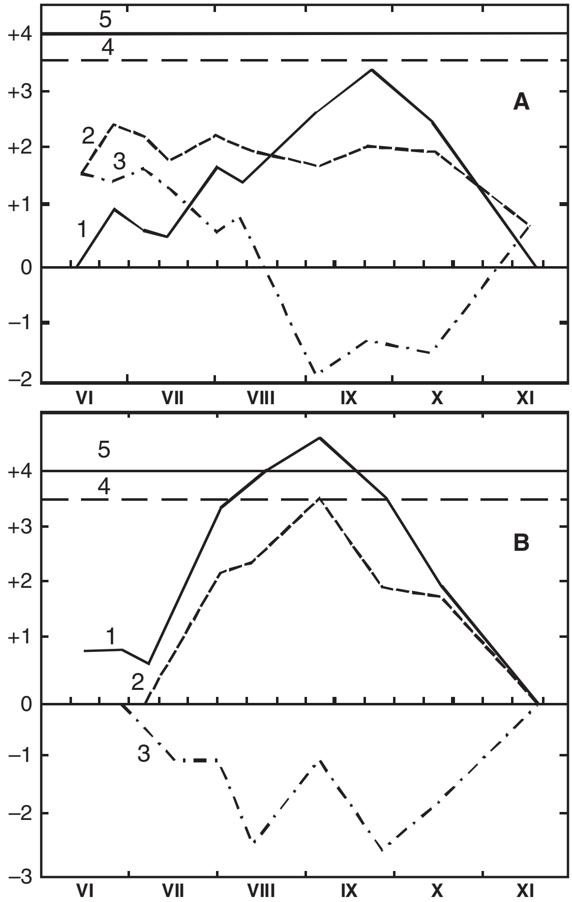

Fig. 15.2 The dynamics of cotton aphid (*Aphis gossipii*) (1) and its natural enemy (2) population density both in the early (**A**) and late-sown (**B**) cotton fields, 3 – the ratio aphidophages: aphids, 4, 5 – the threatening and operative levels of the ET, respectively. On ordinate axis – logarithm of population density and ratio aphidophages: aphids; on abscissa axis – date

activity for aphid population regulation were proved by the field check experiment when natural enemies in half of the plot were eliminated with DDT treatment (Stolyarov et al. 1974b). Cotton bollworm, during of whole period of investigation in North Afghanistan did not attain the status of potential pest (Table 15.1) as a result of natural enemies pressure (Stolyarov et al. 1974b).

Thus, in North Afghanistan population density fluctuations in cotton ecosystem was associated with arthropod species that were determined by factors of natural control, particularly by general predators activity, where pesticides were not applied for cotton protection on a large scale. In general terms, a constant relation of certain natural enemies with a biotope, their polyphagy and considerable numerical

Table 15.1 The damage potential of cotton bollworm in the Baglan area, Afghanistan (1966–1968)

Year	Plants examined	Quantity of generative organs	Damaged by cotton bollworm caterpillars		Number of caterpillars
			Number	%	
1966	2000	26650	72	0.27	13
1967	1300	13030	62	0.52	24
1968	1350	14300	31	0.21	8

abundance determine their important function as «a biological barrier» preventing pest species reproduction (Sugonyaev, 1969).

The data obtained in North Afghanistan showed that an activity of natural enemy populations is an important natural resource which must be conserved for future cotton pest management program. This stimulated a formation of my concept of pest and its enemy management. Pests and its natural enemies are the links of a single food chain in a given agro-ecosystem, and there is a necessity of their maintenance in a definite quantitative frame acceptable from the economic point of view. Thus, definite ground for an agro-ecosystem stabilization is created.

At present, conventional IPM programs are successive series of operations based on an economic threshold (ET) of a given key pest and do not take into account natural enemies activity. As fast as a pest population density reaches ET one perceives this event as a signal for the treatment of a given crop with pesticide, i.e. ET works as a trigger. However, such approach to plant protection contradicts the ecological principles of the early IPM conception orientated on an use of natural enemy activity as an important component of IPM (Bartlett, 1956; Huffaker and Messenger, 1964; Stehr, 1975; DeBach and Rosen, 1991). That is why emphasis on including in the definition the concept of the word «enemy» – pest and its enemy management (PEM).

But in 1968, High Board of Agriculture Ministry of USSR, the official plant protection circles did not accept my concept of cotton pest and its enemy management on ecosystem basis. Their rejection was motivated by the premise: that a plant protection innovation has been developed under the condition of private small farms, thus not suitable for «an industrial socialistic agriculture» (Sugonyaev, 1977). Nevertheless in Zoological Institute of the USSR Academy of Sciences where an intellectual independence and fundamental knowledge development takes place, our data from Afghanistan and my conception found comprehension and further development.

The prerequisites of our ecological approach to a development of cotton pest and its enemy management are: (a) the known data on great extent of natural enemies activity that occurs naturally in agro-ecosystem; (b) the circumstance that 98–99% of all potential pests are already under a natural enemies pressure; (c) some so called «dangerous pests» are a result of destruction of their natural enemies by use of pesticides; (d) the optimization of established natural enemies in a given agro-ecosystem through conservation and augmentation practices which are most real means of decreasing insecticidal treatments, environment pollution and reducing pest control costs.

The data and information obtained in other areas of Turkmenistan are typical of all areas of the cotton belt of CIS. It is important that data on the great intensive cotton fields in the Murgab Oasis demonstrated a universality of ecological regularities which were revealed by us for the first time in Afghanistan on small farmer fields. Several years of observation on the cooperative farm «Teze durmush» (about 2000 hectares) showed that when chemical pesticide treatments were reduced by 80% in 1972 and then stopped altogether in 1973, the index of species diversity ***d*** and mean population density of general predators per single cotton plant increased noticeably. On the whole, an increase in both the species diversity of the arthropod community in general (***d*** ranged from 220 in 1971 to 270 in 1975) and number of predator complex (densities per single plant ranged from 0.9 in 1971 to 3.6 in 1976) was relatively stable and changed slowly over several observation years (Sugonyaev et al., 1977; Alexeev and Niyazov, 1977).

However, under the condition of Baglan Province in North Afghanistan and in the Murgab Oasis the species diversity can change dramatically during the growing season as a result of arthropod species movement both from neighbourhood localities and surrounding fields, particularly from alfalfa fields. Observations in early-sown fields (middle of April) and late-sown ones (middle of May) showed differences in the cotton arthropod community. The temperature and humidity in rows under cotton canopy in the experimental fields explain this phenomenon as a result of the different power of both field types in their attractiveness for a settling with insect species, particularly predators. In the early-sown field a fast growth of cotton creates an optimal microclimate and results in abundant plant exudates secreted by cotton leaves, which attracts adult predators, for example, lacewings (*Chrysopa carnea*) and coccinellid beetles. As a consequences of which, the cotton arthropod community in the early-sown field develops rapidly during late May, resulting in diversity peak in late June (Fig. 15.3(1)). During the same period in the late–sown fields, because of the weak growth of cotton and an unfavourable microclimate, development of the arthropod community takes place very slowly and is ultimately less diverse (Fig. 15.3(2)). Thus, the characters of crop establishment and the abundance of natural enemies in the agro-ecosystem determine a steady or unsteady states of field, which was confirmed by direct surveys (Sugonyaev and Kamalov, 1976).

Significant correlation between diversity index values, a number of generalist predators, and population fluctuation of cotton pests indicate that the diversity index may be used to predict general trends in change of species numbers in a given field. These diversity–index data have been the basis for calculations of the minimal *zoophage efficiency level* (ZEL) required to give acceptable control of pest populations. Narzikulov and Umarov (1977) studied cotton agro-ecosystem in Tadjikistan and concluded that the density of 250–300 natural enemies per 100 cotton plants is enough in order to suppress all pest populations in a given field. They named this density «the entomophage effeciency level». Similar observations were made by Sugonyaev et al., (1977) in Turkmenistan. The generalist predators, zoophages

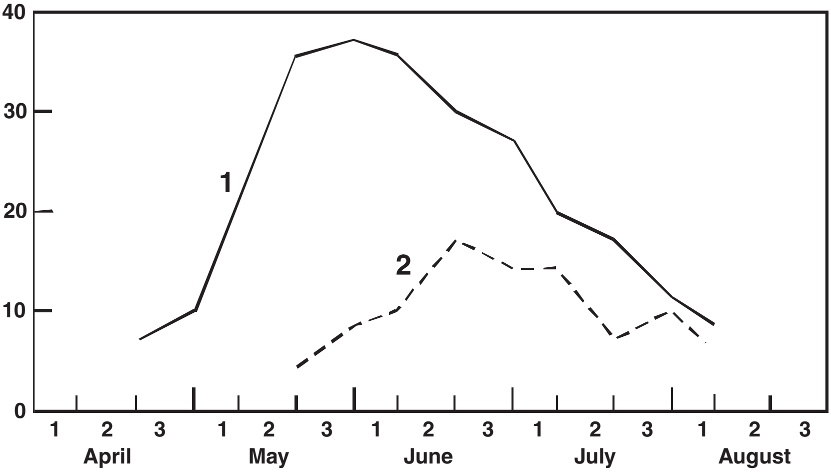

Fig. 15.3 The change in the specific diversity index ***d*** on cotton fields sown in the half of April (1) (every point on the *solid curve* represents a mean index value over 5 years) and those sown during late May (2) (every point on the *broken curve* represents a mean index value over 2 years). $\boldsymbol{d} = \frac{S-1}{\lg N}$, where S – the total quantity of insect species, N – the total quantity of specimens. On ordinate axis – significance of the index ***d***; on abscissa axis – date

attack both insect and mite pests. The ZEL has been found empirically during long-term observation of population fluctuations of both beneficial and harmful arthropod species in cotton fields in different areas of Turkmenistan and determined as the average density of 3 ± 0.5 indicative zoophagous species per 1 cotton plant for management of pest complex in cotton (Sugonyaev, et al., 1977; Sugonyaev, 1994).

In practice, quality of indicative species of zoophages, the most common and easily recognized in the field, are general predators and parasites and these includes predaceous bugs *Nabis palifer* (Nabidae), *Deraeocoris punctulatus, Campylomma* spp. (Miridae), *Orius* spp. (Anthocoridae), ledy beetles *Adonia variegata, Synharmonia conglobata, Stethorus punctillum* (Coccinellidae), lacewings *Chrysopa carnea* (Chrysopidae), predaceous thrips *Aeolothrips intermedius* (Aeolothripidae), *Scolothrips acariphagus* (Thripidae), parasitic wasp *Habrobracon hebetor* (paralysed cotton bollworm caterpillans of 2nd–3rd instars) (Braconidae), wasp *Polistes gallicus* (Vespidae). The population dynamics of predatory species during growing season plays a significant role. The most diverse predatory bug complex (*Orius* spp., *Campylomma* spp., *Deraeocoris punctulatus*) reaches the highest level in the first half of July and remains in stable state before the beginning of September. The numbers of lacewings (larvae) are not high but it is distinguished with stability during June – August period. Lady beetles reach the peak of their numbers in the first half of June and after that stay in a low and stable numbers for rest of the season. On the whole, predator populations density runs to ZEL commonly in middle – last 10 days of July (2.8 specimens per 1 cotton plant), and fluctuates at this level upto the end of August when it reaches the highest value (3.6) (Sugonyaev et al., 1977).

A precise calculation of natural enemies density during twenty four hours indicate that at 9 o'clock the number of predatory bugs *Orius* spp., *Campylloma* spp., *Deraecoris punctulatus* and lady beetls *Adonia variegata* and other species increases in cotton plant canopy, noticeably, and increases or remains at the same level at 12 o'clock. At 15 o'clock the number of most predatory species decreases, but at 18 o'clock it increases again. The exception is the predatory bug, *Nabis palifer* which reaches its quantitative maximum in cotton canopy at 3 o'clock and minimum at 15 o'clock (Tshernyshev et al., 1992). The correct coefficient suggested by Tshernyshev et al. (1992) allows getting more exact information on the predator density at definite times during the twenty four hours (Table 15.2) that has importance for the determination of real ZEL and corresponding decision making.

The effect of the above mentioned indicative zoophagous species on cutworm (*Agrotis segetum*) is insignificant in contrast with cotton bollworm. But the former is infested with the complex of specific parasitic wasps mainly *Apanteles telengai, Rogas dimidiatus* (Braconidae), etc, which parasitized caterpillars at the beginning of summer on a lower scale (on average 8.6%) which is not enough (Eremenko and Ulyanova, 1977; Jumanov, 1977).

The economic threshold (ET) of pest species is the second important parameter in monitoring and decision making process. Fixed ET for any pest species is unreal value. During the plant growth the capacity of plant for compensation of pest damage changes considerably. So, during development of caterpillars of 1st cotton bollworm generation (June – the first 10 days of July) a natural fall of cotton flowers and buds in early (optimal) sown field is about 50–60%, but during of 2nd one (July-August) – 10–15% only (Boldyrev and Kovalenkov, 1977; Sugonyaev unpublished data). That is why the injury of bollworm caterpillars of 1st generation is minimal. Contrary to that the injury caused with cotton bollworm caterpillars of 2nd generation cause maximum losses because the grade of compensation of damaged bolls is low. Clearly a predetermined static ET is not suitable for our case while a dynamic one is a necessity. In accordance with the known data the dynamic ET for bollworm are:

(a) 1st generation – 25 caterpillars or 40 injured fruit per 100 plants for medium staple varieties, and 12 caterpillars or 20 injured fruit for long staple varieties; (b) 2nd generation – 10 caterpillars per 100 plants for medium staple varieties, and 5

Table 15.2 Coefficient for a calculation of real predator population density per 1 cotton plant (in relation of its density at 9 o'clock taken as an unit)

Predaceous species	Time of survey (o'clock)							
	21	24	3	6	9	12	15	18
Deraeocoris unctulatus	1.5	1.3	1.2	1.2	1	1.1	1.8	1.3
Adonia variegate	1.2	1.4	1.2	1.2	1	1.2	1.3	1.5
Coccinella 11-*punctata*	1.2	1.5	1.1	1.1	1	1.4	1	1.7
Propylaea 14-*punctata*	1.7	1.9	1.1	1.1	1	1.7	1.5	1.9
Chrysopa carnea (larvae)	1.6	1.1	2.3	2.3	1	1.7	1.4	2.3

caterpillars per 100 plants for long staple varieties (Tansky, 1969, 1988; Sugonyaev, 1994).

The ET of cutworm (*Agrotis segetum*) changes and dependes on broad-leaf weed density per 1 m^2 or a lack of them in cotton field: (a) no broad-leaf weeds present – 1 caterpillar per 1 m^2; (b) broad-leaf weeds present – 3 caterpillars per 1 m^2. There are two points explaining of this ET variance: first, presence of broad-leaf weeds which distract caterpillars from cotton sprouts, and they concentrate and feed under them; second, in case broadleaf weeds are absent caterpillars attack cotton sprouts. There are economic thresholds for other the major cotton pests but they are static and tentative (Sugonyaev, 1994).

15.3 Accomplishment of Survey, Monitoring and Decision Making

A field survey is the operative ground of PEM program, observations of seasonal changes in species composition and population density of phytophagous and zoophagous species in a given cotton field are made once every week or 10 days. The general sampling scheme includes: a) visual examination of 50 ($p < 0.05$) or 100 ($p < 0.01$) cotton plants, recording the indicative zoophagous species, main cotton pests, and from the beginning of June – caterpillars of cotton bollworm and injured fruit at four points around the field margin (5–25 m from the edge), and sampling of 25 plants (five groups with five plants in the row) at each point; b) the use of pheromone traps attractive for cotton bollworm male moths (1 trap per 2 ha) with the ET an average 3 specimens per 1 trap during a week.

Routinely, only 50 cotton plants are surveyed and simultaneously pheromone traps are checked. In the course of time the cotton bollworm only maintains its status of a pest while other phytophagous species no longer remain pests of any consequences. For example, in Turkmenistan outbreaks of cotton bollworm still occur in favorable years even if predator numbers reach ZEL. However, on average such outbreaks occur once every three years. During two years from three year cycle, cotton bollworm population is controlled by natural enemies, and it is very important to determine when the pest population indicates a tendency to increase.

Late-sown cotton fields attributes to the unsteady type and is more subject to outbreaks of cotton bollworm, cotton aphids and spider mite. More careful survey is desirable, i.e. examination of 100 cotton plants once every week. At farm level, the demonstration of advantages of cotton pest and its enemy management program in the field is essential i.e. in farmer's school, for further extension of the innovated technology of the crop protection. Training of scout personnel from the members of given cooperative or state farms has a decisive and significant role for implementation and adoption of the cotton pest and its enemy management methods. In a given farm trained scouts (who are provided with motorcycles) inspect about 20 ha daily or ∼200 ha during every one 10 days' cycle. The field (or plot) where the population of cotton bollworm, for instance, reaches ET marks, the scout puts up a small flag. The scouts pass all information to the supervisor who decides whether control measures are needed. Thus, all data on the cotton field type and population of both pest and zoophage populations are available, and one needs to take it into consideration for decision making. Undoubtedly, a decision making process is most important for implementation of the cotton pest and its enemy program, and it requires to pay attention to some additional question.

The principle of the cotton pest and its enemy management program is the that any broad-spectrum chemical pesticide treatment in a given agro-ecosystem will result in ecological catastrophe by destroying natural enemies activity. Moreover, it provides some positive trends in natural enemies establishment. Balance between ecological and economic expediency is a starting point, and ET must not work as a trigger. In fact every dynamic ET has its economic value which is variable and estimated to cause 5 and 7% yield loss which is acceptable (Tansky, 1988; Sugonyaev and Monastyrskii, 1997). A yield loss compensated should justify the costs, which either does not repay the expenses of protection measure or gives insignificant returns with respect of probable ecological preferences, for example, preservation of natural enemies population density. In other words 5% yield loss is admissible, which is the pay off costs for ecological stability of a cotton agro-ecosystem. If an economic threshold consists of two levels – threatening and operative ones (see below) then the cost of the former is 5% yield loss and of the latter 7%.

This conclusion laid the foundation of the monitoring system for observation of both beneficial and injurious species density on cotton fields with different sowing times. Instead of the conventional monitoring system oriented on a fixed number of cotton bollworm caterpillars per 100 cotton plants for decision making, this innovative system emphasizes the priority of ZEL in a decision making process.

It is obvious that concept of pest and its enemy management (PEM) regard all natural enemy activity in a given agro-ecosystem as a basic and essential component of decision making process. Either we should take into consideration natural enemies activities as a natural part of pest control, or we reject their regulative role as unimportant from practical point of view, and rely on use of broad-spectrum chemical pesticide applications. "Ecologization" and similar unscientific attempts to unite into single IPM program, a natural enemy activity with strong broad-spectrum chemical pesticide application, i.e. use of opposite vectors, when the latter destroys achievement of the former, will never create an ecological stabilization of a given agro-ecosystem.

Thus, there is an urgency to develop IPM program with alternation of environment friendly compounds/measures working in the same direction, i.e. means of equal vector and there is considerable probability to develop an effective PEM program (Sugonyaev, 1994; Sugonyaev and Monastyrskii, 1987) instead of recent interpretation of IPM concept which is based on the use of ET as a trigger for pesticide application. So, a rational decision is based on experienced estimation. If the ZEL is equal 1.0–1.5 indicative species of zoophages per 1 plant then the ET for cotton bollworm, cotton aphids and spider mite remains unchanged. However, if the ZEL is equal to 3 ± 0.5 then the ET for cotton bollworm increases by 50%, e.g. 15 caterpillars per 1 plant on medium staple varieties for the 2nd generation. Thus, two levels of the ET are defined, namely the lower, or *threatening* one (10 caterpillars) and upper, or *operative* one (15 caterpillars). In case of pheromone trap the operative level is 6 adults per trap during a week. Observation of a threatening level calls for a repeat of the inspection of the field after 3–4 days in order to make a definite decision. In the same situation for cotton aphids and spider mite, their ET are increased by 25%. This method of applying variable thresholds related to predator density, i.e. ZEL allows rapid implementation of cotton pest and its enemy management principles among farmers. There are two alternatives: first, if the density of zoophages reaches ZEL or greater than that, and the densities of cotton bollworm and other main pests are lower than ET or nearby it in a given field, then some interventions in natural process must be rejected. Second, if the density of zoophages reaches ZEL, and at the same time the density of cotton bollworm is equal or higher than operative level of ET (15 caterpillars) in a given field a need for immediate pest managing action arises. As the conservation of zoophagous species is one of the primary aims of the pest and its enemy management concept, a choice of some environment friendly measures is a very important part of decision making.

15.3.1 Biological Control Component

Biological control that occurs naturally in cotton agro-ecosystem would be regarded as the backbone of the cotton pest and its enemy management program. An augmentation of established natural enemies in a given field and its role in pest population regulation is a paramount task. Application of bacteria compounds based on *Bacillus thuringiensis*(Bt), or bioinsecticide (BI) is a more perspective way of cotton bollworm suppression without negative impact on both natural enemy populations and diversity of the arthropod community.

The experiments with Bitoxibacillin™ (BTB-202) (1%) and Entobacterin™ (2%) indicated: the biological effectiveness of BTB-202(68.2% against mortality on the second day after application of BI, and 79.5% on the whole). Similar result was obtained with Entobacterin™ (62.1 – and 90.0%, respectively) (Davlyatow, 1977). In other experiments the applications of BTB-202 and Lepidocid™ caused larval mortality of 86 and 88 per cent, respectively after 10 days (Niyazov, 1992). All BI do not kill natural enemies (Davlyatow, 1977; Sukhoruchenko et al., 1976), and they are good tools for cotton pest and its enemy management. From formal toxicological point of view, the above mentioned biological effectiveness of BI is rather low but is satisfactory tool for change of number between prey and predator, in favour of the latter. Thus, an impact of predator activity on a prey population increases significantly without the release of some quantity of predators reared in laboratories. Thus, biological control component of the cotton pest and its enemy management program is a harmonious combination of microbiological and biological agents, thus increasing their effectiveness reciprocally in suppression of pest population.

Augmentation of natural enemies by means of release of parasitic wasps *Trichogramma* spp. and/or *Habrobracon hebetor* for suppression of cotton bollworm eggs and caterpillars, respectively, in Tadjikistan showed unstable effectiveness. As a consequence of *Trichogramma* release at the rate 200000 numbers per 1 ha the quantity of infested cotton bollworm eggs varied from 0.0 to 12.9% on the fourth day after release. The infestation of cotton bollworm caterpillars with *H. hebetor* was 5.3–29.5% (at the rate 200 numbers per 1 ha) (Tashpulatov, 2007). But the same parasitic wasps used at high rates: 600000 specimens per ha for *Trichogramma* sp. and 3000 specimens per ha for *H. hebetor* infested their hosts by 30 and 56%, respectively (Kovalenkov and Aleshev, 1977; Hamraev and Abdel-Kavi, 1977).

15.3.2 Chemical Component

Conventional pesticides are an effective tool for pest population suppression in Tadjikistan but its use is limited in Turkmenistan. The desired characteristics of pesticide based pest management are: (a) selective action on target species, (b) relative harmlessness for natural enemies, and (c) narrow spectrum of action. As a rule, the need for chemical pesticide arises under the condition of late-sown cotton field, an agro-ecosystem of which is more “crumbly”, and it is mainly predisposed for sucking pests outbreaks. Selective acaricids, such as chlorfensulfide, dinobuton, dicofol, bromopropylate, halektron, propargite, tedion, and cyhexatrin, are toxic to spider mite (LD_{50} is 0.0006–0.001%) but have minimal impact on natural enemies (Sukhoruchenko et al., 1976; Niyazov, 1992; Sugonyaev, 1994). On the basis of experimental results, phosalone has been chosen for suppression of sucking pest on cotton because its impact on natural enemies is minimal (Table 15.3) (Sukhoruchenko et al., 1976).

Insecticide like carbaryl (carbamate) showed that this compound changes the relation between phytophages and entomophages -: 2.8/1 – before treatment; 16.1/1 – 5 days after treatment, and 237.0/1 – 20 days after treatment, respectively (Sukhoruchenko et al. 1976). A negative influence of this kind of insecticide on the initial ecological situation in the cotton field, i.e. the violation of natural equilibrium between phytophagous and zoophagous species, compelled to recommend bacteria compounds, instead of chemical ones, for example, BTB-202 and Lepidocid^{TM}, which cause bollworm caterpillars mortality about 70–80% (in comparation with carbaryl which has similar effect – 82.2%) without suppression of natural enemies activity in a given agro-ecosystem. It is important to note, the high summer temperature (more 33 °C) may decrease of biological effectiveness of BI that is why these compounds are more effectively applied during the evening hour (Niyazov, 1992). Unavailability of biological means of control is the main reason for chemical pesticide application. In any case, aerial application of chemical pesticide, and so called “prophylactic” application of these must be rejected. Local use of insecticide in a damaged plot or spot application of plot is obligatory.

15.3.3 Agronomic Component Including Environment Manipulation

Several agronomic factors stimulate the rapid growth and closing of the cotton plant canopy, which is needed to produce rapid development of beneficial community

Table 15.3 An impact of phosalone on the number of spider mite, cotton aphids and their natural enemies

Time of survey (Days after treatment)	Population per infested plant and P/PD*											
	Phosalone			Control			Phosalone			Control		
	Spidermite	Acariphage	P/PD	Spidermite	Acariphage	P/PD	Cotton aphids	Aphidophage	P/PD	Cotton aphids	Aphidophage	P/PD
0	116.8	1.86	62.7/1	191.1	1.6	119.4/1	9.0	1.6	5.7/1	4.4	1.8	2.4
9	1.1	2.4	0.4/1	13.0	3.6	3.7/1	2.1	1.5	1.5/1	4.7	5.2	0.9/1
20	6.5	2.5	2.6/1	108.8	3.1	35.1/1	7.9	1.8	4.5/2	12.2	2.3	5.4/1
30	1.2	2.1	0.6/1	177.0	3.7	47.8/1	32.4	3.14	10.3/1	34.4	4.2	8.2/1

* P/PD – prey/predator.

and general stabilization of the agro-ecosystem. These factors include: (a) use of stimulants as seed treatment to accelerate growth of seedlings, (b) optimal sowing season (∼middle of April), (c) sowing on narrow rows (60 cm between rows), (d) sowing on ridges, and (e) precise irrigation scheduling.

The differences in canopy closure between optimal and late plantings can influence the relative humidity and temperature on the soil surface and in the canopy. These differences can influence the development of the beneficial community, which generally prefers a milder microclimate. The unattractive late-sown field microclimate discourages immigration of natural enemies and thereby increases late pest problems.

The frequent alternation of cotton and alfalfa fields in a rotation is desirable because of the similarity between entomophage communities in the two crops (Jaccard's index of similarity: 41.3%) during the first and second years after alfalfa sowing particularly (Niyazov, 1992).

A weed management in cotton field during seedling growth period is a way for decreasing cutworm injury because the destruction of broad leaf weeds provokes passage of caterpillars from weeds to cotton plants. Hence, desirable time for cultivation is conditioned by beginning of cutworm pupation. Suppression of weeds outside the fields must be prudent because many zoophagous species are reproduced in wild grasses in spring and at the beginning of summer.

A fertilization scheduling and composition of fertilizer are important matter for increasing the cotton plant immunity particularly to sucking pest. Periodical use of a balanced NPK compound (without nitrogen surplus) during cotton planting is recommended.

Selection of cultivars resistant to pest is an important measure in increasing of general build up and it provides insurance to the crop against pest attack. As it was ascertained in Tadjikistan the long staple varieties: 9883-I, 6249-V are not attractive for population establishment of cotton bollworm and lygus bug (*Lygus pratensis*). The medium staple variety Mehrgon does not attract cotton bollworm and cotton whitefly (*Bemisia tabaci*) but is highly preferred by lygus bug (Tashpulatov, 2007).

15.4 Impact of Cotton Pest and its Enemy Management Programs

The achievement of cotton pest and its enemy programs development in Turkmenistan and Tadjikistan during the1970s–1980s demonstrates the benefits of an ecological approach to cotton protection. The number of chemical pesticide-treated cotton fields in Turkmenistan in general, and the Murgab Oasis in particular, have decreased: in Turkmenistan, from a high of 850000 treated ha in 1970 to a low of 900 treated ha in 1990, and in the Murgab Oasis, from a high of 120000 treated ha in 1980 to a low of 90 treated ha in 1990, i.e. 13 times and many fields were increasingly left untreated. This is due to natural control forces, natural enemies activity mainly work in these cotton fields. But it is not a return to subsistence (extensive) phase (Doutt and Smith, 1971) as in Afghanistan in the1960s (Sugonyaev, 1969). It is as a result of decision of two basic problems; (a) stopping of natural enemies destruction, (b) finding the methods of their conservation and increasing their regulative role. As a result, over the same period, the use of biological control agents (bacteria compounds mainly) on cotton has increased from 54.8% in 1986 to 85.3% in 1990. Considerable economic benefits took place also – the mean yield of raw cotton in the Murgab Oasis increased by 0.26 tons/ha from 1981 to 1990. In addition, introduction of cotton pest and its enemy management principles in the 1980s–1990s at most cotton plantations in Turkmenistan produced saving about $ 4–5 million annually from reduction in pesticide expenses alone (Sugonyaev, 1979, 1994; Niyazov, 1992; Sugonyaev and Niyazov, 2004).

The decreased threat of pesticide pollution is a major benefit of cotton pest and its enemy management programs that are based on an ecological approach and is a significant step in environment preservation. So, upto 1990 the mean load of pesticides was 0.2 kg/ha throughout Turkmenistan, and 0.1 kg/ha in the Murgab Oasis (Niyazov, 1992) which is considerably lower than amounts previously recorded for Central Asian republics on the whole (Narzikulov and Kovalenkov, 1977).

In Tadjikistan, where more conventional scheme of IPM permitting use of universal, broad-spectrum chemical pesticides has been implemented, the decreasing of the number pesticide-treated cotton fields has decreased 3.5 times from 1967 to 1976 (2000000 hectares in 1967 and 570000 hectares in 1976) (Kovalenkov and Aleshev, 1977). This trend was maintained from 1980 to 1989 (Vanyants, 1991). Economically, cotton IPM program has been very effective, and yield of raw cotton has increased by about 30%. Ultimately the return of expenditure on cotton protection has been 13–14 times higher in the IPM areas, and additional income has equaled $ 1100–1200/ha. Simultaneously, ecological effectiveness of cotton IPM has been significantly high because the mean load of pesticides per hectare has decreased 6.8 time (from 35.2 kg/ha to 5.2 kg/ha) over 20 years.

The characteristic feature of the cotton IPM program in Tadjikistan during 1970–1990 was the combination of *Trichogramma* spp. release, Dendrobacillin$^{\mathrm{TM}}$ and broad-spectrum pesticide applications, i.e. biological means and chemical compounds of opposite vectors that resulted in pest outbreaks locally. The cotton pest and enemy management program in Turkmenistan has been based on alternation of environment friendly compounds only working on conservation of natural enemy populations and stabilization of the agro-ecosystem, i.e. means of equal vector. As a result of the number of chemical pesticide-treated cotton fields has decreased more essentially here, and pest density has fluctuated lower ET during long-term time while a high profit of cotton production has been maintained.

General trends in cotton IPM development throughout the world shows that there are two main directions: (a) IPM program based on mathematical simulation model and computer-generated expert system oriented on a wide area; (b) pest and its enemy management (PEM) program based on an empirical data adapted for individual farmer's use.

(a) The main aim of the first, area-wise approach is the development of the model simulated on basic relationships in to the ditrophic system consisting of a plant and its consumer. The ditrophic system is manageable for assimilation of both information on pest population fluctuation in relation to ET and phases of plant growth data necessary for prediction and decision making. However, some attempts of modeling of multitudinous relationships in the tritrophic system consisted of plant, phytophage and its natural enemy on an agro-ecosystem level have been found inoperable. Probably, Thompson (1939) has been the first who showed that "there is no way of developing a method (mathematical, E.S.) that can reduce to manageable form the appalling complexity of natural factors".

The USA and Australia have been pioneers in developing of simulation model and computer-generated expert system for cotton and cotton insects (Luttrell et al., 1994). In 1979 in Albany, Department of Biological Control, University of California, the author had the opportunity to acquaint himself with the work of the operative computer – generated expert system based on the ditrophic system model, which was the great achievement in cotton protection at that time. The use of the ditrophic system model in relation of ET was responsible for the spreading of usage of ET as a trigger for pesticide treatment, commonly in order to prevent increasing pest population from reaching the economic injury level. As a result of this, IPM concept has turned gradually into well regulated program of chemical pesticide applications with all the typical features as the ecological narcotics (DeBach and Rosen, 1991). In spite of the significant progress in the philosophy of integrated pest management in the USA, chemical pesticide applications averaged about 6 in 1992, and in some localized areas, 15 or more applications. In Australia, cotton growers apply 10–12 applications of insecticides to cotton; some apply upwards of 16–18 applications (Luttrell et al., 1994). Similarity of situation with cotton protection in the USA and Australia show inadequacy of the usage of the ditrophic system model oriented on ET as a trigger operation instead of real cotton pest and its enemy management on an ecosystem basis. High number of pesticide treatments will never allow to create an ecological stabilization of a given agro-ecosystem, but are the precursor of unsteady ecological situation, and, in future there is every possibility of the crop failure (Bottrell and Adkisson, 1977; DeBach and Rosen, 1991). Ehler and Bottrell (2000) consider significant difficulties in IPM implementation in the USA as «predicting pest and natural enemy population trends is difficult because of "chaos" in agro-ecosystem». As the above-mentioned authors state, absolute predominance of chemical pesticides in IPM programs, and often, an ignorance of natural enemy populations' activity by many pest consultants are common for contemporary situation in plant protection in the USA (Ehler and Bottrell, 2000).

(b) The second approach in development of cotton protection is based on the FAO principle «a farmer as an expert in his own field», and oriented on elaboration of pest and its enemy management (PEM) program. Apparently, typical features of PEM are:

First- A maximal simplicity in any recommended management strategy (on condition that it is based on thorough fundamental research).

Second- The knowledge of cotton grower about the main harmful and useful arthropod species in cotton field.

Third-The use the zoophage efficiency level (ZEL) as a basic parameter of the systems approach to cotton insect management, and decision making process.

Fourth-The use of the dynamic economic threshold (DET) (different for different generations of target species, and type of cotton plant) for the key insect pests e.g. cotton bollworm.

Fifth-The use of environment friendly compounds only, e.g. bacteria, virus and selective pesticides.

Sixth- The adoption of agronomical measures for creation of an ecologically stable field, e.g. optimal sowing (early) time, right weed management, resistant variety, etc.

Possible criticism of the PEM concept approach can be leveled at the method of decision making process because it is subjective and imperfect. Ehler and Bottrell (2000) mentioned the problems with implementation of IPM in the USA as discussed above. The requirement for precise method results in some additional difficulties. "The monitoring schemes developed for pest and natural enemy populations may be too sophisticated and expensive to be a practical tool for the pest consultant," as highlighted by Ehler and Bottrell (2000). Meanwhile the empirical data of 20 years in different areas of Turkmenistan and Tadjikistan show the ZEL in relation to ET is the reliable method of monitoring and decision making that is the cause for significant decrease of cotton pest injury, and increasing of additional income. Ehler (2000) shared the ZEL concept actually when showed two predatory bugs per plant is enough for beet protection in Northern California.

Any approach to cotton pest and its enemy management must be developed under the different conditions of developed and developing countries and if they reply to one basic arrangement: work on an utilization of the great natural resource – natural enemy populations activity, and stabilization of the agro-ecosystem.

15.5 Part II: Apple Pest and its Enemy Management on an Ecosystem North-West Caucasus, Russia

At present broad-spectrum chemical pesticides cover about 95% of all apple orchards in the south of Russia, nevertheless harmfulness of apple pests, particularly the codling moth (*Cydia pomonella*), remains very high (Storchevaya, 2002). It is known that the great fauna of beneficial arthropod – about 1000 species of natural enemies including 100 ones attacking codling moth – is common for orchards in the south Europe (Zerova et al. 1992). However, this productive natural resource is destroyed recklessly with broad–spectrum pesticides. An urgent search of alternative strategies of orchard protection, an elaboration of apple pest and its enemy management program in orchards based on conservation of natural enemy populations and stabilization of the agro-ecosystem are our research priorities. The research is being conducted in cooperation with All Russian Institute of Biological

Control and Kuban Agriculture University in the Krasnodar area. Two pest species – the codling moth and the green apple aphid (*Aphis pomi*) are the subjects of our examination.

15.5.1 Codling Moth

There is a serious problem with suppression of this key pest which is a real barrier to the development of ecological approach in apple orchards protection in the south of Russia. The cause of failure is an arbitrary alternation of pesticides with different properties in the conventional IPM programs of orchard protection. The official published recommendations on apple orchard protection are: (a) for the Stavropol area (Central Caucasus) in 2003 were alternation of environment friendly (+), and broad–spectrum environment dangerous (−) compounds namely, Insegar (+) → Carhate (−) → Zollon (−) → Phuri (−) → Summiton (−) → Match (+) → Bileton (−); (b) for the Krasnodar area in 2007 – Insegar (+) → Calipso (+−) → Chlorpirhiphos (−) → Match (+) → Zollon (−) → BI58 (−). Typically, the ecological consequences of application of either are ignored. Meanwhile, the use of biological based compounds, e.g. natural hormone analogist (Insegar, Match, etc) and biopreparation (Lepidocid$^{\text{TM}}$, Biotoxibacillin$^{\text{TM}}$, etc), are not harmful for natural enemy populations and promote the agro-ecosystem stabilization. Contrary to this, broad–spectrum chemical pesticides destroy most of arthropods, and in the first turn, natural enemies, thus destabilizing the apple ecosystem.

The conventional pesticide treatment programs are commonly based on compounds of opposite trend, or vector (in ecological sense) when the broad spectrum pesticides negate the gains of biological compounds. From this point view, IPM programs based on alternation of both chemical pesticides and biological based compounds with opposite ecological effects will never create an ecological stabilization of a given agro-ecosystem, and, hence, there is a necessity to develop a program which is only based on environment friendly compounds, working in the same direction, i.e. preparations of equal vector. Thus, the question of the possibility of the use bio-compounds only as a mean of codling moth management came up for research. In 2007, two experimental programs with different alternations of compounds both in the commercial (𝒩o.1) and the experimental (𝒩o.2) farms have been tried.

In the first conventional apple pest management program the alternation of compounds with different properties, i.e. environment friendly (+) and environment dangerous (−) ones have been used in the succession: Insegar (+) → Cipi plus (−) → Dimmilin (+) → Phosban (−) → BI58 (−) → Diasol (−) → Cipi plus (−) in combination with Match (+) → Lepidocid$^{\text{TM}}$(+) – in all 8 treatments per season (Fig. 15.4). The average number of moth males trapped in pheromone traps exceeded ET in all cases. As a consequence the mean damage of apple fruit by codling moth in all orchards in farm 𝒩o.1 reaches 18% at the time of harvest (the ET is 5% of damaged fruit) (Fig. 15.4).

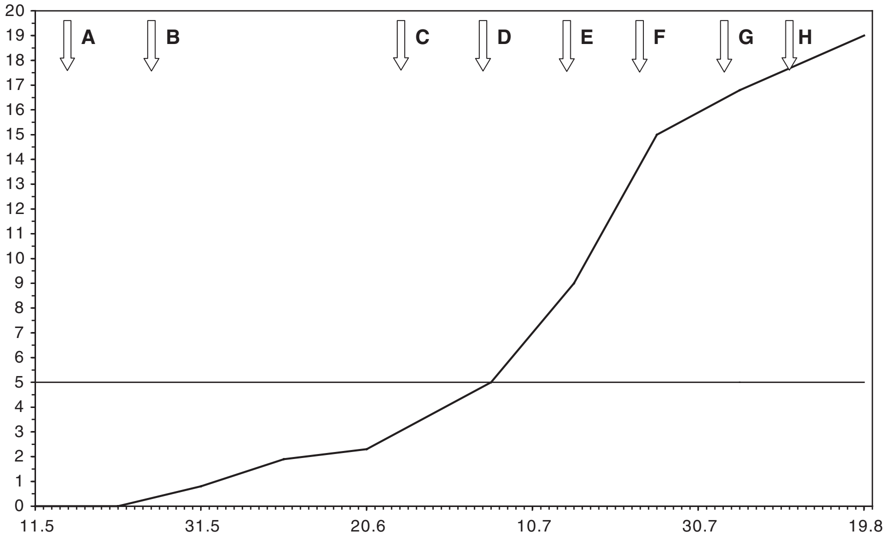

Fig. 15.4 The dynamics of apple fruit damages by codling moth caterpillars in the farm N 1 orchards during summer of 2007 (*curve*). The *arrows* show the treatments with definite compounds (see in text). Horizon line – the ET. On ordinate axis – quantity of damage fruit, %; on abscissa axis – date

In the second experiment, apple pest and its enemy management program the alternation of environment friendly (+) compounds only have been used in the succession: Insegar (+) in combination with Match (+) → Match (+) → Phytoverm^{TM}(+) in combination with Lepidocid^{TM}(+) → Phytoverm^{TM}(+) in combination with Lepidocid^{TM}(+) → Dimmilin (+) – in all 5 treatments per season (Fig. 15.5). During the experiment the monitoring of codling moth population fluctuation carried out with pheromone traps (four traps per hectare).The ET is 8 codling moth male specimens per 1 trap during 1st week. The average number of the hibernated moth males of the 1st and the 2nd generations had exceeded ET, and were twice the number(16 codling moths).

The mean damage of apple fruit by codling moth in two experimental orchards in farm $\mathcal{N}$o. 2 was 1.2% at the time of harvest (Fig. 15.5). The results indicated that; (a) an alternation of environment dangerous and environment friendly compounds in the same insecticide treatment program is not effective, besides (or owing to) its ecological incompatibility; (b) an alternation of environment friendly compounds only in the same insecticide treatment program is effective, ecologically compatible, thus showing the principle possibility of apple pest and its enemy management program as was done in case of cotton crop.

15.5.2 Green Apple Aphid

A high population density of green apple aphid on shoots of apple tree for prolonged time period (April–July) makes it necessary for repeated organophosphorus

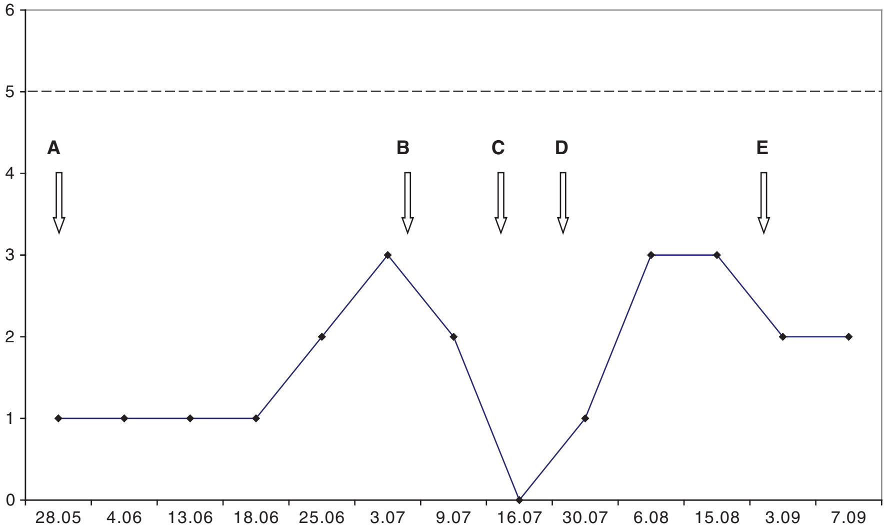

Fig. 15.5 The dynamics of apple fruit damages by codling moth caterpillars in the farm N 2 orchards during summer of 2007 (*curve*). The *arrows* show the treatments with different compounds (see in text). Horizon line – the ET. On ordinate axis – quantity of damage fruit, %; on abscissa axis – date

insecticide treatments. The observations showed a high density of aphid and ants' activity which attended aphid colonies for food and at the same time provided protection against of aphidophages. In this case, the ant species *Formica* sp. was the most in number and aggressively attacked predaceous bug, lady beetle and other entomophages both in aphid colony and outside of it. Novogorodova and Gavrilyuk (2007) have found that many species from the genus *Formica* are most active protectors of aphids. In the aphid colonies protected by *Formica* spp., aphidophages were 5–11 times less than in ones protected by ant species from other genera. Hence, a removal of ant from aphid colony will allow in creating situation favourable for aphidophage activity.

In the experiment where the sticky ring has been made of tree trunk the numbers of the predaceous bug, *Campylomma verbaci*, increased by 4.3 times within fifty days (Table 15.4) while ants disappeared. Simultaneously, the numbers of other species (aphidophages) also increased significantly (Table 15.4). Later in the season, after appricable decrease of aphid population on experimental trees; *C. verbasci* began to migrate from experimental trees and settle on trees infested with aphid. That is peculiar natural insectaries – the phenomenon noted by DeBach and Rosen (1991).

In general, the tree apple system presents a more complicated perennial agroecosystem to manage because of its greater persistence than annuals, as former allows development of a more evolved community of arthropods. Definite obstacle for development of an ecological approach to apple orchard protection is based

Table 15.4 Populaion of green apple aphid, *Formica* ant and aphidophages onexperimental (with sticky ring) and control (without sticky ring) apple trees

Experimental or control trees	Date of survey	Population of aphid counted on 10 shoots 25 cm long/tree, in grade of aphid number per 1 shoot					Number of *Formica* ant	Number of aphidophages				
		I 1–10	II 11–25	III 26–50	IV 51–100	V >100		*Campylomma* bug	Lady beetle	Lace-wing	Syrphyd fly	Cecidomyiid fly
Exp	17.07	3	8	6	8	19	491	25	1	–	–	3
Cont		9	9	8	9	–	143	30	3	–	–	2
Exp	22.07	5	3	2	2	–	–	108	13	–	14	28
Cont		6	5	5	4	–	124	49	–	–	2	11
Exp	30.07	1	–	–	–	–	–	12	–	3	–	–
Cont		5	3	2	3	1	97	18	–	–	–	3
Exp	06.08	2	–	–	–	–	–	14	–	–	–	–
Cont		7	4	3	–	–	48	12	2	–	–	–
Exp	14.08	1	–	–	–	–	–	16	–	–	–	–
Cont		6	2	–	–	–	28	15	–	–	–	1

on the concept of direct or indirect injury of insects (Turnbull and Chant, 1961). But the previous assertion that, codling moth population cannot be controlled with natural enemies because it damages apple fruit directly required reconsideration. At present bio-compounds particularly natural hormone analogs, allow to keep codling moth population lower than ET (Fig. 15.5) without suppression of natural enemies activity that will increase their useful role step by step. The pest species with indirect injury are more manageable with biological control as rise of aphidophage activity in suppression of green apple aphid has demonstrated (Table 15.4).

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Chapter 16
Dissemination and Impact of IPM Programs in US Agriculture

Kristopher L. Giles and Nathan R. Walker

Abstract The influence of historical farming practices, successful insect biological control programs, pest-resistant cultivars, and the benefits/risks associated with pesticide use shaped the development of IPM programs in the US during the 20th century. Recently, in several cropping systems, development of pest management programs that focus on deployment of transgenic crops have altered those based on pest ecology. Current IPM programs in the US are delivered to stakeholders through a network of private and public organizations, often with federal oversight dictated by national initiatives and funding programs. The impacts of these IPM programs vary among cropping systems and are often defined by specific management goals. In this chapter we review available information on US corn, wheat and cotton IPM programs, and discuss dissemination approaches, adoption trends among stakeholders, and the impact on production agriculture.

Keywords IPM dissemination · United States Pest Management · transgenic crops · corn · wheat · cotton

16.1 IPM in the United States

16.1.1 Historical Development and Current Approaches

The progression of Integrated Pest Management (IPM) both theoretical and in practice continues in the United States as agricultural producers, private industry, university personnel, and government agencies evaluate continuously changing agricultural production systems and producers who adopt innovations, incorporate ecological findings and attempt to adjust to local and federal requirements (Kogan 1998, Koul and Cuperus 2007). Elimination of key pests, invasive species, rapid adoption and widespread planting of transgenic crops, and changes in pesticide use

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has quickly altered many agro-ecosystems in the US and subsequently the ecological context of IPM dissemination (Fuchs 2007, Spurgeon 2007). One result of these rapid changes is the continuing intense debate among IPM theoreticians, practitioners, industry representatives, government personnel and the public on how new IPM systems will function (Shelton and Bellinder 2007). The debates about utilization of transgenic crops in IPM systems, however, are similar in context to those that occurred during the development of IPM theory and application. Similar to the past, debates revolve around terminology and conflicts between theoretical concepts and availability of practical proven innovations based on ecological data (Kogan 1998, Royer et al. 1999, Spurgeon 2007).

Relative to insect pests and pathogens, the foundations of IPM can be traced to the long history of those involved in agriculture who selected crops/commodities that survived or avoided attack or disease, recognized dangers associated with early pesticides, and incorporated the benefits of natural enemies (Norris et al. 2003). Plant pathologists do not regularly associate themselves with IPM (Jacobsen 1997, Royer et al. 1999), however, many in this discipline have long stressed the ecological components of IPM including breeding for resistance, deployment of cultural approaches that reduce inoculum density, exclusion, and utilization of epidemiological models and disease forecasting (Jacobson 2007). IPM is often identified with and among entomologists (Jacobsen 1997, Royer et al. 1999) because a majority of entomologists who work with pests identify themselves as IPM practitioners, they work in areas defined by IPM, and were associated with formalizing the widely recognizable Economic Injury Level (EIL)/Economic Threshold (ET) concepts (Stern et al. 1959, Kogan 1998, Stejskal 2003).

Formalization of IPM in the 20th century required that practitioners and theoreticians develop unifying principles as they relate to management of pests (Cate and Hinkle 1994, Kogan 1998, Royer et al. 1999, Norris et al. 2003). Based on the dramatic successes attributed to biological control of insects, and concerns about ecological disruptions caused by synthetic insecticides, the Integrated Control Concept was developed in the 1950's (Stern et al. 1959, Cate and Hinkle 1994). Integrated control was based on integrating the impact of natural enemies and pesticides (in the context of the whole agro-ecosystem) with potential economic losses, in an effort to justify curative suppression tactics, preserve available control strategies and reduce the negative impacts of pesticides on agro-ecosystems. As Kogan (1998) pointed out, following the Stern et al. (1959) article, IPM practitioners and theoreticians generally agreed on the ecological principles of IPM, but debated for decades over terminology. As IPM gained in acceptance, it became clear that practitioners dealing with pests were readily embracing the Economic Threshold concept often without justification (Stejskal 2003), while ignoring (1) interactions between the agro-ecosystem and pest ecology, and (2) long-term management strategies (National Research Council 1996, Royer et al. 1999, Koul and Cuperus 2007).

16.1.2 IPM in Practice

The ever changing large body of literature that has been developed by IPM theorists (Stern et al. 1959, National Research Council 1996, Norris et al. 2003, Koul and

Cuperus 2007) clearly documents a significant focus towards system and landscape based recommendations for IPM implementation and dissemination. IPM theorists are often quite willing to cite limited agro-ecological data (ex. pest and beneficial movement) and recommend system approaches for management of pests, while practitioners and producers are left to respond to pest outbreaks in the face of significant environmental events, increasing input costs and issues related to landlord requirements (National Research Council 2000, Spurgeon 2007, Koul and Cuperus 2007, Gurr et al. 2007, Hoy et al. 2007, Keenan et al. 2007a,b). Keenan et al. (2007a,b) investigated the pest management concerns of wheat producers in the US Great Plains during a wide-spread drought. Based on either experience or willingness as early adopters (Fuchs 2007, Keenan et al. 2007a,b), many of these producers regularly considered and incorporated IPM tactics such as host plant resistance, crop rotations and other cultural controls, conservation of beneficial insects, and field scouting in a proactive effort to manage pests within their farming systems. However, as alternative crops failed from lack of rain, as fuel costs continued to rise, and as landlords continued to demand continuous wheat production to reduce risks of crop loss, these producers were forced to make decisions on whether insect suppression was justifiable in crops that might not survive the drought.

Producers in most production systems regularly face environmental uncertainties and extremes and out of necessity, IPM practitioners who work with producers continue to focus on short-term management strategies (Spurgeon 2007) often centered around utilization of ET's. Short-term management strategies are often necessary because of regular changes in crop cultivars each with unique EIL's, alternative new crops each with their own EIL's, and rapid changes in the size of individual farms (Koul and Cuperus 2007). Fully describing and incorporating ecological relationships among plants, pests and natural enemies are noble endeavors and form a portion of the basis of IPM (Royer et al. 1999, Koul and Cuperus 2007). However, incorporating predictable ecological processes can be difficult because agricultural systems change so rapidly (crops/cultivars and tillage practices) often within just a few field seasons. Within ever changing agricultural systems, IPM practitioners and producers are often forced to focus on preventing pests from reaching EIL's through the use of cost effective pesticides (Koul and Cuperus 2007). A major accomplishment of this forced approach was the education of the public on alternatives to scheduled pesticide applications. This movement was quite successful in many crops as an increasing number of producers considered the cost-benefits of pesticide application. However, many believe that this EIL centered approach became synonymous with IPM to the public (National Research Council 1996).

As Spurgeon (2007) pointed out, relative to the conceptual ideas of IPM, very little has actually been accomplished; IPM should not be viewed as an entity, but a conceptual idea that integrates ecological knowledge and the real world constraints of modern production systems. IPM theorists and practitioners should consider a two tiered approach and develop meaningful real-world short-term solutions to economic damage caused by pests, and over time work towards integration of long-term management approaches within changing production systems. The ephemeral nature of agricultural systems suggests that IPM must be implemented and disseminated within a moving ecological target and that a two tiered approach is necessary. Indeed, there are many examples of successful dissemination and implementation of IPM programs for short-term management goals (Harris 2001). Holistic EIL's, disease forcasting models, and sampling approaches that consider multiple pests and system impacts must be accurately quantified and easy to use if producers are to move towards long-term approaches that prevent pest injury and reduce damage (Spurgeon 2007). The recent loss of many of the broad spectrum pesticides commonly used in production agriculture (due to the Food Quality Protection Act) may force the hand of IPM practitioners and producers to implement innovative two tiered approaches. Additionally, all involved must be aware that IPM is information based, and that dissemination of information will change as agricultural systems change and new ecological information becomes available.

16.1.3 The Changing Agro-Ecosystem

A change in crops or cultivars can have dramatic effects on pest dynamics and damage potential within an agro-ecosystem, particularly when plants vary in their suitability and/or susceptibility to pest attack (Norris et al. 2003). Development of pest resistant plants (Host Plant Resistance: HPR) is a long-term venture that must anticipate future markets for commodities and pest issues, while balancing yield and quality goals. For plant pathogens, breeding for resistance or tolerance has been the dominant management strategy for many field crops (Bell 1999, Jeffers 2004, Jacobson 2007). Traditional breeding efforts aimed at reducing or preventing damage by pests have been an integral part of IPM programs (Norris et al. 2003), but examples of immunity are rare and reliance on sampling/ET's has been common. The development of genetically engineered crop plants (GE's) that are resistant to plant pathogens is gaining momentum (Jacobson 2007), and it is expected that a surge in GE plants resistant to pathogens will be available to producers in the next 15 years, however this effort has not nearly been at the rate of GE's targeted for insect and weed control (Shelton and Bellinder 2007).

Agricultural landscapes in the US have changed dramatically during the past decade as genetically engineered crops have become readily adopted (Fernandez-Cornejo 2006). Scientists and IPM practitioners are continuing to evaluate long-term economic and environmental impacts (Frisvold et al. 1999, Obrycki 2001, Benbrook 2004, Rice 2004, Hurley et al. 2006), however, since 1996, US producers have continued to plant a larger percentage of their acreage to genetically engineered crops (Fernandez-Cornejo 2006, NASS 2007). Adoption of GE's are highest among producers who grow soybeans and cotton with herbicide-tolerant (HT) traits, followed by producers who target insect-resistant cotton and corn. Crops with HT traits were developed to survive broad spectrum or more selective herbicides as targeted weeds are killed. Cotton and corn cultivars containing genes from the soil bacterium *Bacillus thuringiensis* (*Bt*) have been planted since 1996 to reduce damage caused primarily by lepidopteran pests, and more recently coleopteran pests (Frisvold et al. 1999, Hurley et al. 2006). The most widely grown *Bt* plants produce a protein in their tissue (s) that is toxic to targeted insects and protect plants over an entire growing season (Brown et al. 2007, Illinois IPM 2007, Iowa IPM 2007).

The increase in GE crops grown in US agricultural landscapes has been dramatic and rapid (Fernandez-Cornejo 2006). For example, based on 2006 data, HT soybean acreage increased from 17 to 89 percent, from 1997 to 2006. Acreage of GE cotton and corn with HT and *Bt* traits has also steadily increased during this period. The increasing percentage of GE soybeans, corn and cotton in the US clearly demonstrate a significant ecological shift on production land in the US (Benbrook 2004). Shelton and Bellinder (2007) are optimistic in their assessment and state that GE crops and other forms biotechnology are more in line with IPM philosophy and will (1) result in new management tools, (2) allow scientists to explore fundamental processes, and (3) allow for truly integrated programs that are biologically based. For example, the use of transgenic cotton following Boll weevil eradication was well justified because several key pests were historically well above EIL's (Spurgeon 2007). Resulting *Bt* cotton systems are more sustainable with potential for further reductions in pesticide use (Benbrook 2004). The widespread use of GE crops means that IPM and dissemination of information will clearly have to adapt and function within these new transgenic systems.

16.1.4 Dissemination and Adoption of IPM

The Morrill Act (1862), Hatch Act (1887), and Smith Lever Act (1914) which established the land grant college system, agricultural experiment stations, and the agricultural extension service, respectively, continue to form the foundations of the research implementation paradigm of IPM in the US (Kogan 1998, Fuchs 2007). The Cooperative Extension Service (CES) continues to play the major role in disseminating IPM program information, and individual states have IPM coordinators who are associated with land grant universities and work with a multidisciplinary group of faculty and varying structures of regional and county extension educators to deliver IPM to stakeholders. Additionally, USDA Agricultural Research Service (ARS) scientists often cooperate with university personnel to discover, develop and evaluate IPM technologies. Stakeholders are identified primarily as growers, but also include commodity groups, private businesses with crop advisors and larger agricultural companies who interact with universities and ARS personnel together to evaluate and disseminate IPM technologies (Fuchs 2007).

Several studies have clearly indicated that stakeholders directly acquire IPM information and recommendations from several sources, but primarily through local contacts at elevators or fertilizer dealers (Probst and Smolen 2003, Koul and Cuperus 2007). However, much of this information can be indirectly traced back to dissemination events/materials organized or developed by extension personnel or private companies that include extension meetings, field days, handbooks and fact sheets, or newer comprehensive websites. Likely, the future of dissemination lies in delivery of information and recommendations via the internet at centralized IPM websites (Fuchs 2007).

Adoption of IPM technologies among stakeholders is a complex process, but often follows patterns outlined by Copp et al. (1958) and Nowak (1987). Producers who are aware of a pest management issue gather interest, and attempt management trials prior to adopting new technologies (Copp et al. 1958). Nowak (1987) includes in this process interaction with a third party (IPM practitioners and/or all other stakeholders defined earlier) that calls attention to problems unknown to producers. As Fuchs (2007) illustrates, widespread adoption is often a long term process and is usually reliant on innovators and early adopters (Fig. 16.1). However, dissemination and adoption of IPM can be constrained by the complexities associated with new technologies (Nowak 1987). This point is easily illustrated when comparing rapid adoption of transgenic corn or cotton, versus reluctance towards newly developed methods for sampling aphid winter wheat pests in the Southern Plains. Planting transgenic corn or cotton adds little complexity (other than refuge requirements) to farming operations, whereas aphid and parasitoid sampling in winter wheat requires knowledge of pests and natural enemies, additional time spent sampling, and predictions about future grain values (Elliott et al. 2004, Spurgeon 2007). Mandatory refuges are easy to delineate and clearly of little concern to producers, compared with scouting procedures in wheat, especially when seed companies assist with Insect Resistance Management (IRM) technology agreements. Transgenic crops have fewer factors that inhibit dissemination and decrease adoption, therefore they appear to avoid complexity factors that inhibit adoption. Additionally, seed companies often sponsor field days that decrease peer pressure problems associated with dissemination and adoption (Fuchs 2007).

Dissemination models for IPM often assume that growers are the stakeholders who make final decisions in regard to implementation of new technologies (Fuchs 2007). However, many producers rent land and/or interact with lending institutions that dictate farming operations and management approaches based on personal preferences and changes in farm legislation (Fuchs 2007, Koul and Cuperus 2007). For example, according to the Crop Profile for Corn in Illinois (2000), most farming land is owned by landlords and they have little tolerance for fields that are not properly

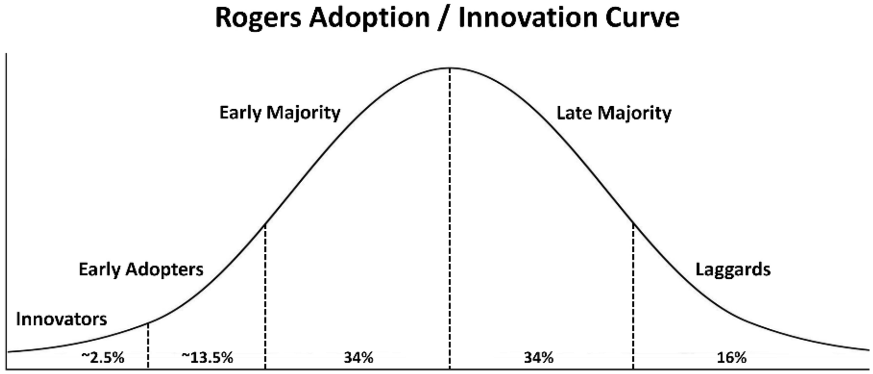


Fig. 16.1 Innovation adoption curve adapted from Everett M. Rogers 1995

managed. Approaches designed to disseminate IPM information to landlords and bankers are not well studied, but clearly needed.

16.1.5 Influence of National Initiatives and Funding Programs

Kogan (1998) summarized the history of IPM progress in the US including several of the funding initiatives that continue to influence dissemination in production agriculture today. The USDA Regional IPM Program was initiated in 1985 and continues today administered among four Regional IPM Centers (http://www.ipmcenters.org/) that coordinate grant opportunities and summarize research, extension, education and policy information. This program and other factors led to the National IPM Initiative developed by the Clinton administration that aimed to increase IPM in the US. The Food Quality Protection Act of 1996 (FQPA; http://www.epa.gov/pesticides/regulating/laws/fqpa/) was the most comprehensive evaluation of pesticide and food safety laws in the US by the Environmental Protection Agency (EPA). The most notable result of the FQPA was that many of the cheap pesticides (primarily organophosphates and carbamates) long used in production agriculture are no longer registered for pest suppression in several crops. The newer regulations also limited the total the number of uses for a given pesticide which required the removal of some crops from pesticide labels. Additionally, in the 1990's, the USDA-ARS initiated the Areawide IPM System program to evaluate multi-year research, demonstration and dissemination projects aimed at areawide suppression of pests (Kogan 1998). The goals associated with the Regional IPM Program, National IPM Initiative and Areawide IPM System programs influenced the direction of research and extension programs throughout the US and were readily adopted by IPM practitioners. These changes in IPM research and extension had a significant effect on IPM dissemination, particularly programs that were affected by FQPA. Clearly, the loss of available pesticides to FQPA, coinciding with replacement by more costly selective pesticides, forced the hand of IPM practitioners and most importantly producers to evaluate alternative approaches based on agro-ecosystem functions (Fuchs 2007).

In 2000, the proceedings from a National Research Council meeting and the Committee on the Future Role of Pesticides in US Agriculture were published (National Research Council 2000). The committee strongly stated that pesticides need to be maintained as management tools, but that alternatives need to be increased. These alternative IPM technologies would only be viable if future funding initiatives: (1) targeted long-term studies on sustainable Ecologically Based Pest Management systems, (2) provided opportunities for implementation, dissemination and adoption/diffusion research, and (3) promoted evaluation of commercially compatible technologies. A perusal through the current IPM grants programs administered by USDA-CSREES (http://www.csrees.usda.gov/nea/pest/pest.cfm) indicates quite clearly that this report influenced both short and long-term IPM priorities. These IPM grant programs vary significantly, however, incorporation of systems research, a focus on alternative pest management approaches, but most importantly demonstrated accountability to stakeholders and their needs (discovery, dissemination and impact) appear as common themes. Advancements and promotion in academia and ARS are often closely correlated with grant funding success, and predictably IPM theorists and practitioners have tailored there current and future programs to meet the priorities associated with IPM grant programs.

16.2 Cropping System Examples: Programs, Dissemination and Impact

16.2.1 Evaluation Criteria

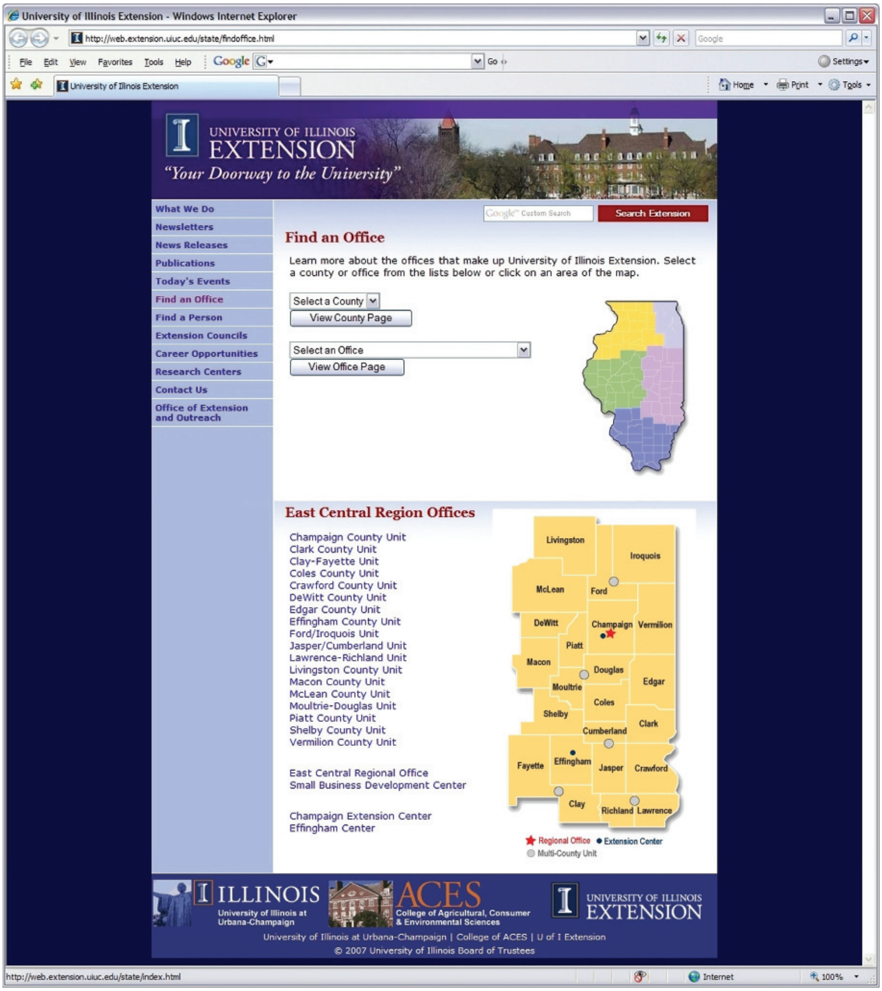
In the following sections, we discuss pest management issues for corn, wheat and cotton, and included our evaluations on the progression of IPM dissemination in these systems. We based our discussion of corn IPM on activities in Iowa and Illinois, our discussion of wheat IPM on activities in Oklahoma and Texas, and our discussion of cotton IPM on activities in Georgia and Texas. We described past and current pest issues including a critical evaluation of how IPM dissemination and adoption of technologies/advancements have changed over time.

16.2.2 Corn in the Midwestern US

Between 20–25 million acres (8−10 million ha) of corn are planted annually in Iowa and Illinois (Crop Profile for Corn (Field) in Iowa 1999, Crop Profile for Corn in Illinois 2000, NASS 2007). Corn is grown either as a rotational crop with soybeans or other crops, or less frequently grown continuously. Several arthropods can damage corn (Royer et al. 2004), but the principle pests in Iowa and Illinois continue to be the European Corn Borer (ECB, *Ostrinia nubialis*) and the rootworm complex that includes the Western Corn Rootworm (WCR, *Diabrotica virgifera*) and the Northern Corn Rootworm (NCR, *Diabrotica Barberi*). Combined average losses associated with these pests during non-outbreak years are less than 2%, but typically up to 15% of corn fields have severe infestations that can reduce yields up to 16%; during outbreaks, millions of hectares can be infested with damaging levels of ECB and/or rootworms. The primary ECB management options that can be implemented within a growing season include altered cultural approaches, scouting and curative insecticide applications or use of transgenic *Bt* cultivars. Management options for WCR and NCR vary among regions and rootworm strain, but those that can be easily implemented include crop rotation, fall scouting for adults followed by management or rotation, spring applications of soil insecticides, or use of resistant cultivars primarily those with *Bt*.

Low levels of disease reduce stands, yields and seed quality each year in Iowa and Illinois and the most commonly diagnosed pathogens are various species associated root rots, stalk rots, ear rots, leaf blights, and viruses. Jeffers (2004) states that pathogens regularly influence corn production in the US and that diseases cause between 2–15% in annual losses. Management of plant pathogens is based on (1) vigorous cultivars that are relatively resistant/tolerant to many common diseases, and (2) standard fungicidal seed treatments that help to protect seeds and seedlings, or monitoring overwintering populations of insect vectors of corn pathogens (Jeffers 2004, Illinois IPM 2007).

Historically, IPM information and technologies in corn have been disseminated through traditional CES approaches that include presentations at field days, grower meetings, and pesticide certification meetings. In Iowa and Illinois, CES personnel at the state levels interact with individuals within Areas/Regions, and at individual county offices to develop and disseminate IPM information (Fig. 16.2). Clearly CES personnel continue to be the driving force in IPM dissemination. Published



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Crawford County Unit
DeWitt County Unit
Edgar County Unit
Effingham County Unit
Ford/Iroquois Unit
Jasper/Cumberland Unit
Lawrence-Richland Unit
Livingston County Unit
Macon County Unit
McLean County Unit
Moultrie-Douglas Unit
Piatt County Unit
Shelby County Unit
Vermilion County Unit

East Central Regional Office
Small Business Development Center

Champaign Extension Center
Effingham Center

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Fig. 16.2 Illinois cooperative extension map/East Central region offices. http://web.extension.uiuc.edu/state/findoffice.html; http://web.extension.uiuc.edu/state/findoffice_EC.html documents, in the form of 'Fact Sheets' or production manuals that incorporate IPM recommendations in the context of crop production goals, are developed and provided to stakeholders by CES and/or other IPM practitioners. As stated earlier, producers most often acquire IPM information through local contacts at elevators and/or fertilizer dealers (Koul and Cuperus 2007). These contacts regularly incorporate IPM recommendations produced by CES personnel and information provided by seed dealers. IPM information for corn has historically been disseminated by a collection of CES personnel and other stakeholders to producers, who in the end may need to incorporate the requirements of landlords and bankers prior to making management decisions.

Currently, the most comprehensive and easy to use organization of IPM information for arthropods and diseases in Iowa and Illinois was developed by CES personnel and is available on individual IPM websites (Illinois IPM 2007, Iowa IPM 2007) that are linked to each other. CES IPM practitioners continue to focus heavily on personally disseminating information at grower and professional meetings, however, it is clear that websites form the most effective foundation for IPM dissemination because of the ability to centralize all pest management recommendations, hot-link topics, and quickly update information. Certainly, the management approaches on these websites are based on experimental and demonstration data, but also on the philosophical approaches of the IPM practitioners who developed management information; IPM recommendations for corn pests are presented relatively holistically on these websites. The most striking part of the ECB websites (particularly for Iowa) are the outlines that give equal "billing" and linked details on borer biology and IPM related approaches (Iowa IPM: http://www.ent.iastate.edu/pest/cornborer/manage). The outline for the ECB web-site for Iowa (Fig. 16.3) infers a holistic approach to management, whereas the Illinois web-site outline is limited to ecology, scouting and insecticides, and the use of *Bt* corn (Fig. 16.4). Centralized websites for rootworm management are not as well organized, but hot-links to current information in the region, recommendations, and topics of interest create a useful collection of easy to access resources.

Interestingly, information available on CES websites reflects a relatively cautious approach towards recommendations of *Bt* corn. *Bt* corn (several products) is presented as one of many management tactics for insect suppression that must be preserved via IRM. IRM information available at seed company websites reflects a similar philosophy towards *Bt* corn. For example, the websites developed by Monsanto Corporation for *Bt* corn market IRM as responsible stewardship and a way to preserve the benefits of resistance for the future. Additionally, relative to plant pathogens, both CES and Monsanto websites promote *Bt* products as a way to reduce ECB and rootworm injury, and secondary entry for pathogens.

Despite the apparent agreement over IRM and benefits of reduced levels of pathogens, there is a distinct separation in the way seed companies and CES present IPM information on there websites. As stated earlier, CES websites present multi-tactic outlines for IPM that includes scouting and pesticide recommendations, or links to sites and information that are multi-tactic in approach. Some links are to discussion articles about independent evaluations of *Bt* products and their

Components of Management

Good decisions for managing European corn borer depend on several biological and economic factors. Researchers from several states, cooperating and coordinating their investigations through the NC-205 Regional Research Project on Integrated Crop Management Effects on Stalk-boring Lepidoptera, are accumulating data to update the European corn borer management models they have developed. Over a 5-year period, the component of the management model that predicts the time of egg laying for the second generation has been tested in numerous fields in seven states. In all but one field, the model's predictions were within 3 days of the actual second-generation egg-laying period.

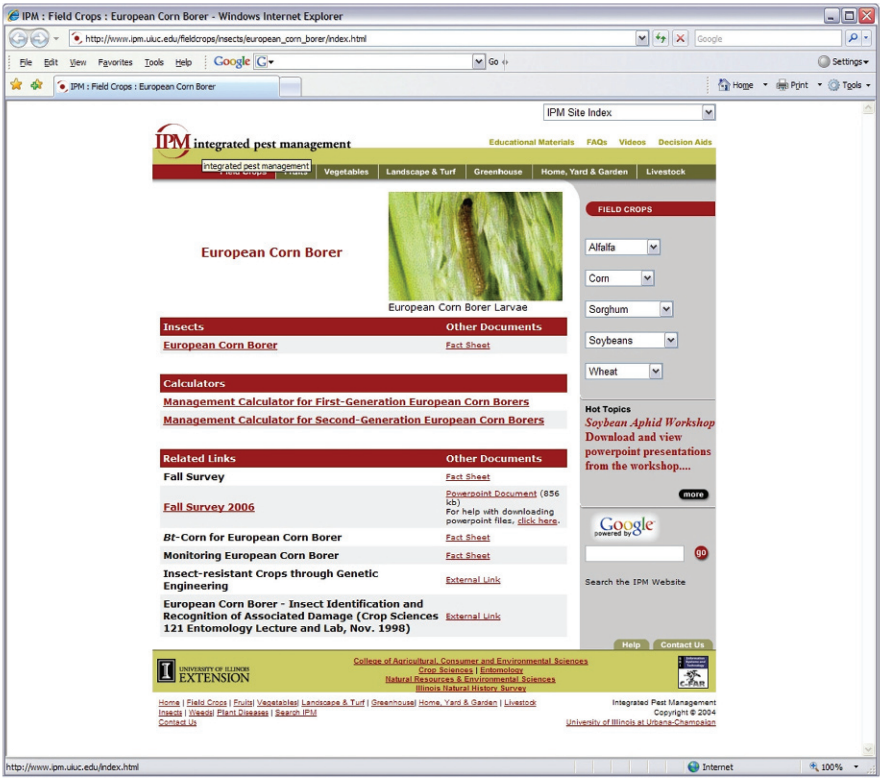
Simple management models for European corn borer are presented in the following sections with appropriate examples and calculation charts for reaching a management decision. More complex, yet easy-to-use, microcomputer management models are available from the Cooperative Extension Services at Iowa State, Kansas State, Pennsylvania State, and Nebraska Universities.

In regions where intensive management of corn production occurs, European corn borer is usually not the only pest. Pest management specialists operating in an intensive corn production environment usually are in each corn field once a week making observations and counts throughout the growing season. These may be included for European corn borer and other borers, rootworms, cutworms, mites, armyworms, diseases, weeds, moisture, and fertility. A pest management specialist needs to use his or her time efficiently. Consequently, adaptations made by an experienced pest manager to the following techniques are acceptable, as they better suit a weekly routine, without sacrificing data gathering.

Fig. 16.3 Iowa State University European Cornborer Management website. http://www.ent.iastate.edu/pest/cornborer/manage

effectiveness. Monsanto Websites for *Bt* corn products (Monsanto Company Website 2007: http://www.monsanto.com/monsanto/ag_products/input_traits/corn.asp) do not readily discuss or link to field data trials, but do focus on a few key topics: protection from insects, agronomic benefits of this protection, reduced insecticide inputs, and IRM approaches. Specific points on these topics are dependent upon the *Bt* product, however, there are no recommendations on scouting and/or additional pesticide use: the Monsanto *Bt* corn websites have chosen to ignore procedural specifics and infer that IPM is in the seed bag.

Which entity (CES or seed companies) has been most effective at disseminating IPM information? We may be able to answer this question by documenting levels of adoption relative to recommendations. Seed companies clearly want producers



European Corn Borer

European Corn Borer Larvae

Insects	Other Documents
European Corn Borer	Fact Sheet

Calculators
Management Calculator for First-Generation European Corn Borers
Management Calculator for Second-Generation European Corn Borers

Related Links	Other Documents
Fall Survey	Fact Sheet
Fall Survey 2006	Powerpoint Document (856 kb) For help with downloading powerpoint files, click here.
Bt-Corn for European Corn Borer	Fact Sheet
Monitoring European Corn Borer	Fact Sheet
Insect-resistant Crops through Genetic Engineering	External Link
European Corn Borer - Insect Identification and Recognition of Associated Damage (Crop Sciences 121 Entomology Lecture and Lab, Nov. 1998)	External Link

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Fig. 16.4 University of Illinois Extension European Cornborer IPM website. http://www.ipm.uiuc.edu/fieldcrops/insects/european_corn_borer/index.html

to plant *Bt* seed and they have succeeded. *Bt* corn acreage (*Bt* only or stacked with HT genes) has grown from 8% to 49% in the US, from 1997 to 2007 (Fernandez-Cornejo 2007a). In Iowa and Illinois, 59% of the available corn acres were planted with *Bt* seed in 2007 (Fig. 16.5). Recent increases in acreage are largely due to new *Bt* corn products that help to suppress rootworm damage.

It appears that corn growers are also continuing to follow recommendations for insecticide use outlined by CES personnel. Although Benbrook (2004) claims only a small reduction in insecticide use in corn, reductions in total amounts of insecticides in corn have been significant. In 1997, Illinois corn producers used 4,266,000 lbs (1,939,090 kg) of insecticides (Crop Profile for Corn in Illinois 2000). Data from Illinois in 2005 (NASS 2007) reveals that 1,202,000 lbs (546,364 kg) of insecticides were applied to corn acres (Table 16.1). Despite new *Bt* hybrids, much of the insecticide is targeted for rootworm suppression. Interestingly, Monsanto now offers *Bt* corn products that are pretreated with insecticides, which may ultimately increase the kilograms of insecticide applied to corn acres in Iowa and Illinois. Recommendations to combine *Bt* corn with additional prophylactic insecticides have, however, caused some concern among IPM practitioners in the US corn belt (Steffey 2007).

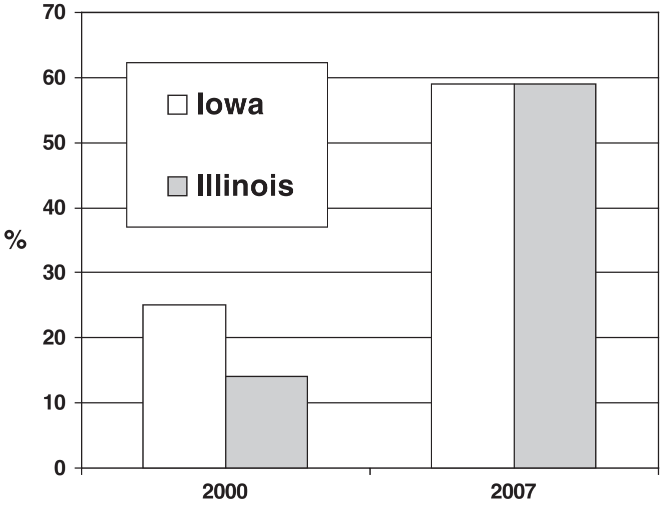


Fig. 16.5 Percentage of *Bt* only plus stacked gene corn varieties planted in Illinois, 2000 and 2007. Fernandez-Cornejo 2006

Table 16.1 1997–2005 annual total insecticide (1000 kg) applied in Illinois and Iowa corn, and Georgia and Texas cotton (NASS 2008. Based on available data converted to kg. 1 kg = 2.2 Ibs)

	Corn		Cotton	
	Illinois	Iowa	Georgia	Texas
1997	1, 939	1, 056	407	2, 876
1998	907	697	395	1, 288
1999	833	1, 119	371	10, 644
2000	–	–	330	9, 381
2001	812	393	166	6, 630
2002	495	196	–	–
2003	745	283	339	1, 410
2004	–	–	–	–
2005	546	–	520	2, 703

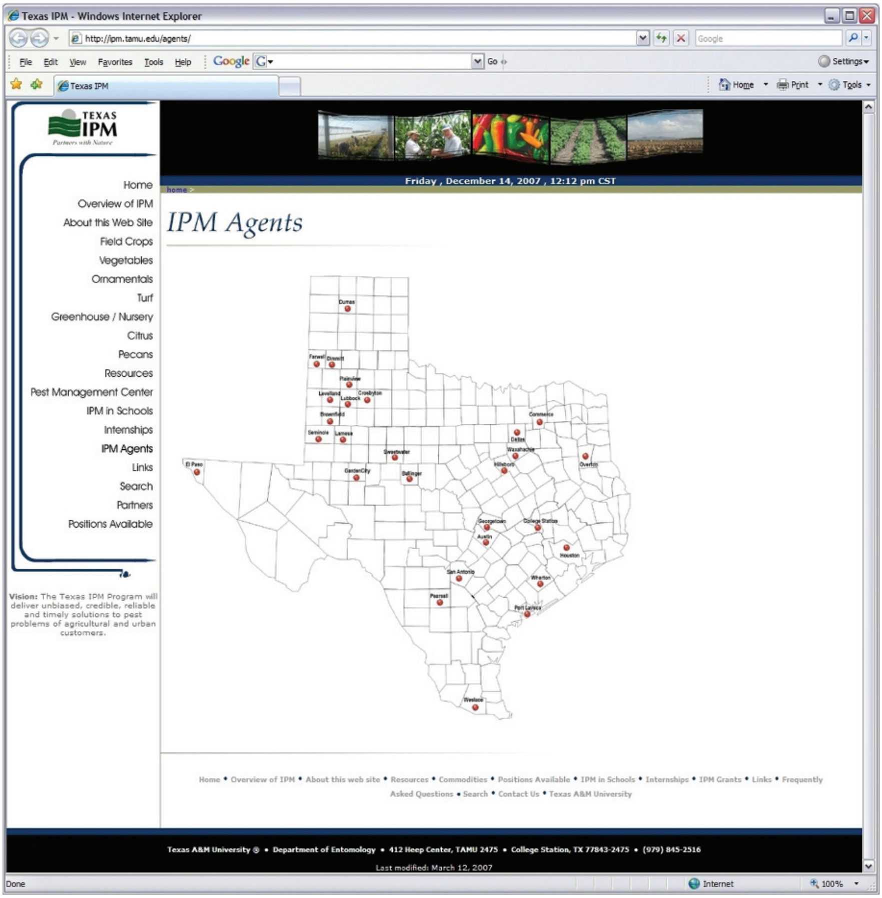
16.2.3 Wheat in the Southern Great Plains

Over 12 million acres (4.8 million ha) of winter wheat are planted each year in Oklahoma and Texas (Epplin et al. 1998, Smith and Anisco 2000, Crop Profile for wheat in Oklahoma 2005, NASS 2007). Wheat fields in these two states are regularly faced with aphid pressure, primarily greenbugs (*Schizaphis graminum*) and bird-cherry-oat aphids (*Rhopalosiphum padi*), and occasionally with other pests including Hessian Fly (*Mayetiola destructor*) and armyworms (Royer and Krenzer 2000). Aphids can cause severe damage during both the fall and spring because of the relatively mild winter climate in the Southern Plains. Therefore, the impact of aphids must be evaluated throughout the growing season (~September - May). Management of aphids primarily involves insecticide recommendations following scouting procedures for aphids and parasitoids (*Lysiphlebus testaceipes*) (Giles et al. 2000, Giles et al. 2003, Royer et al. 1998, 2004a,b Elliott et al. 2004). Producers in Oklahoma and Texas have only a few aphid-resistant cultivars (Porter et al. 1997, Lazar et al. 1998) available: TAM-110 and OKField (with the Gb3 resistance gene) are resistant to greenbug biotypes C, I, and E. TAM 110 was developed for production limited to the High Plains (dry climates) because it is susceptible to leaf rust and stripe rust, whereas OKField grows well in areas with greater rainfall, but is susceptible to wheat soilborne and/or spindle streak mosaic viruses. Leaf rust and stripe rust are the two most important and widespread diseases of wheat in the Southern Plains (Royer and Krenzer 2000). Producers have options relative to disease management; several wheat cultivars developed for the Southern Plains have significant resistance to common diseases (Edwards et al. 2006). Plant pathologists suggest that cultivar selection is the most important management decision when considering disease management however fungicide applications against rust can be effective, and when wheat prices are high cost-effective.

The majority of producers in Oklahoma and Texas do not plant resistant wheat cultivars but focus on cultivars with growth/production characteristics that maximize yield and grain quality (Royer and Krenzer 2000). For example, 'Jagger' and 'Jaggelene' are the most commonly grown cultivars in Oklahoma, but both are susceptible to aphids, Hessian Fly, and leaf rust (Edwards et al. 2006).

Similar to Iowa and Illinois, CES personnel at state levels in Oklahoma and Texas interact with individuals at area/regional and county offices to develop and disseminate IPM information. Organizationally, Oklahoma CES functions similarly to most states, however in Texas, additional groups of experts (IPM Agents (Fig. 16.6) and practitioners associated with the Texas Pest Management Association (TPMA) are distributed throughout the state and function as applied researchers and extension educators. In each state, fact sheets and production manuals, developed by CES and/or other practitioners incorporate IPM recommendations that are based on applied research, and/or the experiences of other stakeholders. Prior to publication, this IPM information is presented at traditional venues: field days, grower meetings, professional development meetings, and pesticide certification meetings. As documented in other cropping systems in the Southern Plains (Koul and Cuperus 2007), this information is readily shared among producers at elevators and fertilizer dealers, however, CES personnel are often the source of this initial IPM information in wheat.

In Oklahoma and Texas, wheat producers remain concerned about the potential for aphid damage. Surveys and focus groups indicate that a majority of producers in this region consider aphids to be a serious to very serious problem (Smolen and Cuperus 2000, Kelsey and Mariger 2002, Keenan et al. 2007a,b). Severe infestations of aphids in this region typically only occur every 5–10 years, however, these severe outbreaks influence how wheat growers (1) perceive the importance of aphids and (2) implement management programs. Until recently, during non-outbreak years, many hectares of wheat have been treated with pesticide to "protect" fields as aphid populations approach or exceed economic thresholds (ET's). For example, during the 1995/1996 growing season over 800,000 acres (320,000 ha) in Oklahoma were



Vision: The Texas IPM Program will deliver unbiased, credible, reliable and timely solutions to pest problems of agricultural and urban customers.

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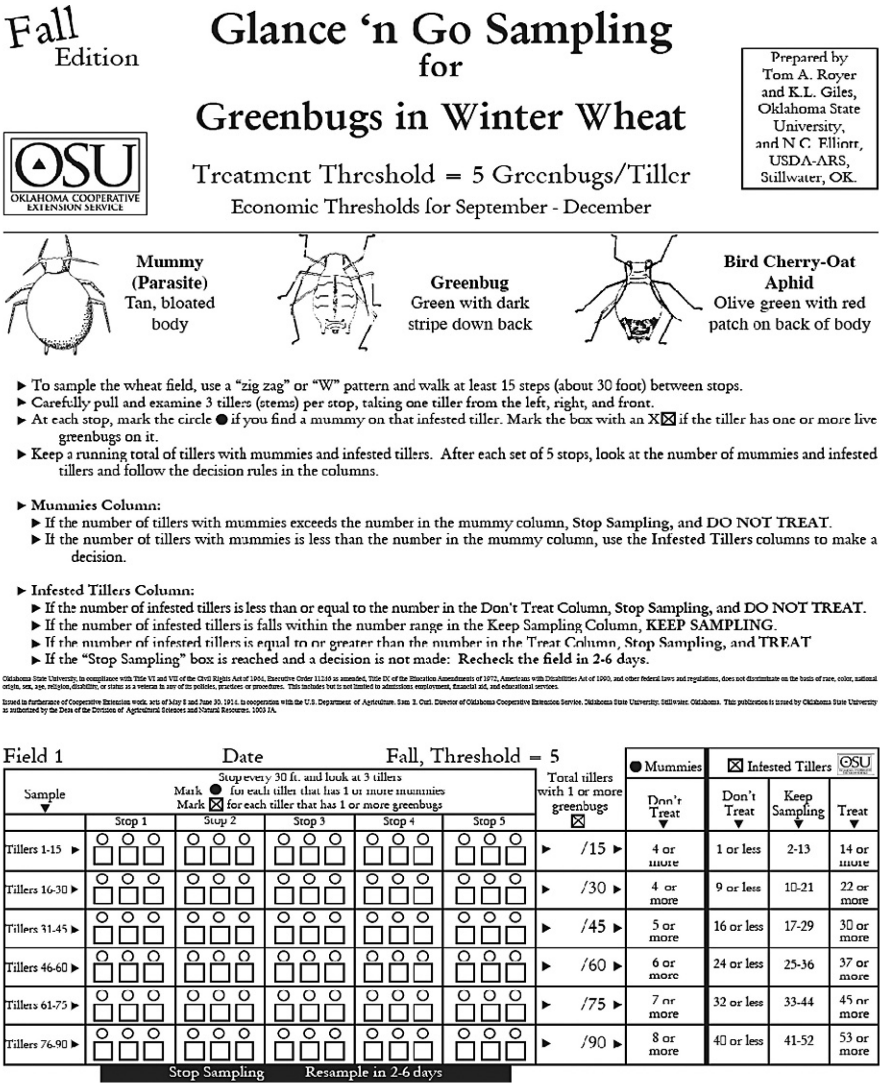
Last modified: March 12, 2007

Fig. 16.6 Texas IPM Agents Map. http://ipm.tamu.edu/agents/

treated to "protect" wheat yields even though most aphid populations were below EIL's (Crop Profile for wheat in Oklahoma 2005, NASS 2007). During these applications the parasitic wasp *L. testaceipes* had begun to decimate aphid populations and most of the insecticide applications likely provided no economic benefit.

Recent studies indicated that aphids remain below EIL's when *L. testaceipes* are present at threshold levels (Natural Enemy Threshold = NET) during the growing season (Jones 2001, Giles et al. 2003). These findings resulted in the development of presence/absence sampling plans for aphids and parasitoids in wheat applicable to Oklahoma and Texas (Giles et al. 2000, Elliott et al. 2004, Royer et al. 2004a,b). These novel binomial sampling plans allow for efficient classification of the impact of parasitoids and/or greenbug infestations in wheat. These sampling and management plans (Glance n′ Go system) were incorporated into laminated foldable pocket-sized tables for multiple-year use with dry erase markers, and are also



Fall Edition

Glance 'n Go Sampling for Greenbugs in Winter Wheat

Treatment Threshold = 5 Greenbugs/Tiller

Economic Thresholds for September - December

OSU OKLAHOMA COOPERATIVE EXTENSION SERVICE

Prepared by
Tom A. Royer
and K.L. Giles,
Oklahoma State
University,
and N.C. Elliott,
USDA-ARS,
Stillwater, OK.

Mummy (Parasite) Tan, bloated body

Greenbug Green with dark stripe down back

Bird Cherry-Oat Aphid Olive green with red patch on back of body

- ▶ To sample the wheat field, use a "zig zag" or "W" pattern and walk at least 15 steps (about 30 foot) between stops.
- ▶ Carefully pull and examine 3 tillers (stems) per stop, taking one tiller from the left, right, and front.
- ▶ At each stop, mark the circle ● if you find a mummy on that infested tiller. Mark the box with an X☒ if the tiller has one or more live greenbugs on it.
- ▶ Keep a running total of tillers with mummies and infested tillers. After each set of 5 stops, look at the number of mummies and infested tillers and follow the decision rules in the columns.

- ▶ **Mummies Column:**
  - ▶ If the number of tillers with mummies exceeds the number in the mummy column, Stop Sampling, and **DO NOT TREAT.**
  - ▶ If the number of tillers with mummies is less than the number in the mummy column, use the Infested Tillers columns to make a decision.

- ▶ **Infested Tillers Column:**
  - ▶ If the number of infested tillers is less than or equal to the number in the Don't Treat Column, Stop Sampling, and **DO NOT TREAT.**
  - ▶ If the number of infested tillers is falls within the number range in the Keep Sampling Column, **KEEP SAMPLING.**
  - ▶ If the number of infested tillers is equal to or greater than the number in the Treat Column, Stop Sampling, and **TREAT**
  - ▶ If the "Stop Sampling" box is reached and a decision is not made: **Recheck the field in 2-6 days.**

Field 1 Date Fall, Threshold = 5

Sample ▼	Stop every 30 ft. and look at 3 tillers Mark ● for each tiller that has 1 or more mummies Mark ☒ for each tiller that has 1 or more greenbugs					Total tillers with 1 or more greenbugs ☒	● Mummies	☒ Infested Tillers OSU		
	Stop 1	Stop 2	Stop 3	Stop 4	Stop 5		Don't Treat ▼	Don't Treat ▼	Keep Sampling ▼	Treat ▼
Tillers 1-15 ▶	○ ○ ○ ☐ ☐ ☐	○ ○ ○ ☐ ☐ ☐	○ ○ ○ ☐ ☐ ☐	○ ○ ○ ☐ ☐ ☐	○ ○ ○ ☐ ☐ ☐	▶ /15 ▶	4 or more	1 or less	2-13	14 or more
Tillers 16-30 ▶	○ ○ ○ ☐ ☐ ☐	○ ○ ○ ☐ ☐ ☐	○ ○ ○ ☐ ☐ ☐	○ ○ ○ ☐ ☐ ☐	○ ○ ○ ☐ ☐ ☐	▶ /30 ▶	4 or more	9 or less	10-21	22 or more
Tillers 31-45 ▶	○ ○ ○ ☐ ☐ ☐	○ ○ ○ ☐ ☐ ☐	○ ○ ○ ☐ ☐ ☐	○ ○ ○ ☐ ☐ ☐	○ ○ ○ ☐ ☐ ☐	▶ /45 ▶	5 or more	16 or less	17-29	30 or more
Tillers 46-60 ▶	○ ○ ○ ☐ ☐ ☐	○ ○ ○ ☐ ☐ ☐	○ ○ ○ ☐ ☐ ☐	○ ○ ○ ☐ ☐ ☐	○ ○ ○ ☐ ☐ ☐	▶ /60 ▶	6 or more	24 or less	25-36	37 or more
Tillers 61-75 ▶	○ ○ ○ ☐ ☐ ☐	○ ○ ○ ☐ ☐ ☐	○ ○ ○ ☐ ☐ ☐	○ ○ ○ ☐ ☐ ☐	○ ○ ○ ☐ ☐ ☐	▶ /75 ▶	7 or more	32 or less	33-44	45 or more
Tillers 76-90 ▶	○ ○ ○ ☐ ☐ ☐	○ ○ ○ ☐ ☐ ☐	○ ○ ○ ☐ ☐ ☐	○ ○ ○ ☐ ☐ ☐	○ ○ ○ ☐ ☐ ☐	▶ /90 ▶	8 or more	40 or less	41-52	53 or more

Stop Sampling Resample in 2-6 days

Fig. 16.7 Example of "Glance n' Go" greenbug+parasitism worksheet

available as the Greenbug Management Decision Support Tool on the web (Royer et al. 2004a,b, www.entoplp.okstate.edu/gbweb/index.htm, Fig. 16.7).

As in corn systems, the most comprehensive and easy to use IPM information for arthropods and diseases infesting wheat is available on centralized individual IPM websites for Oklahoma and Texas. Information on these sites can be accessed by area/regional and county CES personnel, but also by producers and other stakeholders. The Oklahoma IPM web-site (Oklahoma IPM 2007) is a central resource area, organized primarily by commodity, which allows access to fact sheets, newsletters, computer decision support models, and other projects including IPM for insect pests in schools. The Greenbug Management Decision Support Tool that incorporates Glance n′ Go is found within the computer decision support section of the web-site and allows any user to instantly develop and print sampling and decision plans for greenbugs in wheat.

The Texas, IPM (2007) web-site describes itself as a central resource:

> "This website is designed to provide a window or a one-stop guide to IPM information from Texas A&M University and its many departments, units and agencies. It also provides a link to related information from other sources. Much of the information is available because of links to departmental sites on campus and at Texas A&M Research and Extension Centers located across the state. This is not meant to detract from any other site but rather as a customer service feature to those seeking IPM information from Texas A&M University."

This website is also organized primarily by commodity allowing access to printable fact sheets, newsletters, and computer decision support models. The Texas IPM web-site is quite unique in that the first topic on the outline provides a link to the Overview of IPM (Fig. 16.8). This overview emphasizes the philosophical approach that practitioners in Texas take towards IPM and its dissemination, and includes detailed discussion on the following topics: What IPM Is Not, History of IPM, Strategies, Benefits, Role of Pesticides, and About the Texas IPM Program.

Friday , December 14, 2007 , 12:12 pm CST

Texas IPM Program

Providing science-based solutions to pest problems using methods that minimize health, environmental, and economic risks

Chilli Thrips Invade Texas Landscapes, Gardens

South Texas Sago Palm Pest Headed North

Texas A&M University Offers State's First Forensic and Investigative Sciences Degree

Insect CD Good For What Bugs Homeowners, Gardeners, Farmers

Vision: The Texas IPM Program will deliver unbiased, credible, reliable and timely solutions to pest problems of agricultural and urban customers.

Texas A&M University ® • Department of Entomology • 412 Heep Center, TAMU 2475 • College Station, TX 77843-2475 • (979) 845-2516

Last modified: December 7, 2007

Fig. 16.8 Texas IPM Website. http://ipm.tamu.edu/

Clearly, dissemination of IPM information for wheat in Oklahoma and Texas is based on CES activities, programs, and websites. The newly developed Glance n′ Go sampling and management plans allows for efficient economical management of aphids in wheat, but are producers aware of and utilizing this resource? In focus groups, Keenan et al. (2007a) documented the IPM perspectives of wheat growers in the Southern and Central Great Plains. These focus group discussions were designed to elicit perspectives without lead-in questions that bias answers towards IPM concepts. A few growers acknowledged that they were aware of field scouting procedures for aphids, but that those methods were too difficult to use and required too much time. At the time of these focus groups (2002–2003), Glance n' Go was newly developed, therefore these producers were likely describing older more cumbersome aphid sampling methods (Patrick and Boring 1990, Royer et al. 1999). Indeed, the results of an unpublished survey of producers who attended field-days and other extension meetings during this time indicated that less than 1% of producers had heard of Glance n' Go (T. A. Royer Unpublished Data). It appeared that wheat growers were not aware of or following new recommendations for aphid management outlined by CES personnel. A large scale extension and evaluation effort for Glance n' Go was initiated in 2004 and will continue through 2009, and CES personnel are planning to document awareness and adoption of this new sampling approach.

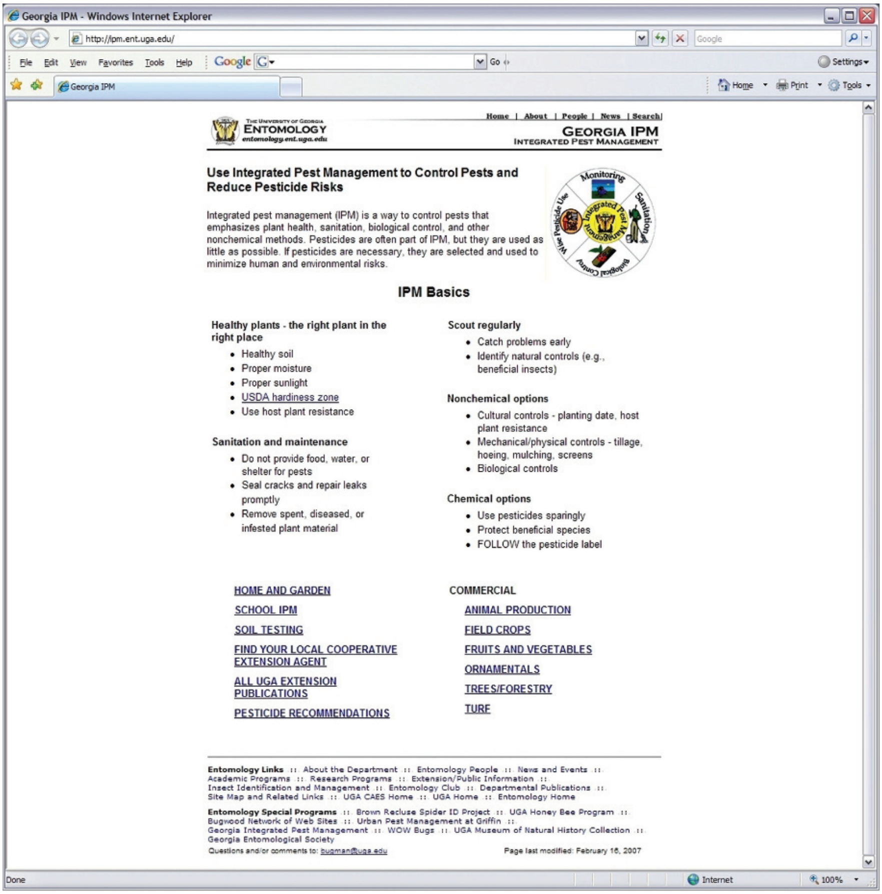
16.2.4 Cotton in the Southern US

In Georgia and Texas, over 7 million acres (2.8 million hectares) of cotton are planted each year (Crop Profile for Cotton in Texas 1999, Brown et al. 2007). Cotton is grown throughout the Southern US because it requires a long growing season for proper maturation. The major insect pests of cotton have historically included boll weevils (*Anthonomus grandis*), bollworms (*Helicoverpa zea*), fleahoppers (*Pseudatomoscelis seriatus*), aphids (*Aphis gossypii*), and thrips (*Frankliniella occidentalis*), with occasional secondary pests that include beet armyworms (*podoptera exigua*) and lygus bugs (*Lygus hesperus*) and several species of cutworms, spider mites and stinkbugs (Leonard et al. 1999). Insect pest management in cotton changed dramatically following (1) the highly successful Boll Weevil Eradication Program (BWEP) and (2) the introduction and adoption *Bt* cotton for suppression of Lepidopteran pests (Brown et al. 2007, Spurgeon 2007). For example, following the BWEP in Georgia, the number of insecticide applications per year decreased from 10–12 to 4–5, and further decreased to 3 per year following widespread adoption of *Bt* Cotton (Crop Profile for Cotton in Georgia 2006, Brown et al. 2007, NASS 2007). In Texas, with the exception of increased Malathion use as a component of the BWEP (Table 16.1), a long history of variety selection, cultural approaches, scouting and natural enemy conservation have helped to maintain on average a low annual number of insecticide applications in cotton (Crop Profile for Cotton in Texas 1999, Harris 2001, Muegge et al. 2002). Reduced applications of insecticide have conserved the abundance and effects of beneficial predators and parasitoids, but allowed the resurgence of lygus and stink bugs (McAlavy 2005, Crop Profile for Cotton in Georgia 2006). Indeed, increasing stink bug populations in Georgia may be responsible for increased total amount of insecticide applied to cotton from 1997–2005 (Table 16.1, NASS 2008). CES personnel in Georgia and Texas clearly emphasize that management of insect pests must include scouting in both non-*Bt* cotton and *Bt* cotton, and selective suppression of pests as they occur (Crop Profile for Cotton in Texas 1999, Moore et al. 1997, Crop Profile for Cotton in Georgia 2006, Brown et al. 2007)

In the US, cotton diseases reduce production by over 12% which equates to over 1 billion dollars annually (Bell 1999). In Georgia and Texas, several diseases are of concern to growers including various seedling fungi (*Rhizoctonia solani, Pythium* spp, *Thelaviopsis basicola*, and *Fusarium* spp.), nematodes, boll rots, verticillium wilt and root rots (Crop Profile for Cotton in Texas 1999, Crop Profile for Cotton in Georgia 2006, Brown et al. 2007). The long history of cotton breeding has resulted in cultivars that have variable levels of resistance to many common diseases, and newer *Bt* cottons that are injured less by insects reduce entry opportunities for pathogens. Crop rotation is highly recommended by CES personnel as a cultural strategy to avoid diseases common in continuous cotton. As with corn, cotton seedling diseases are managed primarily with seeds that are abundantly pre-treated with fungicides, and infrequently by in-furrow fungicides. In Georgia particularly, root-knot or reniform nematodes can be an important problem in continuous cotton and may require soil sampling and costly soil fumigation or incorporation of nematicides in the production system program (Brown et al. 2007).

Similar to Iowa, Illinois, and Oklahoma, CES personnel in Georgia at state levels interact with district directors and individuals at county offices to develop and disseminate IPM information. As mentioned before, in Texas, IPM agents and professionals associated with the TPMA interact with CES personnel at all levels and with other stakeholders. As with other crops, centralized IPM websites (Georgia IPM 2007, Texas, IPM 2007, Brown et al. 2007) for Georgia and Texas contain comprehensive information for management of arthropods and diseases affecting cotton. IPM Information (fact sheets, newsletters, production manuals/handbooks/guides, and computer decision support models etc.) on the cotton web-sites can be accessed by all CES personnel, and also by producers and other stakeholders who have computer access.

IPM recommendations for cotton are presented holistically on Georgia and Texas websites. Similar to the Texas IPM site, the Georgia IPM site (Georgia IPM 2007) immediately addresses the definition of IPM and is organized primarily by tactics and commodities which are linked to printable IPM information and recommendations (Fig. 16.9). As with IPM sites for corn in Iowa and Illinois, the cotton websites give equal "billing" to all IPM approaches including variety selection and *Bt* cotton, seed treatment recommendations, cultural approaches, conservation of natural enemies, and scouting/ET information. A holistic approach towards management of arthropods and diseases in cotton has been quite successful for decades in Texas and Georgia following the BWEP. Likely because of ongoing successful cotton IPM



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GEORGIA IPM
INTEGRATED PEST MANAGEMENT

Use Integrated Pest Management to Control Pests and Reduce Pesticide Risks

Integrated pest management (IPM) is a way to control pests that emphasizes plant health, sanitation, biological control, and other nonchemical methods. Pesticides are often part of IPM, but they are used as little as possible. If pesticides are necessary, they are selected and used to minimize human and environmental risks.

IPM Basics

Healthy plants - the right plant in the right place
- Healthy soil
- Proper moisture
- Proper sunlight
- USDA hardiness zone
- Use host plant resistance

Sanitation and maintenance
- Do not provide food, water, or shelter for pests
- Seal cracks and repair leaks promptly
- Remove spent, diseased, or infested plant material

Scout regularly
- Catch problems early
- Identify natural controls (e.g., beneficial insects)

Nonchemical options
- Cultural controls - planting date, host plant resistance
- Mechanical/physical controls - tillage, hoeing, mulching, screens
- Biological controls

Chemical options
- Use pesticides sparingly
- Protect beneficial species
- FOLLOW the pesticide label

HOME AND GARDEN
SCHOOL IPM
SOIL TESTING
FIND YOUR LOCAL COOPERATIVE EXTENSION AGENT
ALL UGA EXTENSION PUBLICATIONS
PESTICIDE RECOMMENDATIONS

COMMERCIAL
ANIMAL PRODUCTION
FIELD CROPS
FRUITS AND VEGETABLES
ORNAMENTALS
TREES/FORESTRY
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Questions and/or comments to: bugman@uga.edu

Page last modified: February 16, 2007

Fig. 16.9 University of Georgia IPM website. http://ipm.ent.uga.edu/

programs in these states, CES personnel are relatively cautious in their approach to *Bt* cotton which is clearly presented as a component of IPM.

As with *Bt* corn, Monsanto company websites for *Bt* cotton focus on protection from insects, agronomic benefits of this protection including reduced secondary pathogen activity, reduced insecticide inputs, and IRM approaches as responsible stewardship of agricultural land (Monsanto Company Website 2007). *Bt* cotton has been improved over time to be more effective in a variety of growing locations with different pest pressures. For example, Bollgard II cotton expresses two *Bt* insecticidal proteins (versus Bollgard with 1 protein) which prevents damage from a broad range of lepidopteran pests. In contrast to *Bt* corn, *Bt* cotton is purposely marketed by Monsanto as a component of a holistic IPM approach that conserves beneficial insects and reduces pesticide applications. Specifically, the IRM guidelines for Bollgard call for careful monitoring of targeted and non-target insects and use of ET's as appropriate, although no specific recommendations or links to procedures are available. This website does, however, describe additional cultural approaches such as timely harvest schedules, stalk destruction, and appropriate soil management as IPM practices that ensure success of *Bt* cotton.

Although CES personnel in the US initially approached the immediate widespread adoption of *Bt* cotton with caution, it appears now that all involved in disseminating IPM information for cotton support the utilization of *Bt* cotton in the context of a holistic pest management program. It has been suggested by Spurgeon (2007) that cotton producers focus on short-term production goals, and that short-term IPM solutions such as *Bt* cotton are preferentially adopted. A unified approach to promoting *Bt* cotton between CES personnel and seed companies would suggest rapid and widespread adoption of these varieties. Indeed, this assertion is supported by 2007 data (Fig. 16.10) that documents an estimated 85% of cotton growers in Georgia used *Bt* cotton (NASS 2007). Suntornpithug (2004), however, suggested that growers were relatively cautious in their adoption of *Bt* cotton over time, and that diffusion required trial and error learning prior to full scale implementation. This trial and error approach by growers may be reflected in the lower levels of adoption of *Bt* cotton in Texas. The estimated 42% of cotton growers in Texas who used *Bt* cotton in 2007 (Fernandez-Cornejo 2007b) may be attributable to several possibilities including lower overall pest pressures (Spurgeon 2007) and/or a more cautious approach towards adoption based on previous success with cotton IPM programs disseminated by CES personnel (Harris 2001).

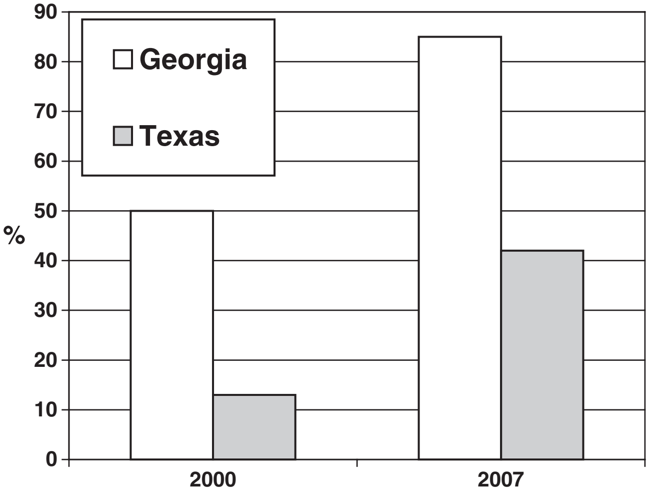

Fig. 16.10 Percentage of *Bt* only plus stacked gene upland cotton varieties planted in Georgia and Texas 2000 and 2007. Fernandez-Cornejo 2006

16.3 Conclusions

Current IPM programs in the US, which are often dictated by national initiatives and funding programs, are disseminated to stakeholders by a network of public and private organizations. The Cooperative Extension Service is unique to the US and those involved in IPM have functioned primarily to disseminate holistic recommendations for managing pests in cropping systems. With the development of transgenic crops, primarily those with *Bt* insecticidal proteins, private industry personnel have become increasingly involved in disseminating IPM recommendations, particularly in corn and cotton systems. Adoption of *Bt* crops has increased dramatically during the past 10 years, however, growers are clearly utilizing information disseminated by both CES and private industry. Much of the current information for IPM is disseminated via centralized CES websites as electronic and print on demand documents. Also, as documented by Koul and Cuperus (2007), IPM recommendations and information continue to be disseminated by local private contacts and fellow growers.

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Chapter 17
Advances with Integrated Pest Management as a Component of Sustainable Agriculture: The Case of the Australian Cotton Industry

Gary Fitt, Lewis Wilson, David Kelly and Robert Mensah

Abstract Insect pests represent a significant limitation for production of many crops. Traditional reliance on pesticides brings significant economic costs and environmental liabilities of off-target drift, chemical residues and resistance. IPM has long been proposed as an alternative. The adoption of IPM in the Australian cotton industry provides a valuable overview of the key components of IPM and the issues around successful implementation. IPM must be founded on a thorough understanding of the ecology of pest and beneficial species and their interaction with the crop and will provide a range of tactics which must be integrated by the producer to achieve economic and environmental sustainability. The emerging era of insect resistant transgenic cottons offers real prospects to provide a foundation for more sustainable, economically acceptable IPM with the integration of a range of non-chemical tactics and much less reliance on pesticides.

Keywords Cotton · IPM · Integrated Pest Management · Sustainability · *Helicoverpa*

17.1 Introduction

Insect pests are a major constraint on production of many crops worldwide through direct yield and quality reductions, through damage in storage and through the costs associated with attempts at control. Pest management using traditional approaches with pesticides can often be effective but imposes significant economic, environmental and social costs and risks of insecticide resistance which must be managed. Integrated pest management has long been proposed as a more sustainable approach for many situations, however, the adoption of a truly integrated pest management approach has been extremely patchy. More often IPM relates to integrated pesticide management.

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Broadly IPM can be defined as "the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment. IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms." (FAO 2002).

In this paper we will illustrate the progress that has been made in implementation of IPM in field crops by reference to the Australian cotton industry where more sustainable IPM systems have been developed and where the challenges of integration and implementation are common to many other field crops. IPM in the cotton industry illustrates the key components and processes needed for successful adoption and impact.

Many aspects of IPM have been applied in the cotton industry since the late 1970s when the computer based decision support system, SIRATAC, was released to industry (Hearn and Bange 2002). The minimal IPM approach involved the simple use of sampling systems and thresholds to better time the use of pesticides to cotton fields. However, today IPM represents a more expansive approach which seeks to minimise pesticide use and include a broader range of tactics such as pest resistant varieties, conservation and augmentation of beneficial insect populations, use of selective and short residual insecticides, recognition of the compensatory capacity of the plant and various cultural control practices which have long been associated with the IPM concept.

17.2 Integrated Pest Management – The Components and Principles

The Australian cotton industry faces a number of challenges in pest management (Fitt 1994). These include damage from key pests (the noctuid moths *Helicoverpa armigera* Hübner and *H. punctigera* Wallengren, spider mites (*Tetranychus urticae* Koch), aphids (*Aphis gossypii* Glover), mirids (*Creontiades dilutus* Stål) and silverleaf whitefly (*Bemisia tabaci* (Gennadius))); insecticide resistance in the primary pest (*H. armigera*) and three secondary pests (mites, aphids and silverleaf whitefly); escalating costs of production and environmental concerns over off-farm movement of insecticides. Control of the primary pest, *Helicoverpa* spp. with broad spectrum insecticides often results in outbreaks of secondary pests, such as spider mites, aphids and silver leaf whitefly which are often controlled by generalist predators and some host specific parasitoids. Although IPM principles of sampling, thresholds and recognition of beneficial species had been implemented in Australian cotton for several years, the industry faced a crisis in pest management in the 1998–99 growing season, following a winter of high rainfall which generated abundant weed growth on which pest species could build. The subsequent high pest numbers on cotton led to high control costs and served as a catalyst within the industry to try a broader IPM based system.

To address these issues, a major research effort has focused on reducing dependence on insecticides through the development and implementation of integrated pest management (IPM) systems (Wilson et al. 2004, Fitt 2000). To be valuable to the cotton industry an IPM system needed to reduce insecticide use, whilst maintaining yield and early maturity and maintaining the susceptibility of pests to new selective insecticides. At the same time it needed to be practical and workable in the context of the whole farming system, and importantly be relevant to both conventional cotton and transgenic (Bt) cotton varieties which *both* form important components of the current industry.

Additionally growers and consultants needed to understand and accept the basic premises on which IPM is built. These were:

- the mere presence of a pest species does not justify action for control
- IPM is about containment of a pest situation, not eradication
- no single control measure can be applied to all pest complexes
- some level of damage or loss to the crop should be tolerated
- IPM utilizes a diverse array of control options to minimise pest abundance or damage, with pesticides used as the last resort.
- IPM does not seek to eliminate the use of pesticides, but aims to utilise the least disruptive options and to reduce the use of pesticides for pest control to the lowest practical levels.

The Australian cotton IPM system addresses these goals through 7 key objectives:

1. Using best practice crop agronomy to grow a healthy crop
2. Effective sampling for pests, beneficial insects and plant damage, combined with thresholds
3. Conservation and use of beneficial insects, including preferential use of selective insecticides;
4. Preventing the development of insecticide resistance, including Bt-cotton
5. Managing crop and weed hosts
6. Using trap crops effectively
7. Supporting IPM through communication and training (including area wide management).

Overriding these objectives is an emphasis on both profitability and sustainability as measures of effectiveness, ensuring that both input costs and yield are considered, rather than the traditional emphasis on maximizing yield. Our approach recognizes that cotton is only one crop in a farming system, and that all the farm management activities and crops need to be accommodated into an IPM framework. Furthermore IPM relevant activities can occur throughout the annual cycle of production, not just during the cotton growing season. A final consideration is supporting IPM through communication and training (including area wide management), which is discussed later.

These principles were captured in the ‘Guidelines for Integrated Pest Management in Australian Cotton’ (Deutscher et al. 2005). This IPM strategy focuses on the 7 objectives described above and provides a framework to achieve them by aligning them with phases of the annual crop cycle. To do this the crop cycle was divided into five key periods: planting to first flower; first flower to first open boll; first open boll to harvest; a post harvest period; and a pre-planting period. The three first periods deal with the growth cycle of the cotton crop. The final two deal with the "off" season or winter period, during which other crops may be grown. Inclusion of the winter period was essential, since many of the actions taken through this period have important implications for the success of IPM in the following growing season.

For each objective, the activities involved were mapped to the relevant phase(s) of the crop cycle. Key non-insecticidal tools that can be used to manage pests or to enhance abundance of beneficial species were indentified and included a range of agronomic, varietal and crop physiological factors that are part of the farming system, but not normally thought of as pest control tools. These include optimising fertilizer rates and irrigation strategies, the timing of the last irrigation, and the time to defoliate the crop. These factors can all be manipulated to contribute toward the goals of IPM. They also highlight that IPM requires a long-term ecosystem wide approach which must fit within a farming system context and not be perceived as an add-on.

17.3 IPM Objectives in Practice

The crop itself is the template on which a broad range of interactions between pests and their environment are formed and is thus the starting point for any IPM system. In the Australian cotton system the advent of transgenic Bt-cotton, firstly the INGARD varieties (containing Cry1Ac) and more recently a suite of Bollgard II varieties (containing Cry1Ac and Cry 2Ab) has revolutionized pest management by dramatically reducing the need to control the primary pests. Fitt and Wilson (2000) demonstrate that insect resistant transgenic cottons are a good platform for IPM. They reduce the need to control *Helicoverpa punctigera*, the primary early-season cotton pest in Australia, thereby reducing disruption to beneficial insects caused by insecticide use, and conserving and maximizing beneficial insect activity. Transgenic Bt cotton is an important tool for IPM because it provides a very powerful foundation which helps growers to realize the benefits of IPM more easily (Fitt 2003). In the 2006–07 cotton season, about 85% of the Australian cotton area was planted to Bollgard II varieties and the remainder to conventional (non-Bt) cotton. This emphasizes the need for IPM systems that can be applied across a mix of Bt and non-Bt cotton.

Below we briefly describe the components of each objective and how they fit into the crop cycle. Wilson et al. (2004) provide more detail.

17.3.1 Using Best Practice Crop Agronomy to Grow a Healthy Crop

IPM can reduce crop losses to pests but cannot increase the intrinsic yield potential or fibre quality of the crop, which is largely determined by the interaction between variety, climate and agronomy. Crop agronomy in particular can interact positively and negatively with an IPM system and it is possible to manage the crop and pest management approach – so-called Integrated Crop Management (ICM) - to achieve the greatest positive benefit.

17.3.1.1 Optimal Planting Time

Planting outside the optimal time period (early October in most established production regions) adversely affects yield potential and is counter-productive to IPM. Very early planting (mid September) in cool districts increases the risk of damage due to frost, severe cold, slow early growth and greater susceptibility to diseases and herbicide and early pest damage, especially from thrips. Late planted cotton result in a greater variability in yield potential and increases the risk of late infestations of *H. armigera* control of which further increases risks of outbreaks of spider mites, aphids and silverleaf whitefly that are difficult and expensive to control.

17.3.1.2 Optimal Water Management

Irrigation decisions should be based on knowledge of the soil water holding capacity, moisture status and an objective assessment of crop need. Over-frequent in-crop irrigations and unnecessary late irrigation will result in excessive vegetative growth and extend the period of attractiveness to pests with no enhancement in yield potential. Optimal irrigation management can avoid this problem.

17.3.1.3 Strategic Use of Plant Growth Regulators

Excessive nitrogen fertilizer use and over-irrigation can result in crops with excessive vegetative growth, with not only reduced yield potential but remain attractive to pests and mature late, thereby increasing the need to pest control. The plant growth regulator mepiquat chloride helps to reduce the severity of excessive vegetative growth when used in conjunction with a regular crop monitoring program to determine timing and quantities of application.

17.3.1.4 Defoliation of the Crop Promptly at Maturity

This can be assessed by cutting bolls and examining the color of the seed coats. Timely defoliation reduces the risk that further pest populations develop, which could require control.

17.3.1.5 Optimisation of Fertilizer Strategies to Avoid Excessive Plant Growth

Most nitrogen fertiliser for cotton is applied prior to sowing, often several months beforehand. Nitrogen availability can directly affect pest management as well as potential yield and maturity. Too little nitrogen will decrease yield. Excessive nitrogen can create excessive end-of-season plant growth, making the crop more attractive to *Helicoverpa*, aphids and silverleaf whitefly. This may require additional inputs of expensive insecticides for control, potentially delay crop maturity by 1–2 weeks, expose the crop to the risk of honeydew, and make crops harder to defoliate (Rochester et al. 2001). Growers are advised to manage nitrogen on a field-by-field basis based on soil tests and in-crop tissue tests (Constable and Rochester 1988) using DSS such as NutriLOGIC and NUTRIpak to select appropriate fertilizer rates (Deutscher and Bange 2003).

17.3.1.6 Matching of Cotton Variety to Region and Pest Complex

Australian growers have access to a wide range of varieties adapted to certain geographical regions or production situations. Selection of the most appropriate varieties for the combination of season length, yield potential, fibre quality, disease resistance, pest complex and agronomic situation is critical for IPM. Aside from the transgenic Bt traits, cotton plants have a number of naturally occurring biochemical (tannins, terpenoids) and morphological (leaf shape) defences against arthropod (insects and mites) pests and a high capacity to compensate for pest damage since the plant produces many more flowerbuds than it can mature as bolls. Several conventional host plant resistance traits have been incorporated into modern varieties. These include resistances to key diseases (bacterial blight, *Verticillium, Fusarium*, Cotton Bunchy Top) and morphological traits (okra leaf, smoothleaf) which reduce the development of pest populations. However there remains much genetic variability in insect resistance traits and in the potential of cotton to compensate for damage (Sadras 1995, Sadras and Fitt 1997).

17.3.2 Effective Sampling for Pests, Beneficial Insects and Plant Damage, Combined with Thresholds

17.3.2.1 Rigorous and Regular Crop Sampling

Regular crop sampling for pests, plant damage, crop development and beneficial insects is critical for effective IPM (Deutscher and Wilson 1999a). Regular sampling (every 3 days during crop development) means that decisions to delay control can be monitored and action taken if the situation changes while the pest population can still be effectively controlled with selective insecticides.

17.3.2.2 Use of Combined Pest and Damage Thresholds

Thresholds are an essential tool to ensure that insecticides are only applied if economic loss is reasonably expected to occur (Deutscher and Wilson 1999b, Farrell 2006). However, thresholds based solely on pest numbers alone assume that all cotton crops respond to pest density in a similar way and does not account for the impact of beneficial insects. Many other factors may ameliorate crop response to pests (e.g. vigour, disease, temperature, moisture status and nutrition) such that the crop compensates for damage. Guidelines have been established for the amount of damage that plants can tolerate without loss of yield or delay (Wilson et al. (2003)). By integrating compensatory responses into thresholds it is possible to identify those situations where pests may have exceeded a threshold but the crop will recover without loss, or that the crops yield potential is such that insect damage is not the yield limiting factor; as often is the case in raingrown crops. In these situations, where insect control in non-economic, insecticide applications may be prevented.

17.3.3 Conservation and Use of Beneficial Insects

Cotton fields typically harbour a rich diversity of arthropods. In Australia, up to 450 different species have been recorded in unsprayed fields (L. Wilson unpublished) and a significant proportion of these are beneficials. It is striking that the key beneficial groups in cotton are similar in many parts of the world (Hearn and Fitt 1992), but their impacts and value have often proven difficult to demonstrate.

While predators and parasites are important components of IPM systems there are often severe limitations in the capacity of beneficials to control some pests, particularly the Heliothines. These pests are highly mobile, highly fecund, well adapted to exploit diverse cropping systems (Fitt, 1989, 1994) and capable of explosive infestations of crops. Consequently an important area of research, beyond simply minimizing the use of disruptive chemicals, has been to identify means to conserve, augment or manipulate beneficial populations. Conservation of natural enemies requires considerable ecological understanding of their seasonal phenology, habitat and prey requirements. Extensive research has now defined the key predators and parasitoids and their basic biology. The majority of predators are generalists, able to sustain populations on a diversity of prey types. Predator abundance can be readily monitored and estimates of abundance utilised in decision making through a predator/prey ratio which indicates when predators are sufficiently abundant to have impact (Mensah 2002a,b). Mechanisms to encourage beneficial insects during the cotton season include:

17.3.3.1 Preferential Use of Selective Insecticides

New generation insecticides are much more selective than the older suite of organophosphate, carbamate and pyrethroid pesticides which characterised Australian cotton a decade ago. A number of new compounds and chemical groups (e.g. spinosad, emamectin, indoxacarb, pymetrozine, diafethiuron and methoxyfenozide) together with biologicals (NPV virus and Bt sprays) provide powerful IPM tools as they are less disruptive to beneficial populations. Independent information on the efficacy and non-target effects of all current insecticides has been obtained locally (Wilson et al. 2002). Understanding the particular characteristics of insecticides is important. For example, spinosad (Tracer®) has a low impact on predatory Coleoptera and Hemiptera, but is very disruptive of micro-Hymenoptera (including *Trichogramma*), ants and thrips, which eat mite eggs (Wilson et al. 1996).

17.3.3.2 'Site-specific' Pest Management

Historically cotton growers often treated the whole farm as the unit for pest management. While this practice reduced application costs and provided some streamlining of farm operations it also meant that beneficial populations could be impacted over wide areas, leaving no refuge for beneficials to recolonise sprayed fields. By treating only fields that are over threshold with selective insecticides, this disruption can be minimised. 'Site specific management' is in a fundamental sense a type of precision agriculture.

17.3.3.3 Selection of Appropriate Insecticidal Seed Treatments

By definition, the use of 'at planting' insecticides, applied in the soil (such as aldicarb or phorate) or applied directly to the seed as a seed treatment (such as imidocloprid, thiodicarb and fipronil), is 'prophylactic' and may not seem compatible with an IPM approach. The main targets of these seed treatments are thrips and soil insects, (e.g. false wireworm) and the insecticides themselves are reasonably selective (Wilson et al. 2002) with minimal impact on many beneficial groups. Their selectivity is based on the fact that they do not contaminate the foliage but are absorbed by the plants. Since beneficial insects do not feed directly on the plant they are largely unaffected by seed applied insecticide treatments or in furrow application of these insecticides. Therefore, in situations where there is a reasonable expectation of an economic benefit from control of thrips or soil insects, the use of 'at planting' insecticides may be a better choice than the conventional approach of treating at pest threshold.

17.3.3.4 Effective Use of Nursery Crops

Perennial crops such as lucerne which are attractive to many insects and offer a permanent habitat on-farm can provide an effective buffer against the unpredictability of natural populations. Beneficial populations can be manipulated by cutting the crop or with the aid of 'food' sprays to enhance their movement into cotton crops (Mensah, 2002 a,b). Establishment of these crops is best done in winter so that crops are tall enough to serve as a habitat for insects.

17.3.4 Preventing the Development of Insecticide Resistance, Including Bt Cotton

Australia has a long history of problems with the evolution of pesticide resistance in key pest populations, but also a world leading position in effective resistance management (Forrester et al. 1993). The IPM system needs to accommodate the need to protect new pesticide technologies. All new selective pesticides are incorporated in the Insecticide Resistance Management Strategy (IRMS) developed under the auspices of the industry based Transgenic and Insecticide Management

Strategies (TIMS) committee. A rigorous and pre-emptive resistance management strategy is also in place for Bt cotton varieties (discussed later). A key component of resistance management for *H. armigera* is the destruction of diapausing pupae that are a potential reservoir of resistance genes (Fitt and Daly 1990). This is a core non-insecticidal component of both the IRM and IPM strategies. Growers are advised to sample cotton stubble for overwintering pupae, and by using published guidelines, determine and prioritise which fields require control. Fields which have grown Bt cotton require mandatory cultivation and incorporation of the crop residue to eliminate plant regrowth and destroy pupal stages of potentially resistant pest populations.

17.3.5 Managing Crop and Weed Hosts of Key Pests

Some rotation crops provide an over-winter host for pests and some cotton diseases (eg. faba beans (mites, aphids), safflower (mites, mirids), chickpeas (*H. armigera*) or cereals (*H. armigera* and thrips). At the same time winter rotations provide a seasonal refuge for beneficial insect populations. Balancing these issues needs to be taken into account in the choice of rotation crop and its management. Similarly, weeds and cotton regrowth following harvest can provide over-winter hosts for a number of pests including *Helicoverpa*, mites (Wilson 1994), mirids, aphids, tipworm, cutworm, armyworm and silverleaf whitefly. Poor in-field hygiene is particularly a problem with spider mites, aphids and mirids as these pests can move off the weeds and onto seedlings in the following season. Again weeds provide a refuge for beneficial species and the trade-off between pests and beneficials needs to be considered. At the scale of individual fields on farms it is likely that the safest course is for strict management of in-field weeds and regrowth.

17.3.6 Using Trap Crops Effectively

Trap crops are by definition attractive to key pests and can be managed to concentrate the pest population into a defined, preferably small area, where they can be more easily controlled. One example is the use of spring chickpea crops to capture eggs from *H. armigera* moths that emerge from over-wintering diapause (Ferguson et al. 2000). These moths are potential carriers of genes for pesticide resistance from one season to the next (Daly and Fitt 1990). Trap crops are a means to concentrate *H. armigera* populations into a limited area where they can be destroyed using biopesticides or by cultivation of the trap crop thereby reducing the carry-over of resistance genes and overall population size. This practice has been employed on an area-wide scale in some districts.

A second example is the use of spring lucerne trap crops to capture adults of the green mirid, *Creontiades dilutus* and avoid infestation of adjoining cotton. Green mirids are important pests in cotton, often causing plants to shed squares (flower buds) or young bolls and damaging maturing bolls, causing yield loss. Green mirids prefer lucerne (new growths or shoots) to cotton. Lucerne crops adjacent to, or as strips within, cotton crops act as a sink for green mirids. By alternatively slashing half of the lucerne at four weekly intervals, new regrowth of lucerne can be maintained and the green mirids can be maintained in the lucerne without moving into the cotton (Mensah and Khan 1997). This strategy is not however, widely utilized in Australia.

17.4 Transgenic Bt Cottons in IPM

Transgenic cotton varieties expressing the delta-endotoxin genes from *Bacillus thuringiensis* subsp. *kurstaki* (Bt) offer great potential to dramatically reduce pesticide dependence for control of the major lepidopteran pests and consequently offer real opportunities as a component of sustainable and environmentally acceptable IPM systems.

Bt cotton varieties expressing the Cry1Ac protein were first registered in Australia in 1996 (INGARD®) and have since been superseded by the Bollgard II varieties, which express the Cry 1Ac and Cry 2AB proteins, since 2004. Fitt (2003; 2004) provide a comprehensive assessment of the impact of Bt cotton in Australia over the first six years of commercial use while a more recent description of the benefits of Bollgard II cotton can be found in Pyke (2007). In comparison to the average usage of insecticides on conventional crops, average usage on Ingard® crops over the eight seasons 1995/96 to 2003/04 was 44 percent lower. Over the four seasons 2002/03 to 2005/06, average insecticide/acaricide usage was 82 percent less on Bollgard®II than on conventional crops. As discussed later there has been a similar trend of reduced pesticide use on conventional cotton. These reductions in insecticide use on Bt cotton have been reflected in other countries as well (Fitt 2008).

The most consistent “winner” from Bt cottons has been the environment, with reduced pesticide loads, while the cotton industry has gained long term sustainability through the progressive adoption of more integrated pest management approaches using Bt-cotton as a foundation. With progressive improvement in varietal performance and experience of growers and consultants in managing the technology economic returns have also been substantial.

17.5 Resistance Management

The major challenge to sustainable use of transgenic Bt cottons is the risk that target pests, particularly *H. armigera*, may evolve resistance to the Cry1Ac or Cry2Ab proteins. For this reason a pre-emptive resistance management strategy was implemented to accompany the commercial release of transgenic varieties (Roush et al. 1998). The strategy, based on the use of structured refuges to maintain susceptible individuals in the population (Roush et al. 1998), seeks to take advantage of the polyphagy and local mobility of *H. armigera* to achieve resistance management by utilising gene flow to counter selection in transgenic crops. By contrast, extensive natural refuges effectively nullify the resistance risk in *H. punctigera*. Indeed *H. punctigera* provides an excellent natural example of the capacity of the refuge strategy to reduce resistance risk

Key elements of the Bollgard II® cotton resistance management strategy are:

1. effective refuges on each farm growing Bollgard II® cotton
2. defined planting window for Bollgard II® cotton to avoid late planted crops that may be exposed to abundant *H. armigera* late in the growing season
3. mandatory cultivation of Bollgard II® crops and crop residues after harvest to destroy most overwintering pupae of *H. armigera*
4. removal of volunteer Bollgard II® plants
5. defined spray thresholds for *Helicoverpa* to ensure any survivors in the crops are controlled
6. monitoring of Bt resistance levels in field populations

Australian growers can currently choose from 5 different refuge options (sprayed conventional cotton, unsprayed cotton, sorghum, maize or pigeon pea) each with a different area determined by the relative productivity of the refuge (Fitt and Tann 1996, Baker et al. 2008 in press). Refuge crops cannot be treated with Bt sprays, and must be in close proximity to the transgenic crops (within 2 km) to maximise the chances of random mating among sub-populations (Dillon et al. 1998).

An additional element of the strategy was a phased introduction of INGARD® varieties and a cap on the area at 30% of the total cotton area. In their first year INGARD® varieties were grown on 30,000 ha representing about 8% of the total cotton area in that year. After that the area increased in 5% increments each year up to the 30% cap. Bollgard II® varieties were approved for use in 2003 and have replaced Ingard completely. The 30% cap was removed with Bollgard II, due to the greater protection against resistance afforded by the two genes, and Bollgard II varieties now account for about 85% of the planted area. The two gene varieties provide much better efficacy and hence even greater reduction in pesticide requirement, but their main purpose is to provide much greater resilience against the risk of resistance (Roush, 1998).

This necessity of a pre-emptive resistance management strategy has been borne out by resistance monitoring: the estimated R frequency for alleles conferring resistance to Cry1Ac in Australia is < 0.0003 with a 95% confidence interval (CI) between 0 and 0.0009. In contrast, the estimated R frequency for alleles conferring resistance to Cry2Ab in Australia is 0.0033 with a 95% CI between 0.0017 and 0.0055 (Mahon et al. 2007). These frequencies have been unchanged over the ten years that Bt cotton has been used in Australia. A benefit of the reduction in insecticide use on Bt cottons has been a decline in resistance levels to conventional insecticides in *H. armigera* and other pests such as mites and aphids (Herron and Wilson, 2006; Rossiter and Kauter, 2006).

Bt cotton varieties are not perceived as "magic bullets" for pest control in Australia. Instead they are viewed broadly as an opportunity to address environmental and social concerns about cotton production and more specifically as a foundation to build IPM systems which incorporate a broad range of biological and cultural tactics (Fitt, 2000; Wilson et al. 2004; Fitt 2008). In the past, the broadspectrum character of most available insecticides and the need for season long control of *Helicoverpa* spp. greatly hampered the capacity to implement IPM beyond simple elements such as sampling and use of thresholds. Research has shown little effect of Bt cottons on non-target species, including non-lepidopterous pests, beneficial insects, and other canopy dwelling and soil dwelling species (Fitt, 2000; Fitt and Wilson, 2002; Whitehouse et al. 2005). Survival of beneficials is markedly higher than in conventional sprayed cotton, and they provide control for some secondary pests, particularly those that are induced pests in sprayed cotton (eg. mites, aphids and silverleaf whitefly).

17.6 Extension and Implementation of IPM

Defining and formalising an IPM system is just the first step. Achieving effective implementation requires a consistent and coherent communication and extension effort. The cotton industry has been well served by a National Cotton Extension Team resourced largely by the Cotton R&D Corporation and the Australian Cotton CRC and by a highly professional core of professional consultants. The extension team has representatives in all the main cotton regions, and provides a highly coordinated vehicle for consistency and co-operation in providing information.

The extension team used a range of strategies to deliver the IPM system (Christiansen 2002). These included field days to discuss IPM issues, co-ordinated experiments and demonstrations across several regions, production of regular newsletters, the published IPM Guidelines themselves, together with other technical information which forms ENTOpak. This compendium of pest management information includes the IPM guidelines, a pest and beneficial identification guide, and supporting documents providing detailed information on pest thresholds, sampling, pupae control, selectivity of insecticides, crop damage monitoring and planning of last irrigation. Importantly these documents are cross-referenced to other ‘Paks’ which provide support in implementing IPM, for instance MACHINEpak, NUTRIpak, WATERpak, WEEDpak and DISEASEpak, all of which include issues or approaches relevant to IPM.

As part of a drive to enhance environmental management of cotton farms, the industry has also implemented a Best Management Practice (BMP) approach (Williams and Williams 2000). This provides a framework for growers to evaluate their management performance against the best standards in the industry, for identifying areas of improvement, and documenting this in an auditable fashion. The core principles of the IPM guidelines form one module in the ‘Best Management Practice’ Manual. This provides growers with a means to assess how they are progressing in adopting IPM principles on their farm.

Effective extension has also fostered the development of regional IPM; or Area Wide Management groups, where groups of growers agree on core goals and communicate throughout the season to achieve a local regional approach to pest management. In some instances this participatory research approach (Dent 1995) has grown to a truly area-wide management system where pest management efforts are co-ordinated across a region by using understanding of the pests' ecology and interactions with the farming system to reduce abundance (Ferguson and Miles 2002).

The cotton industry has undertaken a significant capacity-building exercise through formalized education in IPM under the premise that people who understand the IPM system will be able to make better IPM decisions. A tertiary level Cotton Production Course developed and delivered by the University of New England [NSW, Australia] and the Cotton Cooperative Research Centres has produced 180 graduates in 13 years, comprising many of the industry's field agronomists, extension personnel and growers. At a vocational training level, a short-course in IPM was developed specifically for cotton growers and delivered by the Cotton CRCs between 2001 and 2005 with 221 graduates; mainly cotton growers and their immediate staff (Hickman 2006).

Since the inception of the SIRATAC system, computer based decision support systems (DSS) have been a feature of the Australian cotton industry. The CottonLOGIC suite of DSSs provide support for the key elements of IPM and provides a benchmark against which decisions can be compared (Deutscher and Bange 2003). CottonLOGIC allowed users to input regular pest and plant damage counts and evaluate them against defined pest and damage thresholds to determine if control is economically justified. Entomologic included 'smart' thresholds such as a combined sucking pest threshold, to allow for the effect of multiple pests each below threshold, a *Helicoverpa* spp. development model to forcast abundance over the next three days based on current populations of eggs and larvae (allowing for mortality) and a mite threshold model that predicts yield loss from mites based on the time and rate of increase of populations. CottonLOGIC was also deployed on mobile hand-held devices [the Palm® OS] and provided further flexibility with a portable system to support objective sampling for pests and beneficials, access to the pest development models and yield loss predictions (Hearn and Bange 2002) and previous crop history all available in real time in the field. Data can later be downloaded for more thorough analysis of pest and crop performance.

The final critical factor in gaining support for IPM systems has come from favourable economic analyses of IPM. Hoque et al. (2000) analysed economic and agronomic performance data from cotton growers and showed that the "soft", IPM approach generally had equal or higher gross margins than a more traditional approach using "hard", more disruptive chemicals. The difference was attributed to higher beneficial insect populations in the fields managed with more selective insecticides. This assertion was supported by (Mansfield et al. 2006) who found higher beneficial populations in fields with softer spray regimes. Such studies have now been extended to other regions with similar results. These studies and analysis were critical in providing 'economic' credibility for the IPM approach, not just use of selective insecticides, but tacit recognition of the value of beneficial populations and the role of other ecosystems factors such as nursery crops, selection of winter rotations, and the role of non-cultivated vegetation in contributing to beneficial populations.

17.7 Impacts of IPM

Adoption of an IPM approach, incorporating many of the elements above, has had a dramatic uptake over the past 4 years (Christiansen and Dalton 2002). There has been significant change in grower attitudes over the past 5 years, increased uptake and use of the CottonLOGIC DSS for its scientific values in IPM decision support as well as for accurate record keeping (Deutscher and Bange 2003). More importantly there have been significant reductions in pesticide use (expressed as active ingredient) on both conventional and transgenic crops (Fig. 17.1), achieving environmental gains and enhancing future sustainability of the industry.

Care must be taken in interpretation of Fig. 17.1 since insecticide use is linked to pest abundance and *Helicoverpa* has been at relatively low densities during the prolonged drought in many cotton areas. Likewise several newer pesticides are active at much lower concentrations than the pesticides they replaced. It also seems unlikely that the reduction in pesticide use on conventional cotton results from the regional impact of Bt cotton on *Helicoverpa* abundance since over the period from 1996 to 2003, the area of Bt cotton was limited to a maximum of 30% of the cotton in a region. A number of factors are likely involved here, but one important possibility is that the coincident release of Bt cotton and the industry wide extension effort on IPM, allowed many growers to build confidence in the potential for IPM by managing their Bt cotton crops. They were able to become more comfortable with seeing a “living” crop, filled with numerous and mostly innocuous or beneficial insects, more attuned to the critical importance of managing agronomic inputs, and

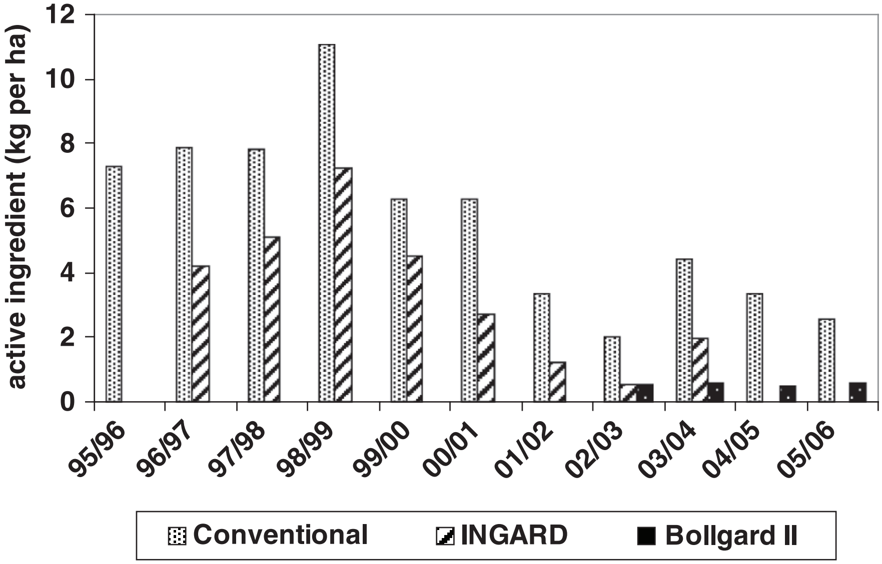

Fig. 17.1 Changes in active ingredient of insecticide applied to Bt (Ingard or BGII) cotton crops in Australia compared to conventional varieties grown in the same seasons

more willing to work cooperatively with neighbours through the IPM and areawide groups.

It is interesting however that in the years since the release of Bollgard II insecticide use on conventional cotton has increased and decreased, probably largely reflecting pest pressure, but also the effects of drought and low cotton prices which encourage greater use of the cheaper but broader-spectrum insecticides such as organophosphates and synthetic pyrethroids that tend to lead to secondary pest outbreaks. Sprays applied to Bollgard II are chiefly for control of green mirids, which are no longer controlled by sprays applied against *Helicoverpa* spp. and can now build through the season and cause significant damage to squares and young bolls. A recent survey shows that many sprays applied against mirids were at below both the pest abundance and plant damage thresholds (Whitehouse 2006). This may reflect lack of confidence in sampling and thresholds for these pests and hence at least for this pest we face some of the attitudinal challenges formerly faced for *Helicoverpa* in the mid 1990s.

17.8 Conclusions

IPM systems for future production of many broadacre and horticultural crops will, of necessity, be more complex than the pesticide based systems currently in place, and will require greater effort on the part of crop managers whether they be professional consultants or farmers themselves. In essence IPM reflects a sound interaction of science and pragmatism to achieve productive, viable and sustainable production systems. A key ingredient will always be investment in education and extension to build on the values of sound science.

An added benefit from the level of communication and awareness of insect pests engendered by an inclusive IPM approach is that potential biosecurity incursions may be more rapidly noticed. Australia's next big IPM challenges may well come from incursions of new pests or plant disorders (e.g. viruses) vectored by new or existing insects. Australia's geographic isolation gives it an advantage in this respect; however recent incursions of the silverleaf whitefly (*Bemisia tabaci* Biotype B) and a range of other pests serve as reminders of the vulnerability of agriculture to invasive species. In an effort to manage this risk, the Australian cotton industry, in association with researchers, Federal and State governments and Plant Health Australia in 2006 developed a National Biosecurity Plan for the cotton industry (see http://www.planthealthaustralia.com.au/project_documents/); a living document that identifies key threats and situation-specific strategies to rapidly identify and manage incursions should they occur. Critical to the early identification of new pests, disorders and diseases are consultants and agronomists, who are regularly monitoring crops, highlighting how important it is that this practice of regular crop checking be maintained in Bt crops. The incursion and subsequent spread of silverleaf whitefly in the 1990s illustrated that successful management relies on a well co-ordinated IPM approach.

As farming systems change the pest complex will also change. The fundamental role of IPM in reducing pest pressure and insecticide use means that it must continue to evolve. This evolution is evident in the changing pest complex in Bollgard II crops. The ongoing adoption of IPM remains a significant challenge, even under a system where a high proportion of area is under Bt cotton. While Bt cotton has provided a good platform for IPM, historically the big driver for IPM adoption was the immediate and significant threat of insecticide resistant pests. Under a Bt dominated system, the immediacy or urgency of pest threats tend to be fewer, and subsequently the level of interest in concepts of Area Wide Management and some of the more novel IPM tools has waned somewhat. In this scenario we run the risk in time of people forgetting the basics; the hard lessons learned during the period before Bt cotton.

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Chapter 18
Impact of IPM and Transgenics in the Chinese Agriculture

WenJun Zhang and Yi Pang

Abstract The cultivation of transgenic pest-resistant crops may reduce pesticide application, improve production and increase economic benefit. Breeding and planting transgenic pest-resistant crops is expected to be a promising way to control pests.

Pest-resistant transgenic researches in China began in the early 1990s. In 1992, China developed the country's first Bt protein gene (CryIA gene) with the intellectual property right of its own. Up till now, the exogenous genes, such as Bt protein gene, trypsin inhibitor gene (CpTI gene), etc., have been transformed into cotton, and more than 50 commercially approved transgenic cotton varieties were developed. Since the 1970s, with the widely uses of chemical pesticides in cotton production, the pesticide-resistance of cotton bollworm (*Helicoverpa armigera* (Hübner)) dramatically enhanced. Cotton acreage in China declined from 6.835 million ha in 1992 to 4.985 million ha in 1993. In subsequent years, cotton bollworm seriously occurred every year. Since 1998 the adoption of insect-resistant varieties has effectively controlled the outbreak of cotton bollworm. Since the late 1990s, the cultivation area of transgenic insect-resistant cotton in China has been rapidly expanding, and its proportion in the total domestic cotton planting area has been increasing year by year. In 1998, transgenic insect-resistant cotton began to be planted in the Yellow River valley, and that year's acreage reached 240,000 ha, only 5.4% of the total cotton planting area; The planting area increased to 647,000 ha, 1.2 million ha, 1.933 million ha, 1.867 million ha, 3.067 million ha, and 3.104 million ha in the years 1999–2004, accounting for 17%, 31%, 40%, 45%, 60%, and 50% of the total area, respectively. The planting area of domestic transgenic insect-resistant cotton accounted for 30%, 60%, and 70% in the years 2002–2004. Due to the cultivation of transgenic insect-resistant cotton, pesticide application in China reduced by 123,000 t and cotton yield increased by 9.6% during the three years 1999–2001. Currently, almost all of the planted cotton in Hebei, Henan, and Shandong Province is transgenic insect-resistant cotton. In the Yangtze River valley, transgenic insect-resistant hybrid cotton holds the dominant position and its planting

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area has been growing in the past years. So far, the total planting area of transgenic insect-resistant cotton in China has reached 4.667 million ha, with an average income of 2,130∼2,400 RMB Yuan/ha. Annual reduction in chemical pesticide application reaches 20,000∼31,000 t, equivalent to 7.5% of China's annual total production of chemical insecticides. Breeding of transgenic insect-resistant rice in China developed quickly in the past years. To date, CryI, CpTI, and GNA genes, etc., have been transformed into the rice, and some insect-resistant rice varieties (strains) were developed in China. They can be used to suppress rice insect pests such as *Chilo suppressalis* (Walker), leafrollers, and brown planthopper. Researches showed that the adoption of transgenic insect-resistant rice can reduce 70∼80% of insecticide application and would not affect the rice biodiversity. From recent years' field trials in Hubei and Fujian, indicated that insecticides were seldom used throughout the growing season and rice yield can increase by 12%. So far, the safety evaluations and experiments on the commercial production of transgenic insect-resistant rice have not yet showed any significant security issues. However, as rice is the main food crop in China, the application for commercialization of transgenic rice has never been approved. In addition to cotton and rice, the insect-resistant transgenics for wheat, soybean, maize, and other crops have being made in China. China has imported some of the transgenic crops and resulted in certain impacts. For example, due to the low production cost and better quality, the transgenic soybean of the United States exhibits the obvious economic advantages. The import of transgenic soybean of the United States resulted in the serious stock of domestic soybean production, and undermined the economic interests of Chinese farmers.

So far, the most significant negative impacts for planting transgenic insect-resistant crops, in particular cotton, are the outbreak of secondary pests and the impairment of arthropod community, etc. Due to the problems of planting transgenic insect-resistant crops, such as the narrow insect-resistance spectrum, the increased resistance of insect pests to transgenic crops, the possible outbreak of secondary insect pests, and the potential environment and biodiversity risks, it is necessary to follow IPM principles and combine the other control measures. Chinese scientists have summarized the practical problems in planting transgenic insect-resistant crops and explored various IPM measures, such as resistance management, intercropping, seed purifying, protection of natural enemies, etc., to address these problems. The IPM measures have being implemented in China.

Keywords Transgenics · IPM · insect pests · resistance · agriculture · China

18.1 Introduction

A major way to achieve greater crop yields is to minimize the pest associated losses, which are estimated at 14% of the total agricultural production: 84% in cotton, 83% in rice, 74% in potato, 59% in maize, 58% in soybean, and 52% in wheat (Oerke et al. 1994; Sharma et al., 2000). Transgenic pest-resistant crops are strongly lethal to pests. Transgenic pest-resistant crops are the plants carrying exogenous pest-resistant genes that artificially separated, constructed, and introduced into plant, which can be efficiently expressed in vivo and can maintain the genetic stability, and through which plants may synthesize not less than one kind of substance that are toxic to specific pests (Gu et al., 2005; Xiong et al., 2006). Breeding and planting transgenic pest-resistant crops is a promising way to control pests. Cultivating transgenic pest-resistant crops provides a new way to reduce pesticide application, improve production and increase economic benefit (Qiu et al., 2005; Wang et al., 2006).

Transforming pest-resistant gene and constructing transgenic pest-resistant crops must be conducted through such techniques as gene gun, *Agrobacterium*-mediated transformation, PEG, electroporation, and other methods (Zhang et al., 2001). There are currently three kinds of the most studied insect-resistant genes (Gu et al., 2005): (1) *Bacillus thuringiensis* (Berliner) (Bt) toxic protein gene. The Bt gene has many different strains and the δ-endotoxin gene within different strains is specific to different insects. Bt has been discovered to have more than 60 sub-species, and their genes are in general classified as six major categories in accordance with their insecticidal spectrum, of which CryI is only toxic to lepidopterans, CryII is toxic to lepidopterans and coleopterans, CryIII is only toxic to coleopterans, CryIV is only toxic to dipterans, CryV and CryVI are specifically toxic to nematodes. The insecticidal crystal protein that resists hymenopterans and nematodes has also been discovered (Hu et al., 2006). At present transgenic Bt crops account for the largest proportion of transgenic insect-resistant crops. In the United States alone, there are dozens of crops for field experiments. As early as in 1997, Bt cotton, Bt maize and Bt potato were commercially produced in the United States, Australia, Japan, Canada, South Africa, Argentina and some of the European countries (Sun et al., 2002). The Bt crystal protein is toxic to insects. It will be hydrolyzed into toxic peptides in the alkaline intestinal environment after it was fed by insect, and thus the intestinal epithelial cells and organs can be damaged. (2) Protease inhibitor (PI) gene. Plant protease inhibitors are the most abundant proteins in the nature. They are abundant in the seeds and tubers of plants. Currently used genes of plant protease inhibitors in breeding of transgenic insect-resistant cotton, which have been transformed into plants, include soybean trypsin inhibitor gene (SKTI), cowpea trypsin inhibitor protein gene (CpTI), and Arrowhead trypsin inhibitor protein gene (API). Compared with Bt gene, they exhibit certain advantages, such as the broader spectrum of insect-resistance, no side effects on human, and the lower insect tolerance, of which CpTI was studied in-depth and widely used at present. CpTI gene exhibits a broader spectrum of insect-resistance. It is resistant to spodopterans, the Chrysomelidae insects, the Sphingidae insects, and cereal insects. It can kill cotton bollworm (*Helicoverpa armigera* (Hübner)), the Curculionidae insects, and corn borers, and is toxic to locusts. Once the insect feeds on protease inhibitor, the later can affect the normal digestion of food protein. Meanwhile, EI composite formed by protease inhibitor and digestive enzymes stimulates the excessive secretion of digestive enzymes, and through feedback from the nervous system the insect yields anorexia reaction, ultimately causing the abnormal development and death of the insect. (3) Exogenous lectin gene. Exogenous lectin is a protein widely existed in the plant tissue. It is particularly rich in storage organs and reproductive organs. Once it is fed by insect it will be released from the digestive tract and will be combined with the glycoprotein on gastrointestinal membrane, and thus retard the normal absorption of food nutrients. Meanwhile, it will likely induce disease lesions in the digestive tract, promote the proliferation of digestive bacteria, and thus kill the insect. In addition to the above three types of genes, there are several additional genes, like the amylase inhibitor gene, insect neural hormone gene, chitinase gene, ribosomal protein inactivation gene, lipoxygenase gene, disease infection gene of cotton bollworm, synthesis gene of toosendanin, and peroxidase gene, are available.

The first transgenic crop born in 1983. In 1986, Abel and his colleagues firstly obtained a CP gene transgenic TMV-resistant tobacco plant. In 1987 the Belgian scientists firstly reported the transformation of exogenous insect-resistant gene to tobacco (Vaeck et al., 1987), followed by Barton (Barton et al., 1987) and the Monsanto's Fischhoff (Fischoff et al., 1987), who reported their transgenic insect-resistant tobacco and tomato plants. Transgenic rice plants also came out in 1988. All of these achievements created a new area for plant pest-resistance breeding (Zhang et al., 2001; Sun et al., 2002). In 1993 the transgenic tomato featured by fresh preservation and ripening delay, developed by Cagene, was licensed for marketing in the United States, which initiated the commercial application of transgenic crops in the world. Up till now a variety of insect-resistant genes have been transformed into tobacco, rice, maize, cotton, potato and other crops, and insect-resistant transgenic plants were obtained. Some transgenic insect-resistant plants have been licensed for commercial production or for field releases (Hu et al., 2006).

So far, the global transgenic crops for commercial cultivation include soybean, maize, cotton, rapeseed, potato, tobacco, tomato, pumpkin, and papaya, etc. Most of them carry insect-resistant genes; about 18% of transgenic maize varieties (lines) carry insect-resistant genes, while the other varieties contain both herbicide-tolerant and insect-resistant genes; 73% of the transgenic soybeans, maizes and rapeseeds have herbicide-tolerant genes. In 2002, transgenic soybeans and rapeseeds were all herbicide-tolerant; and 32% of transgenic cottons were herbicide-tolerant. The major transgenic crops that resist both herbicides and insects are maize and cotton. Transgenic crops with both herbicide-tolerant and insect-resistant traits in the world account for about 8% of total planting area (Yang et al., 2005). According to the statistics, in 2004 there were 14 countries with planting area of transgenic crops larger than 50,000 ha. From the largest to the smallest acreage, they were the United States, Argentina, Canada, Brazil, China, Paraguay, India, South Africa, Uruguay, Australia, Romania, Mexico, Spain, and the Philippines. In 1996 transgenic plants began to be commercially produced, and the planting area in that year was 1.7 million ha. After about 10 years' development, it reached more than 81 million ha in 2004 (Zhu and Ni, 2006), and reached 114.3 million ha in 2007 (ISAAA, 2007).

In China, as early as the 1950s, the insect-resistant wheat varieties "Xinong 6028" and "Nanda 2419" were cultivated to control wheat midges (Wang et al., 2006). In 1987, the transgenic insect-resistant Bt tobacco and tomato were obtained for the first time. In 1991, China's "863" high-tech development plan initiated a project on transgenic insect-resistant crops, and then the state transgenic plant projects, the special fund for cotton production from the Ministry of Agriculture, Chinese agricultural science and education fund, and the industrialization projects of National Planning Commission were sequentially implemented in China. In 1992 the CryIA insect-resistant gene with independent intellectual property right was artificially synthesized in China, which made China the second country after the United States for independently constructing the insect-resistant gene with intellectual property right (Qing and Zhao, 2004; Xia et al., 2004).

At present, nearly 50 transgenic plant species, involved about 100 genes, are being studied in China. Many of the pest-resistant genes and the genes related to resilience, yield, quality and fresh preservation have been cloned, seven BYDV-resistance, powdery mildew-resistant, and wheat scab-resistant wheat varieties have been validated, and the accumulated planting area has reached 100×10^4 ha (Yang et al., 2005). More than 100 genes, involved about 50 transgenic plant species like rice, wheat, maize, soybean, potato, peanut, poplar, papaya, tobacco, sweet melon, and pepper, etc., are being at different stages of development (Yang et al., 2005). The plants such as cotton, tomato, sweet pepper, and *Petunia hybrida* (Vilm), etc., genetic engineering vaccines, and some microorganisms for forage uses, were licensed for commercial production. Cotton, soybean, tobacco, tomato, pepper, potato, rice, cucumber, poplar, maize, and several microorganisms have been approved for environmental release. In February 2004, the Ministry of Agriculture of China issued the notice No. 349 for safety certificates of the first batch of imported agricultural transgenic organisms, including the transgenic Kangnonda soybean applied by Monsanto, the transgenic insect-resistant and herbicide-tolerant maize, transgenic insect-resistant cotton, and herbicide-tolerant cotton (Wang et al., 2005). Currently, the development of transgenic insect-resistant cotton and rice in China has been at the advanced level in the world (Zhang et al., 2004).

18.2 Pest-resistant Transgenics and Its Impact

18.2.1 Transgenic Insect-Resistant Cotton

18.2.1.1 Breeding of Transgenic Insect-Resistant Cotton

China is a major country of cotton production in the world. Since the 1920s, China has started to collect cotton germplasm resources. China's cotton germplasm resources were further expanded and enriched through numerous surveys, collection, and exchanges on international cotton germplasm (Gu et al., 2005). In order to find ways to control cotton bollworm, China's "863" high-tech development plan approved the "transgenic insect-resistant cotton" research in 1991. In 1992, the Chinese Academy of Agricultural Sciences (CAAS) synthesized an insect-resistant Bt gene, i.e., CryIA gene, which was different from the one of Monsanto in the United States, and obtained China's own intellectual property right. Collaborating with Shanxi Academy of Agricultural Sciences and Jiangsu Academy of Agricultural

Sciences, CAAS transformed the modified CryIA gene into cotton and obtained the engineering plants with high resistance to cotton bollworm. Moreover, the whole sequence of Bt insect-resistant gene was artificially synthesized and a high efficient expression vector was successfully constructed based on Bt protein active site and the principle of codon preference (Kong et al., 2004; Gu et al., 2005). In 1993, by using *Agrobacterium*-mediated transformation and a new invented method, the pollen tube channel technique, the insect-resistant gene constructed earlier were successfully transformed into the major cotton varieties in China, Zhongmian 12, Simian 3, etc., and yielded a positive response in the molecular detection. Their insect-resistance surpassed 90% in the biological test on pesticide. Meanwhile, the transgenic cotton strain with higher insect-resistance was obtained, which made China become the second country to artificially synthesize insect-resistant gene and transform it into cotton in the world. Since 1995, the construction of the insect-resistant gene has developed to bivalent gene from monovalent gene. Cotton researches on bivalent insect-resistant gene were conducted. CryIA + CpTI genes were transformed into a number of dominant cultivars and produced some bivalent transgenic cotton lines, and were approved for commercial production (Qing and Zhao, 2004). At the same time, China began to construct genes for improved quality and yield. The promoters for the expression of green top tissue and phloem tissue, genital-specific expression, fiber and boll skin specific gene expression, etc., were successfully developed. All of these works laid a solid foundation for the correct expression of functional genes, the improvement of growth and traits of cotton development, and the improvement of cotton yield and quality. Besides common used *Agrobacterium*-mediated transformation and gene gun methods, Chinese scientists invented the method of pollen tube transformation. The transformation rates for three methods reached 5%, 8% and 5%, respectively; transformation efficiencies increased by 4%, 3%, and 1%; and transformation cycle was shortened to 4.5–7 months; more than 10,000 transgenic plants were constructed. The pipeline operation for plant genetic transformation was initially realized (Xia et al., 2004).

Until 2006, China has bred 52 cotton varieties (lines), of which 21 varieties passed safety evaluation, and 12 varieties passed validation. In these varieties (lines), another 7 insect-resistant hybrid cotton varieties and 3 bivalent transgenic insect-resistant cotton varieties were included. Moreover, Hebei Province and Anhui Province have also founded joint ventures with the Delta Cotton Company of the United States and imported seven transgenic insect-resistant cotton varieties (Xiong et al., 2006).

18.2.1.2 Insect-Resistant Effect of Transgenic Cotton

An on-site investigation and field survey in China indicated that the number of eggs of cotton bollworm on Bt cotton and conventional cotton had not significant difference (Wang et al., 1999; Xu et al., 2004), but there was a significant difference in the residual number of larvae; the number of larvae on Bt Cotton was significantly lower than that on conventional cotton. Bt cotton would not yield any significant impact on the occurrence of cotton aphid, *Aphis gossipi* (Glover) (Wang et al., 1999).

Different tissues and organs of the insect-resistant cotton exihibit different resistance capacity to cotton bollworm. Insect-resistance of vegetative organs is stronger than that of reproductive organs. The general orders of the resistance to larvae of cotton bollworm is: mature leaves > young leaves > boll > young boll > flower (Zhang et al., 2001; Pei et al., 2005). Bt cotton has a strong resistance to younger larva, particularly the 1st instar larva, and the resistance capacity tends to be weak as the increase of instars.

According to the surveys, the resistance capacity of transgenic Bt cotton to cotton bollworm declined steadily as the growth and development of cotton plant (Chai et al., 2000). The resistance of transgenic Bt cotton plant to the larva of cotton bollworm was 97%, 72%, 48% on June, July, August, and September, respectively (Zhang et al., 2001). Resistant effects of bivalent cotton (CryIA + CpTI) to sensitive and resistant strains of cotton bollworm may remain on “very strong resistance” and “strong resistance” levels respectively, and resistance level of the boll of bivalent cotton was significantly higher than Bt cotton, which demonstrated the obvious advantages of bivalent cotton over Bt cotton (Fan et al., 2001; Xu et al., 2004). Application value of bivalent cotton in IPM is not only maintaining a certain level of control effect on the target insects with certain resistance to bivalent cotton, but also slowing down the development of insect’s resistance to bivalent cotton, because bivalent cotton can simultaneously express two distinct genes with different resistance mechanisms.

Most of the transgenic insect-resistant cottons contain Bt gene only. Bt cottons show a narrow insect-resistance spectrum and mainly control a few lepidopterans as cotton bollworm, pink bollworm (*Pectinophora gossypiella* (Saunders)), etc. They have only weak resistance to the larvae of *Spodoptera exigua* (Hübner), and *Agrotis ypsilon* (Rottemberg) (Dong et al., 1996; Xia et al., 2000). Bt cottons are not effective to most of the insect pests fed on cotton (Kong et al., 2004; Miao et al., 2004; Gu et al., 2005; Xiong et al., 2006; Huang et al., 2007).

Even to target lepidopterans such as *Spodoptera litura* (Fabricius), the bivalent cotton varieties like Zhongmiansuo 45 and 41, etc., show a weak resistance only (Huang et al., 2006). Transgenic insect-resistant cotton could mildly inhibit cotton aphid, whitefly (*Bemisia tabaci* (Gennadius)), *Lygocoris lucorum* (Meyer-Dür), *Empoasca flavescens* (Fabricius), and other non-target insects while preserving a strong resistance to cotton bollworm (Zhang et al., 2001; Zhou et al., 2004). However, it was also reported that transgenic insect-resistant cotton was not effective on such sucking insect pests as cotton aphid, red mite (*Tetranychus cinnabarinus* (Boisduval)), the Miridae insects, and their occurrence tended to be more serious (Wang et al., 1999; Chen, 2006).

The gene expression of transgenic insect-resistant cotton is unstable with time and space, i.e., Bt crystal protein can be synthesized in all of the newborn cells but, newborn cells will decrease and the resistance will weaken with the growth and aging of cotton plant. Thus, the insect-resistance of transgenic cotton will decline as the growth of cotton, i.e., the resistance capacity will be mainly released in the first and second generations of cotton bollworm, and it will significantly decline in the third and fourth generations (Zhang et al., 2001; Wang et al., 2002; Xiong et al., 2006). As a consequence, IPM is still needed in the late phase of cotton growth.

18.2.1.3 Impacts of Transgenic Insect-Resistant Cotton on Community Structure and Arthropod Diversity

Biodiversity is an important natural control mechanism on insect pests in cotton field. There are many kinds of natural enemies in the cotton fields of China. China scientists have conducted a number of surveys and trials to understand the impacts of transgenic insect-resistant cotton on community structure and arthropod diversity in cotton fields (Pei et al., 2005).

According to a field survey, the evenness index of insect community in Bt cotton field was higher than conventional cotton field and insecticide treated cotton field; the diversity index on Bt cotton was the highest, seconded by that on bivalent cotton, conventional cotton, and insecticide treated cotton; the cultivation of bivalent cotton would not reduce the stability of insect community, and the stability of insect community, pest sub-community, and natural enemy sub-community would be improved; the populations of insect pests and natural enemies tended to be stable (Cui et al., 2006a). Due to the reduction of insecticide application in transgenic insect-resistant cotton field, the diversity of arthropod community in the middle and late phases of cotton growth were significantly improved, which is conducive to the stability of cotton ecosystem and IPM (Li et al., 2003a, b). It was also found that the structure of arthropod community was more stable in wheat-cotton intercropping system than in cotton system, the former demonstrated a stronger buffering capacity to environmental changes and population fluctuations (Xia et al., 1998).

A field investigation demonstrated that on average there were 15 insect families, 19 species in Bt cotton, 14 families, 17.5 species in conventional cotton field, and 13.5 families, 17.5 species in insecticide treated cotton field, were found respectively; The number of individuals of major insects in Bt cotton field was greater than that in conventional cotton field and insecticide treated cotton field. These results indicated that Bt cotton was conducive to the protection of biodiversity and ecosystem management in cotton field (Wang et al., 1999; Li et al., 2003). Another survey showed that there was no significant difference between transgenic cotton and conventional cotton in dominant natural enemies (Zhang et al., 2001). Bivalent cotton would not exert an obvious impact on predators; the individual number of some natural enemies, such as *Propylaea japonica* (Thunberg), *Chrysoperla sinica* (Tjeder), increased and became the dominant species in Bt cotton field (Cui and Xia, 1999; Zhou et al., 2004; Cui et al., 2006b). Bt cotton was also proved to exert a positive impact on *Harmonia axyridis* (Pallas) and *Erigonidium graminicolum* (Sundevall) (Cui et al., 2006b). Compared with the conventional cotton, planting transgenic Bt cotton would further proliferate predators by 24.0% (Xia et al., 1999). However, the number of some major natural enemies would be reduced (Zhou et al., 2004).

According to another field survey, the species richness of insect community in Bt cotton (110 species) was slightly higher than conventional cotton (109 species), and the relative abundance of insect pests (71.5%) in Bt cotton was lower than conventional cotton (73.1%); the species and abundances changed in Bt cotton field, the chewing insect pests such as cotton bollworm were effectively controlled, and the sucking pests such as red mite, the Miridae insects, cotton aphid and other secondary insect pests became the dominant pests (Xia et al., 1998).

To date most of the studies tended to demonstrate that the structure and composition of arthropod community could not be substantially changed in transgenic insect-resistant cotton field.

18.2.1.4 Impacts of Planting Transgenic Insect-Resistant Cotton on IPM and Economic Benefits

Based on a two years' questionnaire survey on 245 farmers in 6 counties, Hebei Province, Wu et al. (2005) conducted a comprehensive comparison on benefit-cost and IPM effects between transgenic Bt cotton and conventional cotton. The results showed that in 2002 and 2003, the cotton yield, pesticide cost, total cost and revenue of the transgenic Bt cotton variety were higher than conventional cotton. According to a report, during 1994–1998, the results achieved in the indoor, cages, field plots and field experiments demonstrated that planting transgenic Bt cotton and adopting some control measures in earlier, middle, and late phases of cotton growth would save insecticide application by 60∼80% as compared to conventional cotton (Xia et al., 1999). Transgenic Bt cotton varieties showed a better insect resistance in the seriously occurred area of cotton bollworm; resistance capacity was greater than 80%; Bt cotton demonstrated a good performance in yield; chemical insecticide application declined by 50∼80%, and there was not an obvious yield difference between Bt cotton and conventional cotton (Kong et al., 2004; Hu et al., 2006). In China, the insecticide application on transgenic insect-resistant cotton may be reduced by 24∼63 kg/ha compare to conventional cotton (Zhu and Ni, 2006). According to the statistics in China (Huang et al., 2002), during 1999–2001, about 12∼29% of the farmers planting conventional cotton varieties were poisoned by pesticide because they have exposed to a higher dosage of pesticides. However, only 5∼8% of the farmers planting Bt cotton varieties were poisoned by pesticides. Insecticide application was obviously lower on Bt cotton than on conventional cotton, and the insecticide application would be reduced by 70∼80% in some areas.

In the 20th century, cotton bollworm was the major pest to affect China's cotton production. Since the 1970s, with the widely uses of chemical pesticides in cotton production, the pesticide-resistance of cotton bollworm dramatically enhanced. In 1992, cotton bollworm seriously occurred in the Yellow River valley, which resulted in a direct economic loss of over 8 billion RMB Yuan and posed a serious threat on the steady development of China's cotton production. Cotton acreage in China declined from 6.835 million ha in 1992 to 4.985 million ha in 1993, a 27% sharp reduction. In subsequent years, cotton bollworm seriously occurred every year, and cotton production stagnated. A new insect-resistant Bt cotton variety, 33B, developed by Delta Cotton Company in the United States, and domestic insect-resistant varieties were used in cotton production in 1996 and 1998, and have effectively controlled the outbreak of cotton bollworm. China's cotton production thus started to be stabilized (Xia et al., 2004).

In 1997 the Ministry of Agriculture of China approved transgenic insect-resistant cotton varieties for environmental releases in five provinces Hebei, Henan, Jiangsu, Liaoning, and Xinjiang, and for commercial production in Shandong, Shanxi, Anhui and Hubei Province (Qing and Zhao, 2004). Since the late 1990s, the cultivation area of transgenic insect-resistant cotton in China has been rapidly expanding, and its proportion in the total domestic cotton planting area has been increasing year by year. In 1998, transgenic insect-resistant cotton began to be planted in the Yellow River valley, and that year's acreage reached 240,000 ha, only 5.4% of the total cotton planting area; The planting area increased to 647,000 ha, 1.2 million ha, 1.933 million ha, 1.867 million ha, and 3.067 million ha in the years 1999 to 2003, accounting for 17%, 31%, 40%, 45% and 60% of the total area, respectively, an average annual rate of over 10% (Xia et al., 2004; Fig. 18.1). The planting area of domestic transgenic insect-resistant cotton accounted for 30%, 60%, and 70% in the years 2002–2004. Due to the cultivation of transgenic insect-resistant cotton, pesticide application in China reduced by 123,000 t and cotton yield increased by 9.6% during the three years 1999–2001 (Zhang et al., 2004). Currently, almost all of the planted cotton in Hebei, Henan, and Shandong Province is transgenic insect-resistant cotton. In the Yangtze River valley, transgenic insect-resistant hybrid cotton holds the dominant position and its planting area is growing year by year (Zhu

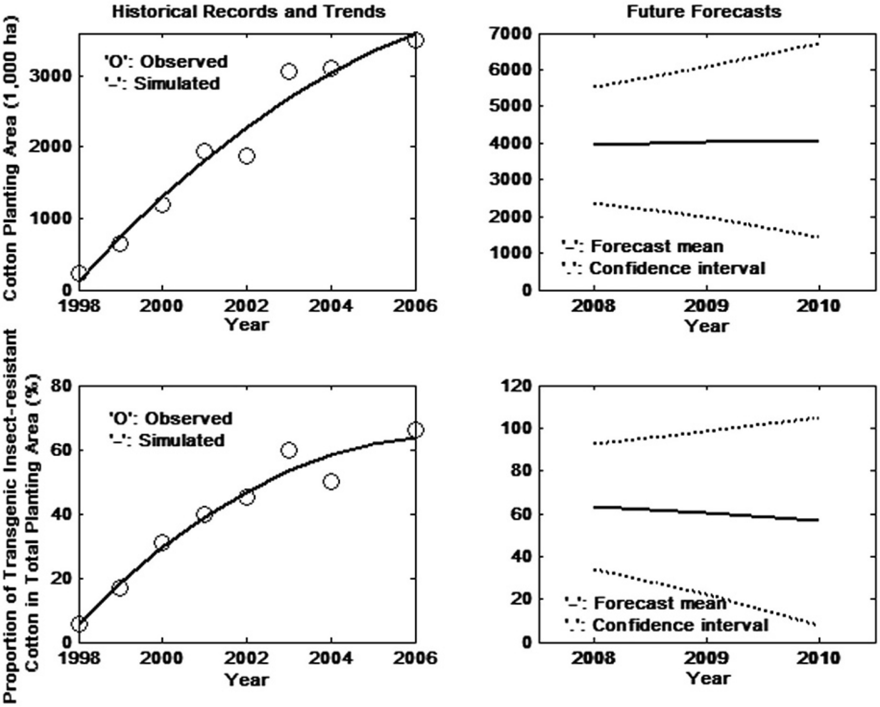

Fig. 18.1 Production situation of transgenic insect-resistant cotton in China. The forecasts for the years 2008–2010 were given by polynomial function (Mathworks, 2002). The 95% confidence intervals of the forecasts for the years 2008–2010 were also indicated

and Ni, 2006). So far, the total planting area of transgenic insect-resistant cotton in China has reached 4.667 million ha, with an average income of 2,130∼2,400 RMB Yuan/ha (Xiong et al., 2006). Annual reduction in chemical pesticide application reaches 20,000∼31,000 t, equivalent to 7.5% of China's annual total production of chemical insecticides. Cotton bollworm problem has become a history in China.

According to an estimate, the cultivation of transgenic insect-resistant cotton will annually yield the welfare of one billion US dollars for China (Yang and Li, 2006).

18.2.2 Transgenic Insect-Resistant Rice

18.2.2.1 Breeding of Transgenic Insect-Resistant Rice

Rice is the staple food crop in China. Rice stem borers (*Chilo suppressalis* (Walker), *Tryporyza incertulas* (Walker), *Cnaphalocrocis medinalis* (Guenée)) and rice planthoppers (*Nilaparvata lugens* (Stal), *Sogatella furcifera* (Horvath), *Laodelphax striatellus* (Fallen)) are the most important insect pests in rice fields of China. Insect-resistant resources are poor in rice. Therefore the breeding of transgenic insect-resistant rice varieties provides a new way for rice pest control (Feng et al., 2000; Wang et al., 2005).

As early as in 1989, Yang Hong, a Chinese scholar and colleagues transformed Bt gene into the protoplast of rice varieties Taigeng 209, Taipei 309, and Zhonghua 8 using protoplast fusion technology, and obtained the regenerated transgenic plants (Wang et al., 2004). So far, the countries that have been reported to successfully obtain transgenic rice plants include China, United States, Philippines, United Kingdom, Japan, and India, etc. The transformation technology goes to mature and transformation frequency increases gradually (Zhang et al., 2001). Currently, the major techniques for rice resistant gene transformation include gene gun method, followed by *Agrobacterium*-mediated transformation, PEG method, electroporation method; the most widely used genes are Bt toxin gene, pin, CpTI, and GNA gene, etc. (Wang et al., 2004).

In China, the scientists in Zhejiang University have transformated Bt gene CryIA (b), in which the codon had been optimized, into rice variety Xiushui 11 using *Agrobacterium*-mediated transformation. The Bt toxic protein expression of the resistant strain obtained accounted for 0.5∼0.3% of the total soluble protein, and can kill 100% of the 1st to 5th instar larvae of *C. suppressalis, C. medinalis*, and *Naranga aenescens* (Moore); it was also highly resistant to eight lepidopterans. The resistant strain has been formally named as "Kemingdao". A batch of insect-sensitive rice cultivars such as early indica rice Zhefu 504, Zhefu 123, Jiazao 935, late japonica rice Daoxiushui 63, Bing 9402, Bing 9311, and some of the indica-preserving strains and restoring strains, were transformed and some transformed plants were obtained. The transformed plants shared the similar agronomic traits with the original cultivars (Xiang et al., 1999; Cui et al., 2001). Zhu (2001) fused CpTI gene, signal peptide, and coding sequence on endoplasmic reticulum that localizes signal KDEL, and obtained the fusion gene signal-cpti-KDEL (SCK). Using the gene, some transgenic rice plants highly resistant to lepidopterans such as *C. suppressalis*, etc., including Minghui 81 and Minghui 86, were obtained. Hybrid combinations prepared from these plants have put into field trial. Tang et al. (2001) have transformed GNA (*Galanthus nivalis* (L. Agglutinin)) into japonica rice varieties Eryi 105 and Erwan 5 using gene gun method and obtained a batch of transgenic strains which could significantly reduce the survivorship, fecundity, and feeding amount, and retard the development of brown planthopper, *N. lugens*. Using gene gun technique, Feng et al. (2001) transformed alkaline chitinase genes RC24, RCH10, rice acidic chitinase genes RAC22 and alfalfa β-1,3-glucose enzyme gene (β-1, 2Glu) to indica rice varieties Qisiruanzhan, Teqing, Qimiaoxiang, Jiuliuling, and japonica rice variety Zhonghua 8, and obtained a batch of transgenic lines that were highly resistant to rice blast disease and rice sheath blight disease, such as Zhuzhuan 68 and 70, etc. Zhai et al. (2000) transformed Xa21 gene into China's five rice varieties using *Agrobacterium*-mediated method, and obtained preserving strains and restoring strains of the white blight disease resistant rice, Minghui 63, Yanhui 559, and Zhengshan 97B. Transgenic hybrid indica rice varieties Shanyou 63 and 559 were developed using these strains. The results demonstrated that the two transgenic hybrid rice varieties exhibited a broad-spectrum resistance, and their resistance spectrum was similar to IRBB, the XA21 gene source. Currently these hybrid combinations have been put into field trial. In addition to the above, there are many other examples for introducing insect-resistant genes into rice and obtaining insect-resistant plants (Wang et al., 2004). In recent years, the transgenic researches on Bt gene have been increasing. Transgenics has been successfully used in indica rice, fragrant rice, Java rice, hybrid rice, and deep-water rice. Bt rice has gone to the phase of environmental release. Some insect-resistant rice varieties that can be used in the rice production were expected (Wang et al., 2005).

Up till now, transgenic insect-resistant rice varieties (strains) are mainly effective to a few of lepidopterans like *C. suppressalis, C. medinalis*, and some homopterans as brown planthopper (Wang et al., 2005). Some transgenic rice varieties are resistant to rice blast, sheath blight, and bacterial blight, etc.

18.2.2.2 Impacts of Transgenic Insect-Resistant Rice on Community Structure and Arthropod Diversity

There are many arthropod species, including insect pests, natural enemies, and neutral species in and around the conventional rice field (Zhang et al., 2004; Zhang and Barrion, 2006; Zhang, 2007a,b,c; Fig. 18.2). A study made by Chinese scientist showed that Bt rice exhibited a stronger resistance to major target insect pests such as *C. suppressalis, T. incertulas*, and *C. medinali* (Han et al., 2006). Chen et al. (2004) tested the feeding and ovipostion behaviors of brown planthopper (BPH) on CryIA(b) transgenic indica rice, SCK transgenic rice restoring lines, and their respective parent controls. The results showed that three tested transgenic insect-resistant rice materials were unfavorable to BPH feeding, but no significant impact on oviposition of BPH. After two years of extensive field research, it was demonstrated that bivalent (CryIA(c) + SCK) rice would unlikely trigger the catastrophic outbreak of non-target BPH (Fu et al., 2003; Liu, 2004). Liu et al. (2005) investigated the impacts of bivalent rice and its hybrid offspring on insect pest community

Fig. 18.2 Conventional rice fields in Qinxing County, a famous scenic spot in Guangdong Province, China. Guangdong Province, adjacent to Hong Kong and Macau, is one of the most developed provinces in China. Agricultural intensification and excessive pesticide application has been threatening the food security and farmers' health in some areas of the province. Biodiversity in and around rice fields is always a stabilization mechanism for sustainable natural control of rice pests. Biodiversity conservation, biological control and pesticide use reduction are being implemented in Qinxing County and some other areas of Guangdong Province (Photo by W.J. Zhang, August 2007)

and found that bivalent rice was extremely resistant to rice leafroller, *C. medinali*; the hybrid offspring also exhibited the stronger resistance to the rice leafroller.

Transgenic insect-resistant rice yielded no significant impacts on development and growth of non-target insects, planthoppers, leafhoppers, predatory natural enemies, and on the stability of arthropod community in rice field (Jia et al., 2005; Han et al., 2006); it could increase the number of predatory arthropod individuals, and increase species richness in predatory arthropod sub-community (Fu et al., 2003; Liu, 2004). Liu et al. (2006) found that at the community level, bivalent insect-resistant rice had no significant negative impacts on species richness, diversity index, evenness index, predominant index, the temporal dynamics of these indices, and total number of individuals of parasitic wasps. However, transgenic rice could reduce individual number of parasitic wasps during mid-term of cotton growth. The number of individuals of parasitic wasps that parasitize the target pest, rice leafroller, but not other parasitic wasps, was significantly lower in transgenic rice field. Throughout the growing season there was no significant difference between Bt rice and conventional rice in both species and individual number of spiders (Cui et al., 2002; Liu et al., 2002; Qiu et al., 2005). Bt rice yielded no significant impacts on species composition and individual number of aquatic organisms (Chen et al., 2003b). The composition of major insect pests on bivalent rice were found to be similar to that on conventional rice; the reduction of target pest population had not obvious impacts on rice pest community and had not resulted in any changes of predominant insects (Liu et al., 2005).

18.2.2.3 Impacts of Transgenic Insect-Resistant Rice on IPM and Economic Benefits

The research showed that planting transgenic insect-resistant rice can reduce pesticide application by 70∼80% in China. Recent years' experiments conducted in Hubei, Fujian, and other provinces demonstrated that throughout the growing season the pesticide could basically not be used in transgenic insect-resistant rice field, and rice yield may rise by 12%. The effectiveness of insect-resistance of Bt rice has been evaluated under greenhouse conditions worldwide, despite the Bt rice is not licensed for planting in practice (Jia et al., 2005). In China, Bt rice has been put into field trials and environmental releases. So far, no obvious safety risks were found in the safety evaluation and experiments for commercial production of transgenic insect-resistant rice (Zhang et al., 2004; Wang et al., 2005). However, because rice is the staple food crop in China, genetically modified rice products have been cautiously treating in China (Wang et al., 2005). Since 2004, the application for commercial production of transgenic rice was annually submitted to the Biosafety Committee of Agricultural Transgenic Organisms for discussion, but they have never been approved due to serious disputes among various members.

According to an estimate, the cultivation of transgenic insect-resistant rice would annually bring China with three billion US dollars of welfare. If the planting percentage of transgenic rice increases from 50% to 80%, the national welfare would rise from 2.65 to 3.11 billion US dollars (Yang and Li, 2006).

18.2.3 Other Transgenic Pest-Resistant Crops

Transgenic maize holds an important position in the world. There are more than 20 lines for transgenic maize. The majority of them are herbicide-resistant maize; about 50% of them are both insect- and weed-resistant (Liu and Chen, 2005). In total of 17 transgenic maize varieties (lines) have been licensed for commercialization, and have achieved significant economic benefits. But transgenic maize meet some limitations and the successful cases for gene transformation are not common, due to the lower transformation frequency, poor repeatability, higher randomness, the dependence of regeneration capacity on genotypes, etc. (Li and Hu, 2006). Transgenic maize researches in China are still backward compared to the advanced international level, and there are not any commercial varieties up till now.

There are currently more than 10 commercial lines of transgenic soybean, of which the herbicide-resistant transgenic soybean is the main transgenic crop for commercial production. In 2000, the acreage of transgenic soybean accounted for

59% of all transgenic crops. As early as in 1994, Monsanto developed a transgenic soybean: glyphosate-resistant soybean, and has been licensed in the United States for human consumption.

Since mankind obtained the first transgenic wheat plant in 1992, the researches on transgenic wheat have achieved many significant advances. Approximately 200 cases on transgenic wheat have been reported at home and abroad, of which about 80 cases are transgenic herbicide-resistance wheat, about 50 cases are transgenic insect- or disease-resistant wheat, about 30 cases are transgenic quality-improvement wheat, about 20 cases are transgenic salt-tolerant and drought-resistant wheat, and other cases (Zhao et al., 2006; Table 18.1). For example, transforming aphid-resistant gene into wheat plants and thus inducing the differentiation of transgenic cells, finally obtaining the insect-resistant transgenic wheat plants, which are resistant to homopterans such as aphids, brown planthopper, and leafhoppers.

There are currently about 20 transgenic rapeseed strains for commercial production, and some of them are herbicide-resistant (Liu and Chen, 2005).

At present, transgenic soybean holds the largest growing area (58.60 million ha) in all of transgenic crops worldwide, seconded by maize (35.20 million ha), cotton (15.00 million ha), and rapeseed (5.50 million ha) (ISAAA, 2007). A growing proportion of transgenic maize and soybean are being used to manufacture bio-fuels.

In respect to the insect-resistant transgenic potato breeding in China, Bu et al. (2005) constructed an expression vector of diploid potato protease inhibitor II gene. Jiang (2001) constructed CryIB(a) plant expression vector, and transformed it into potato variety Desiree, which showed a high insect-resistance (Wu et al., 2006). CAAS has constructed CryIB (a3)+CryIIIA(a7) plant expression vector and obtained transgenic potato line. The results indicated that the insect-resistance of transgenic potato was improved significantly (Wu et al., 2006).

The pollen of transgenic CryIA gene maize was reported to yield no adverse effect on the survival of three species of predators, *Coleomegina acucatum, Orius insidious* (spp.), *Chrysoperla carnea* (Stephens) (Plicher et al., 1997; Duan et al., 2002; Wu et al., 2007). However, the Swiss scientists studied the impacts of Bt maize on *C. carnea*, and found that compared with the control, *C. carnea* feeding European corn borer that fed on Bt maize, showed a high mortality rate, and a sluggish development (Hibeck, 1998).

Table 18.1 Breeding status of some transgenic crops

	Reported cases	Proportion of total varieties (lines)		
Transgenic Crops	Wheat	Maize	Soybean	Rapeseed
	a + b (50 cases)	a (18%)	c (100%)	c (100%)
Pest-resistant types	c (80 cases)	a + c (82%)		
Main references	Zhao et al., 2006		Yang et al., 2005	

Note: The symbols a, b, and c mean insect-resistant, disease-resistant, and herbicide resistant, respectively. a + b means both insect- and disease-resistant. a + c means both insect- and herbicide-resistant Some data were derived from the authors.

18.3 Prospects and Risks of Transgenic Pest-Resistant Crops

18.3.1 Prospects on the Impacts of Transgenic Pest-Resistant Crops

The most direct impact of foreign transgenic crops on the plantation industry in China is the planting of transgenic soybean (Xiao, 2003). Due to the low production cost and better quality, the transgenic soybean of the United States exhibits the obvious economic advantages compare to China's soybean. The imports of China's soybean jumped to the 10.4191 million t in 2000 from 801 t in 1991, occupying a 21.4% of import volume in the world. The export fell to 211,000 t in 2000 from 1.109 million t in 1991. The import of transgenic soybean of the United States resulted in the serious stock of domestic soybean production, and undermined the economic interests of Chinese farmers (Xiao, 2003). In exception of wheat, the crops maize, wheat, cotton and oil will also face the impact of foreign transgenic products in the future, and the majority of them are expected to be transgenic varieties. Impacts of transgenic insect-resistant crops on IPM and economy of China should be frequently evaluated.

The main rice producing areas are distributed in the developing countries of Asia, and the major part of rice production is for local consumption. In 2000, China's rice production reached 0.188 billion t while rice import reached 458,900 t and export reached t 5.6801 million t. Annual trade volume of rice of China accounted for only 3.27% of total production. Thus the import and export of rice is expected to yield a small impact on rice production and IPM in China (Xiao, 2003).

18.3.2 Potential Negative Impacts of Planting Transgenic Pest-Resistant Crops

While transgenic pest-resistant crops, especially cotton, have been extensively planted in China, and have produced the significant economic and social impacts, however, there are also potential risks and negative impacts for planting transgenic pest-resistant crops and some have begun to exhibit the adverse consequences.

18.3.2.1 Impacts on Yield and Quality of Crops

Compared to conventional varieties, the yield and quality of transgenic insect-resistant cotton bred by China are not ideal, which further affect the economic gain of farmers. According to a survey in Jiangsu Province (Xu et al., 2004), despite the cultivation of Bt cotton may reduce the pesticide application in cotton fields and save labor costs, but the yield of Bt cotton was significantly lower than conventional cotton, along with the high cost of Bt cotton seeds, the direct economic benefit of Bt cotton farmers declined, and the biggest decline was recorded as 10.36% of yield and 1,710 RMB Yuan/ha of income in Lianyungang City. In another experiment conducted in Anhui Province, in four transgenic Bt cotton varieties the weight of single boll of three varieties was between 4.26 g and 4.81 g. The average yield of transgenic insect-resistant cotton, with mildly occurred cotton bollworm, was 1,178.4 kg/ha, a reduction of 8.95% relative to the conventional cotton. The yield of transgenic insect-resistant cottons was overall similar to or lower than conventional cottons (Chai et al., 2000). These situations may partially explain the decreasing proportion (of the increment) of transgenic insect-resistant cotton forecast for the years 2008 to 2010 in Fig. 18.1.

A reason for the low yield of transgenic insect-resistant cotton is that the reproductive traits and morphological features have been changed based on conventional cotton. If the conventional measures for cultivation are still used, the yield potential of transgenic insect-resistant cotton cannot be normally exhibited, and the yield even decreased significantly in different ecological areas of cotton cultivation. For example, in the higher fertilized fields of the Yangtze River valley, Zhongmiansuo 41 showed an excessive reproductive and vegetative growth, while in the Yellow River valley it exhibited the early weak symptom. Transgenic cotton, GK22, exhibited the excessive vegetative growth, falling of many bolls, and declined yield in the Yangtze River valley.

Thus, the cultivation and management technologies in transgenic cotton fields cannot follow the conventional varieties. They must be conducted based on their own laws of growth and development, and the corresponding high quality cultivation techniques must be matched in transgenic cotton fields. By doing so, the reproductive advantage, insect-resistance advantage, and yield advantage may be realized (Gu et al., 2005).

Anyway, improving yield and quality by breeding new varieties will still be the major focus in the future. Field management and cultivation techniques should always match the improved traits of new crop variety.

18.3.2.2 Problems on Pest Resistance to Crop

The insect-resistance of transgenic crop is unstable (Gu et al., 2005; Wang et al., 2006). Gene silence and deactivation seriously affects the application of transgenic insect-resistant crops in agricultural production. It is also the reason why many transgenic insect-resistant crops have not stepped to commercial production. Therefore, how to improve the expression of exogenous insect-resistant genes in the plant is an important research topic in insect-resistant genetic engineering (Sun et al., 2002).

Bt gene is expressed continuously in plant cell, the insect pest by surviving on Bt insecticidal protein across the whole season of plant growth promotes the resistance of insect to transgenic plant. It is known that at least 10 species of moths, two species of beetles and four species of flies have generated the resistance to Bt toxin (Wang et al., 2006). According to a survey, successive planting of transgenic cotton resulted in heavy occurrence of cotton bollworm, due to the increased resistance of cotton bollworm to Bt toxin and degradation of toxin protein after multiple generations of planting of Bt cotton (Gould, 1994; Wang et al., 2006). Transgenic insect-resistant cotton has been in the earlier years planted in Hebei Province, but the residue individual number of the second and third generations of cotton bollworm in 1999 were greater than that in 1998 although the overall occurrence in 1999 was still lower than that in 1998. In Shandong Province, the cultivation of transgenic cotton began in 1997. However the third generation of cotton bollworm in some areas was more seriously occurred in 1999 than in 1998 (Wang et al., 2005).

The survey in a main cotton-producing region, Zaoyang, Hubei Province, demonstrated that with the popularization of transgenic insect-resistant cotton, a lot of problems arose, such as too many varieties, varying quality of cotton seeds, a larger difference between insect-resistances of different varieties. All of these have resulted in the declining trend of cotton yield (Chen et al., 2005). Therefore, it is necessary to standardize the cotton breeding and seed market, and maintain seed purity and stable traits.

Presumably, the effectiveness of monovalent transgenic insect-resistant cotton could preserve 8 to 10 years, and for bivalent cotton the resistance would persist for 20 to 30 years (Gu et al., 2005).

18.3.2.3 Problems on Narrow Insect-Resistance Spectrum and Secondary Pest Outbreaks

Transgenic insect-resistant crop has the narrow insect-resistance spectrum (Gu et al., 2005; Wang et al., 2006). According to the statistics, there are currently dozens of major insect pests damaging cotton in China, including cotton bollworm, pink bollworm, cotton aphid, and red mite, etc. (Xiong et al., 2006). The transgenic insect-resistant cottons used in China's cotton production are effective to some lepidopterans such as cotton bollworm and pink bollworm. However, the species and community of insect pests will likely change after a period of the planting of transgenic insect-resistant cotton; some secondary sucking insects and the lepidopterans that occurred slightly in the early period tend to heavily occur. The research showed that the individual number of red mite and the cotton aphid in the seedling stage were significantly higher than the control. The scientists in Chinese Academy of Sciences have conducted a tracing investigation on the production of Bt cotton in North China from the beginning of 1999, and found that the pesticide application used against secondary insect pests, in particular the Miridae insects, appeared to increase since 2004 (Huang et al., 2007). Currently, the insect pests seriously occurred in transgenic cotton fields, include mainly cotton aphid, red mite, beet armyworm (*S. exigua*), the Miridae insects, thrips, and vegetable leafminer (*Liriomyza sativae* (Blanchard)). In particular, the Miridae insects have become the predominant cotton insect pests in northern China.

The serious outbreak of secondary insect pests may significantly reduce the advantages of transgenic insect-resistant crop, or even lead to more serious insect pest problems. Huge resurgence risk of secondary insect pests is expected to be the most significant problem in planting transgenic insect-resistant crop. This would also partially result in the decreasing trend (of the increment) of proportion of transgenic insect-resistant cotton forecast for the years 2008–2010 (Fig. 18.1).

18.3.2.4 Potential Impacts on Biodiversity and the Environment

As a "foreign factor" released into the ecosystem, whether transgenic crops will destroy the original relative balance of ecosystem and produce the other adverse biological impacts on human health or even cause damages (Klig, 1996; Thacker, 1998; Wei and Yang, 2006), is the world focus (Asako, 1998, 1999). It was reported the results of a study, in which the pollen of Bt maize was fed by a non-harmful butterfly larva and resulted in the death of the later (John et al., 1999). The report attracted a widespread concern on the ecological safety of transgenic crops (Ehsan, 1999). Some study abroad showed that the genetically engineered herbicide-resistant maize gene bleached to the surrounding areas of wild millet plants; the genetically engineered herbicide-resistant rapeseed gene bleached to the nearby wild plants (Xia et al., 2001). In summary, the ecological risks of transgenic insect-resistant crops include genetic pollution of the surrounding plants resulted from gene drift (Han et al., 2006; Wang et al., 2006), the toxic accumulation effects resulted from biological toxic protein, and the injury of ecological balance.

The genes of transgenic crops drift and genetically pollute the surrounding plants by, such as generating a new type of weed after being released. There are four possibilities of becoming weeds (Chen and Zhang, 2000; Zhang et al., 2005): (1) transgenic plants themselves become weeds. The introduction of new genes would result in a plant that exhibits the better survival and competitiveness than its parents or wild plant species; (2) genetic plants are extremely vital, which would destroy the natural diversity of plants and become weeds; (3) the resistant genes of transgenic plants are transferred to the wild flora and transform the wild plants into weeds; (4) transgenic plants invade into new ecological regions and thus undermine the ecological balance. For rice, once the exogenous genes escape and are fused into the wild rice species (including weedy rice) and expressed normally, it may proliferate or expand in wild rice population through sexual and asexual reproduction. If exogenous transgenic genes do not affect the ecological fitness of wild rice, such as high-protein content, improved genes, special vitamins, and the natural selection pressure for wild rice survivor are not related to these genes, then the gene drift of transgenic crops generally do not lead to any significant ecological risk. If some of the exogenous genes from transgenic crops are related to the ecological adaptability of wild rice, such as pest-resistance, and various resistant genes are accumulated in wild rice, then these exogenous genes will likely improve the ecological adaptation of wild rice, and the wild rice will rapidly grow and expand its distribution to become the weeds. On the other hand, the hybrids and their offspring of wild rice carrying the exogenous genes will spread further and may lead to the pollution on original types of wild rice species, or even result in the disappearance of the endangered wild rice in the local area (Zhang et al., 2005; Han et al., 2006). Cotton is a highly domesticated crop. It is not affinitive to the weeds reported. So cotton is unlikely to become weeds. However, the pollen drift of transgenic cotton would yield genetic pollution between different cotton varieties and lines (Liu and Chen, 2005).

Accumulated toxic effects of biological toxin proteins include poisonous effect on natural enemies, and on other neutral organisms. It was reported that after Bt cotton have been extensively cultivated the population of natural enemies reduced or even disappeared due to natural enemies' feeding on the cotton bollworm that carries Bt toxin protein (Gould, 1994). Studies have found that (John et al., 1999; Cui, 2001), the aphids sucked Bt toxin protein on transgenic Bt crop were preyed by predatory bettles and the Bt toxin protein was thus transferred to the beetles, and ultimately affects the reproduction of beetles; Bt insect-resistant crops could kill hymenopterous natural enemies; the pollen of Bt insect-resistant maize would also poison a beautiful butterfly in America. The toxin protein of Bt insect-resistant crops could also leak into soil from the root or reach soil through leaves, thus damage the invertebrates in the soil and water. After Bt toxin protein has leaked into the soil, it would lead to a certain changes in species and quantity of soil microorganisms and changes in activity of soil enzymes (Wang, 2005; Chen and Su, 2006). Toxin protein was also reported to generate certain toxicity to human. A British survey showed that the consumption of transgenic food has resulted in the human allergies of 1.4∼1.8% (Jiang and Yin, 2002).

Planting transgenic insect-resistant crop would negatively affect the composition and structure of arthropod community, and impair the ecological balance. Some research demonstrated that the diversity index of pest-natural enemy community directly depended on that of pest sub- community; the diversity indices of insect community, pest sub-community, and natural enemy sub-community in transgenic Bt cotton field were lower than that in conventional cotton and IPM cotton fields; and the ecological stability of insect community was lower in transgenic Bt cotton field than in conventional cotton and IPM cotton fields (Cui and Xia, 2000).

A popular argument is that planting transgenic crops will save much of the insecticide application. However, a good IPM plan and biodiversity conservation strategy will also largely reduce the insecticide application and, in particular reduce the impairment of beneficial organisms (Andow, 1991; Pimental et al., 1992; Kremen et al., 1993; Way and Heong, 1994; Zhang et al., 2004; Zhang, 2007a,b,c; Fig. 18.3). Our focus is not Yes-or-No on impacts of transgenic crops, but what kind of the impacts and, in what extent will transgenic crops exert impacts on biodiversity and the environment. Risks and impacts of transgenic crops on biodiversity and the environment should be studied extensively in the future.

18.4 IPM and Transgenic Pest-Resistant Crops

Due to the problems of planting transgenic insect-resistant crops discussed above, such as the narrow insect-resistance spectrum, the increased resistance of insect pests to transgenic crops, the possible outbreak of secondary insect pests, and the potential environment and biodiversity risks, it is necessary to follow IPM principles and combine the other control measures, in order to control insect pests effectively, and maintain the natural ecological balance (Kong et al., 2004; Huang et al., 2007). Chinese scientists have summarized the practical problems in planting transgenic insect-resistant crops, and explored various IPM measures to address these problems

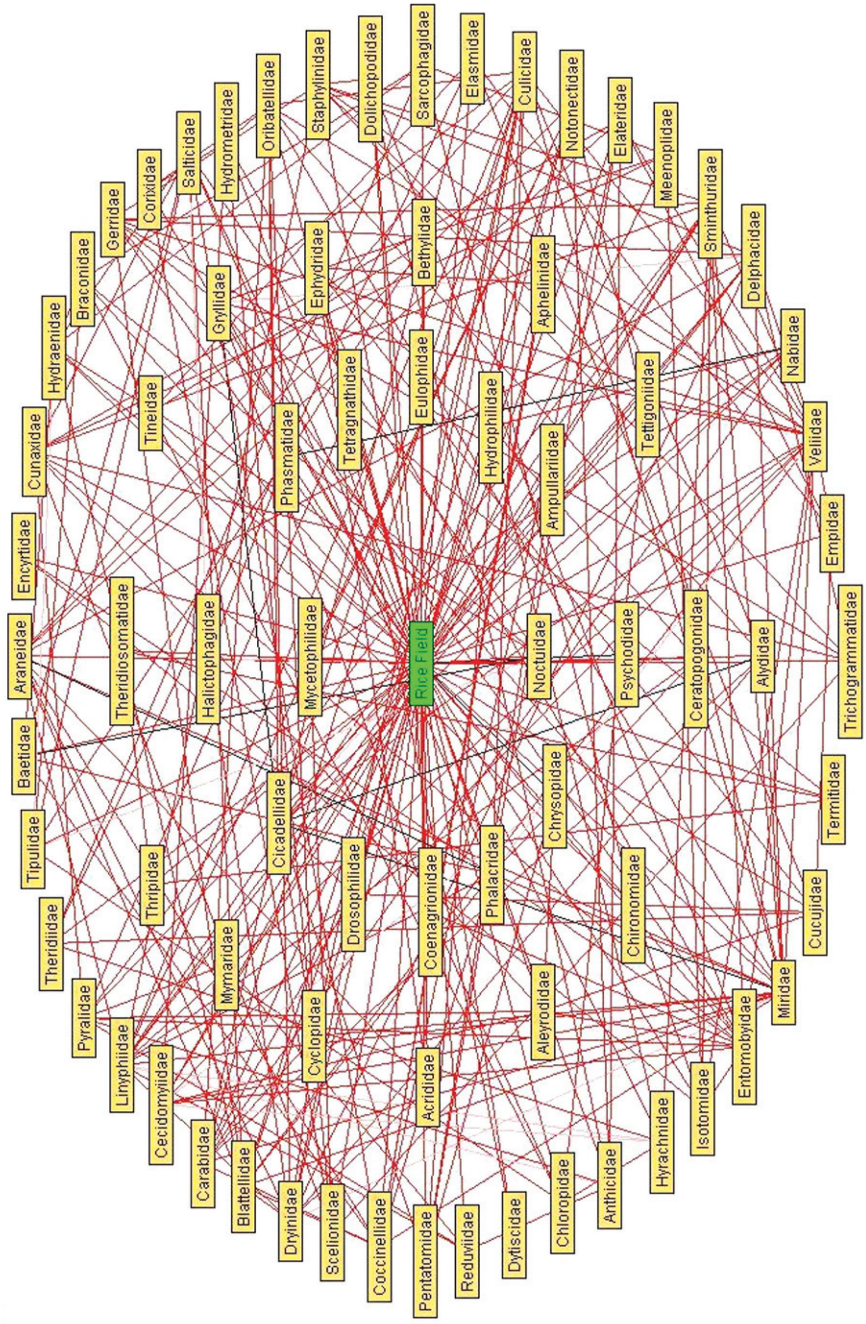

Fig. 18.3 The network of direct or indirect ecological interactions of invertebrate families in a rice field (Zhang, 2007a)

(Wang et al., 1999; Chai et al., 2000; Cui and Xia, 2000; Miao et al., 2004; Son and Gao, 2006). The IPM measures have being implemented at certain extent in China.

About the unsatisfactory performances for the insect-resistance and yield of transgenic crops, scientists have conducted a number of surveys to find some reasons. In Shandong Province, cotton farmers had been yearly reflecting the weak insect-resistance of transgenic cotton. After the field survey, it was confirmed that the reasons were summarized as follows (Miao et al., 2004): (1) a larger weed population in transgenic insect-resistant cotton field. Not weeding cotton timely, the weed population created a better growth habitat for cotton bollworm; (2) transgenic cotton was intercropped by another crop. If control measures had not been adopted for pests on another crop, then pests would seriously damage cotton plants; (3) a higher hazard for corn borer occurrence. If there was not any crop, including maize, around transgenic cotton field, then corn borers would seriously occur in cotton field; (4) no timely control; (5) the low purity of cotton varieties. In Jiucheng prefecture, Anhui Province, a popular survey indicated that transgenic insect-resistant cotton exhibited some drawbacks as compare to the conventional cottons although the former could yield certain economic benefits (Chai et al., 2000): (1) insect-resistance was unstable. The resistance of Bt cotton to cotton bollworm, pink bollworm, etc., decreased gradually with the development and growth of cotton. In 1998, cotton bollworm outbreak in Jiucheng prefecture; in total 4,167 hectares of less controlled cotton field was found to have 0.27 cotton bollworm per hundred plants and 1.52% of boll injury on July 25, they separately increased to 13.33 and 11.14% on August 25; (2) a weak growth vitality and early-exhaustion of transgenic insect-resistant cotton. In 1999, according to the survey on the transgenic cotton, Zhongkang 29, and a conventional cotton, Wanza 40F1, it was found that the vegetative growth of Bt transgenic cotton was slow and its vitality was weak; but its reproductive growth came earlier, and there was a higher rate for bolls' generation; therefore the early-exhaustion occurred easily in the late phase of cotton development due to the poor cooperation between vegetative growth and reproductive growth; (3) small bolls and low fiber content. There was not high-yield advantage for transgenic Bt cotton. Of four transgenic Bt cotton varieties, the single boll weight of three varieties was only between 4.26 g to 4.81 g. The yield of Bt cottons was generally similar to or slightly lower than conventional cottons. In 1999, the cotton bollworm occurred mildly, however the average yield of transgenic insect-resistant cotton tested was 1,178.4 kg/ha only, a reduction by 8.95% against the conventional cotton (Chai et al., 2000).

For the problems discussed above, Chinese scientists proposed some IPM measures (Table 18.2). Cui and Xia (2000) argued that because there are fewer natural enemies in the transgenic insect-resistant cotton field, the application of chemical pesticides should therefore be avoided. Moreover, measures should also be taken to protect the natural enemies, such as planting maize or sorghum for lure use, using the selective pesticides that are safe to natural enemies to control pests, such as red mite, etc. In Xinxiang City of Henan Province, the larva population of the second generation of cotton bollworm in the transgenic Bt cotton field is always below the control index and thus no control is needed. However, the third and fourth generations of cotton bollworm should be controlled according to the population size.

Table 18.2 Suggested principles for IPM of transgenic insect-resistant cotton in China

Cotton Growth Phase	Chemical Control	Biological Control	Fertilization	Others
Preparation of seeds of transgenic insect-resistant cotton	Pesticide treatment of seeds to control plant diseases and underearth insect pests			
Sowing cotton			Provide enough basal fertilizers	Weeding
Before mid-phase of cotton growth	Less insecticide application to control cotton aphid, red mite, etc.	Conservation of natural enemies; Releases of predatory or Parasitic natural enemies; Releases of microbial agent to control insect pests	Appropriate fertilizing	Intercrop by maize, sorghum, etc. Weeding
Late phase of cotton growth	Reasonable insecticide application to control cotton bollworm, cotton aphid, etc.	Conservation of natural enemies	Provide enough bolling fertilizers	Weeding

The control index of cotton bollworm in the United States is 20 larvae per hundred plants. However, this control index has not yet been established in China (Wang et al., 1999). IPM of Bt cotton should also consider the control of the seedling cotton aphid, red mite, and the summer cotton aphid in the bolling stage of cotton. Miao et al. (2004) suggested some IPM measures in Shandong Province: (1) adopting high pure cotton varieties; (2) intercropping cotton with maize but not other crops (Fig. 18.4). Maize is used to attract corn borers for oviposition, and the corn borers should be eliminated; (3) weeding cotton timely. Using herbicides, such as acetochlor, to eliminate weeds after sowing of transgenic cotton; (4) strengthening the forecast and prevention of insect pests, especially the second and third generations of cotton bollworm. When the number of $1^{st}\sim2^{nd}$ instars larvae of the third generation of cotton bollworm reaches 15 per hundred plants, 1,000 folds of pyrethroid insecticide may be sprayed for the control. When the injury rate of plants from red mite reaches 20%, 1,000 folds of mitecide, Saomanjing, can be sprayed for the control. Chai et al. (2000) argued that the fertilizer application on transgenic Bt cotton should in general be increased by 10–30%. Of total nitrogen fertilizer, 60∼70% is for basal and bolling fertilizer (Chai et al., 2000). In Xingjiang Province, the major cotton pests from seedling phase to mid-July are cotton aphid, red mite, and the second generation of cotton bollworm. During this period the biological or ecological control should be the first choice, supplemented by chemical control in which the

Fig. 18.4 A cotton-maize intercropping field in Fuping County, Shaanxi Province, China. The Chinese agriculture was initially originated in Shaanxi Province, and some other provinces, as early as 2000 B.C.∼4000 B.C. With its splendid ancient civilization, Shaanxi Province is now also a major area for cotton production in China. The cotton-maize system will increase the biodiversity, improve the ecological stability, and enhance the effect of IPM, as discussed in the context (Photo by W.J. Zhang, July 2004)

first application of pesticide should be postponed and the dosage should be reduced as soon as possible to avoid producing a direct impact on natural enemies (Son and Gao, 2006). After mid-July, cotton aphid, red mite, and the 3rd∼5th generations of cotton bollworm are major pests of cotton. The abundance of natural enemies decline significantly due to the increasing air temperature, and insect-resistance of transgenic Bt cotton decreased also. The chemical control should be the first choice during this period, supplemented by the biological or ecological control measures, however, the natural enemies should be maximally protected (Son and Gao, 2006).

In the theory of IPM, resistance management is an important consideration. Some management strategies against resistance of pests to transgenic Bt crops, including high/low dose expression, refuges, specific/indicible expression and other tactics to supplement them were proposed (Ouyang et al., 2001). Of these strategies, refuge strategy is a major method for pest resistance management. The principle is planting non-Bt crops, i.e., the refuges of sensitive pests, around Bt crop, in order to let the sensitive individuals mate with resistant individuals randomly. The heterozygous offspring are not able to survive on Bt plants. There are two types of refuges: (1) planting the mixed seeds of Bt crop and conventional crop; the individuals of different crops will be randomly distributed; conventional crops are treated as the refuge of sensitive pest source; (2) planting non-Bt crops in specific area around Bt crop

(Han et al., 2006). The combination of "high-dose" and "refuges" strategies, easily accepted by farmers, was considered to be the best way for Bt resistance management (Zhao and Huang, 2001; Han et al., 2006). Some scientists suggested for using refuges, as done in the United States and Australia, to delay the resistance of cotton bollworm. The 80% of the transgenic Bt cotton and 20% of conventional cotton are intercropped, no chemical control or less control for insect pests on transgenic Bt cotton but normal control for insect pests on conventional cotton; or 96% of the transgenic Bt cotton and 4% of conventional cotton are intercropped or mixed, no chemical control for insect pests on both Bt cotton and conventional cotton. In China, apart from the Xinjiang cotton region and the large farms where refuges needed to be artificially established, the refuges have been naturally provided in other areas due to the intercropping system of multiple crops. However, measures should be adopted to protect these natural refuges; particularly, transgenic Bt cotton and Bt maize should not be cultivated in the same area, and the biological products of Bt should not be used on the host crops of cotton bollworm (Chen et al., 2003a).

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Chapter 19
Can Transgenic Crops and IPM Be Compatible?

George B. Frisvold

Abstract Drawing on the lessons from Bt cotton, this chapter considers how and to what extent transgenic crop varieties can become a useful component of broader IPM strategies. In the United States, Bt cotton has been successfully incorporated into IPM programs to control pink bollworm because several pre-conditions have been met. These have included science-based regulatory oversight of new variety introduction, active collaboration between university scientists and both regulatory agencies and agricultural producers, and significant cooperation and self-regulation among producers themselves. Bt cotton also possesses unique characteristics compatible with IPM strategies. The U.S. experience of Bt cotton suggests transgenics *can* be part of IPM strategies. But, this is no guarantee that transgenic varieties with different characteristics, deployed in countries with different institutional capacities will be compatible with IPM. Emerging challenges are longer-term integrated resistance management (IRM), the need for cross-commodity IPM, and maintaining the flow of information between scientific, regulatory and agricultural communities.

Keywords IPM · cotton · transgenic · genetically modified · biotechnology · resistance · Arizona · California · China · refuge · insecticides

19.1 Introduction

There is no single definition of integrated pest management (IPM). Bajwa and Kogan's (2004) compendium lists 67 definitions of integrated pest management (IPM). IPM relies on an understanding of factors that influence pest populations such as pest predators, host plant resistance, and choice and timing of cultural practices. Applied IPM usually involve scouting fields, application of insecticides based

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on scouting and established thresholds, use of crop rotations, rotating chemicals by mode of action, and timing planting, irrigation and harvesting to reduced pest damage.

If there is one over-arching theme to IPM, it may be the substitution of knowledge and information for insecticides. What must be integrated is knowledge of agronomy, plant genetics, economics, pest population dynamics, and ecology. IPM is not only an intensive user of scientific knowledge, but also requires multi-disciplinary knowledge. IPM also requires a two-way flow of information between the scientific/university community and agricultural producers.

There are several potential benefits of adopting IPM. First, there are the direct economic benefits of reduced expenditures on insecticides, more efficient use of insecticides that are applied, or both. Second, there are non-pecuniary benefits from reduced negative impacts on beneficial insects, pest predators, non-target species, water quality, and human health.

Third, in the longer-run, IPM may conserve the efficacy of insecticides by limiting their use and delaying development of pest resistance to them. Farmers may thus avoid a pesticide treadmill. In response to widespread use of one pesticide, pests evolve to become resistant, rendering the pesticide ineffective. Farmers then resort to new (and often more expensive) pesticides that are then widely used, repeating the cycle of resistance and replacement.

This chapter poses the question, are genetically modified, transgenic crops compatible with IPM systems? Making use of pest-resistant cultivars has been a traditional part of IPM for many years (Council on Environmental Quality, 1972; Bajwa, 1984; NCIPM, 1987; Flint et al., 1991; USDA-ARS, 1993; CPM Crop Protection Manager, 1997; University of California State-wide IPM, 1997; Bajwa and Kogan, 2004). Now, however, advances in recombinant DNA techniques have made it possible to transfer genes from different species into plants. Are new transgenic plants that possess pest-resistant traits from other species, simply a newer, better way of developing pest-resistant cultivars? If so, could they not enhance IPM systems? Or, does their widespread adoption thwart IPM by encouraging over-reliance on too narrow a set of pest control strategies?

To address these questions, this chapter considers the relationship between Bt cotton and IPM. Bt stands for *Bacillus thuringiensis*, a soil bacterium. The Bt cells produce crystal-like proteins during the bacterium's spore-forming stage. The proteins bind to and disrupt midgut membranes, killing particular insect pests. The proteins are activated (and become toxic) only by stomach enzymes of only certain caterpillar pests. Normally the proteins are not active against humans, other vertebrates, and most beneficial insects. Spray applications of Bt are one of the most important insect management tools in certified organic production of fruit and vegetable crops in the United States (Walz, 1999; Hutcheson, 2003). Bt sprays have been registered as insecticides by the U.S. EPA since 1961. Because of the low toxicity of Bt insecticides, they are the only registered insecticides without U.S. federal food residue tolerances. Also because of low toxicity, Bt sprays are approved for organic agriculture because Bt is non-pathogenic and naturally occurring.[1] Through genetic engineering, the Bt gene can be “inserted” into cotton, so that the plant produces its own Bt toxin. Cotton plants expressing these modified genes provide control of tobacco budworm, pink bollworm, and cotton bollworm, three major cotton pests.

The adoption rate for Bt cotton has been rapid. Bt cotton first became commercially available in the United States in 1996. In that year, 0.75 million hectares were planted. By 2005, 8.5 million hectares were planted in 8 countries, Argentina, Australia, China, Colombia, India, Mexico, South Africa, and the United States (James, 2005).

Numerous studies have reported significant economic benefits from Bt cotton throughout the world (CRDC, 2002; Doyle et al., 2002; Falck-Zepeda et al., 2000a,b; Frisvold and Tronstad, 2002; Frisvold et al., 2006; Gianessi et al., 2002; Huang et al., 2002a,b,c; Hudson et al. 2003; Ismael et al., 2002; Marra, 2001; Pray et al., 2001, 2002; Price et al., 2003; Qaim et al., 2003; Qaim and Zilberman, 2003; Traxler et al., 2002). Benefits may come from reduced pest damage (enhancing yields) reductions in insecticide sprays, or both. In addition to pecuniary benefits, Huang et al. (2002a; 2002d) found evidence that adoption of Bt cotton contributed to a reduction in pesticide poisonings suffered by Chinese farmers.

This chapter is organized as follows. It begins with a short history of pesticide treadmills in U.S. cotton production followed by discussion of general cotton IPM principles. Next, it presents a history of IPM strategies to control pink bollworm in the southwestern United States. Impacts of Bt cotton on yield, insecticide use, and profits are then discussed along with estimates of the distribution of economic gains and losses from Bt cotton adoption. It then illustrates how Bt cotton has been successfully incorporated in an overall IPM strategy. A crucial part of this strategy has been successful integrated resistance management (IRM) to preserve the efficacy of Bt cotton against pink bollworm (*Pectinophora gossypiella*).

The chapter concludes by discussing crucial features of Bt technology and the pre-existing IPM programs in the southwestern United States that made a successful combination of a transgenic crop and IPM possible. Bt cotton has been successfully incorporated into IPM programs to control pink bollworm because several pre-conditions have been met. These have included science-based regulatory oversight of new variety introduction, active collaboration between university scientists and both regulatory agencies and agricultural producers, and significant cooperation and self-regulation among producers themselves. Bt cotton also possesses unique characteristics compatible with IPM strategies.

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[1] Under U.S. federal standards, crops using low-toxicity insecticides can be certified as organic. Such insecticides include botanicals, such as neem, pyrethrum, sabadilla, insecticidal soaps, such as diatomaceous earth (D.E.), and Bt sprays.

The main lesson is this. The U.S. experience of Bt cotton shows that transgenics can be part of IPM strategies. But, this is not necessarily so. There is no guarantee that transgenic varieties with different characteristics, deployed in countries with different institutional capacities will be compatible with IPM. Emerging challenges are longer-term integrated resistance management (IRM), the need for cross-commodity IPM, and maintaining the flow of information between scientific, regulatory and agricultural communities.

19.2 Trends in Cotton Yield Losses and Insecticide Use

Bt cotton controls the tobacco budworm, *Heliothis virescens* the pink bollworm, *Pectinophora gossypiella*, and to a lesser extent, cotton bollworm, *Helicoverpa zea*.[2] These have been major cotton pests in the United States, accounting for a dominant share of cotton yield damage and pesticide applications. In 1995, the year prior to Bt introduction in the United States, these three pests lowered U.S. cotton yields by over 4%, more than a quarter billion dollars worth of cotton.

When insects are highly mobile, their regional susceptibility to insecticides depend on the collective behavior of individual farmers. Tobacco budworm, cotton bollworm, and pink bollworm are all highly mobile (Rabb and Kennedy, 1979; Kennedy and Storer, 2000; Henneberry, 2007). The more insects are exposed to an insecticide, the faster the species evolves resistance to that insecticide. Individual farmers usually do not account for the evolution of resistance when controlling pests on their own fields. But the more a farmer sprays a particular insecticide in one year, the less effective that insecticide will be on his (and neighboring) fields in the future. Pest susceptibility is a depletable, common-pool resource, just like groundwater resources, which may suffer from over-drafting. Similarly, farmers may overuse insecticides, depleting their effectiveness prematurely because each farmer fails to account for the contribution of individual applications to resistance evolution (Carlson and Castle, 1972).

The history of pesticide use in the United States has been one of pesticide treadmills (Carlson and Wetzstein, 1993). The cycle begins with the introduction of compounds with a particular mode of action, followed by overuse. The overuse leads to resistance (lowering benefits) and greater scrutiny of environmental and human health costs. This in turn leads to regulatory restrictions and outright bans of insecticides. The cycle repeats with introduction of new compounds. Organochlorines, such as DDT, were widely used on U.S. cotton and other crops in the 1960s. Resistance and environmental problems led to their replacement by organophosphates and carbamates. Resistance to these compounds began in the late 1970s and synthetic pyrethroids were introduced (Livingston et al., 2004; Carlson and Wetzstein, 1993). In the U.S. mid-south, however, budworms evolved to be resistant to pyrethroids,

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[2] A second generation of cotton varieties with two Bt toxins instead of one has demonstrated greater effectiveness against cotton bollworm as well as other Lepidoptera.

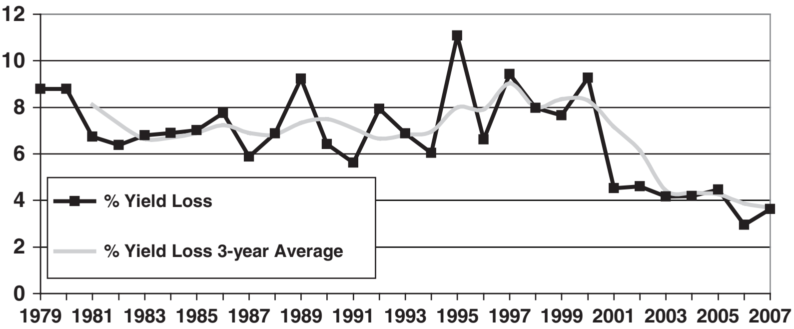

Fig. 19.1 Percent yield loss from all cotton pests in the United States (Williams, 1979–2001)

rendering them ineffective (Bagwell et al., 2000). In 1995, Alabama cotton growers faced the severest resistance problems. Budworm damage reduced Alabama cotton yields by 29% despite growers averaging 6.7 insecticide applications to control them (Williams, 1995).

Over the last 10 years, however, cotton insecticide applications and yield losses have declined in the United States. From 1979 to 1995, cotton growers faced yield losses ranging from about 6 percent to as high as 11 percent (Fig. 19.1). Since 1997, however, the three-year moving average of yield losses has trended downward. Prior to 1996, yield losses were never lower than 5 percent. Since 2001, however, yield losses have never been greater than 5 percent.

U.S. cotton insecticide applications averaged 5.5 per hectare the decade prior to Bt cotton's commercialization, with application rates ranging from 4 to 7 per hectare (Fig. 19.2). Since 1996, growers have made an average of 3.2 applications per hectare, with rates below this average since 2001.

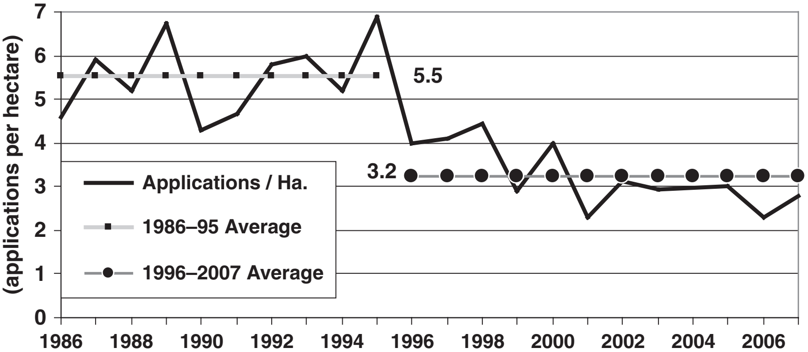

Fig. 19.2 U.S. Cotton Insecticide Applications per Hectare (Williams, 1986–2001)

19.3 The State of Cotton IPM in the United States

In 1993, in joint testimony before Congress, the U.S. Department of Agriculture (USDA), the Environmental Protection Agency (EPA) and Food and Drug Administration (FDA) articulated the Clinton Administration's national goal of implementing IPM practices on 75 percent of U.S. crop acreage (Jacobsen, 1996).

As noted above, there are many definitions of IPM, making it somewhat difficult to determine exactly what the 75-percent goal means and to measure if it is being achieved. One can, however, consider adoption of individual practices that are recognized as key elements of IPM strategies. Table 19.1 lists adoption of such key IPM practices by U.S. cotton growers in 1996. Data reported by Fernandez and Jans (1999) divide the United States into southern and western cotton producing states (Table 19.1). Nearly all definitions of IPM include scouting as a fundamental practice. Scouting was practiced on 88 percent of U.S. cotton acres, with near universal adoption (99 percent) in the western states of Arizona and California. About half of scouted acres are scouted by consultants or pest control advisors (PCAs). Scouting by chemical dealers is relatively more common in the West (34 percent) than in the South (7 percent). Cotton growers keep records of scouting reports to track insects on about half of cotton hectares and use pheromone trapping to monitor cotton pests on about a third of hectares.

Table 19.1 Adoption of IPM practices in U.S. cotton production, 1996 (Fernandez-Cornejo and Jans, 1999)

	South	West	All
	% of planted hectares		
Scouting			
Scouted for insects	86	99	88
Scouted by:			
Operator/family member/employee	26	33	27
Chemical Dealer	7	34	10
Consultant or commercial scout	54	32	51
Monitoring			
Scouted and kept records to track activity of insects	49	73	52
Used pheromone lures to monitor pests	36	17	33
Biological Control			
Considered beneficial insects in selecting pesticides	50	71	52
Used pheromone lures to control pests	7	9	7
Use Bt foliar sprays[a]	5	4	4
Cultural Practices			
Adjusted planting and harvesting dates	26	19	25
Rotation with other row crops	17	3	15
Rotation with other crops and fallowing	14	53	18
Alternated pesticides to control pest resistance	37	70	41

South: Arkansas, Georgia, Mississippi, Louisiana, Tennessee, and Texas
West: Arizona, California
All: Average for All Surveyed States
[a] Applications per insecticide-treated hectare

Growers considered impacts on beneficial insects when selecting pesticides on half of cotton acres in the South and 71 percent of hectares in the West. Cultural practices such as adjusting planting dates and crop rotations can also offer non-chemical means of pest control. Adjusting dates to control pests was practiced on a quarter of U.S. surveyed cotton hectares. Western growers were more likely to rotate cotton with either non-field crops or to fallow land. Western growers were also more likely rotate pesticides, using compounds with different modes of action. This practice is intended to discourage evolution of pest resistance to insecticides.

19.4 From Pesticide Treadmills to Genetic Treadmills?

Several field-plot studies have found Bt cotton reduced target insect damage, the need for insect sprays, or both (Marra (2001) presents an excellent review and summary of these studies). In a national U.S. study using regional data, Frisvold (2004) estimated the impact of Bt cotton on insecticide use, controlling for differences in pest infestations and for the fact that Bt cotton would have higher adoption rates in areas with greater prior insecticide use. He found Bt cotton significantly reduced insecticide applications per infested hectare with reductions ranging from 0.67 in 1996 to 2.3 in 2003.

It would appear that adoption of Bt cotton has furthered an IPM goal of limiting chemical insecticide sprays, at least for the target pests. Bt cotton also appears to exhibit little activity against natural cotton predators and non-target species, especially compared to cotton sprayed with insecticides (Head et al., 2005; Naranjo, 2005; Torres and Ruberson, 2005). Reducing impacts on natural predators is another key element of an IPM strategy.

However, some have raised the question of whether transgenic crops are merely substituting a pesticide treadmill with a genetic treadmill (Altieri, 1998; Altieri and Rosset, 1999; Stone, 2004; Levidow and Carr, 2000). Because the Bt toxin is embedded in the cotton plant itself, pests are exposed to it on a continuous basis. There is thus great selection pressure and, given the extensive adoption of Bt cotton, the potential for rapid resistance development to the Bt toxin. Initially, many entomologists feared pests would quickly evolve resistance to Bt crops. This was based on experience with other pesticides, laboratory selected resistance to Bt toxins in insects, and the development of in-field resistance to Bt sprays by diamondback moth (*Plutella xylostella*) (Gould, 1998; Heckel et al., 1997; Tabashnik et al., 2003).

The possibility of insect resistance to the Bt toxin is a concern to organic agricultural producers that use Bt foliar sprays (Hutcheson, 2003). Foliar Bt sprays are also an important component of vegetable IPM. Because Bt sprays degrade quickly and only work during specific times of pest life cycles, they require scouting and careful timing to be effective. They also show little activity to pest predators. Bt sprays fit well with IPM strategies of monitoring, timing, application of thresholds, and protection of natural pest predators. There is concern then, that overuse of Bt cotton could lead to resistance, affecting not only cotton producers, but destroying its usefulness in vegetable IPM and organic agriculture. Economic theory suggests that individual cotton growers would not consider these potential long-term external costs to vegetable and organic producers.

In response to – though not completely allaying – these concerns the U.S. Environmental Protection Agency (EPA) has instituted refuge requirements to guard against development of resistance to Bt cotton (Matten and Reynolds, 2003; Frisvold and Reeves, 2008). To delay resistance, EPA requires growers who plant Bt cotton to also plant non-Bt cotton on a minimum percentage of their total cotton acreage. These non-Bt acres serve as a refuge for susceptible pests, allowing them to survive and mate with adults that have become resistant to the Bt toxin and thereby delay the development of resistance in the pest population. Experimental evidence and results from entomological simulation models suggest that refuges can significantly delay the onset of resistance (Carrière and Tabashnik, 2001; Gould, 1998; Heckel et al., 1997; Tabashnik et al., 2003).

Another concern is that farmers will over-rely on a single gene for pest control, just as they have over-relied on single chemical compounds in the past (Altieri and Rosset, 1999). Cannon (2000) argues that Bt crops remove the need for field scouting, monitoring and careful timing of insecticide applications, at least for pests that Bt varieties target. So, will Bt crops be seen by growers as a substitute for IPM rather than a complement to it? Some authors suggest that multi-faceted, IPM approaches are essential to delaying resistance to Bt crops (Hoy, 1998; Peferoen, 1997; Riebe, 1999). This suggests that the efficacy of Bt crops will not be sustainable *without* IPM.

19.5 Cotton IPM in the U.S. Southwest

W.W. Saunders described pink bollworm as a cotton pest in 1842 based on specimens in India (Henneberry and Naranjo, 1998; Henneberry, 2007). Pink bollworm is believed to have reached Egypt in 1906–07 via cotton from India and the New World via cotton from Egypt some time from 1911–13. Pink bollworm reached Texas in 1917 via cotton shipments from Mexico. Pink bollworm infestations occurred intermittently throughout the U.S. Southwest, pink bollworm did not become a major pest until cooperative, federal, state and private control efforts were discontinued in the early 1960s. By the late 1960s, pink bollworm became a major cotton pest in Southern California, contributing to a sharp decline in cotton acreage there (Burrows et al., 1984). The pink bollworm has become a well-established pest in the U.S.-Mexico border area stretching from Texas and Chihuahua in the east to Southern California and the Mexicali Valley in the west of the border region.

Because adult pink bollworms are highly mobile, a strategy relying heavily on chemical applications with control focusing on farm-level infestations has proven relatively ineffective at controlling the pest (Henneberry, 2007). Localized, farm-level strategies often miss most of the population and there has been growing recognition that area-wide control measures are required.

19.5.1 Avoidance, Behavioral, Biological, and Cultural Control

IPM strategies to control pink bollworm begin with avoidance, i.e. actions taken to keep the pest population below chemical treatment thresholds (Ellsworth and Martinez-Carrillo, 2001). Several cultural practices can limit pink bollworm populations. By having delayed, uniform cotton planting dates, growers can encourage suicidal emergence – moth emergence before host material is available. Late–season pest damage can be avoided by shortening the growing season by terminating irrigation early, applying plant growth regulators, and planting short-season cotton cultivars. Post-harvest, over-wintering of pink bollworm can be discouraged by (a) shredding stalks, disking and plowing-down of crop residue after harvest, (b) winter irrigation, and (c) using crop rotations instead of planting cotton one year to the next on the same field.

In addition to cultural practices, Southwestern growers have also successfully applied biological control methods (Staten et al., 1988). One method is the use of sex pheromone, gossyplure, to disrupt mating. The pheromone is the scent emitted by females to attract males. Release of gossyplure into cotton fields disrupts moth communication, reducing and preventing mating. A slow-release pheromone formulation (Rope®) has proven highly effective at reducing pink bollworm damage. Gossyplure has been determined to have no significant impact on humans, wildlife, and other insect species. Another biological control method is release of sterile moths. Evidence suggests that this method can cost-effectively prevent pest invasions in areas free (or nearly free) of pink bollworm, but works less well in areas with well established populations. As will be discussed below, sterile moth release is an important component of pink bollworm eradication efforts. Sterile moth release also needs to be of sufficient scale to be effective. This calls for area-wide coordination and implementation.

While cultural practices and biological control methods can reduce the need for chemical control, they do not completely eliminate grower demand for insecticide applications. However, the more growers use avoidance and biological control, the less they need to rely on insecticides. Avoiding early-season insecticide applications can preserve natural pink bollworm predators and limit secondary pest outbreaks. In the early 1970s, demonstration projects in Arizona showed that pest scouting could significantly reduce grower pest control costs relative to calendar scheduling (Carruth and Moore, 1973; Olmstead 1976). Arizona cotton growers now have one of the highest rates of pest scouting in the United States (Williams, various years, USDA-ERS).

19.5.2 Area-Wide Control Programs

Grower collective action, facilitated by university research and extension has led to successful area-wide control of cotton pests. In the 1980s cotton bollworm management communities were established among growers in Arkansas. Compared to non-participating communities, participants applied fewer kilograms of active insecticide ingredients, lowered insect control costs, increase yields and increased profits (Cochran et al., 1985; Parvin et al., 1984).

In 1968, a pink bollworm eradication program was initiated in California's San Joaquin Valley that involved cooperation between local grower groups, universities, cooperative extension, county and state agencies and the U.S. Department of Agriculture (USDA). The goal of the program was to keep pink bollworms out of the San Joaquin Valley (one of the largest cotton-producing regions in the United States) by keeping moths migrating from Southern California from becoming established there. The program does not use pesticides. Rather, key elements of this ongoing program are (a) use of pheromone traps to monitor and detect infestations (b) release of sterile insects to disrupt mating, (c) occasional use of gossyplure for mating disruption, and (d) cultural controls through the enforcement of plough-down regulations (Henneberry, 1994).

Most of the program's funding comes from cotton growers themselves, who pay assessments to finance program operations.[3] Other government agencies also actively participate. Plough-down regulations are enforced by county agricultural commissioners. The California Department of Food and Agriculture (CDFA) and the USDA jointly operate a rearing facility that supplies the sterile moths. USDA provides about eight percent of the program's budget. The CDFA has estimated that, in 2000 alone, the program reduced pesticide applications by over six million pounds (2.73 million kg) of active ingredient, saving growers over $80 million dollars.

In California's Imperial Valley, a short-season cotton program was instituted in 1989 to control pink bollworm. The program called for an earliest planting date of March 1 and a latest date of September 1 for defoliant application and of November 1 for plough-down. The program succeeded in reducing larvae per boll, reducing insecticide applications, raising lint yields, and raising lint quality (Chu et al., 1996). In Arizona, a six-year program from 1989–1995 relied on gossyplure for mating disruption (Antilla et al., 1996). Larval infestations in cotton bolls fell from 23% in 1989 to $< 1\%$ by 1995. Hectares chemically treated to control pink bollworm fell dramatically and costs of pink bollworm control fell to $70/ha., well below historic highs of more than $170/ha. (Antilla et al., 1996; Henneberry, 2007). Similar gossyplure-based programs were implemented in Southern California and the Mexicali Valley of Mexico (Staten et al., 1987).

The Southwest has successfully implemented an area-wide pest eradication program – the Southwest Boll Weevil Eradication Program. Arizona suffered intermittent infestations of boll weevil (*Anthonomus grandis*) in the 1960s and 1970s. By 1978, infestations became more regular in Arizona. By 1982, more than 17,800 hectares of Arizona cotton were treated one or more times for boll weevil. Also in 1982, boll weevils spread to southern California. In 1983, California initiated an eradication program. Officials there threatened to quarantine Arizona farm products

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[3] Cotton growers assessment are about $2 per bale of cotton produced and $5 per acre of cotton planted. Given yields in California this about $20–$25 per hectare of cotton planted. Cotton farms have planted an average of about 184 hectares of cotton per farm.

if Arizona did not begin eradication as well. In response, the Arizona Cotton Research and Protection Council (ACRPC) was formed in 1984 as an institutional mechanism to fund and coordinate boll weevil eradication in the state. The Southwest Boll Weevil Eradication Program was established in 1985, covering southern California, western Arizona and northwest Mexico. Participants included the ACRPC, USDA's Animal and Plant Health Inspection Service (APHIS,) the Arizona Commission of Agriculture and Horticulture, the California Department of Food and Agriculture, and Sanidad Vegetal, Mexico. Although assisted by state and federal agencies, the program was largely financed by growers themselves, via per-bale assessments. The program proved successful and by 1991 the boll weevil had been eradicated from Arizona, California and Mexico's Mexicali Valley. On-going monitoring and trapping are still financed via bale assessments.

These area-wide programs have succeeded in both increasing grower returns and reducing insecticide applications. They succeeded in areas where previous control based on individual, uncoordinated pest control, relying heavily on insecticide applications had not. There were several keys to program success. First, the programs relied on different combinations of trapping, monitoring, avoidance, behavioral, and biological control methods as first steps in control. Second, they also involved effective extension and education programs and active cooperation among grower groups and among federal, state and local entities. Third, grower groups were actively involved in self-organization, financing, and implementation of programs. Fourth, in some cases, cooperation reached not only across state lines, but involved international cooperation between the United States and Mexico.

19.6 Enter Bt Cotton

Bt cotton was first approved for commercial sale in the United States in 1996. In that year, about 14 percent of the U.S. Cotton crop was planted to Bt cotton (Williams, 1996). Since 2000, the USDA has begun regularly reporting national estimates of Bt cotton adoption (Fig. 19.3). Adoption rates have risen from 35 percent in 2000 to 59 percent by 2007.

19.6.1 Impacts on Yield, Insecticide Use, and Profits

In a survey of Bt cotton adoption impact studies (primarily in the United States), Marra (2001) found that mean reductions in insecticide sprays ranged from 1.3 to 3.4 sprays per hectare, with reductions varying by region. Using state and substate panel data, Frisvold (2004) estimated Bt cotton adoption reduced insecticide applications for target pests 0.67 sprays per infested hectare in 1996 and 2.3 sprays per infested hectare in 2003. Marra (2001) also reports mean yield changes ranging from a 90 kg/ha decrease to a 370 kg/ha increase, with most studies finding yield gains. Mean changes in profits ranged from increases of $42/ha to $427/ha.

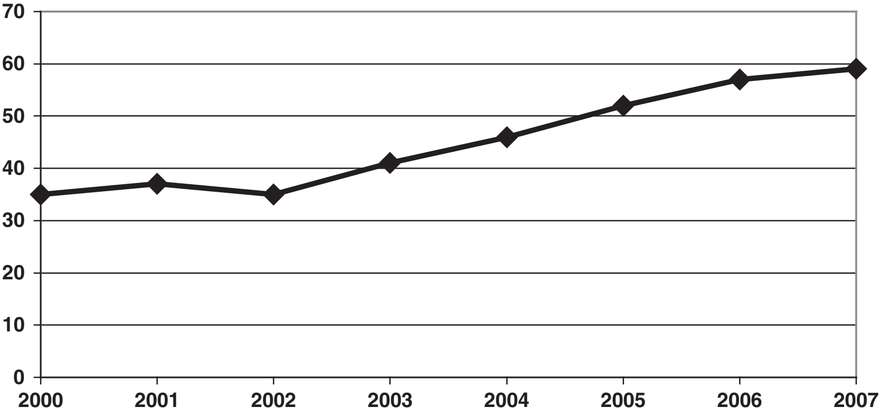

Fig. 19.3 Percent of U.S. cotton hectares planted to Bt Cotton

19.6.2 Distribution of Gains and Losses from Bt Adoption

A few studies have employed multi-market models to estimate the distribution of gains (and losses) from Bt cotton adoption. Falck-Zepeda et al. (1999, 2000a, 2000b) estimated impacts of U.S. Bt cotton adoption from 1996 to 1998. Overall economic gains ranged from \$134–\$240 million, with U.S. producers capturing 43–59 percent of gains and seed suppliers capturing 26–47 percent. Consumers captured only about 10 percent of the gain from Bt cotton via lower prices. Price et al. (2003) estimated overall benefits of \$212.5–\$300.7 million for Bt cotton adoption in 1997. Producers, seed suppliers, and consumers each captured about a third of overall gains. Frisvold et al. (2006) estimated the global impacts of Bt cotton adoption in the United States and China, using a three-region model of the world cotton market. They estimated that, in 2001, adoption of Bt cotton in China and the United States increased world cotton production by 0.7% and reduced the world cotton price by 1.4 cents per pound. Global benefits were \$836 million. China captured 71% of this benefit, the United States captured 21%, and the rest of the world (ROW) captured 8%. The fall in world price reduced ROW producer returns, but net ROW benefits were positive because purchaser gains from lower prices outweighed producer losses. In the United States, producers captured \$179 million and consumers \$48 million, but U.S. taxpayers had to pay an additional \$198 million in U.S. price support payments (a loss). Seed supplier profits increased by \$143 million.[4]

Using a 9-region computable general equilibrium (CGE) model, Frisvold and Reeves (2007) examined impacts of Bt cotton adoption among seven countries (the United States, China, India, Australia, Argentina, Mexico, and South Africa) in 2005. Two non-adopting regions (the EU and the ROW) were also included.

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[4] Price et al. (2003) provide an excellent discussion of how different modeling assumptions affect the size and distribution of gains (and losses) from Bt cotton adoption.

Benefits of international Bt cotton adoption were about $1.4 billion, with China capturing 46 percent of the benefit, the United States and India each capturing 15 percent. Non-adopting regions capture benefits via reductions in cotton prices (from increased supplies). The ROW captures 11 percent and the EU 5 percent of global benefits. Employment, production and trade balances in apparel and textile sectors increase in China and India, but decline elsewhere.

19.6.3 Bt Cotton in the U.S. Southwest

When Bt cotton became part of cotton production in the U.S. southwest it was introduced into an area with well-established IPM institutions, past success in carrying out area-wide programs, and well-established lines of communication between producers, scientists and extension experts, and government regulatory agencies. As I argue below, these have been important factors contributing to the successful integration of Bt cotton into area-wide IPM strategies in the region.

Bt cotton adoption was rapid in Arizona. In 1996 – the first year Bt cotton was commercially available – Arizona cotton growers planted 23% of their cotton hectares to Bt cotton. Growers planted two-thirds of their cotton hectares to Bt cotton by 2001 and more than three-quarters to Bt cotton by 2004 (Williams, 1996–2004).

In the decade prior to Bt cotton introduction, applications per hectare to control pink bollworm and cotton bollworm seldom fell below two applications per year and sometimes exceeded six per year (Fig. 19.4). Data for Arizona cotton insect losses and insecticide applications are available from the Arizona Crop Information Site (ACIS) maintained by the University of Arizona College of Agriculture and Life

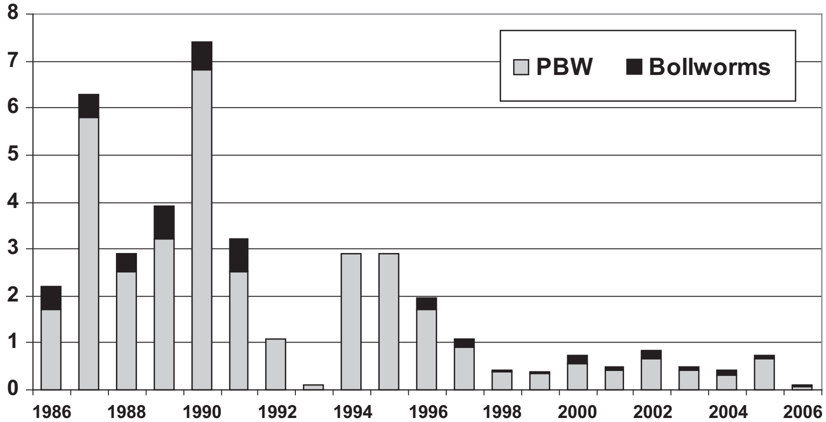

Fig. 19.4 Per hectare applications to control pink bollworm and cotton bollworm on Arizona cotton (ACIS)

Sciences. Since introduction of Bt cotton, applications to control these pests have averaged less than one per hectare per year.

Bt cotton represents a switch from use of broad-spectrum insecticides to the narrow-spectrum Bt toxin to control pink bollworm. Cannon (2000) raised concerns that because Bt cotton would be working continually, it might discourage scouting and monitoring. The shift to narrow-spectrum control, however, meant that growers had to consider pest population dynamics more, not less carefully. Rather than spraying broad-spectrum insecticides for pink bollworm and counting on a certain amount of collateral control of other insects, growers now had to monitor non-target pests more closely. Insect scouting and monitoring has consistently been applied to 95–99% of Arizona cotton hectares with little or no difference between Bt and non-Bt Hectares (Williams, various years; USDA-ERS).

Introduction of Bt cotton in Arizona was coupled with changes in extension IPM recommendations. For example, extension seminars, workshops, bulletins, and field demonstrations sought to educate growers and Pest Control Advisors about the fact that the Bt toxin does not kill small pink bollworm larvae until they enter the cotton boll. Extension programs altered IPM scouting recommendations to emphasize detection of large rather than small larvae (Ellsworth and Jones, 2001).

Reliance on the narrower-spectrum Bt toxin also raises the possibility of greater secondary pest outbreaks. Wang et al. (2006) found such evidence in China. Reductions in broad-spectrum sprays on cotton to control bollworm lead to greater outbreaks of mirids (*Lygus lucorum* and *Adelphocoris spp*. (Hemiptera: Miridae)) as secondary pests. While Bt cotton provided growers with higher net returns in earlier years of adoption, in later years the situation was reversed – Bt cotton provided lower net returns – because of the high level of insecticides used to control mirids. Wang et al. developed a bio-economic model to examine more complex pest interactions. Their results suggest that planting refuges would preserve the profitability of Bt cotton because insecticide sprays to control bollworms on the refuges would also control mirid populations.

Three important lessons can be drawn from this research. First, it highlights the importance of educating growers about more complex agro-ecological relationships. Simply providing transgenic seed varieties to growers is not enough to sustain grower gains.[5] Second, the efficacy of Bt seed varieties is an exhaustible resource that can be conserved via use of refuges. Third, this requires that growers consider inter-temporal trade-offs when deploying transgenic seed varieties. Refuges involve giving up some short-term gain from the Bt technology in order to preserve that technology farther into the future. Fourth, sustaining transgenic technology will require active collaboration between the scientific community and growers and between growers themselves. Individual growers have a short-run (if near-sighted) incentive to disregard refuges. Collective action (or regulation) may be needed to enforce compliance with refuge strategies.

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[5] Pemsl and Waibel (2007) and Pemsl et al. (2008) also discuss results from China illustrating the need to consider more complex ecological relationships to appropriately evaluate Bt cotton.

In Arizona, Cattaneo et al. (2006) carried out an empirical analysis of 81 commercial cotton fields to assess the impact of Bt varieties on insecticide use, yields, and biodiversity. They found Bt cotton had higher yields than non-transgenic cotton for any given number of insecticide applications, but Bt and non-Bt cotton had similar yields overall. What accounted for this result? Growers applied fewer broad-spectrum insecticides on Bt cotton (about 3 fewer sprays in 2002 and 1.5 fewer in 2003). The authors suggest that Bt and non-Bt cotton yields were similar because the extra sprays on non-Bt cotton, significantly reduced damage caused by pests – such as Lygus (*Lygus hesperus* Knight, *Lygus elisus* Van Duzee, and *Lygus lineolaris* Palisot de Beauvois) and whitefly (*Bemisia tabaci*) – that Bt cotton does not kill. The results from these 81 fields suggest that the main advantage of Bt cotton is lower insecticide costs, but not higher yields.

Over the last 20 years, however, insecticide applications for all cotton pests in Arizona as a whole have declined. The need for insecticide applications to control boll weevils ceased by 1990 as a result of the successful eradication program. The year 1996 saw not only the introduction of Bt cotton to control pink bollworm, but the introduction of bio-rational insect growth regulators (IGRs) to control whitefly. Effective integration of Bt cotton and IGRs into overall cotton IPM strategies has led to significant reduction in insecticide sprays to control pink and cotton bollworms and whitefly since 1995 (Fig. 19.5).[6] Lygus has remained a significant cotton pest in Arizona, however.

Looking at the data in a slightly different way, Fig. 19.6 shows the 10-year moving average of insecticide applications to control pink and cotton bollworm and to control all cotton pests in Arizona. The 10-year moving average has fallen from 9 applications per year for all cotton pests, down to 3–4 applications. For pink and

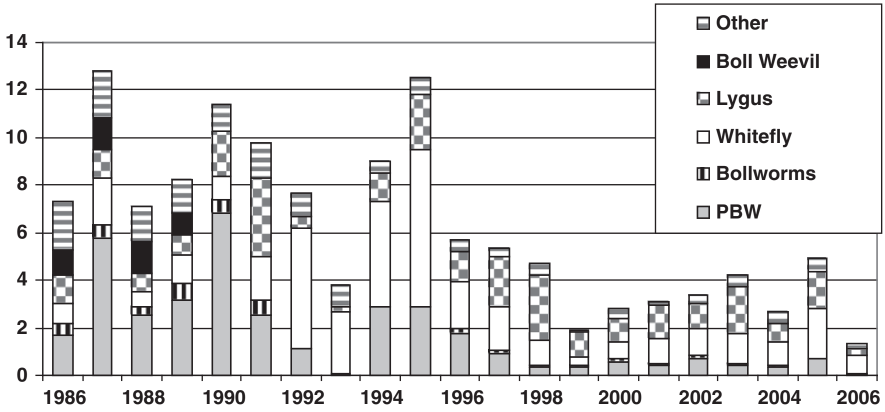

Fig. 19.5 Per acre (1 acre = 0.4 ha) insecticide applications to Arizona cotton (ACIS)

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[6] For more discussion of IPM strategies to control whitefly in Arizona see Ellsworth, and Martinez Carrillo (2001) and Ellsworth and Jones (2001).

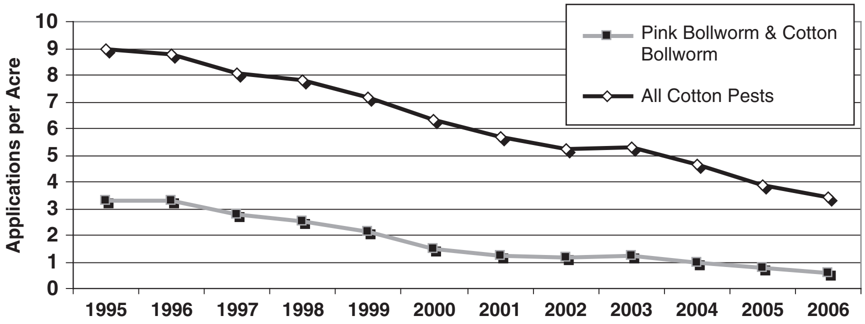

Fig. 19.6 10-year moving average of Arizona cotton insecticide applications (ACIS)

cotton bollworm, the 10-year moving average has fallen from more than 3 applications per hectare per year to less than one application.

Table 19.2 compares per hectare insecticide applications to control pink bollworm, cotton bollworm, and all pests for Bt and non-Bt cotton in Arizona. ACIS reports separate data for Bt and Non-Bt hectares from 1999 onwards. Applications to control pink bollworm were 0.5–2.5 sprays per year less on Bt hectares. This comparison likely understates the impact of Bt cotton on pink bollworm control applications. One would expect adoption of Bt cotton to be greater where underlying pink bollworm pressure is greater and adoption lower where there is less pink bollworm pressure. Had Bt cotton adopters *not* planted Bt cotton, they would likely have applied *more* insecticides than the amount applied to non-Bt hectares.

Applications to control cotton bollworm are also less. In part, this may be from control offered by Bt cotton. However, in Southwestern cotton production, cotton bollworms (*Helicoverpa zea*) are secondary pests and their numbers may be increased by pink bollworm sprays. In all years except 2005, the difference in overall insect sprays on Bt and non-Bt hectares was greater than the difference in pink bollworm and cotton bollworm sprays.

Table 19.2 Insecticide Application per Hectare on Arizona Cotton: Comparison of Bt and Non-Bt Hectares (ACIS, Cotton bollworm is *Helicoverpa zea*. Pink bollworm is *Pectinophora gossypiella*.)

	Pink bollworm		Cotton bollworm		All pests		Difference
	Non-Bt	Bt	Non-Bt	Bt	Non-Bt	Bt	
1999	0.90	0.00	0.17	0.00	2.51	1.59	0.92
2000	1.56	0.02	0.44	0.02	4.13	2.06	2.07
2001	1.33	0.00	0.24	0.00	4.19	2.57	1.62
2002	1.68	0.00	0.45	0.00	4.83	2.36	2.47
2003	1.61	0.01	0.17	0.01	5.62	3.77	1.85
2004	1.65	0.03	0.30	0.03	4.30	2.28	2.02
2005	2.53	0.00	0.22	0.00	6.72	4.33	2.39
2006	0.50	0.00	0.15	0.00	2.44	1.18	1.26

Table 19.3 Insecticide Applications and Yield Losses for Arizona Bt and Non-Bt Cotton (ACIS)

	Applications per hectare		Percent Yield Loss	
	Non-Bt	Bt	Non-Bt	Bt
Mean	4.34	2.52	7.55	4.70
Standard Deviation	1.44	1.05	2.13	1.80
Wilcoxon Two Sample Test Statistic, W	45		45	
Null Hypothesis of Equal Means	Rejected at 1% level (one-tailed test)		Rejected at 1% level (one-tailed test)	

The difference in mean insecticide applications and mean percent yield losses to all cotton pests between Bt and Non-Bt cotton appear to be significantly different (Table 19.3). From 1999 to 2006 mean applications were 2.52 on Bt hectares and 4.34 on non-Bt hectares. Mean yield losses were 4.70% in Bt hectares, but 7.55% on non-Bt hectares. Using a non-parametric Wilcoxon test (to account for the small number of observations) the hypothesis that mean insecticide applications were equal on Bt and non-Bt hectares was rejected at the one-percent level (using a one-tailed test). The hypothesis that yield losses were equal on Bt and non-Bt hectares was also rejected at the one-percent level.

These results underscore those from China that it is important to consider key interactions between transgenic seed varieties, insecticide applications and impacts on non-target species. The efficacy of Bt cotton in Arizona has been maintained through intensive extension and education efforts to help growers understand such complex interactions. U.S cotton production also operates with refuge requirements. In Arizona, compliance with these requirements was estimated to be above 88% in five of six years from 1998 to 2003 (Carrière et al., 2005).

19.7 Importance of Integrated Resistance Management (IRM)

The U.S. EPA requires integrated resistance management (IRM) programs for Bt cotton to delay resistance and maintain its efficacy. IRM strategies have been developed in consultation with federal environmental and agricultural agency staff, university, public interest groups, grower groups, and Monsanto Company (the developer of Bt cotton) (Matten and Reynolds, 2003). The EPA regularly convenes Scientific Advisory Panels to review underlying science and evidence regarding pest resistance and to revise IRM regulations (US. EPA, 2001, 2006a, 2006b). For IRM, EPA requires

(1) mandatory refuge requirements[7]
(2) resistance monitoring

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[7] This has involved requirements that cotton growers either plant non-Bt cotton as refuges or (recently) to make use of natural refuges (from non-cotton host plants) when planting Bt cotton with two Bt toxins.

(3) remedial action plan
(4) IRM compliance monitoring
(5) grower education
(6) grower agreements, and
(7) annual reports.

At the outset of Bt cotton introduction in 1996, there was significant concern among entomologists about the possibility of resistance problems in Arizona cotton. This concern was warranted because it has been possible – in the laboratory – to rapidly select for strains of pink bollworm that were resistant to Cry1Ac, the first Bt toxin commercially available in seed (Bartlett 1995, Simmons et al., 1998; Patin et al., 1999; Liu et al., 1999; Tabashnik et al., 2000; Sims et al., 2001). In response to this concern, a Bt Cotton Working Group was established in Arizona specifically to carry out IRM. Members and collaborators with the group included grower-funded cotton organizations (the ACRPC and the Arizona Cotton Growers Association), research and extension faculty at the University of Arizona, the Arizona Department of Agriculture, and Monsanto corporation.

The University of Arizona's Extension Arthropod resistance monitoring laboratory (EARML) monitored and tested the susceptibility of pink bollworms to Bt cotton both in the laboratory and in the field. EARML has been supported by USDA-ARS Western Cotton Research Laboratory, the Arizona Cotton Growers Association, and Cotton Incorporated (a national U.S. cotton grower group). Pink bollworm samples were collected state-wide and bio-assayed. To date, there has been no evidence of an increase of pink bollworm resistance to Bt cotton in the field.

The ACRPC has collaborated with the University of Arizona in geo-coding cotton hectares in the state. This has made it possible to monitor grower compliance with EPA refuge requirements (Carrière et al., 2001; Carrière et al., 2005). Geo-coded cotton data has been combined with detailed geo-coded pesticide use data collected by the Arizona Department of Agriculture. The University of Arizona's Pesticide Information Office has combined this data to monitor trends in cotton pesticide use since the introduction of Bt cotton and insect growth regulators (Agnew et al., 2000; Agnew and Baker, 2001).

The Bt Cotton Working Group has also examined the efficacy of refuge size and configuration requirements and, based on research, developed recommended changes. For example, in 2000, the Group recommended that "at least one edge of each Bt cotton field be no more than a mile from a non-Bt cotton refuge" (Carrière et al., 2001). This was to help insure that moths with resistant alleles could find and mate with susceptible pink bollworm moths. The Working Groups recommended exceptions to the distance requirements in rare cases where they state seed production regulations.[8] In 2001, the EPA largely adopted these recommendations.

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[8] Arizona is a major producer of crop seeds. To maintain seed product quality, the state maintains field location requirements so that seeds produced are not contaminated from production in neighboring fields.

The Working Group's distance recommendations may seem curious at first, in that they represent a call from grower groups for *stricter* regulation. Why did this happen? First, through extension and education efforts, growers appreciated the value of taking steps to delay resistance. Second, because the recommendations came from "the bottom up," growers already expected the change in regulations and had time to adjust voluntarily before they became binding. Third, the Working Group's science-based recommendations also included calls for regulatory flexibility that benefited growers. New EPA rules allowed for the strict distance requirement to be waived to comply with Arizona state seed production regulations as long as refuges were planted as close to Bt cotton as state regulations allowed. Also, Arizona growers were permitted to plant embedded and in-field refuges. Frisvold and Reeves (2008) estimated that the added flexibility reduced the costs of refuges over 1996–2004 up to 38%. EPA has been willing to increase the flexibility of regulations if this flexibility is scientifically defensible and does not undercut their basic IRM goals.

Through the Working Group, Arizona was also the first state to develop a comprehensive remedial action plan to (a) develop and early-warning system to detect if resistance had developed in the field, (b) take immediate steps to isolate and contain resistant pink bollworm populations and (c) take longer term measures (such as Bt cotton planting restrictions and extra pest control measures) to eradicate locally resistant populations. To date resistant strains have not been found, but pink bollworm populations are continually monitored in the state.

19.8 Importance of Multi-Agent Participation

A number of actors have made the integration of Bt cotton into Southwest cotton IPM strategies possible and to develop IRM strategies to maintain the efficacy of Bt cotton. The EPA has provided regulatory oversight over IRM policies, with refuges playing a major role. Refuges reduce grower benefits from Bt cotton in the short-run but can provide longer-term benefits by preventing secondary pest outbreaks (Wang et al., 2006) or delaying resistance (Frisvold and Reeves, 2008). It is possible that long-run grower profits could be higher under compliance to refuge regulations than if no such regulations were in place.

University research and extension programs have played an important role in several ways. First, they have made growers aware of the public goods aspect of area-wide pest control and delaying resistance. Scientists have been actively engaged in developing and demonstrating IPM and IRM strategies both before transgenics and after they became available. They have also contributed data and analysis to inform regulatory decisions.

Collective action by producer groups has also been instrumental. These groups have financed data collection, education efforts and made data available for research and also for regulatory decisions. Extension education has not been unidirectional from the university to growers. Rather, growers have helped educate scientists and regulators about Bt cotton performance in the field. Grower organizations have also been instrumental in funding and self-enforcement of area-wide IPM practices (such as plough – down requirements and short-season cotton production). The role of growers in providing needed data, funding, and self-regulation presents a challenge to scientists and regulators. If grower assistance is only used to ratchet up regulation, then it will be less forthcoming in the future (Frisvold, 2000). Arizona's experience, however, suggests that grower collective action can fit well into IRM regulatory frameworks.

19.9 Can Transgenic Crops Be Compatible with IPM?

I return to the original question of this chapter. The experience of Bt cotton in the U.S. southwest shows that transgenics *can be* compatible with IPM strategies. Through collaboration between multiple public and private entities, Bt cotton has been successfully included in overall cotton IPM strategies. To date, IRM strategies have successfully prevented pink bollworms from evolving resistance to Bt cotton.

But how far can Arizona's or Bt cotton's experience be generalized? In the United States, there are no other host plants for the pink bollworm, making IPM considerably simpler. For other transgenic cultivars in other situations, cross-commodity coordination of IPM will likely be required. The example of the Southwest United States shows that significant investments in IPM institutional capacity were made well before the arrival of transgenics. Regulatory agencies also had significant scientific capacity to formulate IRM policies.

Other countries now rapidly adopting transgenics have nowhere near the institutional history or capacity developed in the Southwest. Studies of Bt cotton in China by Wang et al. (2006), Pemsl and Waibel (2007) and Pemsl et al. (2008) suggest that introduction in developing countries with less institutional capacity and understanding of pest population dynamics can limit the long-term benefits of transgenics.

Can transgenics be compatible with IPM? Arizona's experience suggests that for transgenics to provide sustainable benefits they will have to be compatible with IPM.

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Chapter 20
Integrated Pest Management, Biofuels, and a New Green Revolution: A Case Study of the American Midwest

John H. Perkins

Abstract Agricultural pest control scientists in the American Midwest currently work in a context created by the intersection of three distinct threads of innovation: (1) practices that increased the yields of corn (also called maize, *Zea mays* L.), (2) new ways of controlling pests, and (3) the use of corn grain and other biomass to produce fuel ethanol. Public policies beginning in the 1970s and strengthening in 2005 promoted the markets for fuel ethanol and thus generated higher average prices for corn producers. The higher prices combined with new insecticidal tools will encourage, under current circumstances, continued reliance on the chemical control strategy for insects attacking corn. Higher prices for corn will also encourage less rotation of corn with soybean (*Glycine max* (L.) Merr.), which in turn will exacerbate problems with corn rootworms. If production of ethanol from cellulose becomes commercially feasible, Midwestern farmers will probably convert land from corn, soybean, conservation, and pasture to switchgrass (*Panicaum virgatum* L.) and *Miscanthus*, thus altering the biological landscape and producing pest control effects that are hard to predict. Farmers currently have a minimal embrace of integrated pest management (IPM), and little suggests that embrace is likely to increase in the near future. As a result, Midwestern corn production remains vulnerable to long-recognized problems with pesticides: resistance, induction of population shifts of various species, and environmental risks. Pest control scientists working within the IPM strategy continue to have stimulating challenges in producing successful IPM practices.

Keywords IPM · integrated pest management · ethanol · biofuels · switchgrass · *Panicum virgatum* · *Miscanthus* · corn · *Zea mays* · maize · green revolution · American midwest · midwest · cellulosic ethanol · Iowa · northern corn rootworm · western corn rootworm · European corn borer · *Diabrotica virgifera virgifera* · *Diabrotica barberi* · *Ostrinia nubilalis* · corn stover

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20.1 Introduction

New technology and industry alter the landscape, sometimes profoundly. Interacting multiple innovations can create even more startling changes. As an example, within the past decade three distinct areas of innovation have started to commingle their respective effects: (1) practices that increase the yields of corn (also called maize, *Zea mays* L.), (2) new ways of controlling pests, and (3) the use of corn grain and other biomass to produce ethanol as a fuel. The confluence of these three technological threads now stands poised to generate a multitude of changes in the patterns of agriculture and pest control in the Midwestern section of the United States.

This chapter reviews the intersections of these three innovative threads and suggests the scope of potential problems. In the American Midwest, the confluence of pest control issues, high yielding agriculture, and biofuels will bring new challenges for IPM specialists.

20.2 Connecting IPM, Green Revolution, and Biomass Fuels

Fuels derived from biomass, known as "biofuels," have sparked high interest among many people in the last 30–40 years. Generally four fundamental factors motivate this enthusiasm:

- the need to reduce carbon emissions from fossil fuels to protect climate;
- the desire to improve energy security by substituting locally produced fuels for imports of oil and natural gas from politically volatile areas;
- the fear that production rates of oil and gas have or soon will reach their respective maxima, thus triggering debilitating price increases; and
- the desire of farmers and political leaders to expand economic demand for farm products in order to improve farm income.

Yields of plant biomass (per hectare per year), however, constrain the potential of biomass to serve as a replacement for fossil fuels. Yields in turn depend upon solar radiation, genetic makeup of the plants, inputs such as fertilizer and water, and the ability to control pests (insects and other animals, weeds, and diseases). Eager interest in biomass for fuel thus calls for research to maximize yields, minimize inputs, and reduce pest damages.

As plant scientists succeed in raising yields of biomass crops, farmers will ask pest control scientists to protect that yield with practical, economical, and environmentally acceptable methods of pest control. Integrated Pest Management (IPM) is the pest control strategy most likely to yield successful methods.

Each of these three areas of science and technology originated in particular circumstances and later changed to fit new situations. Understanding their respective origins illuminates their confluence and the resulting new challenges in pest control.

20.2.1 Integrated Pest Management

Integrated Pest Management (IPM) originated in California in the 1950s and 1960s as a strategy for controlling insect pests in agriculture. In its first form, IPM was called simply “integrated control,” and it sought synergistic suppression of pest insects with both biological control and insecticides (Perkins, 1982).

Subsequently entomologists outlined a more formal strategy based firmly on ecological theory and the study of population dynamics of pest and predatory/parasitic insects. Even later, the concept of IPM moved into new pests (weeds, diseases), new geography (global), and new situations (forestry, urban pest control, animal husbandry, and others).

The science of ecology supplied the theoretical underpinnings of IPM in its first, fully articulated form (Stern, et al., 1959). Three points defined the key elements of the strategy.

First, the pest control decision maker had to see a pest problem within an ecological framework. A pest species was one species among many on the landscape, and the interactions among different species and the physical environment governed the growth of a pest’s population. People, too, had to be seen as one of the interacting species, because humans powerfully disrupted ecosystems and thus promoted growth of pest populations.

Second, the mere presence of a pest species did not in and of itself constitute a “pest problem.” A pest problem existed only when the pest species reached population levels sufficient to cause economic harm larger than the costs to control it. This population level was the *economic injury level*, and a somewhat lower level was the *economic threshold*, i.e. the level at which it became economically rational to initiate control actions.

Third, Stern, et al. (1959) believed that experts, who understood the population dynamics of pest species and their natural enemies, should guide decision making. IPM, in other words, was a strategy based on deep expertise, and only a skilled person could know enough to identify the economic threshold and the proper action. Actions taken could involve many tactics, including biological control and insecticides, but the key was that together the strategies must lower the pest population below the economic threshold.

Significantly, the original framers disavowed goals of eradicating pest populations, i.e. taking the level to zero in an area so that the offending organism would never have to be treated again (Perkins, 1982). Most had no moral objections to eradication, but they believed that in almost all situations eradication was simply impossible as a practical matter. *Management*, not eradication, was the defining goal for IPM.

After its origins in the 1950s, the definition of IPM came to focus as much or more on prevention of economic damage to farmers as it did on the respective populations of insect pests and their natural enemies. In the United States, the Center for Integrated Pest Management, funded jointly by the US National Science Foundation and a variety of allied agricultural industries, provides this current definition of IPM:

> *Integrated Pest Management is the coordinated use of pest and environmental information along with available pest control methods, including cultural, biological, genetic and chemical methods, to prevent unacceptable levels of pest damage by the most economical means, and with the least possible hazard to people, property, and the environment* (NSF Center for Integrated Pest Management et al., 2008).

Hammond, et al. (2006) acknowledged the fluidity of the definition of IPM. They noted that it is immersed in a variety of ideological contexts: sometimes intended to maximize grower profits, sometimes to reduce pesticide use and protect the environment, and sometimes to place pest control on a firm scientific foundation (biology of the pest and its populations). As a result of these shifting definitions and varied ideologies, advocacy for "IPM" must always be accompanied by an explanation of the meaning of "IPM."

At a minimum, development of IPM methods of pest control will focus on the respective population dynamics of the crop plant producing biomass and the various other organisms that suppress its yields. At the same time, the economic aspects of IPM and the potential for environmental contamination by pesticides will be important for the acceptability of IPM-based practices. In addition, IPM specialists will generally not seek eradication but instead focus on management.

20.2.2 Green Revolutions

"Green revolution" originally identified the creation of wheat and rice varieties that responded significantly to fertilizer and water, particularly in Asia. With time the words symbolized more generally the ability to increase agricultural yields in many crops in many areas (Evenson and Gollin, 2003). The prospect of using biomass to produce biofuels thus immediately leads to questions about the feasibility of a green revolution in yields of biomass crops.

The original green revolution rested upon plant breeding and other sciences, but a careful examination of the history of high yielding wheat varieties indicates that green revolution was simultaneously a political economic as well as scientific event (Perkins, 1997). Understanding the potential for green revolution in biomass for biofuels likewise will involve grasping both the scientific and political economic components.

The scientific component emerged as plant breeding in 1900 from Gregor Mendel's particulate theory of inheritance. With Mendelism, scientists rapidly produced new, stable varieties with desirable traits such as disease resistance and higher yields. By the 1940s, genetically improved food crops had started to replace traditional varieties in some cases. Prominent examples include maize in parts of the United States and wheat in India and the United Kingdom (Perkins, 1997).

Until the 1940s, plant breeders worked on local problems in their own areas. World War II, the subsequent dissolution of the British Empire, and the Cold War stimulated the United States government and American philanthropists to internationalize plant breeding. Governments around the world embraced plant breeding as a science that promoted the strength and stability of nation states (Perkins, 1997).

Both scientists and germ plasm began to flow across national borders on a scale never before seen (Evenson and Gollin, 2003).

Corn is not typically included among the crop plants participating in the green revolution, because traditionally the term referred only to wheat and rice. Nevertheless, plant breeders had some of their first successes with corn. Starting in 1900, they learned how to mate parents of different desirable traits and, in the offspring, find new plants that carried the traits of both parents. Breeders sought increased yields and to make the crop more uniform for increasingly mechanized production. Hybrid corn was a major advance.

Plant breeders now routinely collaborate on a global scale in the improvement of plant varieties and the preservation of genetic diversity, the raw materials for breeding projects. After 1980, Mendelian-based plant breeding linked with new methods of molecular genetics, genetic engineering, and genomics to vastly expand its powers.

Proponents of biomass production for biofuels call upon science and the support of governments to increase the yield potentials of biomass crops. Consider for example, Norman Borlaug's plea for a continuation and expansion of government and private support of this scientific work (Borlaug, 2007). He sees the need for biofuels as well as larger amounts of food and fiber. Borlaug's call resonates with the original green revolution, because he was the plant pathologist turned plant breeder who won the Nobel Peace Prize in 1970 for developing high yielding varieties of wheat in Mexico, facilitating their transfer to India and Pakistan, and promoting the green revolution globally in wheat and rice (Perkins, 1997).

A successful green revolution in biomass for biofuels will call for pest management measures to protect these yields. Pest control scientists must play an essential supportive role in maximizing the acceptability of such biomass production schemes. Either loss of yield or disastrous overuse of pesticides will diminish or end the acceptability of any such biomass production schemes. IPM in turn promises to be the best strategy for creating successful, acceptable pest control methods.

20.2.3 Biofuels

Extensive use of biofuels may date to an early event in human evolution. Wrangham (2008) speculates that the emergence of *Homo erectus* from *Homo habilis* about 1.6 million years ago was dependent upon the ability of *H. erectus* to control fire for cooking and protection from predatory animals.

Significantly, Wrangham argues that *H. erectus* was recognizably human but *H. habilis* was still an ape-like primate that did not eat cooked food. If this speculation gains acceptance in the scientific community, it suggests that use of wood and other plant materials as biofuels is an intrinsic and ancient defining human character.

Wood and other plant-derived biofuels continued for millennia to be the most important fuel until the 18th century when it started to lose ground to, successively, coal, oil, and natural gas, the fossil fuels now supplying the vast majority of global energy supplies. Biofuels, however, continue to supply the majority of energy to some pre-industrial peoples.

New proposals for replacing fossil fuels with biomass, however, require significant innovation. Most center not on simple reversions to wood and other plant materials for fire, even though direct combustion provides one route for tapping the energy in biofuels. Instead they envision transforming massive amounts of biomass into liquid and gaseous fuels on a scale never envisioned by *H. erectus* or pre-industrial *H. sapiens*.

Proponents visualize industrial production systems to grow a variety of plant species in high volumes, elaborate thermochemical and/or biological processing factories to transform them to biofuels and other valuable byproducts, and transmission systems to carry the energy potential to widely dispersed consumers.

20.2.4 IPM, Green Revolution, and Biofuels Connect in the American Midwest

The American Midwest—generally considered as the states of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin (Fig. 20.1)—forms one of the world's largest, uninterrupted swaths of land containing rich agricultural soils and adequate rainfall. Originally occupied by a number of Native American nations, the land fell under control of the United States in the 19th century. Its agricultural productivity in turn

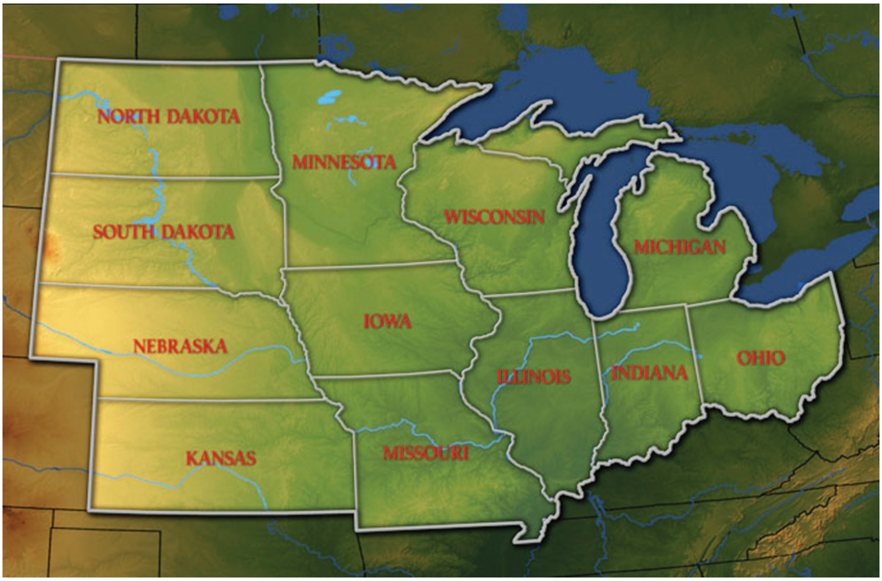


Fig. 20.1 Midwestern States of the United States
Source: Iowa Public Television, accessed at http://www.iptv.org/bestofthemidwest/mappopup_midwest.cfm on 4 May 2008. Used by permission.

became a foundation for American prosperity and food security, a condition that continues to this day.

American settlement of the area was rapid after 1865, and the new arrivals changed the landscape profoundly. The original biogeography was forests and mixed forests-grasslands in the eastern sections and primarily grassland savannahs in the western region. Almost all of this native vegetation was removed by the 1920s, and corn occupied more land than any other single grain crop. In the first half of the 20th century, corn was rotated with wheat, oats, and other crops, but by the last half of the century the dominant rotation was corn with soybean.

High yielding production methods interacted with new pest control methods. Yields increased steadily after 1925 as farmers increasingly used ever cheaper nitrogen fertilizer and new corn varieties, including hybrids. New synthetic pesticides provided a vast new tool box of pest suppression techniques after 1945. IPM started to make inroads in the 1970s. Plant breeders and pest control scientists grew accustomed to interacting with each other and with their farmer clients, and until 1978 these two tracks of innovation generated the major changes in Midwestern agriculture.

Declines in imports of oil from the Middle East in the 1970s ultimately generated a third thread of innovation that today stands poised to dramatically alter the agricultural landscape of the Midwest. In response to shortages of oil supplies, the US Congress exempted gasoline containing ethanol from the federal fuel excise tax in 1978. This new policy fulfilled its intended purpose of stimulating the development of a new biofuel industry: production of ethanol from corn to substitute for gasoline.

Corn-based ethanol production, however, remained a slow-growing, minor industry without much affect on the agricultural industries until about 2002. Use of ethanol as an additive to make gasoline burn with less formation of carbon monoxide stimulated higher levels of production after that year. Further jitters about the security of imported oil supplies increased after the American invasion of Iraq in 2003, and ethanol's popularity expanded dramatically.

In 2005, Congress mandated that Americans use 7.5 billion gallons (28.4 billion liters) of ethanol by 2012. President Bush noted in his 2006 State of the Union address that America was addicted to oil; in 2007 he increased the target for ethanol consumption substantially: "... we must increase the supply of alternative fuels, by setting a mandatory fuels standard to require 35 billion gallons (133 billion liters) of renewable and alternative fuels in 2017" (Bush, 2007).

Identification of ethanol as a strategic resource opened the floodgates for new innovation. Ethanol from corn grain was already a commercial industry, and the growth of distilleries after 2006 steadily generated higher prices for corn grain. At the same time, mandates for mixing ethanol with gasoline stimulated a vast increase in efforts to make ethanol from the cellulose of corn residues, wheat and barley residues, wood residues, and municipal solid waste. "Cellulosic ethanol" promised ever more plentiful supplies that could eclipse grain-based ethanol. For the Midwest, proposals suggested that high yielding grasses such as switchgrass (*Panicum virgatum* L.) and *Miscanthus* could become new crops feeding cellulosic ethanol production.

The quest for ethanol production thus joined innovation in biofuels to the existing innovative threads of increasing and protecting yields. Indeed, some analysts called for a new kind of green revolution that could make the American Midwest a font of fuel along with food and feed. This confluence of three innovative streams now forms the contextual background and the challenges for IPM specialists. The next section outlines the features of this context.

20.3 Ethanol and the Transformation of the American Midwest

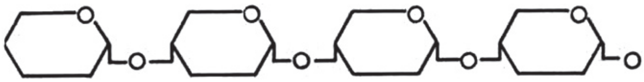
Three facts book no dispute. First, chemical engineers can produce ethanol from either starch of corn grain or cellulose from a variety of sources. Second, farmers, bankers, and venture capitalists have already invested billions of dollars in distilleries to make ethanol from corn grain. Three, mechanical engineers can make an internal combustion engine that functions well using ethanol or ethanol-gasoline mixes as fuel. These three facts together enabled the stream of innovations in biofuels to join the innovation streams in agricultural yields and pest suppression.

Beyond these three undisputed facts, however, lies a vast, gray, murky area of unknown science, unproven technology, uncertain politics and economics, equivocal environmental effects, conflicting objectives, and contested claims. This fuzzy terrain shapes the challenges of pest control and the directions needed for productive IPM research. This section sketches this terrain affecting pest control scientists and farmers involved with proposals for a new green revolution to produce biofuels.

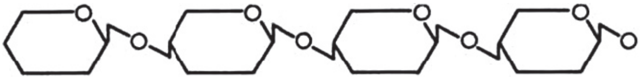
20.3.1 Making Ethanol from Corn Starch and Cellulose

For the chemist, starch and cellulose have much in common. Both are polymers of the simple sugar glucose. They differ primarily in the nature of the chemical bonds joining one glucose molecule to the next. For starch (amylose), the bond is designated as an α-1,4 glycosidic bond and for cellulose it is a β-1,4 glycosidic bond. (Starches found in nature are generally a mixture of amylose (straight chains with α-1,4 bonds) and amylopectin (branched chains with α-1,4 bonds and α-1,6 bonds). Figure 20.2 schematically diagrams the main features of starch (amylose) and cellulose polymers. Despite the similarities, making ethanol from cellulose poses very different problems from the use of starch, a fact that will influence issues with pest control.

Starch in grains is a carbohydrate storage product that serves to nourish the early growth of the seedling sprouting from the grain. Thus the starch is readily available for metabolism to yield energy and chemical building blocks that enable the new seedling to reach the soil surface and begin its own photosynthesis. When an animal feeds on the seed, it, too, readily metabolizes the starch to capture its energy and chemical building blocks. For the engineer, starch stored in seeds is easily converted to glucose (*saccharification*) and fermented to ethanol and carbon dioxide. In short,



Starch: a polymer of glucose with α-1,4 glycosidic bonds



Cellulose: a polymer of glucose with β-1,4 glycosidic bonds

Fig. 20.2 Sketches of the molecular structure of starch and cellulose, two polymers of glucose Source: New Zealand Electronic Text Centre (http://www.nzetc.org/tm/scholarly/Bio14Tuat01-fig-Bio14Tuat01_036c.html, and http://www.nzetc.org/etexts/Bio14Tuat01/Bio14Tuat01_036b.jpg, accessed 1 May 2008.

making ethanol fuel from starch is almost as easy as making beer, something people have known how to do for a very long time.

Cellulose, in contrast to starch, poses many more challenges. First, cellulose, found in cell walls, does not appear in a readily available form. Typically it appears with two other classes of polymers: hemicelluloses and lignins. In its raw form, the material appears as “lignocellulose,” a complex interweaving of cellulose, hemicellulose, and lignin. To make ethanol, therefore, the trick is to obtain the cellulose freed of lignin. Hemicellulose can in theory also be turned into alcohol, but the saccharification and fermentation of the five-carbon sugars of hemicellulose requires different steps from the saccharification and fermentation of the mixture of six-carbon glucose of cellulose. The durability of wood, one of the most plentiful lignocelluloses on earth, attests to the challenges engineers face in making cellulosic ethanol.

For pest control, distinctions between making ethanol from starch and from cellulose will affect pest management primarily through two means: alteration of the harvested material and changing prices. IPM development must recognize these potential changes.

20.3.2 *Ethanol from Corn Starch has Already Altered the Midwestern Corn-Soybean Belt*

Corn (known also as maize or *Zea mays* L.) probably originated in the tropics of Central America and Mexico, and it does not tolerate freezing temperatures. Taxonomists place it in the Family Gramineae (Poaceae), the grasses. Farmers plant corn on an annual basis in the Spring, and harvest follows about 5–6 months later.

Native Americans successfully selected useful varieties and spread them from southern Canada to southern South America and the Caribbean basin. They relied heavily on the food production capacity of corn, and the European and African newcomers after 1492 quickly adopted this New World crop. European expansion subsequently spread the plant globally.

One of the reasons for corn's economic importance stems from its C_4 photosynthesis. The C_4 pathway is one of three known biochemical pathways by which plants can reduce atmospheric carbon dioxide to sugars. C_4 was the latest pathway to evolve, and it occurs in 7000–8000 species, about 3 percent of all plant species. Nevertheless the C_4 plants produce 20–25 percent of the global primary productivity. Corn as a C_4 plant is highly efficient at photosynthesizing when temperatures are warm ($> 25\,^{\circ}\mathrm{C}$), especially in drier climates (Sage, 2005).

Along with wheat and rice, corn now occupies a central place in the agricultural bounty that sustains human life. In the United States, corn occupies about 80 million acres (32.4 million ha), more than 25 percent of the arable land and more than any other single crop plant. US farmers derive more than 10 percent of total farm income from it as they haul about eleven billion bushels (279 million metric tons) of corn from their fields each year. In 2005 it brought in $21 billion to US farmers.

Soybean (*Glycine max* (L.) Merr.) from East Asia joined with corn in the 20th century to create the modern Midwest (Smith, H., 1906; Piper, 1919; Smith, W., 1920). By 1939 farmers were planting 9 million acres (3.6 million ha) in soybean (U.S. Department of Agriculture, 1940), a 180-fold increase in thirty years. This acreage continued to grow to today's levels of over 70 million acres (28 million ha). Soybean is the number two crop in earnings, about $17 billion per year (U.S. Department of Agriculture, 2006a). They became the companion crop to corn after 1950, and what was formerly called the "Corn Belt" more accurately should now be called the "Corn-Soybean Belt."

Over most of the Midwest corn follows soybean in an annual rotation. Both crops yield better after the other compared to after themselves (Hoeft, et al., 2000; Lowenberg-DeBoer and Erickson,. 2005). The cornucopia of Midwestern corn and soybean powers the livestock industries of the United States, Japan, and the European Union, and increasingly some see it as a producer of fuel: ethanol from corn and biodiesel from soybean oil. Three developments between 1900 and 1950 industrialized the Corn-Soybean Belt as the most prolific agricultural area of the entire world.

First, hybrid corn increased yields substantially. Double-cross hybrids first appeared in the 1920s, and by 1950 these varieties dominated the Midwest. After the late 1960s, single-cross hybrids replaced the double-cross varieties, a situation that continues to this day (Troyer and Good, 2005). The American corn crop progressively increased its yields every year, a process continuing even today at about 3.4 more bushels per acre (211 kg/ha) each year. In 1920, the average yield of American corn was 29.9 bushels per acre (1854 kg/ha). This rose to 54.7 bushels per acre (3391 kg/ha) in 1960 and in 2005, the average yield was 148 bushels (9176 kg/ha). It was 151.1 bushels per acre (9368 kg/ha) in 2007 (U.S. Department of Agriculture, National Agricultural Statistics Service, 2008). Some growers think that 300 bushels per acre (18,600 kg/ha) are likely in some areas in the not too distant future (Couser, 2006).

Second, nitrogen fertilizer feeds the plant and enables very high yields. Before 1908, virtually all nitrogen came from nitrogen-fixing bacteria living in the soil or in combination with legumes like peas, beans, and clover. In that year, two German chemists, Fritz Haber and Carl Bosch, learned how to make ammonia from hydrogen and nitrogen. Cheap nitrogen fertilizer moved into agriculture in increasingly large amounts (Smil, 1999).

American farmers used a total of about 2.7 million tons of fertilizer in 1900, but this amount doubled by about 1922, doubled again by 1942, doubled again by 1951, and yet again by 1970 (U.S. Bureau of the Census, 1976). Fertilizer, soybean rotations, and hybrid seed enabled yields of corn to rise steadily.

Third, full industrialization came in with the tractor after 1920. Mules and horses, valuable as they were, could never match the speed and power of motorized tractors and combines. With mechanization, a very few people could produce enormous yields. Farmers became fewer in number, worked increasingly larger farms, and sought specialization as cash grain producers in order to survive economically.

Even with large foreign markets for their grain, American corn farmers produced increasing amounts of grain and prices stagnated. As a result, they were always interested in any idea for new uses of corn. In the 1970s, war and turmoil in the Middle East, plus other factors, triggered a cascade of events and made ethanol an idea hard to ignore.

Currently (2008), the United States has 134 distilleries with a total capacity of 7.2 billion gallons (27.3 billion liters) per year of fuel-grade ethanol. In 2007, US producers made 6.5 billion gallons (24.6 billion liters) of ethanol, up from 4.9 billion gallons (18.5 billion liters) in 2006. These massive installations, owned by farmer-led investors and by non-farm entrepreneurs and corn-processing firms, have an average capacity of 54 million gallons per year. Farmers own 49 (37 percent) of these plants and 28 percent of the total capacity. Corn processors and other investors own the rest (Renewable Fuels Association, 2008 (some figures calculated)).

The U.S. Department of Agriculture estimates that ethanol production used about 20 percent of the US corn crop in 2005–2006, or approximately 2.2 billion bushels (56 million metric tons). The Department projects that ethanol will take approximately 5.4 billion bushels (137 million metric tons) or 37 percent of the corn production in 2016 (U.S. Department of Agriculture, Economic Research Service, 2007; Westcott, 2008, has estimates that are slightly lower).

Current methods of distilling corn-based ethanol—according to most but not all analysts—produces energy somewhat in excess of the fossil fuel energy used to produce the corn and run the distillery; some argue that the ethanol has even less energy than is used in its production (Shapouri, et al., 2002; Pimentel and Patzek, 2005; Farrell, et al., 2006; Hill, et al., 2006; Hammerschlag, 2006). Similarly some analysts have concluded that use of corn-based ethanol compared to gasoline provides a slight reduction in emissions of carbon dioxide (Farrell, et al., 2006).

More recent work, however, argues that land use changes needed to produce biofuels is very likely to result in more greenhouse gas emissions than simply using gasoline. Switching cropland used to grow food and feed to producing biofuels stimulates conversion of land elsewhere from forest or permanent grassland with a consequent loss of carbon storage. The net effect is an increase in release of carbon dioxide (Searchinger, et al., 2008).

20.3.3 Cellulosic Ethanol: The Potential for Corn Stover, Switchgrass, and Miscanthus

Ethanol fuel today (2008) comes primarily from the starch in corn grain, but the real prize if ethanol is to be a major substitute for gasoline lies in a technology not yet proven for large-scale, commercial production. In early 2007, the U.S. Department of Energy awarded up to $385 million to six different companies. Each seeks to demonstrate production of cellulosic ethanol on a significant scale, and each will use a different production system (U.S. Department of Energy, 2007). Based on construction schedules, most of these new plants may be in operation by 2009–2010. At that time, the future of cellulosic ethanol may become much clearer than it is now.

Despite the uncertainty of cellulosic ethanol's economic practicality, chemical engineers and agronomists have already invested considerable effort in studying potential sources of lignocellulose as feedstock for presumptive cellulosic ethanol production plants. Wood residues, municipal solid waste, and agricultural residues can each potentially yield the raw materials needed.

Various global estimates suggest that agricultural biomass residues provide highly significant sources of lignocellulose, ranging from <50 EJ per year to >300 EJ per year. Currently about 365 EJ per year come from oil, gas, coal, nuclear, and hydropower (Berndes, et al., 2003). Lal (2005) estimates that in 2001 the U.S. produced 488 Mg per year of crop residues with an energy value of 9.1 EJ per year, and global crop residues of 3758 Mg per year have an energy value of 69.9 EJ per year. A study at the Oak Ridge National Laboratory (U.S. Department of Agriculture, 2005) estimated that agricultural lands could produce 998 Mg of removable biomass per year while forest lands could produce an additional 368 Mg per year.

Corn stover (above-ground residues of corn after the grain is harvested), switchgrass (*Panicum virgatum* L.) and *Miscanthus* currently occupy the center of research attention as Midwestern sources of biomass. For pest control, increased high-intensity production of one or more may alter the living landscape in ways that scientists cannot yet predict. This section outlines the main features of biomass production potential and likely agronomic and pest control consequences of intensive production of these three crops.

20.3.3.1 Corn Stover

"Field corn," i.e. corn grown for grain that will be used as feed for livestock, dominates the Midwest. Small amounts of field corn move into the direct human food supply as flour for corn bread, tortillas, and other processed products. Similarly, farmers produce small amounts of popcorn and sweet corn. Some farmers, particularly in states like Wisconsin, produce corn for dairy animals, and in this case virtually the entire above-ground plant is chopped and fermented as silage (Massey and Horner, 2003). In all cases except corn grown for silage, the above-ground residue left after harvest of the grain is stover and potentially available as a lignocellulose feedstock for ethanol production.

Soils in the Midwest are naturally deep, fertile, and well watered by rain. Natural fertility notwithstanding, American farmers in 2005 typically added 138 pounds per acre (155 kg/ha) of nitrogen, 58 pounds per acre (65 kg/ha) of phosphate, and 84 pounds per acre (94 kg/ha) of potash (U.S. Department of Agriculture, 2006b; figures are for corn in all surveyed States; application rates vary from State to State). In some areas, additional micronutrients and limestone to adjust pH complete the soil amendments. In the drier, westerly parts of the Midwest, farmers may also irrigate to supplement the scarcer rainfall.

Grain yields, the only yield of interest up to now, reached 160.4 bushels per acre (9945 kg/ha), the highest average ever achieved in the U.S., in 2004 (U.S. Department of Agriculture, National Agricultural Statistics Service, 2008). As noted above, the average yield in 2007 was 151.1 bushels per acre (9368 kg/ha). With the new potential for cellulosic ethanol production, however, yield consists of two parts: grain and the above-ground stover. Modern field corn varieties typically apportion their photosynthetic product so that the ratio of stover to grain may range from 0.55 to 1.50. Several authors estimate that grain and stover occur in equal amounts, i.e. the stover/grain ratio = 1 (Lal, 2005). When grain is the only objective, the stover is "waste."

Cellulosic ethanol production proposes to remove some, most, or all stover as feedstock, thus turning a "waste" product into a valuable part of production. Lal (2005) estimates that stover residues amount to 241.5 Mg per year, or 49 percent of the U.S. total supply of lignocellulose (2001 crop year). Conversion of lignocellulose to ethanol may yield 330–380 liters per metric ton (Morrow, et al., 2006).

Production of ethanol from stover, however, may pose challenges for both soil scientists and pest control scientists. Maintenance of soil fertility and control of erosion both depend upon the plant residues left after the harvest. Sloping fields especially may suffer unsustainable rates of soil erosion from wind and water if too much stover leaves the field for the ethanol plant. Similarly, the carbon-residues in stover and the root systems strongly affect the fertility of the soil, its microbial populations, its water-holding capacity, and its ability to support the succeeding crop as a population of strong, healthy plants (McLaughlin and Walsh, 1998). Removal of stover may thus alter conditions in ways that change populations of pest organisms. In a word, plant residues are not simply "waste" in an agronomic and ecological framework.

20.3.3.2 Switchgrass

Switchgrass (*Panicum virgatum* L.) is a native prairie grass of North America. Its range stretches from 55° North in Canada southward into central Mexico, east of the Rocky Mountains. Classified in the Family Gramineae (Poaceae), Subfamily *Panicoideae*, switchgrass has variable tolerance to cold. With gradual cold hardening, strains adapted to northerly latitudes can tolerate −18 °C, but more southerly varieties cannot. Tolerance of different levels of soil moisture (lowland and upland) distinguishes other varieties (Lewandowski, et al., 2003).

A native plant to the tall grass prairies, agronomists and range scientists integrated switchgrass into commercial agriculture in the mid-20th century. Farmers in central and eastern states appreciate its continued productivity as a forage crop during hot summer months. Once planted, farmers allow one year for the stand to establish, and harvest can commence in the second year. Three varieties already appear to be particularly suitable for biomass production for energy: 'Alamo' in the south, 'Kanlow' in the central latitudes, and 'Cave-in-rock' for the north. Once established, the stand will be productive for a decade or longer (Lewandowski, et al., 2003).

Switchgrass, like corn, is a C_4 plant, which makes it comparatively efficient in warm, dry conditions. In contrast to corn, however, switchgrass produces well on lower quality soils. Stand establishment requires care and precision in soil preparation, seed preparation to break dormancy, seed placement, and weed control. Once established, the plant produces above-ground leaves and tillers higher than 3 meters; below-ground roots extend to 3.5 meters, and the grass also produces rhizomes.

The plant produces maximum yields after 3 years of growth, and those maxima are reached by 1 September each year. Farmers can harvest one time or twice per year, but most experiments on biomass production emphasize one time. If the farmer delays harvest, the yield decreases partly as a result of in-field drying and partly as a result of leaf loss. Delayed harvest, however, also generally allows the plant time to move mineral nutrients from the above-ground parts of the plant to the below-ground organs. This translocation of minerals improves the quality of the biomass sent for energy processing and saves on the need for fertilizer applications (Lewandowski, et al., 2003; Heaton, et al., 2004).

An analysis of peer-reviewed literature on switchgrass showed that switchgrass can produce an average of 10.3(±0.7) Mg per hectare per year (1 Mg = 1 metric ton) (Heaton, et al., 2004). Variability, however, was high and ranged from over 34 Mg with 'Alamo' in Alabama to about 5 Mg with 'Cave-in-rock' in Texas (Lewandowski, et al., 2003). Switchgrass requires 50–100 kg per hectare per year of nitrogen for good yields, but on most sites it produces little extra yield above 70 kg per hectare per year (Lewandowski, et al., 2003). Water supply (rain) and degree growing days seem to have little influence on switchgrass yields (Heaton, et al., 2004).

The above studies were primarily small scale and not performed by farmers operating under commercial conditions. More recently, researchers from Nebraska reported yields, production costs, and net energy yields for switchgrass grown under quasi-commercial conditions for biomass fuel by farmers located from northern North Dakota to southern Nebraska. They concluded that average yields of 5 Mg per hectare were easily achievable at a cost of about \$50 per Mg. Assuming a conversion to ethanol at 380 liters per Mg, this biomass had an average cost of about \$0.13 per liter. Average net energy yields were 60 GJ per hectare per year (Perrin, et al., 2008; Schmer, et al., 2008).

Cultivated switchgrass has some vulnerability to pests. Propagation is by seeding, and weeds can severely interfere. The year before planting, fields need plowing, and several herbicides can control broadleaf weeds. During the first year's growth, mowing at 6–9 cm can help the switchgrass outgrow the weeds. Even with extensive weed growth in the first year, the switchgrass may outgrow them by the second year (Wolf and Fiske, 1995; Lewandowski, et al., 2003).

Insects feeding on switchgrass include grasshoppers (Family Acrididae), crickets (Family Gryllidae), corn flea beetles (*Chaetocnema pulicaria* (Melsheimer)), and others. The plant is also attacked by leaf rusts such as *Puccinia graminis* and *Panicum* mosaic virus (Wolf and Fiske, 1995; Lewandowski, et al., 2003).

20.3.3.3 Miscanthus

Miscanthus is a genus of 14–17 species of grasses from Southeast Asia. The taxonomy is complicated, confused, and still under active study. Many interspecific hybrids form naturally, and some *Miscanthus* species will also hybridize with species from the genus *Saccharum*. *Miscanthus* is in the Family Poaceae, and it occurs mostly in tropical and sub-tropical areas, from sea level to 3000 meters.

For biomass purposes, most attention has focused on a naturally occurring, triploid hybrid, *Miscanthus* x *giganteus*, which may be the result of a cross between *Miscanthus sacchariflorus* with *Miscanthus sinensis*. The former fares better in warmer regions, and the latter does better in the cooler zones. *Miscanthus* x *giganteus* came to Denmark from Japan in 1935 and has been investigated most extensively in Europe (Jones and Walsh, 2001; Lewandowski, et al., 2003; Heaton, et al., 2004).

Farmers must generate stands of *Miscanthus* x *giganteus* with pieces of rhizome, because the hybrid's seeds will not germinate. The lack of fertile seeds is an advantage in that the grass posses less danger as an invasive weed. The necessity to use rhizomes increases the costs of establishment however. Once established, stands may endure up to 20–25 years. Canopies may grow to as high as 4 meters (Lewandowski, et al., 2003; Heaton, et al., 2004).

Photosynthesis in *Miscanthus*, like in switchgrass and corn, utilizes the C_4 pathway. This makes the plant efficient in warm, dry conditions. It tolerates wide variation in soil quality, but it doesn't do well in waterlogged areas. Freezing weather below $-3.4\,^{\circ}\mathrm{C}$ can destroy the rhizomes (Lewandowski, et al., 2003).

Like switchgrass, stands of *Miscanthus* x *giganteus* reach their maximum yields only after three years of growth (Heaton, et al., 2004). Once at full growth potential, however, *Miscanthus* x *giganteus* yields more biomass per hectare per year than either corn or switchgrass. In an analysis of peer-reviewed literature, researchers reported yields of 22.4 (±4.1) Mg per hectare per year, about 12 Mg more than reported in the same study for switchgrass. Significantly, plant breeders have devoted almost no effort to selecting improved varieties of *Miscanthus*, so reason exists to project that genetic improvements would make *Miscanthus* even more productive (Heaton, et al., 2004).

As with switchgrass, this plant has known vulnerabilities to pests. Weeds must be controlled during the first year of a stand's growth, and herbicides suitable for corn offer protection. After canopy establishment, weed growth declines except for species that are shade-tolerant. Weeds germinating in the fall, e.g. *Poa annua*, may create some problems in *Miscanthus* stands. After extensive cultivation of *Miscanthus*, new weed species adapted to the environment created, may appear (Jones and Walsh, 2001).

Current literature indicates no significant diseases, but *Miscanthus* is susceptible to *Fusarium* (noted in Ireland), Barley Yellow Dwarf virus (noted in the United Kingdom), streak virus (noted in Japan), and *Miscanthus* blight (noted in the USA) (Jones and Walsh, 2001). The most thorough monograph on *Miscanthus* has no information on insects attacking the grass, nor does the book even list “insect” as a term in the index (Jones and Walsh, 2001). Thus current evidence suggests that, at least for now, insects will not be a serious problem in the suppression of *Miscanthus* yields.

20.3.4 Harvesting, Processing, and the Socio-Cultural Context

For the last half of the 20th century, the American Midwest was primarily a corn-soybean belt based on its two dominant crops. Other crops such as alfalfa, wheat, and oats occupied some land, but most was given to corn and soybean grown in annual rotation. Pest control problems, accordingly, consisted mostly of controlling the insects, weeds, and plant pathogens that attacked corn and/or soybean. As explained in more detail below, most pesticides used were for controlling weeds and insects attacking these two crops.

Ethanol, particularly the promise of cellulosic ethanol, may lead to major shifts in the biology, economics, and politics of pest control in the Midwest. Instead of being the “Corn-Soybean Belt” of America, it may need to be thought of as the “Corn-Soybean-Switchgrass-*Miscanthus* Belt.” Both the land use of the Midwest and the economic value of crops may shift. With shifts in land use and the advent of new crops like switchgrass and *Miscanthus* will potentially come new population dynamics of insect, weed, and plant pathogen pests.

Use of corn stover as a feedstock for cellulosic ethanol will add a clearly defined economic value to plant residues that currently don’t have monetary value, even if they have agronomic and ecological value. With alteration of the value of the corn plant will come a different calculus of the economic threshold for taking control actions. In addition, if ethanol production in general drives prices of all biomass up, a new calculus of the economic threshold will appear.

In short, the prospect of increasing ethanol production from biomass raised in the Midwest is not just a matter for farmers and economists to sort through. Pest control scientists, too, will find that the challenges they face in protecting biomass have changed. The next section provides a brief overview of how IPM may be affected.

20.4 Pest Control, IPM, and Ethanol in the New American Midwest

20.4.1 Current Profile of Pest Control Practices and IPM

Two factors will be most important in shaping the agricultural landscape of the American Midwest. First, public policies that promote ethanol as a substitute for gasoline will encourage production of corn and, possibly, of cellulosic biomass.

Second, new technology for making cellulosic ethanol, currently under development, may promote production of corn stover, switchgrass, and *Miscanthus*, even if public policies no longer subsidize and mandate the use of ethanol as a gasoline substitute. IPM specialists must follow the course of these two factors in order to understand the challenges they will face in controlling pests on corn, switchgrass, and *Miscanthus*.

The preceding sections demonstrated that changes in technology and public policy have already altered the agricultural landscape of the American Midwest. Even without the advent of ethanol, yield enhancing practices have increased and will continue to increase yields, particularly of corn. With corn-derived ethanol, even higher price incentives encourage farmers to increase yields of corn per hectare and to plant more hectares of corn.

If cellulosic ethanol becomes economically and technologically practical, farmers will have incentives to harvest corn stover and to plant and harvest switchgrass and *Miscanthus*. Land for more corn and for the latter two crops may come from land currently devoted to soybean or to the Conservation Reserve Program or to pastures (Perrin, et al., 2008). Land coming from soybean to corn will diminish the current practice of rotating corn with soybean on an annual basis.

Thus the broad features of the new landscape in the American Midwest will include less land devoted to soybean and to conservation and more land devoted to corn, switchgrass, and *Miscanthus*. Figure 20.3 summarizes the possible changes induced by new yield enhancing practices and by changes in biofuels. Changes will almost certainly alter pest pressures and the need for new pest control and IPM practices. While it is impossible to predict all of the consequences for pest control, it is possible to examine current pest control practices and suggest the likely directions of change.

Unfortunately, the current status of IPM in the American Midwest does not auger well for the vitality of IPM in a "new Midwest" that has been transformed by a green revolution for biofuels production. Pest control scientists working on corn embraced IPM by the mid-1970s (National Research Council, 1975). Despite over 30 years of additional research on IPM practices, however, scientists still lament that adoption

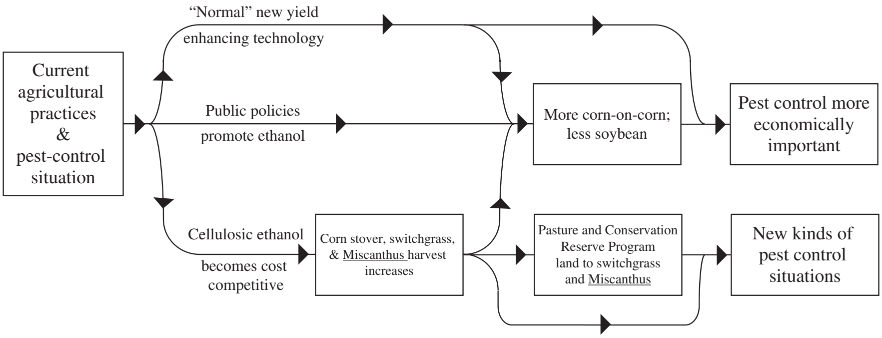


Fig. 20.3 Flow chart for possible developments in a new Midwestern landscape stimulated by new production practices and by developments in biofuels (Figure prepared by Brendan Lazarus)

of IPM by corn growers "... has been weak at best, which leads to the question: 'why?'" (Hammond, et al., 2006). A survey of Wisconsin farmers suggested that the answers depended upon the size of operation and the kind of farm. Large farms (compared to small) and cash-grain farms (compared to dairy) had higher adoption rates of IPM practices (Hammond, et al., 2006).

As Hammond, et al., (2006) note, IPM has clearly not dislodged heavy dependence upon pesticides. Thus the problems initially stimulating the development of IPM (resistance to pesticides and pest population resurgence) (Perkins, 1982) still have an opportunity to once again cause problems. A case-study examines the situation with insects attacking corn.

20.4.2 Case Study: Shifting Insect Problems on Corn

Shifting insect-control practices on corn demonstrate the complexities of IPM development now, and the advent of more ethanol production will increase the challenges faced by pest control scientists. The case study emphasizes Iowa from the period of the mid-1990s to the present.

In 1997, Iowa farmers planted about 15 percent of the US corn acres, and they did about the same proportion in 2007. Total corn planted in Iowa in 1997 was about 12 million acres (4.9 million ha). Corn rose in 2007 to about 14 million acres (5.7 million ha); in 2008 the planted acreage of corn in Iowa dropped to about 13 million acres (5.3 million ha), still substantially above 1997 levels (US Department of Agriculture, National Agricultural Statistical Service, 2008; some figures calculated). The earlier time (1997) was before significant effects resulted from production of corn-based ethanol (Abendroth and Elmore, 2007; Wisner, 2007).

A substantial amount of the increased land in corn in Iowa came, in 2007, from land formerly devoted to soybean. For example, from 1997 through 2006, soybean land in Iowa was over 10 million acres (4.4 million ha) per year. In 2007, however, the Iowa land in soybean declined to 8.6 million acres (3.5 million ha). This drop of approximately 1.6 million acres (640,000 ha) from 2006 was almost exactly matched by an approximate rise in Iowa corn area of 1.6 million acres (640,000 ha) (U.S. Department of Agriculture, National Agricultural Statistics Service, 2008). Indiana reported a similar drop in soybean land in favor of corn (Nielsen, et al., 2007).

Under intensive cultivation, Western corn rootworm (*Diabrotica virgifera virgifera* LeConte), northern corn rootworm (*Diabrotica barberi* Smith and Lawrence), and European corn borer (*Ostrinia nubilalis* (Hübner)) have constituted the most significant insect problems on corn in the Midwest in terms of economic damage and insecticide usage (Wilson, et al., 2005; U.S Department of Agriculture, 1999). This lineup of the three primary pests of corn has remained the same for at least 40 years (National Research Council, 1975; Wilson, et al., 2005).

Control practices for the three species have changed and shifted at different times since the mid-1990s. In the period 1997–2007, important changes, outlined below, reduced insecticides applied to soil and foliage. Despite these changes, however, a profile of insect problems in Iowa corn in 1997 indicated heavy reliance on chemical methods of suppression. Later findings of Hammond, et al. (2006) suggested that reliance on chemicals rather than IPM still predominated in the Midwest.

20.4.2.1 Patterns and Changes Through the 1990s

One part of the significant new technology noted above started in 1996 with the introduction of transgenic corn that produced the toxin of *Bacillus thuringiensis* ("Bt corn") for controlling European corn borer. Wide adoption in Iowa and elsewhere led to declines in the use of insecticides against this insect (Wilson, et al., 2005). In 2002, a survey indicated that 32 percent of farms growing corn used at least some Bt corn against European corn borer. Iowa was a leader in these early uses of Bt corn as 45 percent of its corn-growing farms made some use of Bt corn in that year (U.S. Department of Agriculture, National Agricultural Statistics Service, 2003). Wilson, et al., (2005) reported that by 1998 a decreasing percentage of corn growers perceived European corn borer as a problem.

In contrast with the European corn borer, the situation with Western and Northern corn rootworm developed differently, and these two species still rank as major pests with farmers. Rotating corn with soybean to control these two species was key until 2003, but crop rotation had a convoluted history emblematic of the ambivalence to IPM practices. Before the 1950s, crop rotation was standard for controlling rootworm, and after the 1930s rotation increasingly meant "rotation of corn with soybean."

In the 1950s, new insecticides such as aldrin and heptachlor opened the door to control rootworm without rotating corn with soybean (Lauer and Stanger, 2008). Thus the practice of crop rotations to control rootworms became an option not a necessity. By the mid-1970s, however, problems associated with chemicals prompted pest management scientists to recommend crop rotation instead of reliance on chemicals (National Research Council, 1975). By 1997, Iowa scientists still recommended corn-soybean rotation as "the most effective management tool available for farmers" (U.S. Department of Agriculture, 1999).

The role of crop rotation has been important, but not always used, for many decades, but relatively recent developments in the two rootworm species began to thwart rotation as a successful control practice. By the late 1980s, strains of northern corn rootworm—now present in Iowa, Minnesota, and Nebraska—evolved extended diapause. Eggs laid in late summer and fall survived for two or more winters before hatching, by which time the farmer had rotated corn back to the field. Analogously in the mid-1990s strains of the western corn rootworm—now in Illinois, Indiana, and Wisconsin—evolved the ability to lay eggs in soybean fields. These eggs successfully overwintered and hatched the following spring to find corn rotated into the field. In both cases, the insect was "resistant" to crop rotation as a control scheme (Wilson, et al., 2005; Onstad, et al., 2003; 2006; Tollefson, et al., 2007; Boerboom, 2008).

Partly because of rotation resistance, insecticides continued to have popularity among growers, albeit at a diminishing rate of use from 1997–2007. A 1997 profile of Iowa corn production still listed insecticides as the "standard practice" for corn rootworm, especially for corn following corn (U.S. Department of Agriculture, 1999). Recommendations targeted both soil insecticide treatments for larvae and foliar applications for adults. Despite the prominence of insecticides in the 1997 profile, it noted that "some producers scout for significant populations of adults in mid to late summer" as a way of reducing insecticide treatments during the following spring (U.S. Department of Agriculture, 1999). Scouting is a major component of IPM.

Surveys of insecticide use corroborated the notion that in the mid-1990s corn growers used substantial amounts of insecticide. In a survey representing 90 percent of the US corn acreage, farmers applied insecticide to 30 percent of the corn acres. Iowa corn farmers applied insecticide to only 17 percent of their corn acreage, less than the national survey. Their usage was 13 percent of the total mass, which suggested a slightly lower than average rate of application on the acres treated. Chlorpyrifos, terbufos, carbofuran, and fonofos were the materials used in highest amounts in Iowa (U.S. Department of Agriculture, 1997).

20.4.2.2 Patterns and Changes in the 2000s

By 2005, however, new insecticidal tools had dropped the mass of chemicals applied significantly. Nationally 23 percent of the acres were treated (down from 30 percent a decade earlier), and the total amount of chemical used had dropped to 4.8 million pounds (2.2 million kg) (down from 14.2 million pounds (6.4 million kg) in the earlier survey). Iowa growers treated 11 percent of their acres, still lower than the national average, and they used 187,000 pounds (84,823 kg), down from 1.8 million pounds (826,000 kg) in 1996. Cyfluthrin, tebupirimphos, and tefluthrin were the materials used in Iowa in 2005 (U.S. Department of Agriculture, 1997; U.S. Department of Agriculture, 2006b).

Interpreting the significance of the drop in total amounts of insecticide used, however, requires one further piece of information: application rates per hectare of the new chemicals are drastically reduced from the application rates of the chemicals used in the 1990s. The insecticides used in the largest amounts in Iowa in the mid-1990s (chlorpyrifos, terbufos, carbofuran, and fonofos) were each applied at about 1 pound per acre (1.1 kg/ha). In contrast, the insecticides used in 2005 (cyfluthrin, tebupirimphos, and tefluthrin) were each applied at much lower rates: approximately 0.1 pounds per acre (0.11 kg/ha) for tebupirimphos and tefluthrin, and 0.006 pounds per acre (0.0066 kg/ha) for cyfluthrin.

Thus the drop in amounts of insecticide used on corn in Iowa between the mid-1990s and the mid-2000s stemmed largely from the lower application rates of the new chemical tools. In addition, the proportion of acres treated with soil and foliar insecticides also dropped, from 17 percent to 11 percent.

Beyond the drop in application rates and the drop in proportion of acres treated, a new type of Bt corn was also marketed. As noted above, Bt corn for European corn borer appeared in 1996 and began to lower insecticides applied for that insect. In 2003, seed producers released a new type of Bt corn aimed at controlling both the western and northern corn rootworm. Varieties containing both toxin genes soon followed and thus provided protection against European corn borer and both rootworm species.

New chemicals applied at lower rates per hectare plus new developments with Bt corn probably account entirely for both the lower total amounts of insecticide used in Iowa and the lower proportion of hectares treated with soil and foliar insecticides. It's not that insect control in Iowa was moving away from a chemical control strategy. Instead the patterns of insecticide usage in the mid-2000s reflected new chemicals applied in small amounts and Bt corn substituting for chemicals previously applied to soil or foliage. These figures on the uses of insecticides thus do not seem to contradict the conclusions of Hammond, et al., (2006), noted above, that adoption of IPM by corn growers has been weak.

Yield data strongly suggest that the new technology for insect control successfully protected Iowa corn. Total corn production in Iowa was 1.7 billion bushels (43.2 million metric tons) in 1996 and 2.2 billion bushels (55.9 million metric tons) in 2005. Iowa's average yields per acre increased from 138 bushels per acre (8662 kg/ha) to 173 bushels per acre (10,859 kg/ha) in that period (U.S. Department of Agriculture, National Agricultural Statistics Service, 2008).

Crowder et al., (2005) noted that Bt corn would likely simplify control of corn rootworm and reduce the importance of insecticides and crop rotations as the major management practices for these insects. In turn, Bt corn could reduce the problems associated with direct use of chemicals, particularly development of resistance and environmental contamination. The seed companies, however, under mandate from the U.S. Environmental Protection Agency, required growers to plant 20 percent of their corn as non-Bt corn. The area given to non-Bt corn provided a "refuge" that allowed continued survival of strains of all three species that succumb to Bt toxin. This strategy intended to forestall development of resistance to the Bt toxins.

20.4.2.3 The Current Status of IPM for Corn in the Midwest

IPM, as noted earlier, has undergone an evolution of definitions. Bt corn is a new technology that once again will force reconsideration of the definition of IPM. In a major way, Bt corn is simply a new method of delivering an insecticidal chemical. Use of Bt corn thus puts the farmer in the position of relying, sometimes exclusively, on the insecticidal Bt toxin. In this sense Bt corn is a form of "chemical control," not "integrated control" or IPM.

Bt corn thus raises two of the objections that have long bedeviled reliance on chemicals: loss of effectiveness due to resistance and environmental damage to non-target species and human health. The environmental damage claims have been hotly contested by advocates of Bt corn, and in any case the dangers of Bt should in some way be compared to the situation before transgenic corn, which was heavy reliance on insecticides for control of European corn borer, western corn rootworm, and northern corn rootworm.

The alternative way of looking at Bt corn is to see active management against resistance—by the requirement of refuges—as a practice that may bring Bt into the IPM arena, although perhaps its inclusion requires another expansion of the definition of IPM. In this light, Bt corn has reduced conventional insecticide use, used concepts from population biology, and enabled continued, profitable growth in the yields of corn. These consequences satisfy some of the aims of IPM, especially in its more recent forms.

This case study has focused on the shifting patterns of insect control in corn. It corroborates the general notion that—nearly 50 years after IPM for insect control was first fully conceived—corn insect control in the Midwest remains lodged mostly in the chemical control strategy (Park and Tollefson, 2005). Farmers also used Bt corn, scouting, tillage practices, and weather monitoring, all of which demonstrated some influence of the IPM strategy. As discussed above, however, Bt corn looks a lot like chemical control in its theoretical foundation.

Weed control in corn likewise remains embedded in the chemical control strategy (U.S. Department of Agriculture, 1999; U.S. Department of Agriculture, 2006b; Owen, 2007), but that analysis is beyond the scope of this chapter. Disease control in corn, in contrast to control of insects and weeds, has a mixed appearance of IPM strategies. Plant resistance plus crop rotation provide the best foundation for disease prevention and control, but corn seed is routinely treated with pesticides. Robertson and Munkvold (2007) consider such routine uses part of an “integrated disease management strategy.” Foliar fungicides for disease control, in contrast, are not necessarily profitable even though they can increase yields (Robertson, et al., 2007). Recent price increases of corn may be stimulating more foliar fungicide use but not within the IPM strategy (Boerboom, 2008). Reducing crop rotations and increasing the practice of conservation tillage may increase disease incidence, and herbicides and insecticides may make corn more susceptible to disease (Nyvall and Martinson, 1997).

20.5 Conclusions

The interweaving of new technologies always produces a cascade of consequences with convoluted pathways of influence. As described in this chapter, the meshing of the biofuels technology with ongoing development of plant breeding and pest control seems virtually certain to alter the pest control challenges in the Midwest. At least eight separate impacts show up at this time.

First, regardless of ethanol, plant breeders and pest control scientists continue the quest they have mounted for the past century to constantly enable farmers to obtain higher yields at a profit. The vast majority of these new practices have embraced pesticides and a chemical control strategy, not IPM. Disease control may be an exception, but recent increases in foliar fungicide use may indicate a change in progress. If such uses continue to increase, disease control would also move into the chemical control strategy.

Second, public policies beginning in 1978 succeeded after 2002 in promoting ethanol production and markets. The Midwest has accordingly already changed, and the ethanol economy is shifting prices of biomass, which may increasingly affect pest management. Current trends in public policy will lead to an even stronger embrace of ethanol in the future, which means that effects currently impinging on pest control will become stronger.

Third, markets for ethanol have already increased the price of corn grain. When the price of the harvested crop rises, the economic threshold drops. i.e. the population level of a pest needed to trigger control actions becomes lower. If the control action is use of a pesticide, more pesticide use will be economically rational (even if self-defeating in the long run).

Fourth, increased prices of corn grain may reduce the use of crop rotation with soybean. Concurrent rises in soybean prices may, however, continue to encourage crop rotation. To the extent rotation diminishes, it is hard to see this consequence as anything but a blow against embrace of IPM.

Fifth, if corn stover is successfully converted to ethanol in the near future, the dollar value of the corn plant in the field will go up. As with increases in the prices of corn grain, such a rise will lower the economic threshold and may encourage higher uses of pesticides. Whether the lower economic threshold actually encourages higher pesticide use will depend upon (a) whether current pest populations are already at or above the threshold and (b) whether farmers use economic threshold as a tool in decision making. A lower economic threshold, however, is likely only to increase pesticide use, not decrease it.

Sixth, transgenic crops (Bt corn as discussed above and also Roundup Ready corn for use in glyphosate-based weed control) will continue to play a role in pest control in the Midwest. Rising commodity prices may stimulate more use of transgenic crops. Bt corn may have helped lower the amount of insecticide used, but at the same time Bt corn is a kind of chemical control in itself. Growers using Bt corn may therefore be dropping their uses of insecticides but simultaneously continuing their embrace of a new chemical control strategy.

Seventh, switchgrass and *Miscanthus* may replace soybean and corn, reduce crop rotation, and eliminate land in the Conservation Reserve Program and pasture. All of these will alter the biological landscape and may create new pest species or alter the severity—up or down—of existing problems. Effects on the use of IPM are difficult to predict.

And finally eighth, removal of stover, switchgrass, and *Miscanthus* may alter soils and lead to more soil erosion and altered soil moisture profiles. It's also possible that turning to the perennials of switchgrass and *Miscanthus* will increase carbon storage in soils and reduce soil erosion. Either way, the effects on pest control and IPM are hard to predict in advance.

The net result of the above intersecting pathways may not yet be clear, but at least some (events that raise the value of crop plants and events that reduce crop rotation) are likely to constrain further embrace of IPM by growers. Nevertheless these are the challenges that lie before pest control scientists.

As the old Chinese proverb notes, challenges pose both dangers and opportunities. The need for alternative energy strategies is great and enduring, and pest control scientists have a chance to play an important role in contributing to practical solutions. Farmers, the public, and political leaders will all cheer successful strategies that enable biomass to be used as fuel, especially if those strategies are based on IPM.

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