Rajinder Peshin · David Pimentel
Editors

Integrated Pest Management

Experiences with Implementation, Global Overview, Vol.4

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Preface

World-wide integrated pest management (IPM) is the accepted policy decision for pest management. However, in reality this often becomes “integrated pesticide management”. There is also debate and confusion about the primary quantifiable objective of IPM. The strategy of IPM and its implementation and evaluation has always struggled with interpretation and true progress. There are different schools of thoughts: one promoting the integrated pesticide management, thus training farmers in right use of pesticides to minimize selection for resistance, conserve beneficials and reduce health and pollution risks. Second: integrated pest management incorporating ecologically sound pest management tactics so that pesticides are essentially a last resort. Third: propagating pesticide free pest management. Fourth: overrelying on Bt crops to reduce insecticide use. However, use of pesticides should be limited to where no effective alternatives are available.

World pesticide use stabilized in the last two decades. The insect resistant transgenic crops, IPM and pesticide use reduction programs, and low volume pesticides were the drivers for stabilizing the pesticide use in China, United States of America and India. But lately there has been an increase in the pesticide use in these countries. Introduction of herbicide resistant crops in Canada and United States has increased herbicide use in the US and Canada. European countries, namely Denmark, Netherlands and Sweden, have halved the pesticide use in the last two decades by introducing pesticide action plans, implementing IPM programs and use of low dosage highly toxic pesticides compared with say, DDT (Chap. 19, 20, 21 and 22).

Bt crops are compatible with IPM strategies but Bt crops alone are not sustainable. Overreliance on transgenic crops has already led to the weed and insect resistance (Chap. 4) which may lead farmers into a transgenic-cum-pesticide treadmill. Experiences with implementation of pesticide action plans and IPM programs around the world confirm that reduction in pesticide use by mass is not the robust indicator to measure success of IPM. Low volume pesticides propelled the pesticide use reduction in many countries (Chap. 11, 22). The pesticide treatment frequency index and the environmental impact quotient are better evaluation indicators to measure the impact of IPM programs.

What experiences with IPM technology and IPM extension that are documented in this book can be bracketed successful and viable? In many instances IPM technologies developed at the research level have not been effectively scaled up to industry-wide practice because of the lack of a well conceived and evaluated extension process. Different extension approaches are needed in different situations for greater adoption of IPM by the farmers. IPM practices in most cases are tested for success at pilot scale but fail to factor in the constraints, mainly the IPM attributes, for replication in large scale. The authorities in IPM research and extension throughout the world have contributed to the book and covered the experiences with different IPM approaches and implementation in North America, South America, Africa, Europe, Asia and Australia.

Jammu, India Rajinder Peshin
Ithaca, New York, USA David Pimentel

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I am grateful to Dr. David Pimentel, Professor Emeritus, Cornell University, Ithaca, New York for accepting my invitation to become the co-editor of this volume and to Springer for agreeing to publish this volume. I thank our authors for their very interesting and informative manuscripts. I wish to thank Michael Burgess for his valuable assistance in proofing the book.

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About the Book

This book, the fourth in the series on integrated pest management (IPM), deals with the experiences with implementation and impact of IPM in Africa (Uganda and East Africa), Asia (China, India and Indonesia), Australia, North America (Canada and the United States), South America (Ecuador, Bolivia, and Peru), and Europe (Denmark, Germany, Italy, the Netherlands and Sweden). Despite five decades since the concepts of integrated control and threshold theory were developed, and four decades since IPM programs have been implemented throughout the world, the widespread use of complex IPM practices has not been adopted. In addition the diffusion of IPM from trained farmers to others has not been as extensive as hoped for. In developing countries the farmer field school model of extension alone cannot reach the millions of small-scale farmers. Indonesia which is identified as a success story in implementing IPM and reducing pesticide use is facing problems of scaling up. In developed countries pesticide use is high and the number of famers less than in developing countries. Notable success has been achieved in reducing pesticide use in Sweden, Denmark, and the Netherlands by using low dosage pesticides and other techniques. The scientific authorities in IPM research and extension throughout the world have contributed to this book. The chapters assess the benefits and risks of various IPM technologies and transgenic crops. This book will serve professionals, investigators, academia, governments, industry and students.

About the Editors

Rajinder Peshin is an associate professor at Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, India. His Ph.D. is from Punjab Agricultural University, Ludhiana, India. His research expertise is diffusion and evaluation issues associated with sustainable agriculture research and development programs. He had developed an empirical model for predicting the adoptability of agricultural technologies when put to trial at farmers' fields, and an evaluation methodology for integrated pest management programs. He has published more than 50 scientific papers and chapters of books, and has authored three books. Peshin has also edited two books on integrated pest management, published by Springer in 2009.

David Pimentel is a professor of ecology and agricultural sciences at Cornell University, Ithaca, NY 14853, USA. His Ph.D. is from Cornell University. His research spans the fields of energy, ecological and economic aspects of pest control, biological control, biotechnology, sustainable agriculture, land and water conservation, and environmental policy. Pimentel has published over 700 scientific papers and 40 books and has served on many national and government committees including the National Academy of Sciences; the President's Science Advisory Council; U.S. Department of Agriculture; U.S. Department of Energy; U.S. Department of Health, Education and Welfare; Office of Technology Assessment of the U.S. Congress; and the U.S. State Department.

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Michael Burgess works as a copy editor for Dr. David Pimentel and works in the Cornell University Greenhouses. He has worked with entomological researchers as an experimentalist, library researcher, copy editor and generally aiding researchers in need at Cornell as a technician for over 25 years.

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Anna-Camilla Moonen is a Landscape Agronomist. She graduated at Wageningen University (The Netherlands) specializing in Landscape Ecology, and obtained her PhD at the Agronomy Department of the University of Pisa (Italy), studying non-chemical methods for weed management in arable cropping systems in general and the use of cover crops in particular. She is currently an Assistant Professor at the Institute of Life Sciences, Scuola Superiore Sant'Anna di Pisa (Italy), where she teaches and performs research aimed at developing sustainable cropping systems through integrated management of cropped areas and the surrounding semi-natural habitat at local and landscape scale in order to maximize functional agro-biodiversity.

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Rajinder Peshin is Associate Professor at the Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, India. His Ph.D. is from Punjab Agricultural University, Ludhiana, India. His research expertise is diffusion and evaluation issues associated with sustainable agriculture research and development programs. He has developed a normative model for predicting the adoptability of agricultural technologies when put to trial at farmers' fields, and an evaluation methodology for integrated pest management programs. He has published more than 50 scientific papers and chapters of books and has authored three books besides being the editor of two books on integrated pest management published by Springer in 2009.

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David Pimentel is a professor of ecology and agricultural sciences at Cornell University, Ithaca, NY 14853. His Ph.D. is from Cornell University. His research spans the fields of energy, ecological and economic aspects of pest control, biological control, biotechnology, sustainable agriculture, land and water conservation, and environmental policy. Pimentel has published over 700 scientific papers and 40 books and has served on many national and government committees including the National Academy of Sciences; the President's Science Advisory Council; U.S. Department of Agriculture; U.S. Department of Energy; U.S. Department of Health, Education and Welfare; Office of Technology Assessment of the U.S. Congress; and the U.S. State Department.

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Frank Wijnands is an agronomist graduated from Wageningen University (Netherlands) in 1983. His professional focus is on the development of Integrated and Organic Farming Systems as well as leading farming systems experiments on experimental farms as national pilot farm networks. From 2001–2010 he was leading the Farming with Future Network, focusing on developing and introducing Integrated Pest Management in practice in cooperation with farmers, advisors, traders, manufacturers and other stakeholders. For this innovative and inspiring approach connecting research, practice and policy he was awarded in 2005 the Royal Netherlands Society of Plant Pathology Prize. He is since 2004 member of the IOBC Commission on IP Guidelines.

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Abbreviations

%	Percent
1 bale	=170 kg
2,4-D	2,4-Dichlorophenoxyacetic acid (usually referred to by its abbreviation, 2,4-D) is a common systemic herbicide used in the control of broadleaf weeds. It is one of the most widely used herbicides in the world, and the third most commonly used in North America. 2,4-D is a synthetic auxin (plant hormone) herbicide.
a.i.	Active ingredient
AAFC	Agriculture and Agri-Food Canada
ABARE	Australian Bureau of Agriculture and Resource Economics
ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABM	Agent-Based Model
ABS	Australian Bureau of Statistics
ABSTC	Agricultural Biotechnology Stewardship Technical Committee
ACIS	Arizona Crop Information Site
ACRPC	Arizona Cotton Research and Protection Council
ADB	Asian Development Bank
Aerial application	Use of airplanes to apply pesticides to control crop pests, crop growth regulators/defoliants, or fertilizers.
Aflatoxins	A mycotoxins produced by the fungi *Aspergillus flavus* and *A. parasiticus*. Aflatoxins are highly toxic to birds and mammals.
AIC	Akaike's Information Criterion
AIPMTP	Apple IPM Transition Project
AL	Area Load
ALPS	German Database for non-chemical alternatives in plant protection
AMA	Agriculture Management Assistance
APEP	Agricultural Productivity Enhancement Programme
APHIS	Animal and Plant Health Inspection Service
APLC	Australian Plague Locust Commission

APVMA	Australian Pesticides and Veterinary Medicines Authority
Area-wide IPM	Strategies and tactics which impact pests on an area-wide basis. Field-specific tactics may be applied on a high percentage of fields throughout a production region resulting in area-wide impacts on pest populations.
Atoxigenic fungal strains	Atoxigenic fungal strains do not produce toxins. Atoxigenic strains of *Aspergillus flavus* have been used to competitively displace toxigenic *A. flavus* strains, protecting crops from developing aflatoxins.
At-planting pesticides	At-planting pesticides are applied at planting. They may be formulated as liquid or wettable powder formulations which are mixed with water, or as granules which are applied dry. They may be applied using broadcast, in-furrow, band or in a T-band methods.
AUD$	Australian Dollars
AVRDC	World Vegetable Centre
AWN	AgWeatherNet
AZM	Azinphos-methyl
Banks grass mite	Banks grass mite (*Oligonychus pratensis*) (order Acarina, family Tetranychidae) is a pest of corn, grain sorghum and winter wheat. It is especially troublesome under dry conditions and situations in which natural enemy populations are low. Its high reproductive capacity and ability to quickly "fire" the leaves of crops makes it an important pest of grains, especially in low rainfall regions.
BAPPENAS	Badan Perencanaan Pembangunan Nasional or Indonesian National Development Planning Agency
BCA	Biological control agent
BIOS	Biologically Integrated Orchard System
BMELV	Federal Ministry of Food, Agriculture and Consumer Protection
BMPs	Best Management Practices
BMSB	Brown Marmorated Stink Bug
boll weevil	Boll weevil (*Anthonomus grandis*) (order Coleoptera, family Curculionidae) was—until it was eradicated, 1980s through the present time—the primary pest of cotton in the southern USA. Cotton was its only host plant in the majority of the South. The boll weevil preferred to feed and lay eggs on prebloom flower buds (squares) about the size of a pencil eraser. It was able feed and lay eggs on small bolls less than 12 days old as well. Heavy use of small bolls occurred late in the season as squares become unavailable. Its feeding and egg laying caused significant fiber and seed loss.

boll weevil diapause control programs	Boll weevil diapause control programs were programs which used insecticides (predominately malathion) to target diapausing boll weevil adults as they fed on cotton. Diapausing boll weevils were no longer reproductive and had to feed for approximately three weeks to store sufficient fat (energy) to allow them to overwinter successfully. For these reasons, treatment of diapausing boll weevils could produce large reductions in boll weevil populations with minimal use of insecticides. The limitation was the treatments had no effect on cotton yield the year they were applied. Benefits of the treatment occurred the year after the treatments were made.
Bollworm	Bollworm (*Helicoverpa zea*) (order Lepidoptera, family Noctuidae) was traditionally the second most important pest of cotton throughout the U.S. South. The female moth lays eggs on cotton (and other hosts such as corn, grain sorghum, tomatoes, peppers, etc.). The eggs hatch and the caterpillar larvae feed on terminal growth, squares and bolls, resulting in lint and seed loss. Previously controlled by insecticides, since 1996 bollworm has been effectively controlled—in most cases—by genetically modified Bt cotton. Bt proteins are generally less effective against bollworm than against most other cotton feeding caterpillars.
BPA	Bukalasa Pedigree Hybrid
BPH	Brown plant hoppers
BSA	Federal Plant Variety Office
BSE	Bovine Spongiform Encephalopathy
Bt	*Bacillus thuringiensis*
Bt cotton	Genetically modified cotton in which each plant cell contains insecticidal proteins which originated in the bacterium *Bacillus thuringiensis* (Bt). Bt cotton varieties are effective against many insect pests in the class Lepidoptera (moths and butterflies).
BVL	Federal Office of Consumer Protection and Food Safety
CA	Cellular Automaton
Ca	circa
CABI	Commonwealth Agriculture Bureau
CABI	Commonwealth Agricultural Bureau International
Calcium arsenate	An inorganic compound $Ca_3(AsO_4)_2$ used as an insecticide. It is highly soluble in water—compared with lead arsenate—increasing its toxicity to insects. It was formulated and applied as a dust.

CAMP	Codling Moth Area-Wide Project
CAP	European Union's Common Agricultural Policy
Carbamate insecticides	Carbamate insecticides are compounds with insecticidal characteristics which are made from carbamic acid. They are toxic due to their anticholinesterase action on the nervous system, a mode of action similar to that of organophosphates. Most have a broad spectrum of activity. Many have high levels of mammalian toxicity.
CCM	Corn-cob-maize
CCVT	Central Coast Vineyard Team
CDFA	California Department of Food and Agriculture
CDN	Canadian
CDO	Cotton Development Organization (Uganda)
CEUREG	Central and Eastern European REGional technical forum
cf.	compare
CHC	Canadian Horticultural Council
CICR	Central Institute for Cotton Research
CIPM	Consortium for IPM. This was an EPA, NSF and USDA funded, 17 university effort, 1979–1985, which built upon the foundation of the Huffaker Project and further developed state research and extension IPM efforts. Along with insect pests, it focused on biological and ecological crop processes; development of crop cultivars with resistance to insect, disease and nematode pests, climatic and chemical stresses, and efficient use of resources; improved methods of collecting and processing biological, meteorological and crop data; computer modeling of production and pest management systems as a research guiding tool and to design optimal crop management systems; economic analysis of pest management systems; and pilot pest management systems with enhanced information flow to producers. (see Consortium for IPM)
CIPMC	Central Integrated Pest Management Centre
CMO	Common organization of agricultural markets
CODEX	CODEX Alimentarius Commission
Common waterhemp	Common waterhemp (*Amaranthus tuberculatus (syn. rudis)*) is an annual, dicot weed in the Amaranthaceae family. In Missouri this weed first evolved multiple resistance to 3 herbicide modes of action in 2005. It is problematic and is very competitive with corn, cotton and soybean.

Competitive displacement of toxigenic fungi	A biological control strategy in which atoxigenic strains of a fungus are produced and applied to fields infested with toxigenic fungal strains. The toxigenic strains are competitively displaced by the strains which do not produce toxins. This strategy has been successfully used to protect crops from aflatoxin development.
Conservation Reserve Program	The Conservation Reserve Program (CRP) was a USDA funded program which paid farmers to take highly erodible land out of crop production and plant it in grass.
Conservation tillage	Conservation tillage is any method of soil cultivation that leaves the previous year's crop residue (such as corn stalks or wheat stubble) on fields before and after planting the next crop, to reduce soil erosion and runoff. To provide these conservation benefits, at least 30% of the soil surface must be covered with residue after planting the next crop. Some conservation tillage methods forego traditional tillage entirely and leave 70% residue or more. Conservation tillage is especially suitable for erosion-prone cropland. In some agricultural regions it has become more common than traditional moldboard plowing. The acreage farmed using conservation tillage practice increased dramatically after glyphosate resistant crops became available.
Consortium for Integrated Pest Management	The Consortium for IPM (1979–1985) extended the Huffaker Project to include management of insect, plant disease and weed pests. It was funded by USDA, NSF and EPA; and involved cooperative research and extension projects involving 17 universities. (see CIPM)
Cooperative Extension Service	The Cooperative Extension Service, also known as the Extension Service of the USDA, is a non-formal educational program implemented in the United States designed to help people use research-based knowledge to improve their lives. The service is provided by the state's designated land-grant universities. In most states the educational offerings are in the areas of agriculture and food, home and family, the environment, community economic development, and youth and 4-H.

Cotton aphid	The cotton aphid *(Aphis gossypii)* (order Homoptera, family Aphidae) is a small, soft-bodied insect which feeds on cotton leaves and tender plant stems and terminal growth. Cotton aphid populations are capable of rapidly increasing causing stunting, yield and quality losses. It also excretes a sticky fluid which can contaminate lint. Cotton aphid is frequently a secondary pest. Its populations are often held in check by natural enemies. Aphid populations can increase as natural enemies are killed when broad spectrum insecticide applications are made for other pests.
Cotton fleahopper	The cotton fleahopper (*Pseudotomocellus seriatus*) (order Hemiptera, family Miridae) is a sap sucking pest of cotton. Its feeding on tiny squares causes them to dry up, and fall from the plant.
Cotton leafworm	The larval stage of the cotton leafworm (*Alabama argillacea*) (order Lepidoptera, family *Noctuidae*) is a leaf feeding pest of cotton. After the development of synthetic organic insecticides cotton leafworm became a minor pest and was only occasionally seen in cotton fields.
CPARD	A National Association of State Departments of Agriculture and EPA Cooperative Agreement Project which is operated by Washington State University. CPARD operates a database of state's licensed pesticide applicators.
CPO	Crop Protection Online
CPV	Cytoplasmic polyhedrosis viruses
CRDC	Cotton Research and Development Commission
Crop consultants	Trained experts in crop protection who contract with growers to monitor crops and examine (scout) them for insect pests, plant diseases, weeds, and crop performance. Consultants make recommendations to growers about the use and timing of crop and pest management tactics.
Cry	Crystalline
CSDP	Cotton Subsector Development Project
CSIRO	Commonwealth Scientific and Industrial Research Organisation
Cultural practices or cultural management methods	The manipulation of crop production operations to favor the crop and put pests at a disadvantage are called cultural management methods. Cultural management methods may include: variety selection, planting practices, planting date, cultivation practices, fertilization practices, irrigation practices, crop rotation, harvest practices, crop residue destruction and tillage practices.
DAAS	Danish Agricultural Advisory Service
DAS	Decision Aid System
DBM	Diamond back moth (DBM)

DDT	Di-chloro di-phenyl tri-chloroethane
DEWH	Department of Environment, Water and Heritage
DG Sanco	Health and Consumers Directorate General
Diapause	A period during which growth or development of an insect is suspended and physiological activity is diminished. In some insects such as boll weevil, the sex organs atrophy and after a period of feeding, the body cavity fills with fat which supplies the energy for overwintering.
DMNT	(*E*)-ecimene and (*E*)-4,8-dimethyl-1,3,7-nonatriene
DPH	Doctor of Plant Health
DPIW	Department of Primary Industries, Parks, Water and Environment
DSS	Decision Support System
DSS	Decision support systems
DT	Damage Threshold
Dual toxin Bt cotton varieties	Cotton varieties into which Bt genes coding for 2 protein toxins are present. Each cell of plants with dual toxins produce not one, but two proteins toxic to insects.
DVM	Doctor of Veterinary Medicine
DWD	German Meteorological Service
e.g.	For example
EARML	Extension Arthropod Resistance Monitoring Laboratory
EC	Emulsifiable concentrate
EC	European Community
EC	European Commission
ECB	European corn borer, *Ostrinia nubilalis*
Ecologically-based management tactics	Pest management tactics based on the ecology of the crop and pest.
Ecology	The scientific study of the relationships of organisms with each other and with their natural environment. Components of ecology include species composition, distribution, amount (biomass), numbers, and changing states within and among ecosystems. Ecosystems are composed of dynamically interacting parts including organisms, the communities they make up, and the non-living components of their environment.
Economic threshold	The economic threshold is the point at which an insecticide treatment must be made in order to prevent losses equal to the cost of controlling the pest.

Economic injury level	The economic injury level is the pest population level which will cause damage to the crop equal to the cost of controlling of the pest.
EEE	Eastern Equine Encephalitis
EEP	Environmental Exposure to Pesticides
EFPs	Environmental Farm Plans
Emulsifiable concentrate	Concentrated liquid formulations of pesticides which disperse and are emulsified in water. Emulsifiable concentrate formulations are designated EC formulations.
ENDURE	European Network for the DURable Exploitation of crop protection strategies
EPA	United States Environmental Protection Agency
EPA	U.S. Environmental Protection Agency
EQIP	Environmental Quality Incentive Program
ERA-Net	European Research Area Network
ERS	Economic Research Service
ESU	European size unit
ET	Economic Threshold
ETL	Economic threshold levels
EU	European Union
EUR	Euro
FAO	The Food and Agriculture Organization of the United Nations
FDA	The Food and Drug Administration (FDA or USFDA) is an agency of the United States Department of Health and Human Services, one of the United States federal executive departments. The FDA is responsible for protecting and promoting public health through the regulation and supervision of food safety, tobacco products, dietary supplements, prescription and over-the-counter pharmaceutical drugs (medications), vaccines, biopharmaceuticals, blood transfusions, medical devices, electromagnetic radiation emitting devices (ERED), and veterinary products.
FFS	Farmer field school
Field-based IPM	Decisions to use IPM activities, tactics and strategies on individual fields.
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FL1	First-level field leaders or *pemandu lapangan 1*
FL2	Second-level field leaders or *pemandu lapangan 2*
FP	Farmer's Practice
FRAC	Fungicide Resistance Action Committee
FS2002	Food Systems 2002
FTF	Field training facility

Fumonisins	A fumonisin is a *mycotoxin* produced by *Fusarium* fungi. At least 15 different fumonisins have so far been reported and other minor metabolites have been identified.
FwF	Farming with Future
GAK	Joint task for the improvement of agricultural structures and coastal protection
GAP	Good agricultural practice
GDP	Gross Domestic Product
GEAC	Genetic Engineering Approval Committee
GEF	Global Environmental Facility (GEF)
Genetically modified crops	Genetically modified crops (GM crops, transgenic or biotech crops) are plants, the *DNA* of which has been modified using *genetic engineering* techniques. Genetically modified crops are able to resist pests, herbicides or have improved growth or crop characteristics adding to their value to farmers or buyers.
GIRE	Italian Herbicide Resistance Working Group
GIS	Geographic information system
GIS	geographical information systems
GLM	Generalizad Linear Model
Glyphosate	Glyphosate (*N*-(phosphonomethyl)glycine) is a broad-spectrum systemic herbicide used to kill weeds, especially annual broadleaf weeds and grasses. Because it was a “virtually ideal” herbicide—due to its broad spectrum and low non-target toxicity compared with other herbicides—glyphosate was quickly adopted by farmers. Its use increased when Monsanto introduced glyphosate-resistant crops. They enabled farmers use the broad spectrum herbicide post emergence without killing their crops. Glyphosate’s mode of action is to inhibit an enzyme involved in the synthesis of the aromatic amino acids: tyrosine, tryptophan and phenylalanine. It is absorbed through foliage and translocated to growing points. It is only effective on actively growing plants and is not effective as a pre-emergence herbicide. The development of resistance in some weed species is a costly problem.
GM	Genetically Modified
GMO	Genetically modified organisms

Government Method	The Government Method was a suite of cultural practices for the production of cotton used to minimize damage from boll weevil. Before the advent of effective insecticides, the Government Method made cotton production economically feasible. The Government Method's primary features were shortening the production season and destruction of cotton stalks after harvest.
GPP	Good plant protection practice
GPS	Global Positioning System
GR	glyphosate resistant.
GRCs	glyphosate resistant crops.
GV	Granulosis Virus
ha	Hectare
HaNPV	*Helicoverpa armigera* Nuclear Polyhedrosis Virus
HCH	Hexachlorocyclohexane
HDZT	high disturbance seeding zero-till
HGIC	Home and Garden Information Center
high dose/refuge strategy	Non-selected, susceptible insects are reared in non-Bt refuge crops. The susceptible insects mate with resistant insects emerging in the Bt crop. When the high dose threshold is met, the heterozygotes from matings of resistant and susceptible (refuge reared) adults cannot survive in Bt cotton.
High dose Bt toxin	Sufficient toxicity to result in the death of 99.99% of susceptible insects in the field.
HIPVs	Herbivore induced plant volatiles
Horseweed	*Conyza canadensis* (formerly *Erigeron canadensis*) is an annual plant native throughout most of *North America* and *Central America*. Common names include Horseweed, Canadian Horseweed, Canadian Fleabane, Coltstail, Marestail and Butterweed. It is an annual plant growing to 1.5 m tall, with sparsely hairy stems. The *leaves* are slender, 2–10 cm long and up to 1 cm broad, with a coarsely toothed margin. Horseweed is an especially problematic weed in no-till agriculture, as it is often resistant to *glyphosate* and other herbicides.
HPR	Host plant resistance
HR	Herbicide Resistant
HTCs	Herbicide tolerant crops.
HT	High tillage
Huffaker Project	A six year project involving USDA-ARS, U.S. Forest Service, USDA Cooperative State Research Service and 19 universities. It developed Integrated Pest Management on alfalfa, citrus, cotton, pine trees, pome and stone fruits, and soybeans.

i.e.	That is
ICAC	International Cotton Advisory Board
ICAR	Indian Council of Agricultural Research
icipe	International Centre of Insect Physiology and Ecology
ICM	Integrated Crop Management
ICP	Integrated Crop Protection
IDEA	Investment in Developing Export Agriculture
IFAD	International Fund for Agricultural Development
IFS	Integrated Farming Systems
IGRs	Insect Growth Regulators
Imazethapyr	Imazethapyr is an imidazole compound used as a selective herbicide. It is applied preplant incorporated, preemergence, at cracking, and postemergence. The compound controls weeds by reducing the levels of three branched-chain aliphatic amino acids—isoleucine, leucine and valine—causing a disruption in protein synthesis. It is used to control grasses and broadleaved weeds. Tolerant crops include soybeans, peanuts, dry and edible beans, peas, alfalfa and imidazolinone resistant/tolerant corn.
In-furrow pesticides	In-furrow pesticides are those that are applied in the seed furrow at planting. They can be formulated either as liquids or wettable powders mixed with water, or as granules applied dry.
INNOMIP	Innovación en el Manejo Integrado de Plagas
Inorganic insecticides	Molecules lacking carbon-hydrogen bonds, but which have insecticidal properties.
Insecticide resistance	After repeated use of an insecticide, a target pest is no longer controlled by rates and application methods that previously provided control. Resistance is caused by repeated selection of pest populations with an insecticide, leaving only resistant individuals to reproduce and populate fields.
IOBC	International Organisation for Biological and Integrated Control
IOBC/WPRS	International Organization for Biological and Integrated Control of Noxious Animals and Plants
IP	Integrated Production
IPC	Integrated Pest Control
IPM	Integrated Pest Management is an integrated, multi-tactic system for managing pests below economic injury levels. The basic components of IPM are cultural, biological, mechanical, and chemical control tactics. IPM promotes economic and environmental sustainability, protection of human health, and delayed development of pest resistance through the use of knowledge intensive systems.
IPM-FFS	Integrated pest management farmer field school

IPP	Integrated plant protection
IRAC	Insecticide Resistance Action Committee
IRM	Integrated Resistance Management
IRM	Insecticide Resistance Management
ISIP	Information system for integrated plant production
Italian ryegrass	Italian ryegrass, also called annual ryegrass, is an upright annual grass that behaves like a biennial or short-lived perennial. It grows vigorously in winter and early spring and has developed resistance to glyphosate.
IUs	Implementation Units
IWM	Integrated Weed Management is a weed management system that utilizes all suitable techniques in a compatible manner to reduce weed populations and maintain them at low levels. It is an integrated, multi-tactic system for managing weeds. It may involve cultivation, prompt crop establishment, cover crops, and crop and herbicide rotation to reduce weed competition and seed production. IWM strategies provide the best stewardship of herbicide technology because they rely on multiple herbicides and other tactics for weed control, slowing the development of resistant weeds.
JKI	Julius Kühn-Institut, Federal Research Centre for Cultivated Plants
Kg	Kilograms
Lower Rio Grande Valley	The Lower Rio Grande Valley (LRGV) is found at the southern tip of Texas near where the Rio Grande flows into the Gulf of Mexico. It is an area of intensive production of field crops such as cotton, grain sorghum, corn and sugar cane. Citrus, ornamental plants and vegetable crops are also grown in the LRGV.
LPTB	Lesser Peach Tree Borer
LRF	Federation of Swedish Farmers
LRT	Likelihood Ratio Test
LWC	Lodi Winegrape Commission
m	million
MAARC	Mid-Atlantic Apiary Research and Extension Consortium
MAPAQ	ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec
MD	Medical Doctor
MoA	Pesticide mode of action
MOA	Chinese Ministry of Agriculture
MOA	Ministry of Agriculture
MOF	Ministry of Finance

MRL	Maximum Residue Limit
MRL	Maximum residue level
MT	Metric tons
MT	Minimum till
MUPP	Minor Use Pesticides Program
Mycotoxins	Mycotoxins are toxic secondary metabolites produced by fungi—commonly known as molds—which grow on crops. One mold species may produce many different mycotoxins. Also, the same mycotoxin may be produced by several different mold species.
MYCPP	Multi Year Crop Protection Plan
NAP	National Action Plan
NAP	National action plan on sustainable use of plant protection products
NASS	National Agricultural Statistics Service
NATESC	National agro-technical extension and service center, Ministry of Agriculture, P. R.China
NCIPM	National Centre for Integrated Pest Management
NEPTUN	Field based survey of chemical plant protection products
NEWA	Network for Environment and Weather Awareness
NGO	Non-governmental organization
NPV	Nuclear polyhedrosis virus
NRC	National Research Council
NRCS	Natural Resource Conservation Service
NSF	National Science Foundation
OECD	Organization for Economic Cooperation and Development
OFM	Oriental Fruit Moth
OKSIR	Okanagan-Kootenay Sterile Insect Release
OP	Organophosphate
OPs	Organophosphates
Organophosphate insecticides	A class of insecticides chemically characterized by being esters of phosphoric acid. The organophosphate insecticides are active against a broad spectrum of insects. They exhibit anticholinesterase action on the nervous systems of insects and other animals. Many have high levels of toxicity to mammals and other non-target animals. Examples of organophosphates are: parathion, malathion, methyl parathion, chlorpyrifos, diazinon, dichlorvos, phosmet, fenitrothion, tetrachlorvinphos, monocrotophos, dicrotophos, systox and others.
ORP	Operational Research Project

PAIPM	Pennsylvania Integrated Pest Management program
Palmer amaranth	Palmer Amaranth (*Amaranthus palmeri*) is an annual, dicot weed in the Amaranthaceae family. In Georgia this weed first evolved resistance to glyphosate in 2005. It is highly competitive with cotton, and soybean, and it is a prolific seed producer.
PCPA	Pest Control Products Act
PDL	Plant Diagnostic Laboratory
PDS	Post directed herbicide applications are made using specialized application equipment that directs spray in a way that minimizes herbicide contact with the crop.
Pest management tactic	A technology or strategy to minimize damage from a pest. Examples include: timing of planting, early thorough crop residue destruction, selection of a resistant cultivar, use of a pesticide (product, timing and rate), tillage/cultivation (timing and type), irrigation (timing and amount), fertilization (timing, type and amount), defoliation (product and timing), pest habitat destruction, and harvest (preparation and timing).
Pest resurgence	The rapid numerical rebound of a pest population after use of a broad-spectrum pesticide. Pest resurgence often occurs following the destruction of natural enemies that would otherwise hold the pest in check.
PHP	Petugas pengamat hama or field pest observer
PIPE	Pest Information Platform for Extension and Education
PIPs	Plant Incorporated Protectants, such as Bt proteins, are regulated by the United States Environmental Protection Agency.
plant pathogenic nematodes	Plant pathogenic nematodes are microscopic roundworms in the phylum Nematoda or *Nemathelminthes* which feed on and damage crop plants.
PLI	Pesticide Load Indicator
PMRA	Pest Management Regulatory Agency (part of Health Canada)
PMTP	Pest Management Transition Project
POST	Post emergence herbicide applications are made after the emergence of the crop.
PPDB	Pesticide Property Database
PPI	Pre-plant incorporated herbicide applications are made to the soil before planting along with or followed by mechanical tillage, rainfall or irrigation to incorporate the herbicide into the soil.

PPL	Penyuluh pertanian lapangan or agricultural extension workers
PPM	Parts per million
PPP	Plant protection product
PRE	Pre-emergence herbicide applications are made to the soil after planting, but prior to the emergence of the crop.
preventative IPM tactics	IPM tactics which effectively prevent the development of pest populations.
PRRP	Pesticide Risk Reduction Program
PTB	Peach tree borer
PTC	Perimeter trap Cropping
Pull	Planting the attractive grass as a border crop to act as trap crop
PURE	Pesticide Use-and-risk Reduction in European farming systems with IPM
Push	The technology involves intercropping cereal crops with stem borer moth repellent crops
Pyrethroid insecticides	Pyrethroids are organic compounds similar to the natural *pyrethrins* produced by the flowers of pyrethrum daisies (*Chrysanthemum cinerariaefolium* and *C. coccineum*). Pyrethroids have broad spectrum insecticidal activity because they readily pass through insect exoskeletons. They act upon the nervous system causing insect paralysis and death. Pyrethroids have relatively good persistence on leaf surfaces, but some species of insects—tobacco budworm, and bollworm, and others—have developed resistance to them. In addition, their broad spectrum activity has led to secondary pest resurgence involving aphids, spider mites and white flies. Examples of pyrethroid insecticides are: bifenthrin, cyfluthrin, cypermethrin, deltamethrin, esfenvalerate, fenvalerate, lambda cyhalothrin, permethrin, and tralomethrin.
QS	Quality and security
RADOLAN	Radar-online-adjustment network
RAMP	Risk Avoidance and Mitigation Program
Refuge	The planting of non-Bt cotton within a specified distance of all Bt cotton. The non-Bt refuge cotton allowed the reproduction and survival of non-selected insects which slowed the development of resistance. Refuges were required during the years that single toxin Bt transgenic varieties were planted.

Renniform nematode	The renniform nematode (*Rotylenchus renniformis)*is distributed in tropical, subtropical and in warm temperate zones where it causes significant damage to a large number of crop and non-crop host plants. Infected crops are stunted and capable of only limited production.
Resistance management	Strategies and technologies used to lengthen the effective life of a pesticide or management tactic. Resistance management strategies involve integration of several mortality factors in a resistance management plan to reduce selection pressure on any single control tactic.
SAgE	Pesticides online tool maintained by the Quebec government. It provides information on health/environmental hazards associated with various pesticides.
SARE	Sustainable Agriculture Research and Education
SATU	SerereAlbar Type Uganda
SCAR	Standing Committee on Agricultural Research
Scouting	A systematic crop inspection system used to determine the levels of pests and natural enemy populations present in fields. Scouting is used in conjunction with economic thresholds and best management practices to determine when economically damaging pest levels are present and pest management tactics should be initiated.
Screwworm	The screwworm (*Cochliomya hominavorax*) (order Diptera, family Calliphoridae) feeds as a larvae on the flesh of living animals. In the southern USA it was a very important pest of livestock production and wildlife.
Secondary pest outbreaks	Secondary pest outbreaks occur after the use of a pesticide to control a target pest. The impact of the pesticide on non-target natural enemy populations is most often the cause of the secondary pest outbreak.
Seed treatment pesticides	Seed treatments are pesticides applied to the seed.
Selection pressure	Repeated use of a single pest management tactic or pesticide mode of action which results in selection of the pest population for individuals capable of surviving the pesticide. Survival mechanisms may be either genetic or behavioral. Survival and reproduction of resistant pests may result in control failures.
SES	Social-Ecological System
Short season practices	Cultural practices which resulted in a shortened cotton growing season and exposure of the crop to fewer generations of pests such as the boll weevil. Against boll weevil, tactics used to shorten the season were cotton varieties selected for short season production, appropriate planting dates, fertilization, defoliation, early and thorough harvest, and early and thorough stalk destruction.

SIP	Sustainability in Practice
SlNPV	*Spodoptera litura* Nuclear Polyhedrosis Virus
SLPHT	*Sekolah lapangan pengendalian hama terpadu* or IPM farmer field school
SME	Small and medium-sized enterprises
SNM	Nature and Environment, an NGO in the Netherlands
Southern corn leaf blight	A devastating disease of corn caused by the fungus *Bipolaris maydis*. Eighty-five percent of US corn hybrids were genetically susceptible to the disease in 1970 because they were developed using Texas male sterile hybrid seed corn genetics. That year southern corn leaf blight destroyed 15 percent of the US corn crop.
Southern root knot-nematode	The southern root-knot nematode, *Meloidogyne incognita,* is a pest of many crops in tropical and mild temperate zones. As a result of nematode feeding, large galls or “knots” can form throughout the root system of infected plants. Southern root-knot nematodes cause significant stunting and yield loss in cotton and other susceptible crops.
Squares	The prebloom flower buds of cotton are called squares.
SRBSDV	Rice black stripe dwarf virus
SSA	Sub-Saharan Africa
STAR Committee	Committee on Agricultural Structures and Rural Development
Stink bugs	Insect pests in the order Hemiptera and family Pentatomidae. The adults and immature stages feed on and damage the developing fruit of cotton, soybeans, grains, fruit and berry crops.
SUD	Sustainable Use Directive (EU)
SWP	California Sustainable Winegrowing Program
SYNOPS	Synoptic assessment of risk potential of chemical plant protection products
Synthetic organic insecticides	Synthetically produced molecules with insecticidal properties. To be considered a synthetic organic insecticide a molecule must have a carbon-based structure which includes carbon-hydrogen bonds.

Synthetic organochlorine insecticides	The synthetic organochlorine insecticides, or chlorinated hydrocarbon insecticides, are organic compounds with insecticidal properties which contain at least one covalently bonded chlorine atom. Examples include: DDT, toxaphene, lindane, strobane, BHC, heptaclor, chlordane, endosulphan and dieldrin. As a group, they tend to persist for long periods of time in the environment and accumulate in the bodies of animals—especially those higher in the food chain.
Tag	Tactical Agriculture
Tarnished plantbug	The tarnished plant bug (*Lygus lineolaris*)(order Hemiptera, family Miridae) is a pest of cotton and other crops. It damages cotton by piercing and sucking sap from fruiting structures. Small prebloom cotton buds (squares) abort when fed on by the tarnished plant bug. Tarnished plant bugs may also feed on larger squares, immature bolls, and the growing terminal of the plant. Tarnished plantbug feeding causes delayed maturity and yield/quality loss.
TCP	Technical Cooperative Project
TFI	Treatment frequency index
TMTT	(E,E)-4,8,12-trimethyltridecaca-1,3,7,11-tetraene
Tobacco budworm	The tobacco budworm (*Heliothis virescens*) (order Lepidoptera, family Noctuidae) is virtually identical in appearance to the bollworm in the larval stage. Like the bollworm, the tobacco budworm feeds on terminals, squares and bolls of cotton plants causing delayed crop maturity, and yield/quality loss. Tobacco budworm was traditionally feared by cotton growers more than the bollworm because of its ability to develop resistance to insecticides. It is, however, very susceptible to the protein toxins in Bt cotton and has been of little significance to cotton growers in Bt cotton.
Tobacco thrips	The tobacco thrips (*Frankliniella fusca*) (order Thysanoptera family Thripidae) is the primary thrips species damaging cotton in much of the US cotton belt. Like the western flower thrips it is tiny but destructive. It is most damaging to seedling cotton (1-6 true leaf stage) where its feeding causes leaf and plant stunting, scar tissue formation and upward curling of leaves, slow growth and seedling death in heavily infested fields. Tobacco thrips are especially troublesome when spring temperatures are cold.
TOT	Training of Trainers

Toxigenic fungal strains	Toxigenic fungal strains produce mycotoxins (such as aflatoxins and fumonosins) which are toxic to humans and animals and reduce the value of agricultural commodities.
TPB	Tarnished Plant Bug
Triazine	A triazine is one of three organic chemicals, isomeric with each other, whose molecular formula is $C_3H_3N_3$ and whose empirical formula is CHN. Triazine compounds are often used as the basis for various herbicides. Examples of triazine herbicides are: atrazine, cyanazine, cyprozine, simazine, procyazine, propazine, atraton, prometon, secbumeton, simeton, ametryn, prometryn, terbutryn, symetryn, desmetryne and metribuzin.
U.S. GAO	United States General Accounting Office
UAA	usable agricultural area
UCCE	University of California Cooperative Extension
UCIPM	University of California Statewide Integrated Pest Management Project
UCPIPM	UCCE/USDA Smith-Lever Cooperative Pear IPM Project
UK	United Kingdom
UNDP	United Nation Development Program
USAID	United States Agency for International Development
USD	US Dollar
USDA	United States Department of Agriculture
USDA-ARS	United States Department of Agriculture—Agricultural Research Service.
verticillium wilt	Verticillium Wilt is a wilt disease of over 300 species of eudicot plants caused by the *Verticillium fungi*, *V. dahliae* and *V. albo-atrum*. Many economically important plants are susceptible including cotton, tomatoes, potatoes, eggplants, peppers and ornamentals, as well as other plants in natural vegetation communities.
VfL	Danish Agricultural Knowledge Centre
Western corn rootworm	Western corn rootworm (*Diabrotica virgifera virgifera)* (order Coleoptera family Chrysomelidae) is a key pest of corn production. The adult beetle can cause damage by clipping the silks of the corn ears which can reduce kernel pollination. The larvae are the most damaging life stage, however. They can cause extensive yield loss by feeding on corn roots. Their damage causes reduced water and nutrient uptake and stalk lodging.

Western flower thrips	The western flower thrips (*Frankliniella occidentalis*) (order Thysanoptera, family Thripidae) is a tiny but destructive pest of emerging cotton and other crops. Its feeding on 1-6 true leaf stage cotton seedlings causes stunting, scar tissue and upward curling of the leaves, slow growth and seedling death in heavily infested fields. It is the primary thrips pest of cotton on the Texas High Plains.
WHO	The World Health Organization of the United Nations
WNV	West Nile Virus
WTO	The World Trade Organization
ZEPP	Central institution for decision support systems in crop protection
ZT	Zero till

Chapter 1
Pesticides Applied Worldwide to Combat Pests

David Pimentel and Michael Burgess

Contents

Abstract A major concern in agriculture is that more than half of all food production (including food in storage) is being lost to pests despite more than 3 million tons of pesticides being utilized worldwide. Losses of this magnitude continue at a time when more than 66 % of all the human population is malnourished. Evidence suggests that pesticide use could be reduced 50–60 % without reducing crop yields or substantially reducing cosmetic standards.

Keywords Foods · Pesticides · Malnourishment · Cosmetic standards · Poisoning

1.1 History of Pest Control

Previous to 1945, farmers were able to control some weed, insect, and plant pathogen pests using crop rotations, tillage, and field sanitation. Only a few chemically based products like lead arsenate, arsenic, nicotine, and pyrethrums were available for use on crops.

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In 1945, the development and production of DDT began, soon followed by BHC and dieldrin, 2,4 D herbicide and others. The pesticides DDT and 2,4 D were fast acting and killed most pests and initially fulfilled their promise. They were simple to apply, fast acting and killed target pests. Because of this initial success, a great deal of enthusiasm developed for the use of chemical weapons against pests and their use spread rapidly throughout the U.S. and the rest of the world.

However, the effectiveness of pesticide control of pests soon declined. Within two years after the first use of DDT, houseflies resistant to DDT were detected in New York State dairy barns (Pimentel and Dewey 1950).

In addition to the decreased effectiveness of insecticidal control of insect pests, natural enemies of some insect pests were also killed by these insecticides, allowing some non-pest species populations to explode and become pests themselves. In apple orchards pest mites increased in numbers because their insect natural enemies were destroyed by DDT (Smith et al. 1989). As a result, apple trees turned brown from the heavy mite infestations and apple yields declined. In addition to onsite pest problems caused by the insecticides, pesticide impacts extended beyond the croplands and into the land and water environment. Large fish kills and bird kills were observed and were caused by insecticides and other pesticides (Pimentel 1997). The public and the authorities became concerned when milk and other foods were found to be heavily contaminated with pesticides.

Finally, in 1972 the use of DDT and related chlorinated insecticides were banned in the U.S. (Pimentel 1997). Production and use of pesticides continue, and many of the newer types are extremely potent based on the dosages applied per hectare. Thus, while smaller pesticide amounts are applied per hectare, their toxicity is much greater than that of DDT and the earlier pesticides (Pimentel et al. 1950; Carson 1962). One advantage of the newer pesticides is that they do not persist in the environment like DDT and related materials such as chlorinated hydrocarbons, cyclodienes, carbamates and inorganics such as sulfur and arsenic.

1.2 World Crop Losses to Pests

An estimated 70,000 species of crop pests exist worldwide (Pimentel 1997). These include an estimated 9,000 species of insects and mites, 50,000 species of plant pathogens (USDA 1960), and 8,000 weed species (Ross and Lembi 1985; Pimentel 1997). In general, less than 5 to 10 % of these species are considered major crop pests. In many cases, the pests specific to a particular region have moved from feeding on native plant species to feeding on crops which have been introduced into the region such as the Colorado potato beetle (Pimentel, 1988; Hokkanen and Pimentel 1989).

Despite the annual investment of about $ 30 billion for the production and application of about 3.0 million metric tons of pesticides (Table 1.1), in addition to the use of various biological and other non-chemical controls, about 40 % of the world food production is lost to pests (Pimentel 1991; Oerke et al. 1994). Worldwide,

Table 1.1 Estimated annual pesticide use worldwide. (Modified from Pimentel 1997)

Country/Region	Pesticide Use (10^6 metric tons)
United States	0.5
Canada	0.2
Europe	1.0
Other Developed	0.5
Asia	0.3
China	0.2
Latin America	0.2
Africa	0.1
Total	3.0

insect and mite pests cause an estimated 15 % loss of crops, plant pathogens 12 %, and weeds 13 %. The value of this crop loss is estimated to be $ 400 billion per year (Oerke et al. 1994), yet there is a $ 3 to $ 4 estimated return per dollar invested in pest control.

In the United States, annual crop losses cause by pests are similar to those worldwide or about 37 % (13 % to insects and mites, 12 % to plant pathogens, and 13 % to weeds (Pimentel et al. 1991)). In total in the U.S., pests are destroying an estimated $ 60 billion per year in food and fiber crops despite all the efforts to control them with pesticides and various non-chemical controls. As of 2009, the U.S. invests about $ 11.5 billion in pesticidal controls annually (USCB 2011) which saves crops with an estimated value of $ 33 billion. Non-chemical techniques, including biological controls, save crops estimated to have a value of $ 40 billion per year (D. Pimentel, unpublished data).

Without pesticides and non-chemical controls, the damage inflected by pests would be much more severe than it is at present. Oerke et al. (1994) estimated that world crop losses would increase from 40 to 70 %. Such an increase would cause an estimated economic loss of about $ 500 billion per year and would significantly reduce the world's food supply and increase the current world malnutrition of more than 66 % (WHO 2000). Similarly, U.S. crop losses would increase from the current 37 % to about 70 % and represent an economic loss of about $ 500 billion (Oerke et al. 1994)

Although pesticide use has increased over the past five decades, U.S. crop losses have not shown a concurrent decline, mainly because various changes have occurred in agricultural practices during this same five decades. According to survey data collected from 1942 to present, losses from weeds fluctuated but declined slightly from about 14 to 12 % (Pimentel et al. 1991). A combination of chemical, mechanical, and cultural weed control practices were responsible for the decline. Over the same period, losses from plant pathogens, including nematodes, have increased from 10.5 to 12 %. This occurred, in part, because some crop rotations were abandoned, field sanitation was reduced and more stringent cosmetic standards for many crops were implemented by various groups. According to Pimentel (2011), an estimated 500 introduced plant species have become weed pests, approximately 500 introduced insect and mite species are pests in crops and an estimated 20,000 plant pathogens that are pests in crops, pasture and forests are introduced from outside the United States.

Unfortunately, the share of crops lost to pest insects and mites nearly doubled during the past 40 years (Pimentel et al. 1993a) despite a more than 10-fold increase in both amount and the toxicity of synthetic insecticides used (Arrington 1956; USCB 1971; 2009). Several major changes in U.S. agricultural practices account for this increased crop loss. These include:

- planting of some crop varieties that are more susceptible to insects and mites than those used previously such as 'Green Revolution' crops (Chhetri and Chaudhary 2011);
- destruction of natural enemies by some insecticides, thereby creating the need for more insecticides and miticides;
- significant increase in pesticide resistance developing in some insect and mite populations;
- reduction in the implementation of crop rotations which increased the number of pest populations;
- an increase in monocultures and reduced crop diversity (Pimentel 1997);
- reduced tolerance levels for insects and insect parts in U.S. foods (Pimentel et al. 1977; Hart and Pimentel 2002);
- Increased use of aircraft application of pesticides (note only 25 % of the pesticide gets into the target area treated when applied by aircraft) (Pimentel 1997);
- Less attention given to pest infested fruit and crop residues, with more crop wastes left on the land;
- The use of herbicide types that increase susceptibility of the crops to insect and mite attack (Oka and Pimentel 1976).

Crop plant varieties genetically engineered to be resistant to herbicides (especially to glyphosate (roundup)) has resulted in a 239 million kg increase in herbicide use from 1996 to 2011 in the U.S. alone (Benbrook 2012). Crop varieties genetically engineered to include *Bacillus thuringiensis* endotoxin have over the same 1996 to 2011 period in the U.S. decreased insecticide use by 56 million kg (Benbrook 2012). Added to the damage pests inflict during the growing season are the substantial losses that occur during the lengthy time that many crops are stored prior to their use. Worldwide, an estimated average of 20 to 25 % of food crops not lost during the growing season (ranging from 10 to 50 %) is destroyed by pests during the post-harvest period. In the U.S. the post-harvest losses are lower than the world levels (Pimentel 1997).

Pests are destroying between 40 and 60 % of all world food production despite all efforts to prevent crop losses to pests (Pimentel 1997). Up to now, losses to pests have been offset by increased crop yields achieved by planting high-yield varieties, in addition to the increased use of fertilizers, irrigation, and other changes (Pimentel and Wen 2004). Growing concerns and doubts exist that this kind of compensation for crop losses can be sustained because of reduced fresh water availability, reduced fertilizer applications (due to cost/availability), an increase in crop losses to pests, and the continued loss of cropland due to soil erosion (Pimentel et al. 2010).

1.3 Environmental and Public Health Costs of Pesticide Use

Some pesticide benefits are offset by pesticide-caused problems to public health and environmental problems (Pimentel 2007). The estimated economic costs in the U.S. of human and other costs associated with pesticide use total more than $ 12 billion per year (Pimentel et al. 2005). This conservative estimate does not include costs of possible damage to microorganisms and wild animals. However, if the more than $ 12 billion annual costs were added to the annual $ 5 billion of costs of pesticide treatments, the total costs of using pesticides in the U.S. would rise to about $ 17 billion per year. Thus, based on the estimated savings in crops of $ 20 billion per year from pesticide use, the crop value per dollar invested would decline to only about $ 1. Nonetheless, based on a strictly cost/benefit basis, the benefits of pesticide use appear to be financially positive.

In contrast to the U.S., the worldwide negative impacts of pesticides on public health are enormous; the World Health Organization (1992) reports 26 million human pesticide poisonings and 220 thousand deaths annually (Richter 2002; Eddleston et al. 2002). In the developing regions of the world, the number of human deaths and illnesses caused by pesticide use is high because regulations on the use of pesticides, both in field and during storage are lax, and are frequently not followed by industries, farmers, and laborers (World Health Organization 1992; Richter 2002).

Pesticide residues in foods are much higher in developing countries than in the United States. For example, 80 % of foods sold at market in India have measurable pesticide residues (Singh 1993). Another troubling dimension of the pesticide problem in India that 70 % of all insecticides used in India are chlorinated insecticides DDT and BHC, and their use during the latter part of the twentieth century was growing by 6 % per year (Singh 1993) until DDT was withdrawn for use in agriculture in 1989 and production and sale of BHC was banned in 1997 (CIBRC 2014). Both DDT and BHC are banned in the U.S. and are persistent pesticides that accumulate in soil, water, and biota. Thus, food contamination can be expected to increase with the growing use of these chlorinated insecticides in the agricultural system. These conditions are similar to those existing in other developing countries (NAS 2003).

1.4 New Directions of Pest Control in the U.S.

Over time, many changes have been made in U.S. pest control, not only due to Rachel Carson's book *Silent Spring* (1962), but also because the public has become concerned about the health and environmental problems associated with pesticides. As a result pest control options have enlarged to include numerous non-chemical methods.

IPM has evolved into the first-line of defense with some judicious use of pesticides based on monitoring of both pests and natural enemies to ascertain if and when pesticides should be applied. However, some pro-pesticide groups now use the term IPM to justify their continued heavy use of pesticides for pest control and there is still substantial use of pesticides in IPM programs (GAO 2001; Maupin and Norton 2010).

1.4.1 Pest Management Programs in Agriculture

The 4 broad classes of pest control include pesticides, integrated pest management (IPM), cultural controls, and biological controls. Initially, IPM was designed to emphasize the use of cultural and biological controls as the first line of defense, and pesticides as the defense of last resort. IPM, however, has evolved to rely on the judicious and reduced use of pesticides determined by monitoring both pest populations and natural enemies to ascertain if and when pesticides should be applied. Cultural controls which have been ignored in recent decades are being employed more frequently today. These include crop rotations, crop diversity, host-plant resistance, soil, water, and nutrient management practices, use of short-season crops, altered planting times, trap crops, pest sex-attractants, often used in various combinations. Sometimes a relatively simple change in the agroecosystem, such as how or when the soil is tilled or when the crop is planted, can provide effective control of a troublesome pest.

Before selecting the most appropriate strategy for pest control, the agroecosystem and the diverse ecological factors that cause the pest to reach outbreak levels must be understood (Pimentel 1997). Then the cultural and/or biological control procedures should be tailored to the regional ecosystems, including soils and climate. This approach substitutes ecological knowledge for pesticides, and opens up the possibility of employing diverse strategies for pest control and over the long term pays off in reduced costs for pest control and reduced environmental impacts from toxic pesticides.

Classical biological control relies on the use of natural enemies introduced from the native home of the pest for control. A couple of the successful biological controls associated with this approach include the introduction of the vedalia beetle for control of the cottony cushion scale in California (DeBach 1974) and recently the introduction of insect parasites into Africa to control the mealybug attacking the South American cassava (Herren and Neuenschwander 1991; Mwanza 1993).

Even with these successes, there have been many limitations in the use of classical biological control. One fact that was commonly overlooked in the implementation of such biocontrol strategies was that in any geographical region, between 30 and 80 % of the pests on crops are native to the region and have moved from feeding on local vegetation to the introduced crop (Pimentel 1988, 2011). For example, the Colorado potato beetle moved from feeding on a weed to feeding on the introduced potato crop from Peru and other South American countries.

The difficulty of using classical biological control to control large numbers of native pests is the fact that about 20 introductions usually have to be made to achieve one biocontrol success. These data prompted Pimentel (1961) to suggest and develop the “new biological control approach” (Hokkanen and Pimentel 1989). This approach is best illustrated with the introduction of the European rabbit into Australia. After the European rabbit population exploded, all the natural enemies associated with the European rabbit in Europe were introduced but still effective control of the European rabbit had not been achieved. Finally, the myxomatosis virus, originally associated with the South American rabbit was discovered in the South American rabbit population that has been established in the U.S. (Levin and Pimentel 1981). The myxomatosis virus, it should be noted, had little or no effect on the South American rabbit. However, the new association of the South American myxomatosis with the European rabbit was devastating. The initial spread of the virus in the European rabbit population killed more than 95 % of the rabbits in Australia (Levin and Pimentel 1981). Gradually the remaining surviving rabbits developed some resistance to the virus. In addition, the virus evolved a degree of avirulence toward the rabbit host. The European rabbit population increased in numbers again, but the virus still provides about 40 % control of the rabbit population. This level of control is sufficient to allow many predators to be effective in keeping the rabbit population under satisfactory control (Levin and Pimentel 1981).

Another successful use of the “new association” method was the control of the native pine moth in Columbia, South America. In this case, a wasp parasite of a related moth species found in Virginia was introduced into Colombia (Drooz et al. 1977). The new association between pest pine moth and wasp has provided effective control. In general, about 40 % of the successes in biocontrol are due to “new associations”. The use of this approach is growing because it provides successful control for both native and introduced pests (Pimentel 1961; Hokkanen and Pimentel 1989).

For many decades, host-plant resistance has been a dominant non-chemical method for control of plant pathogens and a few insects. Between 75 and 100 % of all cultivated crops grown have some degree of host-plant resistance to plant pathogens as a result of plant breeding (Oldfield 1984; Pimentel 1991). Scientists have also been successful in breeding plant resistance to some insect pests, such as the Hessian fly resistance in wheat (Pimentel 1991). Now with the availability of genetic engineering, the use of host-plant resistance has greater potential for the control of insect pests and plant pathogens (Paoletti and Pimentel 1996).

1.4.2 Conventional Versus Ecologically Sound Agriculture

The implementation of various cultural technologies that reduce the need for large amounts of chemical inputs, including pesticides and fertilizers, has the advantage of decreasing chemical pollution of soil, water, and food. Furthermore, the use of chemicals that can cause human illness and death are reduced and the degradation of the agroecosystem is diminished. With careful land management such as conservation tillage and crop rotation, soil erosion and associated rapid water runoff can be controlled to preserve soil and water resources. In addition, effective care and application of livestock manure enhances soil nutrition and decreases environmental pollution (Pimentel et al. 1987; Pimentel 1995).

The difference between a conventional corn production system and a modified system that includes the implementation of several environmentally sound practices are presented in Pimentel (1997). The conventional system relied on chemicals for pest control and fertilizers to provide soil nutrients. In the modified system, no pesticides were used, tillage was substituted for herbicides, crop rotation was employed for insect control, and manure was substituted for a large portion of the fertilizers.

In the conventional system, the annual yield was 7,000 kg/ha of corn at a cost of $ 523 (1997 dollars) per hectare, and the total energy used was more that 7.8 million kcal/ha. Crop loss caused by insects with the conventional system was 12 %, while the estimated cost of environmental damage was $ 230 per ha. Also, approximately 20 t/ha/yr of soil was eroded with the conventional system.

The modified system not only yielded more corn than the conventional system (a total of 8,000 kg/ha) (Pimentel 1997), but did so at a lower cost of $ 337 per ha. Crop loss to insects was 3.5 % (Pimentel 1993), considerably below the 12 % in the conventional system. Soil erosion was reduced from approximately 20 t/ha/yr in the conventional system to less than 1 t/ha/yr for the modified system; note that the 1 t/ha/yr erosion rate equals the annual rate of soil formation for this region. Furthermore, in the modified system fossil energy inputs were half those of the conventional system (Pimentel 1997). The total cost of production was reduced by 36 % to $ 337 per ha/yr (Pimentel 1997). As fossil energy resources continue to decline and become more expensive, reducing energy inputs will become critical in agricultural production.

Several additional sound management practices were employed in the modified system (Pimentel 1993). Careful use of manure reduced pollution of ground water and/or adjacent waterways. Also, more effective use was made of manure and its valuable nutrients. The use of manure to recycle organic matter back to soil helps reduce soil erosion.

The selection of an appropriate crop such as soybeans for rotation with corn reduced the corn rootworm problem (Pimentel et al. 1993a), corn disease (Mora and Moreno 1984), and many of the weed problems (NAS 1968, 1989; Mulvaney and Paul 1984). Furthermore, the soil nutrients such as nitrogen biologically fixed and stored by the soybeans are subsequently released when the soybean crop residues are tilled into the soil.

Although mulch and tillage substituted for herbicides in the modified system, this was only to demonstrate that herbicides could be replaced in the corn system. In some situations, combining herbicides and tillage is advantageous (Pimentel 1991).

In summary, in the modified system, pesticide use was eliminated and fertilizer use was reduced and soil and water resources were conserved, while a yield higher than that of the conventional corn system was achieved (Pimentel 1997).

1.5 Reduced Pesticide Use

Reports from several regions of the world detail that when pest control research focuses on the ecology of the pests, appropriate ways to decrease pesticide use without diminishing crop yields can be developed and pesticide use can be reduced from 33 to 75 % (Pimentel and Lehman 1993).

In Guatemala, for instance, the amount of insecticide used for pest control in cotton was reduced by more than 33 % once a strategy was developed to save many natural enemies that usually controlled potential pest problems. Under this system cotton yields increased by 15 % and some large cotton farmers increased their profits by more than one million dollars per year (ICAITI 1977).

In Indonesia, the investment of $ 1 million per year in ecological research, followed by several billion dollars invested in extension programs to train farmers how to conserve natural enemies and how to reduce the use of pesticides paid major dividends. Based on this approach, pesticide use in Indonesia was reduced by 65 % for rice while rice yields increased by 12 % (Personal communication, I. N. Oka 1995). This resulted in the Indonesian government being able to eliminate the $ 20 million in pesticide subsidies that it was paying farmers each year.

By implementing IPM programs in New York State, sweet corn processors saved $ 500,000 per year and maintained high yields while reducing pesticide treatments on sweet corn by 55–65 % (Koplinka-Loehr 1995). Pesticide use in New York State has been reduced on a few other crops. Pesticide use has been reduced in the U.S.by more than 909,090 kg due to the adoption of IPM (Sorensen 2012).

1.6 Conclusion

More than 52 % of all potential food production from crops up through harvest and during the transportation and storage of foods worldwide is being lost to pests despite 3.0 million tons of pesticides are being applied annually worldwide. Losses of this magnitude continue at a time when more than 66 % of the world human population is malnourished (WHO 2000), the largest percentage of people considered malnourished in history. Shortages of cropland, fresh water, fertilizers, and increased energy costs are becoming obvious. Crop losses caused by pests could be reduced substantially if pest control research were focused on the entire agroecosystem. Pesticide use will continue, especially for crops, but should be applied wisely and only when necessary. Estimates are that pesticide use could be reduced 50 to 60 % without reducing crop yields or substantially reducing cosmetic standards (Pimentel et al. 1993b). Reducing pesticide use in crop production will reduce the costs of pest control, protect public health, and reduce the environmental impact of agriculture.

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Part I
North America

Chapter 2
Integrated Pest Management, Bt Crops, and Insecticide Use: The U.S. Experience

George B. Frisvold and Jeanne M. Reeves

Content

Abstract Bt crops have features amenable to IPM systems and their incorporation into such systems has been quite successful in some institutional settings. Widespread adoption of Bt cotton and maize in the United States has contributed to dramatic, unprecedented reductions in insecticide use. When introduced into settings with less-developed IPM systems, however, secondary pest outbreaks and field-evolved resistance have become problems. Pest resistance to Bt has yet to become a serious problem in the United States but remains a concern. A major industry response to potential resistance and grower non-compliance with resis-

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tance management regulations has been development of pyramided Bt varieties and seed mixtures. These address some immediate problems, but may take some discretion in pest management away from growers. IPM principles that recognize the biological complexities of pest management may prove essential for sustaining the benefits of Bt crops.

Keywords Bt · Cotton · Maize · Insecticides · IPM · Resistance · Biotechnology · Pesticides · Genetically modified

2.1 Introduction

Bt crops have been genetically modified to enable those crops to produce crystalline (Cry) insecticidal proteins from the soil bacterium *Bacillus thuringiensis* (Bt). The Cry toxins effectively control a narrow range of insect pests (such as some from the orders Lepidoptera and Coleoptera) while showing little to no activity against other species (National Research Council 2010). Because Bt is highly selective and breaks down quickly in the environment, foliar Bt sprays have been widely used in organic farming in the United States. Such foliar Bt sprays have had long history of safe use (Sanchis 2011). Bt cotton and maize varieties first became commercially available in the United States in 1996. Since then, adoption has been rapid and pervasive. Most U.S. cotton and maize acreage are now planted to Bt varieties (National Research Council 2010).

Bt crops show great promise, but have also raised concerns. By reducing reliance on broad-spectrum insecticide applications, they hold the promise of reducing negative environmental impacts of farming, while increasing farm yields and incomes. The rapid rise of Bt crops, however, has raised questions about their impacts beyond adoption rates, direct economic returns, and chemical applications directed at target pests. These include questions about effects on non-target pests and thus total insecticide use, effects on non-pest species, and about the evolution of pest resistance to Bt toxins and the implications of resistance for organic farming.

Evidence suggests that Bt cotton and maize adoption in the United States has contributed to substantial reductions in insecticide use for both crops (National Research Council 2010). It is important, however, to look beyond insecticide applications to target species. Applications to control target pests of Bt have diminished, while those for non-target pests have increased in some areas (National Research Council 2010; Luttrell and Jackson 2012; Naranjo 2011). This has occurred because overall reductions in broad-spectrum insecticide applications have led, in some cases, to the emergence of new secondary pest problems. Nevertheless, the net effect has been a significant reduction in overall insecticide use (Luttrell and Jackson 2012; Williams various years; Hutchinson et al. 2010). Field-evolved resistance to some Cry toxins, in the United States and abroad, remains a concern (Tabashnik et al. 2009; Tabashnik and Carrière 2010; Tabashnik and Gould 2012). Failure to delay resistance could mean that the current benefits of Bt crops may not be sustainable.

Rather than focus narrowly on target pest applications, we suggest it is better to ask how Bt crops fit into an overall system of integrated pest management (IPM). Kogan (1998) has defined IPM as "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. (emphasis added)." Note the term "pest control tactics" as opposed to "pesticides." While pesticides are important, they are one pest control tactic, among many. IPM is not a "buy and apply approach" where growers are passive consumers, buying products to address the pest problem of the moment. Bajwa and Kogan's (2004) compendium lists 67 different definitions of IPM. A recurring theme in these definitions is substituting knowledge and information for insecticides. IPM is a systems approach that requires intensive use of knowledge about agronomy, plant genetics, economics, pest population dynamics, and ecology (Frisvold 2009). The question is then, how do Bt crops fit among many pest control tactics in complex agro-ecological systems?

The chapter proceeds as follows. Section 2.2 introduces key features of an IPM framework. Section 2.3 discusses trends in U.S. Bt crop adoption, insecticide use, and pest management in cotton and maize. Section 2.4 addresses potential problems of pest resistance to Bt crops and the role of integrated resistance management (IRM). Section 2.5 introduces a case study from Arizona illustrating the successful incorporation of Bt cotton into an area-wide IPM program. Section 2.6 concludes by drawing lessons from the U.S. Bt crop experience.

We draw three major lessons from the experience of Bt cotton and Bt maize in the United States. First, Bt crops have certain features that make them amenable to incorporation into IPM systems and such incorporation has been quite successful in *some* institutional settings. This has led to significant and unprecedented reductions in insecticide applications, with attendant environmental benefits. Second, however, the compatibility of Bt crops with IPM is not a given. When introduced in weaker institutional settings with less-developed IPM systems, secondary pest outbreaks and field-evolved resistance have become problems (Frisvold and Reeves 2010; Tabashnik et al. 2009; Huang et al. 2011). Resistance to Bt has yet to become a significant problem in the United States, but remains a concern. Third, IPM principles may prove essential for sustaining the benefits of Bt crops. Integrated resistance management (IRM) has emerged as a critical part of IPM. A major private industry response to potential resistance problems and grower non-compliance with IRM regulations has been the development and marketing of pyramided Bt varieties (containing multiple Cry toxins) and seed mixtures. The latter, also called "refuge in a bag" addresses problems of grower non-compliance of refuge requirements to delay resistance, but raises other concerns. New, multi-trait seed varieties and mixtures may simplify grower decision making in the short run. In some cases, however, it can take discretion in pest management away from growers. In the case of genetically modified, herbicide resistant crops, "simplifying" weed management decisions led to rapid evolution of herbicide resistance in weeds (Frisvold and Reeves 2010). Cropping systems *are* complex. An IPM system recognizes this and may be the best means to delay Bt resistance.

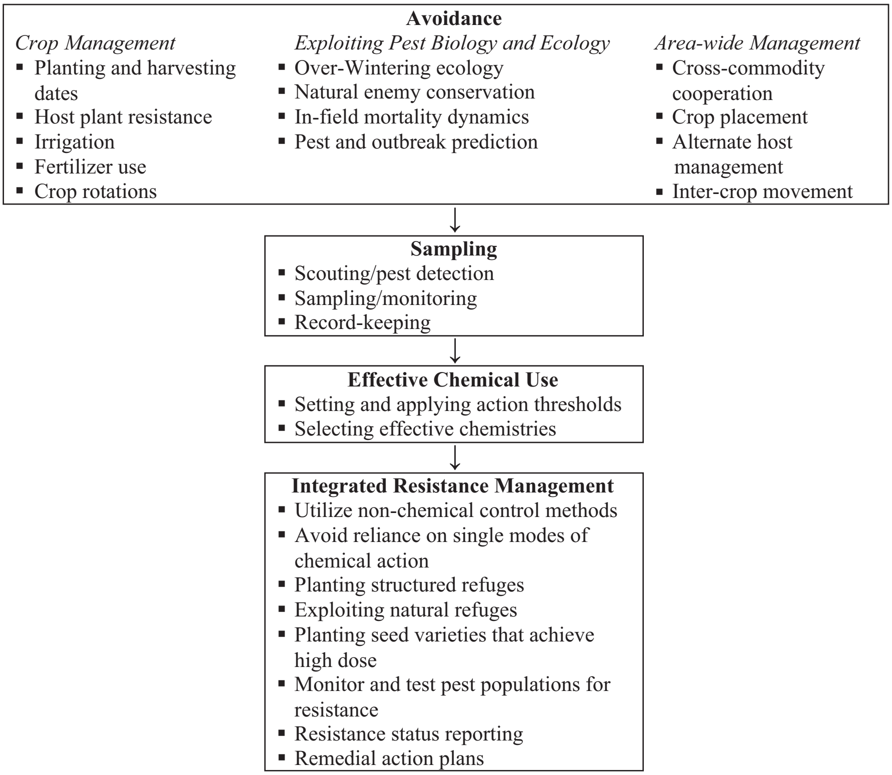

Fig. 2.1 Conceptual model of IPM accounting for incorporation of Bt crops. (Adapted from Ellsworth and Martinez-Carrillo (2001) and Naranjo (2011))

2.2 Building Blocks of IPM: A Conceptual Framework

Following Ellsworth and Martinez-Carrillo (2001) and Naranjo (2011), one may think of IPM in terms of a set of building blocks (Fig. 2.1). The primary tactic for preventing pests from causing economically significant damage is avoidance. This includes a variety of methods to prevent pest populations from growing or becoming established in the first place. Avoidance tactics include crop management, exploiting pest biology and ecology, and area-wide crop management to limit pest populations. Different crop management practices such as choice of planting and harvesting dates, irrigation and fertilizer application practices, and use of crop rotations are all non-chemical choices that can affect pest populations. Another important practice is the host plant resistance of crops and crop varieties selected to plant. Pest control can be improved by using knowledge of pest over-wintering ecology, natural enemy conservation, and in-field mortality dynamics, along with tools to predict pest outbreaks. At an area-wide scale, knowledge of pest movement between crops can facilitate cross-commodity cooperation to control polyphagous pests. The spatial configuration of different crops can affect overall crop damage in a region.

Another key aspect of IPM is the use of economic thresholds to make decisions regarding chemical applications. Instead of prophylactic or calendar-based spraying, this requires scouting and pest detection. Sampling, monitoring and record keeping are important to assess the success of avoidance practices. Action thresholds limit insecticide applications to cases where expected damages avoided outweigh application costs. In addition to the timing and level of insecticide applications, it is important to choose the appropriate chemistry. This includes not only consideration of how effective a compound is at controlling the target pest, but also its effects on natural enemies and scope for creating secondary pest outbreaks. Thus, a knowledge of pest biology and ecology is needed, not just the dose-response relationship between a chemical and a target pest.

Finally, integrated resistance management (IRM) involves avoiding selection pressure that depletes the susceptibility of pests to chemical compounds. Chemical pest control, although a final step in the above IPM framework remains an important step. The effectiveness of compounds, however, is an exhaustible resource, which IRM seeks to conserve. This can be done first by using non-chemical controls. Avoidance practices have both short-run control benefits and longer-term, resistance delaying benefits. Avoiding reliance on any single chemical mode of action is also a key component of IRM. Figure 2.1 extends the approach of Ellsworth and Martinez-Carrillo (2001) and Naranjo (2011) by explicitly including IRM practices for Bt crops. These include planting structured refuges, exploiting natural refuges, planting seed varieties that deliver a high dose of the Bt toxin, monitoring and testing pest populations for resistance to both Bt toxins and applied insecticides, reporting the status of resistance, and developing and implementing remedial action plans to address field-evolved resistance and field failure of Bt crops.

Bt crops have certain attributes that are consistent with IPM, but others that raise some questions. On one hand, Bt crops rely on selective control of specific species. Bt crops substitute for broad-spectrum chemical insecticides for their target species. Lundgren et al. (2009) warn, though, that one must look beyond how Bt crops affect application rates for target pests. IPM relies on predators, parasitoids, and pathogens to control pest populations. It is important to consider how Bt crops affect this entire system of non-target species. Evidence suggests, however, that compared to the insecticides they replace, Bt crops have less harmful effects on non-target species (Marvier et al. 2007; Naranjo 2009; National Research Council 2010).

Another question raised is the extent to which Bt crops represent a movement away from the threshold concept (Hellmich et al. 2008; Kennedy 2008). Because the Bt toxin is ever-present in the genetically modified plants, pests receive greater exposure to the toxin. A counterargument is that Bt crops are just an enhanced form of host plant resistance (HPR), which growers have long used as an IPM strategy (Hellmich et al. 2008; Kennedy 2008). There has been limited success developing crop varieties with improved HPR through conventional plant breeding methods. Recombinant DNA technology simply represents a more efficient means of improving HPR (Kennedy 2008).

The economic realities of commercial Bt crops mean that the threshold issue may be less important than it would first appear. Seed suppliers charge premiums for Bt seeds that can exceed the cost of up to three insecticide applications per hectare. Adoption rates for Bt crops will only be high in areas where target pest populations regularly surpass thresholds. In areas where thresholds are infrequently exceeded, adoption of Bt crops will be low.

Continuous pest exposure to the Bt toxin, however, does raise questions about the selection pressure this creates and the implications for pest evolution of resistance to Bt. Bt foliar sprays are among the most important insecticides used in U.S. certified organic crop production (Hutcheson 2003; Walker et al. 2003; Walz 1999). U.S. federal standards allow crops using low-toxicity insecticides to be certified as organic. In the mid-1990s, U.S. organic growers raised concerns that widespread planting of Bt field crops would accelerate resistance to Bt, threatening the effectiveness of Bt foliar sprays. In response, the U.S. Environmental Protection Agency (EPA) regulates Bt crops under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). EPA requirements include: (a) refuge requirements; (b) resistance monitoring; (c) grower education and grower agreements; and (f) annual reports from technology suppliers (Walker et al. 2003; Matten et al. 2008).

The cornerstone of Bt resistance management is the high dose/refuge strategy. Here, Bt crops express enough of the Bt proteins to deliver a high dose that kills all the susceptible homozygous individuals and nearly all of the resistant heterozygous individuals. Refuges of non-Bt crops planted nearby allow the abundant susceptible individuals to mate with any surviving resistant individuals that survive on the Bt crops. If inheritance of resistance is recessive, then the progeny of this mating will be susceptible to Bt toxins, slowing the evolution of resistance (Tabashnik and Gould 2012; Tiwari and Youngman 2011; Huang et al. 2011).

To implement the high dose/refuge strategy, EPA requires biotechnology firms to provide evidence supporting claims their crop varieties provide a high dose of the Bt protein. EPA has also required growers to plant refuges of non-Bt cotton or non-Bt maize near Bt fields. Regulations cover the spatial configuration of refuges, their size relative to Bt fields, their distance from Bt fields, and what insecticides may be applied on them (Walker et al. 2003; Matten et al. 2008). For pests that move between crops, it is possible for acreage of other crops to serve as a "natural refuges." EPA has waived structural refuge requirements in cases where it has been determined that sufficient natural refuge acreage exists. One may think of the high dose component of this strategy as part of the "selecting effective chemistries" tactic in an IPM system (Fig. 2.1). Refuges are also similar to IPM strategies of crop placement, alternate host management, and accounting for inter-crop movement of pests (Fig. 2.1).

Bt crops *can* fit well into an IPM framework. In the United States, they have reduced pesticide use and conserved natural pest enemies. The high dose/refuge strategy, where carried out as intended, has successfully prevented resistance problems. In the United States and elsewhere, however, field evolved resistance has emerged as a result of a high dose of the Bt toxin not being delivered, poor compliance with

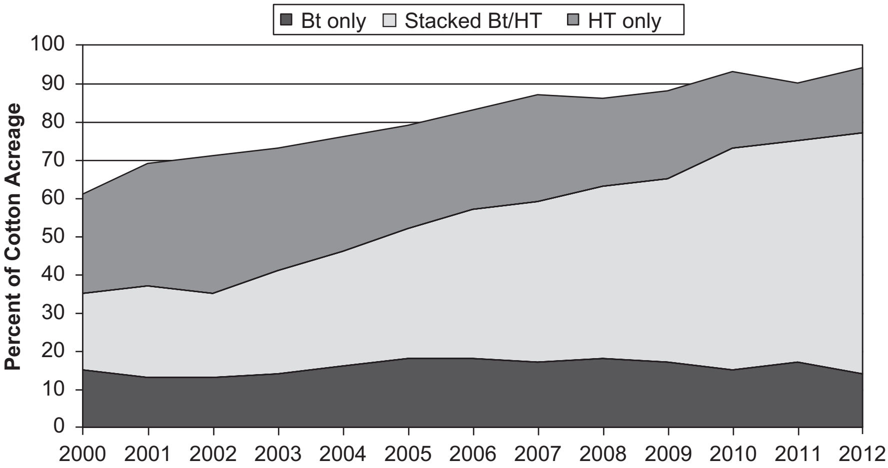

Fig. 2.2 Adoption of genetically modified cotton in the United States. (Source: USDA, ERS 2013)

refuge requirements, or both (Gassman et al. 2012; Huang et al. 2011; Tabashnik et al. 2009; Tabashnik and Carrière 2010; Tabashnik and Gould 2012).

2.3 Trends in Bt Crop Adoption and Pest Management Practices

2.3.1 Cotton

The first generation of Bt cotton varieties, approved for commercial use in 1996, contained a single Cry toxin. In the United States, the three main target pests of these Bt varieties were cotton bollworm, *Helicoverpa zea*, tobacco budworm, *Heliothis virencens*, and pink bollworm, *Pectinophora gossypiella*. They also provided some limited control of other lepidoptera. These first Bt varieties were highly effective at controlling budworm and pink bollworm, but less effective against cotton bollworm.

U.S growers adopted Bt cotton quickly and pervasively. The percentage of upland cotton hectares planted to Bt varieties reached 35 % by 2000 and rose to 77 % by 2012 (Fig. 2.2). Most Bt hectares are planted to "stacked" varieties that are also genetically modified for herbicide resistance (HR). The second generation of Bt varieties, such as Bollgard II® and Widestrike® contained two Cry toxins. This "pyramiding" of different Cry toxins is intended to improve control against cotton bollworm, show more activity against a wider range of lepidoptera, and prove more effective at delaying insect resistance than single-toxin varieties (Head and Greenplate 2012; Naranjo et al. 2008). Bollgard II varieties first became available in

Table 2.1 U.S. cotton insecticide application rates in pre-Bt cotton and post-Bt cotton years. (Source: Williams (various years))

Period		All cotton pests	Boll weevil	Main Bt target pests[a]	All other cotton pests
Pre-Bt cotton 1986–1995	Applications/hectare	5.53	2.70	2.95	2.88
	Percent of total applications		31	35	34
1996–2008	Applications/hectare	3.17	0.52	0.74	2.92
	Percent of total applications		16	23	60
2009–2012	Applications/hectare	2.34	0.01	0.27	2.07
	Percent of total applications		0[b]	11	88

[a] Three main target pests are tobacco budworm, cotton bollworm, and pink bollworm

[b] Less than 0.25 %, numbers of applications/hectare may not sum exactly due to rounding

2003, with Widestrike varieties following in 2005. In 2009, Monsanto's registration of Bollgard I varieties with the EPA expired and use of single-toxin Bt cotton varieties was phased out. Single-toxin Bt varieties accounted for 28 % of Bt cotton acreage in 2009, 9 % in 2010, and was discontinued by 2011 (Williams various years).

The 1996 introduction of Bt cotton immediately followed a period where budworms and cotton bollworms exhibited resistance to pyrethroid insecticides in the Mid-South (Falck-Zepeda et al. 2000; Livingston et al. 2004). Bt cotton's introduction also overlapped with a bollworm eradication program that extended throughout U.S. cotton-producing states. In the decade before the introduction of Bt cotton, boll weevils (*Anthonomus grandis*), the three target pests of Bt (budworm, cotton bollworm and pink bollworm), and all other cotton pests accounted for roughly a third each of all cotton insecticide applications (Table 2.1). Because of the Boll Weevil Eradication Program, applications to control boll weevil have declined dramatically (Table 2.1, Fig. 2.3). The share of U.S. cotton acreage infested by boll weevil fell from 44 % in 1986 to less than 0.2 % in 2012. Insecticide applications to control boll weevil fell from 2.7 per hectare from 1986–1995 to 0.01 per hectare from 2009–2012. There has also been a decline in insecticide applications to control the three target pests of Bt. Applications to control budworm, cotton bollworm, and pink bollworm fell from 2.95 per hectare from 1986–1995 to 0.27 per hectare from 2009–2012.

Because of the Pink Bollworm Eradication Program, initiated in the Southwestern United States and Northern Mexico, insecticide sprays for pink bollworm have essentially ceased in the United States. Today, insecticide applications for Bt's target pests are directed primarily at cotton bollworm.

The reduction in broad-spectrum insecticide applications to control boll weevil and Bt target pests has led to an increase in pressure from non-target cotton pests. Lygus (*Lygus hesperus*) and stinkbugs (*Euschistus servus*, *Acrosternum hilare,* and *Nezara viridula*) have become more of a control problem (Naranjo et al. 2008; Luttrell and Jackson 2012). This is reflected in the increase in applications to control

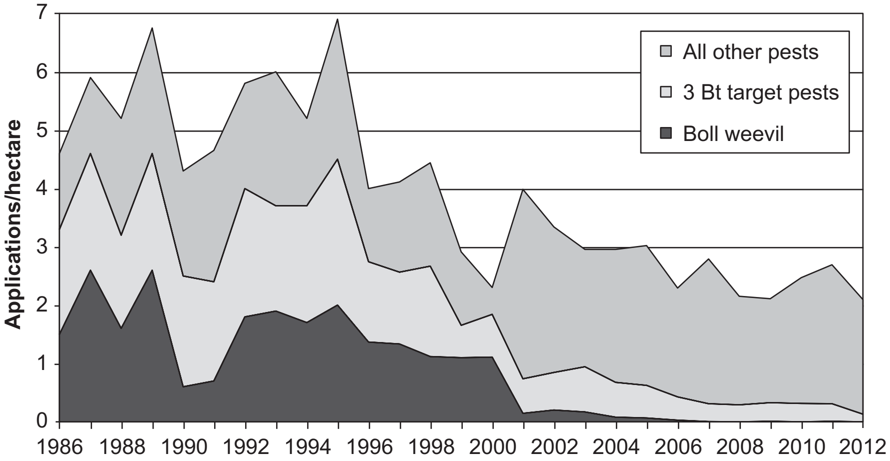

Fig. 2.3 Insecticide applications per hectare, U.S. upland cotton. (Source: Williams various years)

"all other" pests since 1986–1995 (Table 2.1, Fig. 2.3). These other pests accounted for 34% of cotton insecticide applications before Bt cotton. Since 2009, they have accounted for 88% of applications. Despite increased spraying for all other pests, total cotton insecticide applications have declined. Total application rates fell from 5.5 per hectare 1986–1995 to 2.34 per hectare from 2009–2012, the period when single-toxin Bt varieties were being replaced by pyramided varieties.

Luttrell and Jackson (2012) carried out pair-wise comparisons of Bt and conventional cotton for selected states reported by the National Cotton Council's Cotton Insect Losses Survey from 2000 to 2007. They found Bt hectares had a statistically significant, lower rate of total insecticide applications than conventional hectares—2.1 fewer applications per hectare, on average. Applications for non-target lepidoptera were only significantly lower for Arizona Bt acreage. Applications for non-target, non-lepidoptera were lower on conventional hectares, but the difference was statistically insignificant. There was no significant difference in pre-planting insecticide applications or insect monitoring costs between Bt and conventional acreage.

Marra et al. (2003; p. 44) summarized findings on effects of Bt cotton from "field trials, farmer and consultant surveys, expert opinion and secondary data, and studies reporting ex ante estimates of economic impacts." Assessing 24 studies from 10 states, they found Bt cotton contributed to a 2.3–3.4 per hectare reduction in insecticide applications. Klotz-Ingram et al. (1999) estimated an econometric model of insecticide use on Bt and conventional cotton acreage controlling for sample selection (the fact that Bt adopters are likely to face higher pest pressure). They found no statistically significant difference between Bt adopters and non-adopters with respect to organophosphate or pyrethroid applications. They did find that Bt cotton adopters applied significantly less of other synthetic insecticides (e.g., aldicarb, chloropyrifos, oxamyl, and endosulfan). Following a similar approach, Frisvold

Table 2.2 Trends in insecticide applications for 19 major U.S. maize-producing states. (Source: USDA, NASS Agricultural Chemical Usage Survey)

	2001	2005	2010
Insecticides applied in metric tons of active ingredient (a.i.)	4,082	2,177	726
Percent of planted hectares treated with insecticides	29	23	12
kg of a.i. applied per planted hectare	0.15	0.07	0.02
kg of a.i. applied per treated hectare	0.49	0.31	0.19

(2004) estimated Bt cotton adoption reduced insecticide applications for bollworm, budworm, and pink bollworm by 0.5 sprays in per total cotton hectares in 1996 and by 2.8 sprays in 2003.

2.3.2 *Maize*

The first Bt maize varieties became commercially available in 1996. These single-toxin varieties, using Cry1 proteins controlled stalk-boring Lepidoptera (Hellmich et al. 2008; Tiwari and Youngman 2011). The main U.S. targets were European corn borer (*Ostrinia nubilalis*) and southwest corn borer (*Diatraea grandiosella*). Many growers elect not to treat maize with insecticides for European corn borer because insecticides are ineffective once the pest has tunneled into the stalk. These Bt events also offered limited control of *Helicoverpa zea*, which is called the cotton bollworm when feeding on cotton and the corn earworm when feeding on maize. In 2003, Bt maize varieties became available that used Cry3 proteins to control coleopteran pests, specifically, different species of corn rootworm (*Diabrotica* spp). Since then, stacked varieties have been approved with both Cry1 and Cry3 proteins as well as in combination with herbicide resistant traits.

Adoption rose from 35 % of maize hectares in 2000 to 77 % in 2012. As with cotton, stacked Bt-HT varieties dominate, accounting for 63 % of U.S. maize acreage in 2012. Data from the U.S. Department of Agriculture's (USDA's) *Agricultural Chemical Use* survey show a significant reduction in the share of maize acreage receiving insecticide applications, total metric tons (MT) of active ingredient applied, kilograms (kg) applied per planted and treated hectare for major maize producing states (Table 2.2). The survey does not always survey the same number of states. Table 2.2 reports results from years with the most states, common for each year (19). In the 19 states surveyed, applications fell from 4,082 metric tons of active ingredient in 2001 to 726 metric tons in 2010, a more than 80 % reduction. Over the same period, the percentage of maize hectares receiving any insecticide applications fell from 29 to 12 %.

In a 3-year, multi-state study of U.S. maize producers, Pilcher et al. (2002) found that the percentage of growers that had decreased pesticide use to control European corn borer doubled between 1996 and 1998 (from 13 to 26 %). Growers who reduced their insecticide use increased their share of Bt acreage from <20 to 47 %. In a survey of crop consultants in Kansas and Nebraska, Hunt et al. (2007) reported lower insecticide use on Bt maize than non-Bt maize fields. In a survey of U.S. Midwestern maize growers, Wilson et al. (2005) reported more than two-thirds of respondents cited reduced grower exposure to insecticides and reduced active chemical ingredients in the environment as major benefits of using Bt maize. Fernandez-Cornejo and Li (2005) estimated the effect of Bt maize adoption on insecticide use, statistically accounting for the fact that adopters are likely to face more pest pressure than non-adopters are. They found Bt maize adopters applied 0.013 kg per hectare less of active ingredient than non-adopters did. This represented an 8% reduction.

2.3.3 Area-Wide Pest Suppression

There is some evidence that Bt crops have reduced pest populations on an area-wide basis, with overall pest populations declining enough to reduce pest pressure and pesticide use on non-Bt fields. Hutchison et al. (2010) estimated that widespread adoption of Bt maize in five midwestern states significantly reduced European corn borer populations, benefiting non-Bt maize growers as well as Bt maize growers. In fact, they estimated that non-Bt maize growers received $ 4.3 billion of the total $ 6.1 billion in grower benefits over 14 years from European corn borer suppression. This occurred because non-Bt maize growers benefited from area-wide pest control without having to incur the additional cost of purchasing higher-priced Bt maize seed. While Fernandez-Cornejo and Li (2005) found reduction in insecticide use associated with Bt maize adoption in 2001; Fernandez-Cornejo and Wechsler (2012) found no significant difference using 2005 data (although average application rates were lower on Bt fields). Application rates on Bt and non-Bt maize had dropped substantially from the previous study, however. Fernandez-Cornejo and Wechsler (2012) noted that 80% of farmers in the sample did not apply any insecticides to maize and attributed this to the effects of area-wide suppression. Storer et al. (2008) found widespread planting of Bt maize in Maryland led to less pressure from European corn borer and corn earworm and less insecticide use on soybean and vegetable crops. In a 10-year study of Arizona cotton, Carrière et al. (2003) found that in areas of high Bt cotton adoption (>65% of cotton acreage) the long-term population of pink bollworm declined, independent of other factors. They noted, “Such long-term suppression has not been observed with insecticide sprays, showing that transgenic crops open new avenues for pest control (p. 1519).” One such new avenue has been the Pink Bollworm Eradication Program, discussed below.

2.3.4 Effects on Non-Target Species

Effects of Bt cotton and maize on non-target species have received considerable attention (Lundgren et al. 2009; Marvier et al. 2007; Naranjo 2009; National Research Council 2010). Bt crops have less harmful effects on non-target species than the conventional insecticides they replace. While pyrethroids and organophosphates exhibit harmful effects on many non-target arthropods, Bt crops appear to have little effect on arthropods that are not closely related to the target species (Cattaneo et al. 2006; Romeis et al. 2006). The abundance of non-target arthropods has been found to be greater on Bt crop fields, compared to conventional crop fields sprayed with insecticides (Marvier et al. 2007). Meta-analyses have failed to find consistent evidence of harmful effects on pest predators. They have, however, have found that populations of parasitoids that specialize on Bt target pests are consistently reduced (Marvier et al. 2007; Wolfenbarger et al. 2008). The body of evidence, however, suggests that compared to insecticides, Bt crops expand opportunities for biological control of pests (National Research Council 2010).

2.4 Resistance Management for Bt Crops

The EPA requires integrated resistance management (IRM) programs for Bt cotton to delay resistance and convenes Scientific Advisory Panels to review underlying science and evidence regarding pest resistance and to revise IRM regulations. For cotton IRM, EPA required mandatory refuge requirements when Bt cotton was introduced in 1996. Additional rules governed the size of refuges relative to Bt acreage, distances from Bt fields, refuge configuration and conditions under which target pests of Bt could be sprayed with insecticides on refuges. For example, growers who planted refuges equivalent to 20 % of their Bt cotton acreage could spray refuges for Bt cotton's target pests. Alternatively, if growers planted smaller 5 % refuges, they could not spray for these pests. Pyramided varieties with two Cry toxins are believed to significantly delay the onset of resistance and provide more flexibility in design of refuges (Head and Greenplate 2012). The EPA determined that in the eastern part of the Cotton Belt, there were sufficient hectares of "natural refuges"—other crops or vegetation to serve as hosts for susceptible pests. Thus, requirements for structural refuges have been waived in these areas.

For Bt maize, refuge requirements were voluntary until 2000. As part of IRM plans, growers were to plant 20 % refuges for corn resistant to European corn borer and cotton earworm. In cotton growing areas, however, refuges were to be larger (50 %) because cotton earworm/cotton bollworm (*Helicoverpa zea*) is also a major cotton pest. It was felt that resistance would develop faster if this pest were present in both Bt cotton and Bt maize in close proximity.

The record of compliance with refuge requirements has been mixed. Carrière et al. (2005) found compliance with Bt cotton refuge requirements was 88 % or more in 5 of 6 years in Arizona. However, resistance-monitoring programs have been more extensive in Arizona than elsewhere in the country. With active grower participation, they have employed detailed mapping and testing using advanced geographical information systems (GIS) and on-the-ground confirmation of planting practices (Carrière et al. 2005; Tabashnik et al. 2010). Compliance with Bt maize refuge requirements has been less stringent and appears to be decreasing over time. Early phone surveys conducted by the Agricultural Biotechnology Stewardship Technical Committee (ABSTC, 2001; 2002a; 2002b) suggested relatively high rates of compliance. Bourquet et al. (2005) note some problems with this approach. First, it did not account for different compliance requirements by region. Second, compliance measures did not account for multiple compliance requirements. Third, it did not survey smaller scale growers, which could bias results if smaller producers had different compliance patterns. Fourth, there was the potential of non-reporting bias if non-compliant producers did not respond. Goldberger et al. (2005) found that comprehensive compliance rates (i.e., compliance with *all* refuge requirements) was much lower (72–76 %) than rates of 79–96 % reported by ABSTC. They also found that compliance increased with farm size, so that compliance rates were below 65 % on the smallest farms (40.5 ha or less). Jaffe's (2003) examination of USDA records, found 21 % of farms growing Bt corn in 10 states in 2002 were not fully complying with refuge requirements. Follow-up analysis by Jaffe (2009) suggests that compliance rates for Bt maize refuges have been falling in recent years.

Bourquet et al. (2005) also raised concerns about methods EPA relied upon to monitor the evolution of resistance: dose-response bioassays and diagnostic dose assays. They argued that these methods would only confirm high levels of resistance after the fact rather than effectively detecting early signs of resistance. Again, Arizona differed from other areas in the country in taking more pro-active steps to prevent resistance. The University of Arizona's Extension Arthropod Resistance Monitoring Laboratory (EARML) monitored and tested the susceptibility of pink bollworms to Bt cotton in the laboratory and in the field. Pink bollworm samples were collected statewide and bio-assayed. A Bt Cotton Working Group, with representation among growers, university scientists, biotechnology firms, and state agencies collaborated on monitoring and adapting resistance management practices. In some cases, the Group even recommended stricter requirements to EPA (Frisvold 2009). To date, there has been no evidence of an increase of pink bollworm resistance to Bt cotton in the field (Tabashnik et al. 2012).

There have been two examples of field-evolved resistance to Bt in the United States. The cotton bollworm had only been moderately susceptible to single-toxin Bt varieties. Increasing evidence from bioassays suggested that the cotton bollworm had evolved resistance to single Bt toxins in the Mississippi Delta (Tabashnik and Carrière 2010). While in the late 1990s, growers averaged less than one spray to control cotton bollworm, in the 2000s, application rates were as high as two or three in some areas, even on Bt cotton fields (Williams various years). In Iowa, the western corn rootworm has exhibited field-evolved resistance to the Cry3Bb1 toxin (Gassmann et al. 2012). Again, this toxin does not kill enough resistant individuals to constitute a high dose. This coupled with insufficient compliance with refuge requirements and continuous planting of maize with the Cry3Bb1 toxin are contributing factors. Field evolved resistance to Bt crops in developing countries has also been documented. There, IPM systems are less developed, with less compliance with IRM, while growers are more likely to plant unauthorized seed varieties that do not deliver a high dose of the Bt toxin (Tabashnik et al. 2009; Huang et al. 2011).

One biotechnology industry response has been to develop and market pyramided Bt varieties that possess more than one Cry toxin. Theoretical models of resistance evolution suggest that resistance should develop much more slowly in such pyramided varieties. However, the efficacy of pyramided varieties will be compromised if insects are already resistant to one of the Cry toxins. Further, Tabashnik and Gould (2012) warn of the possibility of cross-resistance across pyramided varieties. They note that even pyramided Cry3 proteins may not offer a sufficiently high dose to delay resistance to corn rootworm and have argued that required refuge sizes for rootworm-resistant Bt maize varieties should be greatly expanded. As have Gassmann et al. (2012) they warn against continuous planting of rootworm-resistant Bt maize varieties and recommended use of a broader set of control tactics. Stacking multiple traits in single crop varieties can also take discretion away from growers, dictating certain pest management and weed control choices (Onstad et al. 2011). Where different genes for resistance to different pests are combined, it may increase selection pressure in areas where pests do not require control, accelerating resistance evolution without short-run pest control gains.

Another response to resistance and grower compliance problems has been the development of seed mixtures, also known as “refuge in a bag.” Here, bags of seed are sold with Bt and non-Bt seeds pre-mixed together. This has certain advantages (Onstad et al. 2011). First, it addresses problems of non-compliance of structural refuge requirements. Second, it addresses problems of adult insect movement between Bt fields and structure refuges, and may thus improve resistance management. Seed mixtures raise some questions, however. It is uncertain how they will affect secondary pests and biological control. By making pest monitoring difficult, it may discourage scouting and grower attention to the ecology of farm fields. The U.S. experience with herbicide-resistant crop varieties suggests that “simplified” production systems (requiring less grower attention and biological knowledge) can discourage resistance management (Frisvold and Reeves 2010).

2.5 A Brief History of IPM in Southwestern Cotton

The experience of Bt crop introduction in the Southwestern United States has been unique. By the time Bt cotton was introduced, Southwest cotton production had well-established, area-wide IPM programs. There were also open lines of communication between producers, scientists and extension experts, and government regulatory agencies. These were important for the successful adoption of Bt cotton into the region’s IPM strategies. Active grower involvement with pest management as well as extremely pro-active monitoring and adaptation strategies has allowed the Southwest to avoid resistance problems. Further, they have made possible an ambitious Pink Bollworm Eradication Program, a first of its kind program to apply biotechnology to pest eradication.

In the early 1960s, pink bollworm became a major cotton pest across the breadth of the U.S.-Mexico border, from Texas and Chihuahua to Southern California and Baja California. Pink bollworm spurred major reductions in Southern California cotton acreage in the late 1960s (Frisvold 2009). Southwestern growers have a number of avoidance tactics to control pink bollworm. By avoiding early-season pesticide applications, growers can preserve natural pink bollworm predators and limit secondary pest outbreaks. If growers uniformly delay planting, moths may emerge before host material becomes available. By planting short-season cultivars or terminating irrigation early, growers can avoid late-season pest damage. Growers can reduce pest over-wintering through crop rotation, applying irrigation in winter and by shredding stalks, disking and plowing-down of crop residue after harvest.

Southwestern cotton growers have also relied on biological control methods such as gossyplure (a sex pheromone). Releasing it into cotton fields reduces and prevents mating by disrupting moth communication. Release of sterile moths is another biological control option, which can cost-effectively prevent pest invasions in areas free of pink bollworm or suppress already-low populations. Sterile moth release does not work as well when there are large, well-established pink bollworm populations, however. To be effective, sterile moth release needs to be of sufficient geographic scale. This calls for an area-wide approach.

Adult pink bollworms are highly mobile so reliance on chemical control, focusing on farm-level infestations proved ineffective (Frisvold 2009). Farm-level control often missed most of this mobile pest population. It became apparent that area-wide control measures were needed. In 1968, grower groups, universities, cooperative extension, county and state agencies and the USDA initiated a pink bollworm eradication program in California's San Joaquin Valley (among the largest of U.S. cotton-growing areas). The program's goal was to prevent moths migrating from Southern California from becoming established in the Valley. Instead of relying on pesticides, the program uses: (a) pheromone traps to monitor and detect infestations; (b) release of sterile moths to disrupt mating; (c) gossyplure to disrupt mating; and (d) enforcement of plow-down requirements to prevent over-wintering.

Most program funding comes from cotton growers who pay an assessment per bale of cotton sold. County agricultural commissioners enforce plow-down requirements. The USDA and the California Department of Food and Agriculture (CDFA) jointly operate a sterile moth rearing facility. The CDFA has estimated that, in 2000 alone, the program reduced insecticide applications by more than 2,700 metric tons of active ingredient, saving growers more than $ 80 million.

In California's Imperial Valley, a short-season cotton program was instituted in 1989 to control pink bollworm that set an earliest planting date as well as latest dates for applying defoliants and for plow-down. The program reduced larvae per boll and insecticide applications, while increasing lint yields and quality (Chu et al. 1996). In Arizona, a 6-year program from 1989 to 1995 that relied on gossyplure led to reductions in larval infestations in cotton bolls from 23 % in 1989 to < 1 % by 1995. Hectares treated with insecticides fell and pink bollworm control costs fell from highs of $ 170 per hectare to $ 70 per hectare (Antilla et al. 1996; Henneberry 2007). Growers in Southern California and in Mexico's Mexicali Valley implemented similar gossyplure-based programs (Staten et al. 1987).

Growers also successfully implemented the Southwest Boll Weevil Eradication Program. Arizona suffered intermittent infestations of boll weevil in the 1960s–1970s, with infestations becoming regular in the late 1970s. In 1983, California initiated an eradication program and officials there threatened to quarantine Arizona farm products if Arizona did not also begin eradication. The Arizona Cotton

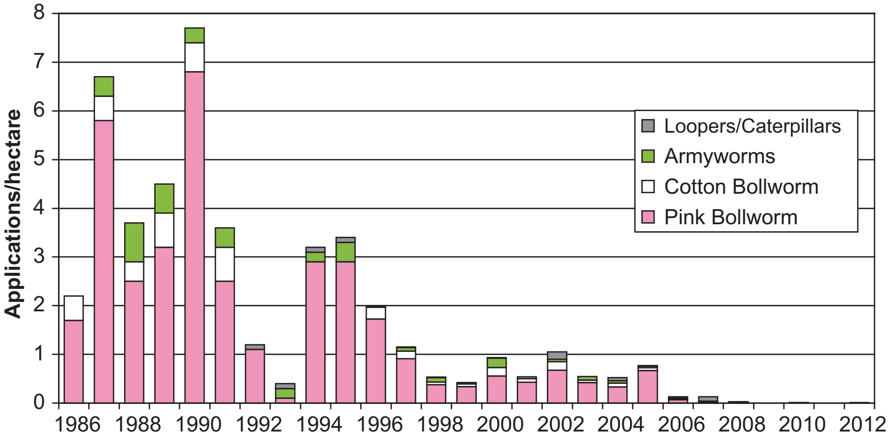

Fig. 2.4 Insecticide applications to control pink bollworm, cotton bollworm, armyworms, loopers, and caterpillars in Arizona cotton. (Source: ACIS)

Research and Protection Council (ACRPC) was then formed in 1984 to finance and coordinate boll weevil eradication. In 1985, the Southwest Boll Weevil Eradication Program—covering Southern California, western Arizona and northwest Mexico—was established. The program included the ACRPC, USDA's Animal and Plant Health Inspection Service (APHIS) the Arizona Commission of Agriculture and Horticulture, the CDFA, and Sanidad Vegetal, Mexico. While state and federal agencies provided some funding, grower organizations funded the program largely through per-bale assessments. By 1991, the boll weevil had been successfully eradicated from Arizona, California and the Mexicali Valley. Bale assessments fund continued monitoring and trapping.

The area-wide programs reduced insecticide applications and increased grower returns. They improved upon individual, uncoordinated pest control that relied heavily on insecticide applications in several ways. Programs relied on trapping, monitoring, avoidance, cultural, and biological control as first steps. They included extension and education programs, maintaining cooperation between growers and federal, state and local entities. Growers were active participants in program organization, funding, and implementation. Finally, programs included cooperation between the United States and Mexico, as well as interstate cooperation.

2.5.1 Introduction of Bt Cotton

Despite earlier efforts toward area-wide IPM, insecticide use in Arizona cotton production was still quite heavy before Bt cotton was introduced in 1996. In the decade before Bt cotton's introduction, Arizona growers averaged three applications per hectare per year to control pink bollworm alone, with six or more applications in some years (Fig. 2.4). Data for Arizona cotton insect losses and insecticide applica-

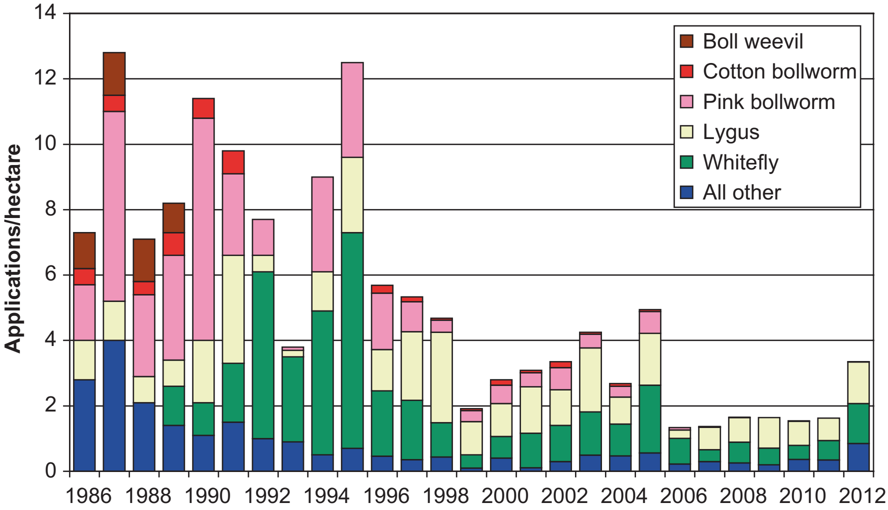

Fig. 2.5 Insecticide applications on Arizona cotton. (Source: ACIS)

tions are available from the Arizona Crop Information Site (ACIS) maintained by the University of Arizona College of Agriculture and Life Sciences. Total insecticide applications exceeded 10 per year in some years (Fig. 2.5). Arizona growers were quick to adopt Bt cotton, with the share of acreage planted to Bt varieties rising from 23 % in 1996 to 65 % by 2001 and 75 % by 2004 (Williams various years).

Bt cotton represented a switch to the narrow-spectrum Bt toxin to control pink bollworm and away from reliance on broad-spectrum insecticides. With the switch to narrow-spectrum control, growers had to consider pest population dynamics more carefully. Instead of relying on broad-spectrum insecticides for pink bollworm to achieve collateral control of other insects, growers had to monitor non-target pests more closely. Growers have consistently practiced pest scouting and monitoring on 95–99 % of Arizona cotton hectares (Williams various years).

Relying on the narrow-spectrum Bt toxin also raised the possibility of secondary pest outbreaks. Cattaneo et al. (2006) analyzed Arizona commercial cotton fields to assess the impact of Bt varieties on insecticide use, yields, and biodiversity. Bt cotton had higher yields than non-Bt cotton for a given number of insecticide applications, but Bt and non-Bt cotton had similar overall yields. This occurred because growers applied fewer broad-spectrum insecticides on Bt cotton (about 3 fewer sprays in 2002 and 2.5 fewer in 2003). Cattaneo et al. (2006) suggested Bt and non-Bt cotton yields were similar because the extra sprays on non-Bt cotton reduced damage from Lygus, whitefly (*Bemisia argentifolii*) and other pests that Bt cotton does not kill. The main advantage of Bt cotton appeared to be lower insecticide costs, but not higher yields. Over the last 20 years, total insecticide applications for all cotton pests in Arizona have declined (Fig. 2.5). The success of the Boll Weevil Eradication program meant applications for boll weevil were no longer needed by 1990 (Fig. 2.5).

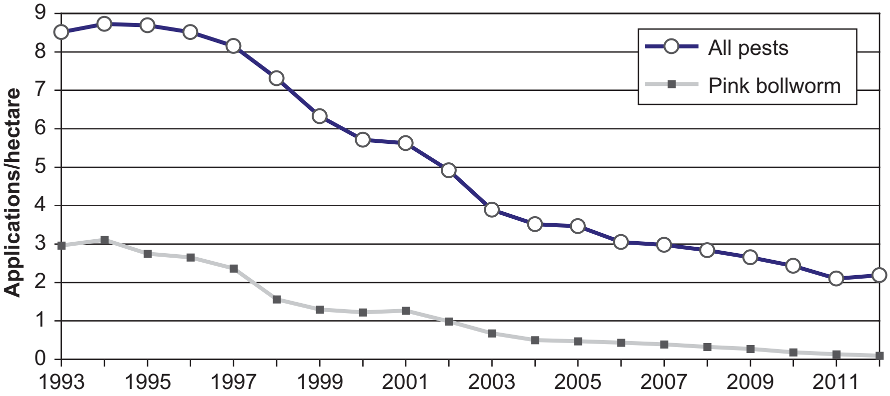

Fig. 2.6 Eight-year moving average of Arizona cotton insecticide applications. (Source: ACIS)

In 1996, Bt cotton was introduced to control pink bollworm, while insect growth regulators (IGRs) were introduced to control whitefly. Effective integration of Bt cotton and IGRs into overall cotton IPM strategies led to significant reduction in total insecticide applications since 1995 (Fig. 2.5). Bt cotton varieties pyramiding two Cry proteins, offer better control of cotton bollworms, armyworms, caterpillars, and loopers. Since pyramided varieties became available in 2003, applications for pink bollworm and these pests combined have been less than one per year (Fig. 2.4). Lygus, whiteflies, and other pests now account for a larger share of cotton insecticide applications as Bt cotton's target pests have been effectively controlled (Fig. 2.5). Insecticide applications increased in 2012, primarily for lygus and whitefly. In the long term, total insecticide applications has trended downward, however. The 8-year moving average applications fell from more than eight applications per year in the mid-1990s to just over two per year in 2012 (Fig. 2.6).

2.5.2 *Pink Bollworm Eradication*

Area-wide suppression of pink bollworm populations had reached such an extent by the end of the 1990s that eradication of the pest in the Southwest became possible (Tabashnik et al. 2010, 2012). To suppress populations further, growers were encouraged to plant as much of their cotton acreage as possible to Bt varieties, essentially eliminating refuges. To prevent resistance, sterile moths were released on an area-wide basis. Resistant bollworms would mate with sterile moths (rather than susceptible moths from refuges) to control resistance. The program began in 2001 in West Texas, New Mexico, and northern Chihuahua, Mexico. Implementation was carried out in phases, spreading east to west, and reaching Western Arizona, Southern California, and Mexico's Mexicali Valley by 2008. The program included other components to track progress (Tabashnik et al. 2010). Populations were monitored for resistance using DNA screening. Pink bollworm abundance was measured by inspection of non-Bt cotton bolls for larvae and by field capture of male moths using pheromone-baited traps. Insecticide sprays continued until 2009 (Figs. 2.4 and 2.5).

2.6 Bt Crops and IPM: Lessons Learned

The U.S. and especially Southwestern experience illustrates that Bt crops *can* be compatible with IPM. To date, Bt cotton and maize have led to dramatic reductions in insecticide use and less harmful effects on natural pest enemies, all of which enhance the scope of biological pest control. In the Southwest, Bt cotton was introduced in a setting of strong pre-existing IPM institutions. Several factors have contributed to the successful deployment of Bt cotton there. First, regulatory institutions provided the framework to guide resistance management. Second, growers were committed to cooperatively and actively managing resistance. Third, the university extension system provided a strong scientific and information base to inform both regulators and growers. Fourth, there has been a continuous, multi-directional flow of information between, regulatory, university, biotechnology industry, and grower participants. In the Southwest, the susceptibility of pink bollworm to Bt cotton has been successfully maintained. Area-wide pest suppression has made implementation of area-wide eradication possible.

The sustainability of Bt crops is not a given, however. Where institutional circumstances have supported the high dose/ refuge strategy, it has proved quite successful at delaying resistance. Where compliance with IRM strategies has been weak, resistance problems for Bt crops have emerged. While this has been a problem in some developing countries, it has not led to serious control problems in the United States, yet. Industry strategies of offering pyramided or stacked traits for insect resistance, herbicide resistance, or both may limit grower discretion. Concerns have been raised about incentives that seed mixes create for active grower involvement in pest and resistance management. A main lesson from the U.S. Southwest is that active grower involvement in IPM, rather than a passive "buy and apply" approach to pest management can be a highly successful means of sustaining the benefits of Bt crops.

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Chapter 3
Experiences with Implementation and Adoption of Integrated Pest Management in Northeastern USA

Rakesh S. Chandran

Contents

Abstract Integrated Pest Management (IPM) has been adopted to varying extents in the northeastern United States. In this region, IPM encompasses a wide range of activities ranging from IPM in agriculture to school and urban IPM. With global and regional trends in population growth and demands to keep food production sustainable, safe, economic, and socially acceptable, IPM continues to gain momentum in all agricultural operations. There is a growing awareness among consumers about IPM as they begin to recognize products that feature IPM as part of their production. Consumer awareness stimulates growers to practice even more IPM. Each state in the northeast region has an IPM coordinator housed in the state's leading land grant university, who is charged

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with supporting and promoting IPM in that state and serving as a liaison to the federal government. IPM programs are often carried out on a collaborative basis between states within the region, and the IPM coordinators meet annually to discuss topics of common interest and also to discuss how successful programs have been implemented. The 12 states in the northeast region have research and extension programs that address IPM. There is also an IPM Center intended to reach out to a broader stakeholder base to facilitate IPM efforts by various role players in the discipline. Often times, IPM involves multiple disciplines, and to carry out successful multidisciplinary programming efforts in research and outreach certain obstacles may be faced. This chapter provides a broad overview related to implementation of successful IPM programs in the northeast region of the United States, and discusses several specific success stories in individual states as well as some of the challenges faced today.

Keywords Integrated pest management · Pest control · Sustainable agriculture · Reduced pesticide use · Alternative pest control · Non-chemical pest control · IPM coordinator · Environmentally friendly pest management · Green pest control · Eco-friendly pest control

3.1 Introduction and Overview

In the northeastern United States, integrated pest management (IPM) encompasses a wide range of activities ranging from IPM in agriculture to school and urban IPM. With global and regional trends in population growth and demands to keep food production sustainable, safe, economic, and socially acceptable, IPM has become a mainstay in both commercial agricultural operations and noncrop situations. Moreover, consumers are becoming more aware of IPM, and they recognize products that feature IPM as part of their production.

Many innovative efforts begun in the northeast region have been adopted by other regions. A few noteworthy contributions include: regionwide collaboration to address IPM and pesticide residue issues in public schools; incorporating IPM into public school curricula as a form of public education; collaboration with USDA/Natural Resources Conservation Service (NRCS) to ensure that IPM is a component of conservation payment programs; leadership in urban IPM programming; development and sharing of publications and other educational material; development of product labeling systems to inform consumers about IPM practices; success in leveraging funds from state agencies in support of IPM programming; and the development of listservs to coordinate the efforts of the various partners involved (Table 3.1).

3.2 IPM Programming in the Northeastern United States

In the northeast, similar to other regions, each state has an IPM coordinator who is in charge of supporting and promoting IPM in the respective state and serving as liaison to the federal program. The IPM coordinator often collaborates with state

Table 3.1 Examples of Integrated Pest Management Programming Impacts in the Northeastern United States from 2000 to 2010

State	Crop	Strategy	Impact
Connecticut	Tree fruits	Monitoring guidelines, pest identification, economic thresholds	Reduced insecticide use by 8.8 fewer treatments per grower
	Vegetables	Monitoring, pest identification, non-chemical control, perimeter trap crops	40 % savings on pesticide use among participating growers
	Sweet corn	Reduced rates of herbicide use	Reduction of atrazine and metolachlor use by 1.34 kg/ha
Delaware	Dairy	Integrated fly management program	Reduction of fly population by 60 % and insecticide use by 30 %
Maine	Potato	IPM-based information and recommendations	Two to four applications per year reduced (total savings of $ 12 million per year)
Maryland	Beekeeping	Integrated approach to control Varroa mites	Pest populations suppressed by 40 %
Massachusetts	Cranberry	Physical control (flooding)	Total control of cranberry fruitworm (*Acrobasis vaccinii*)
	Greenhouse	Use of biocontrol agents	Non-toxic pest management material use increased by 68 %
New Hampshire	Apple	IPM methods to control tree fruit pests	Savings of $ 250/ha; pest injury reduced by 7 %
New Jersey	Blueberry	Reduced risk pesticides and IPM practices	Insecticide applications reduced from 6 to 1–2; savings of $ 250/ha
	Vegetables	Web-based monitoring and information delivery	48 % savings on pesticides and nutrients
	Landscape horticulture	Use of horticultural oils and insecticidal soap	42 % reduction in conventional pesticide use
New York	Tree fruits	Pheromone traps and other IPM methods to control tree fruit pests	Cost savings to growers due to fewer rejections of fruit truckloads
Pennsylvania	Tree fruits	Reduced risk pesticides	Environmental risk reduced by 5.3 times
Rhode Island	Tree fruits	Scouting, timely information delivery	17–30 % reduction of fungicide use; 35–67 % reduction of insecticide use; 37–85 % reduction of miticide use
Vermont	Corn	Use of cover crops, crop rotation, mechanical control	Reduced the use of herbicides
West Virginia	Corn	Banded application of residual herbicides	Reduced the use of atrazine by participating farmers by 50 %

government agencies, universities, and other federal agencies. The IPM coordinator is unique in his or her ability to link state-level IPM networks with regional and national IPM networks. The 12 states in the northeast region have academic, research, and extension programs that address IPM. Integrated pest management programs are often similar in adjoining states, so collaboration across state lines has always been practiced to a certain extent.

The IPM coordinators meet annually to discuss topics such as emergent pest issues in each state, programming efforts, funding in IPM, and success stories. Each IPM coordinator reports progress and accomplishments related to IPM to the United States Department of Agriculture (USDA). The following information is compiled based on personal communication with state IPM coordinators, reports made available at annual IPM coordinator meetings, and those furnished to USDA by each state since 2000 (http://www.pprs.info/IPM/ViewAR.cfm).

3.2.1 Connecticut IPM Program

The Connecticut IPM program produced a regionally recognized training module containing various publications and teaching materials towards curriculum development for school IPM. The curriculum for teaching IPM was intended for grades 7–8. It contains 25 individual activities that address the social, ecological, and scientific aspects of IPM. Descriptive and sample materials were presented to 200 teachers from 80 different school districts. The presentation triggered a high level of interest from teachers in 19 school districts. Two curriculum units were adapted for use by 4-H and Scout groups.

In tree fruits, research and extension efforts for fruit growers developed monitoring guidelines, informed growers about which insect species are primarily responsible for observed fruit damage, and developed economic injury levels. This information allowed growers to use insecticides only when it is economically justified. As a result, apple growers involved were able to reduce the number of pesticide treatments by an average of 8.8 fewer treatments/apple grower. Peaches are grown in southern New England mostly for the fresh market and in Connecticut there are an estimated 111 peach growers. Among the major pest problems encountered by growers are the “catfacing” insects. These insects cause the most fruit injury and they are difficult to monitor because of their high mobility. An applied research and extension project was carried out to determine the color of sticky traps (white or pink) for effective monitoring of both *Lygus lineolaris* (tarnished plant bug; TPB) and oak-hickory bugs (*Lygocoris* spp.) in peaches. The results from this project indicated that both white and pink traps were useful in monitoring plant bug populations, and provided a relatively simple method to keep track of the pest population levels.

Researchers developed a soil test procedure that includes extracting weed seeds and analyzing soil physical and chemical properties. Weed populations can be predicted based on this information. Field corn growers adopted spot treatment of broadleaf herbicides instead of broadcast applications as a result. Both the rate and number of applications of field corn herbicides were reduced as a result of this.

Educational events promoted IPM training programs for greenhouse growers that focused on monitoring for key insects and diseases on a weekly basis from August to December. Educational efforts for participating greenhouse growers increased their IPM knowledge base by 15%. Connecticut IPM was highly successful in establishing a strong working relationship with the Natural Resources

Conservation Service to provide funds towards the provision of technical service by university IPM staff to train growers for IPM implementation. This was carried out with the agency's Environmental Quality Incentive Program (EQIP). Reductions in pesticide use were also documented in vegetables as a result of IPM adoption. Grower trials conducted on 20 ha of commercial vegetable cropland showed herbicide savings were possible on 40 % of the acreage.

Programs dedicated to vegetable growers provided them with IPM methodology to encourage them to try newer IPM techniques. All sessions included information on IPM methodology including pest identification, biology, monitoring, chemical and nonchemical management, and a range of pesticide issues. The program also provided weekly IPM training for commercial vegetable producers, and provided information through the *Vegetable Management Guide* and other publications, individual consultations, farm visits, newsletters, articles for an IPM website (http://www.hort.uconn.edu/ipm/greenhs/htms/herbmanl.htm), and a weekly recorded telephone/Internet message. Vegetable growers were trained to implement perimeter trap cropping (PTC; Boucher et al. 2003).

Invasive nonnative plants are one of the most serious threats to native species and the environments in which they are found. The Connecticut Invasive Plant Working Group launched a new website to provide public access to information concerning invasive plants. The Working Group is a consortium of individuals, organizations, and agencies concerned with invasive plant issues. Connecticut participated in efforts to reduce purple loosestrife infestations using biological control methods. Efforts also focused on educational outreach and surveys for giant hogweed (*Heracleum mantegazzianum*), an invasive nonnative poisonous plant that causes severe light-mediated dermatitis upon contact. This weed was found in several towns in Connecticut. Fact sheets on giant hogweed were prepared and posted on the Web or provided to the public upon request. A display on giant hogweed was prepared with photos, descriptive information, and printed media coverage of the occurrence of this invasive plant. Several newspaper articles were also published.

Some of the outcomes of the IPM program in Connecticut are as follows. In field and sweet corn, atrazine and metolachlor use was reduced; these are two of the most commonly used field herbicides, the use of which poses higher risks to groundwater. An average of 1.34 kg of herbicide active ingredient was reduced per hectare in commercial vegetable production. Growers who tried out PTC commented that they had used fewer pesticides and that the system was simpler and more profitable to use than spraying entire fields with pesticides

3.2.2 Delaware IPM Program

The Delaware IPM program has made numerous contributions in the areas of vegetables, field crops, potatoes, and dairy. In vegetables, spider-mite management strategies were developed in watermelons that included the use of reduced risk insecticides and weed management in rye strips resulting in reduced miticide use and related savings (Johnson et al. 2004). A disease-forecasting system (Melcast Disease Forecasting System) gained popularity resulting in reduced fungicide use and cost savings. This is a weather-based disease prediction model based primarily on the temperature and duration of leaf wetness to predict the development of fungal diseases, mainly in vegetables. Other practices that have been adopted as a result of research and extension programs include the use of new seed treatments to improve stand establishment and the use of alternative controls for white mold on lima beans. In bell peppers, in addition to the introduction of softer chemistry for pest control, the use of *Trichogramma ostriniae* as a biological control strategy was presented in farm demonstrations. The Delaware IPM program has also generated successful biocontrol agents to control invasive weeds such as mile-a-minute (Colpetzer et al. 2004). In peaches, the use of mating disruption was successful in the control of oriental fruit moth.

An integrated fly management program on dairy farms resulted in a 60 % reduction in fly populations and reduced in-season insecticide use by 30 %. The following practices were included in the program: (1) fly tapes and bait applications for adult fly populations season-long; (2) a residual space spray for adult flies when fly populations exceeded the threshold (50 spots/card per week); (3) parasites released season-long in calf barns (1,000 parasites per pen per week); (4) hister beetle (*Histeridae* family of beetles that includes over 3,000 species) predators released for egg and maggot control; (5) alternative bedding of peanut hulls; (6) citric acid used along edges of calf pens to reduce maggot numbers; and (7) potash used in outside cow pack areas to reduce moisture levels.

In field corn, soil insect scouting techniques implemented by producers resulted in reduced insecticide use. Scouting techniques for corn earworm in soybean fields also resulted in reduced insecticide use. Innovations in field crop pest management and IPM systems included new seed treatment technology to reduce soil insecticide use in field corn; surveys for soybean aphid; monitoring for resistance in corn earworms in soybeans; seed treatments for aphid in barley; yellow dwarf management in wheat; reduced risk chemistry for spider-mite management in soybeans; use of weather models to predict pest outbreaks; postemergence weed control in field corn using weed development and degree-day models; thresholds and reduced risk chemistry for wheat and barley diseases; and new varieties for soybean cyst management in soybeans.

Soybean rust and soybean aphids emerged as potential pests of soybeans in the mid-2000s. Through funding from the Southern IPM Center based at North Carolina State University, the Mid-Atlantic states were able to survey and document the incidence of these pests using standard protocols or sentinel plots, through a program called IPM-Pest Information Platform for Extension and Education (IPM-PIPE). The information was entered into a national database to track the movement of these pests. This was an effective mechanism to manage these emergent pests in soybeans which could have had devastating results without IPM-PIPE. IPM programs in no-till systems for slug management were also demonstrated statewide. With the emergence of the brown marmorated stink bug (*Halyomorpha halys*; BMSB) soybean fields were sampled season-long for stinkbugs to evaluate sampling methods, thresholds, and the effectiveness of perimeter sprays.

3.2.3 Maine IPM Program

Maine has had historically strong IPM programs in potato, vegetable, and fruit crops. The Maine IPM program has also expanded to schools (through law), greenhouses, and to homeowners. Potatoes are Maine's largest agricultural crop by acreage. Many pest problems plague potatoes, but one of the most serious is late blight. In potato, weekly "Potato Pest Alert" newsletters are mailed to growers for 11 weeks during the growing season. Farms are routinely monitored for pest pressure/populations. At the farms monitored, growers are taught how to scout fields, implement pest thresholds, and utilize disease-forecasting strategies. Additional IPM tools such as Heliothis-style pheromone traps for European corn borer (*Ostrinia nubilalis*), sticky type pheromone traps for European corn borer, yellow pan water traps for aphid collection, and pheromone traps for black cutworm (*Agrotis ipsilon*) detection are also provided to participating growers. Pest management conferences and several other educational presentations were also made available. A colored booklet and poster of potato pests was considered useful for pest identification. A Late Blight Hotline is also maintained to provide information about this seasonal disease. In the instance of an outbreak of aphids which are virus vectors, warnings were sent that helped growers to protect their seed from unexpected virus spread.

Comments from growers as well as surveys conducted indicated that smaller farms were willing to pay to avoid or minimize environmental risks compared to larger producers (Ziegler et al. 2002). Surveys also indicated an average of two to four applications of pesticide was saved per grower per year, as a result of the information and recommendations delivered. This brought about huge savings (typically over $ 12 million/year) for growers. Based on such savings, the program estimated an average return of $ 33 for every dollar invested by USDA on IPM programs. The role of soil management on potato yield and Colorado potato beetle (*Leptinotarsa decemlineata*) population levels were elucidated in research trials carried out in Maine (Alyokhin et al. 2005; Mallory and Porter 2007).

In apples, orchard monitoring visits are performed by the Maine Apple Monitoring Co-op of the University of Massachusetts Extension Apple IPM Program with some funding support supplied by the Maine State Pomological Society. Consultations are carried out to troubleshoot problems and explore IPM options. Useful publications include the "Apple Pest Report" newsletter, and Apple IPM Web pages. Educational events on apple IPM were provided at various venues. Forecasts make use of the Orchard Radar system. Orchard Radar translates hourly weather observations and 10-day forecast values into IPM scouting and control date advisories for apple scab, flyspeck, fire blight, plum curculio (*Halyomorpha halys*), European red mite (*Panonychus ulmi*), codling moth (*Cydia pomonella)*, apple maggot (*Rhagoletis pomonella*), tentiform leafminers (*Phyllonorycter blancardella*), and other major pests. Some pests are represented through well-tested phenology models such as MaryBlyt and Cougarblight for fire blight, and the codling moth degree-day egg hatch model. These are supplemented with empirical models to estimate pesticide residue depletion and need for reapplication. Estimates are updated and published twice daily on a publicly accessible website.

Strawberry farms are typically scouted during the prebloom to harvest period to monitor populations of major insect pests. At the start of the strawberry pest season, IPM training sessions are held for strawberry growers to review pest monitoring techniques and action thresholds and discuss improvements to the information-sharing system. Management recommendations are offered based on the results of scouting data and the information gathered from these fields are shared with other growers through a weekly newsletter, updated Web page and prerecorded phone hotline messages.

In sweet corn, IPM training sessions are held to encourage growers to learn about and adopt IPM strategies. Farms are monitored for pest problems throughout the season.Weekly newsletters, websites, and recorded hotlines were considered to be useful tools to provide information to growers. Approximately 80 % of the farmers responding to a survey changed their pest management practices based on IPM recommendations. About two-thirds believed that following the IPM recommendations reduced their costs and 85 % believed that following IPM recommendations improved the quality of their crop.

3.2.4 Maryland IPM Program

Maryland IPM efforts are focused on minimizing economic, environmental, and health risks through innovation and site-specific evaluation of biological, cultural, physical, and chemical tactics. Programs and projects are created and directed by Maryland Cooperative Extension and the Maryland Agricultural Experiment Station faculty and staff. Collaborative efforts in IPM-based activities are conducted on instate, interstate, regional, national, and international levels.

Maryland IPM activities support a number of advances in educational outreach and information delivery strategies. Major stakeholders include those representing agriculture, green industry, urban and structural IPM, natural resources conservation service, master gardeners, and so on.

Educational activities encompass on-farm demonstration programs, various levels of classroom training, short courses and workshops, field-level individualized and small group training, newsletters, hotlines, technical publications, and access to long-distance education via the Web. The Internet, campus-based long distance education facilities, and televised special programs enhance traditional educational methods to provide insight for all Maryland citizens.

Varroa mites (*Varroa destructor*) are a major pest problem for beekeepers. Maryland participates in the Mid-Atlantic Apiary Research and Extension Consortium (MAAREC), a regional effort to develop sustainable hive management practices that allows beekeepers to use a mixture of pest control techniques to keep pest populations below a point where they do not cause monetary losses. Scientists at Penn State, cooperating in MAAREC, have tested a large number of essential oils, of which several have been found effective against bee mites. A method developed by the USDA in which screened bottom boards with a depth of 5 cm have been useful in suppressing Varroa mites by as much as 40 %. This approach takes advantage of their natural falling behavior and inability to re-infest bees.

The IPM program houses a Plant Diagnostic Laboratory (PDL) which routinely examines pest specimens sent for identification and control recommendations, and keeps detailed records for all samples. Priority is assigned to samples submitted by extension agents that represent high-value agricultural, nursery, or greenhouse crops over home garden samples. The PDL cooperates with the university extension, research, and teaching faculty, and with researchers at the USDA and the regulatory group at the Maryland Department of Agriculture. Good samples and accurate information are considered essential for proper diagnosis. Efforts are made to train newly hired extension agents and IPM scouts on proper sample selection and shipping. Digital photographic technology is effective in certain situations. Most diagnoses are based on microscopic examinations and identification of causal agents based on symptoms and signs. Overnight incubation in a moist chamber is sometimes necessary for proper identification. Other procedures may be required for diseases caused by bacteria, viruses, viroids, and some fungi. When the PDL is not equipped to perform these tests, the specimens are sent to a commercial testing laboratory. In 2007, the facility was expanded to establish the Plant Protection Center enhancing and broadening its scope to allow the Maryland IPM Program to maintain its essential program components through expanded public/private partnership.

One of the most popular IPM programs of Maryland is the Home and Garden Center Information Center (Traunfeld et al. 1998). It was established in 1989 to provide up-to-date environmental horticulture information to the general public. As Maryland's urban and suburban population has grown, the demand to provide audiences with environmental horticulture information increased. This is a comprehensive program that attempts to meet IPM-related questions of urbanites. The home garden samples received by the plant diagnostic laboratory are referred to the Home and Garden Information Center (HGIC) for future inquiries. The Center is staffed by expert specialists and other trained staff. The specialists also collaborate on demonstration gardens, plant sample diagnosis, television, radio, professional meetings, field days, and applied research projects. The Center is committed to providing self-help educational information that is available in a variety of formats.

In vegetables, the Maryland IPM program provides growers with access to the best insect control recommendations, resistance management programs, and IPM programs available. During the summer months, contact with the growers, county agents, pesticide suppliers, food processors, and the like is made in large part through the weekly insect and plant disease clinics. Also, demonstration plots and field days are established for practical training and education of the growers and general public. Farm visits in cooperation with the county agents are made almost daily. During the winter months grower contact is maintained through a series of winter meetings. Also insect control publications are prepared for use during the growing season. Publications such as "Commercial Vegetable Production Recommendations," "Control of Insects Attacking Home Vegetable Gardens," and "Pest Management Guide for Field Crops" are used extensively throughout the Mid-Atlantic region. IPM programs have been developed for the following vegetable crops: sweet corn (fresh and processing), peas, snap and lima beans, tomatoes, potatoes, peppers, cucurbits, and cole crops. Resistance management programs have also been developed for the Colorado potato beetle.

In soybeans, the soybean cyst nematode is considered to be a major pest in the Mid-Atlantic region. To assist in controlling this pest, Maryland soybean growers and the University of Maryland soybean breeding project directed resources to evaluate existing cultivars and the development of new cultivars carrying resistance to this pest. Resistant cultivars were identified and marketed for production in Maryland. The IPM program has also carried out several field trials and educational programs to evaluate and demonstrate the role of genetically engineered crops.

Western flower thrips is one of the major pests of concern to greenhouse bedding plant producers. Based on field trial releases of the predacious mite *Amblyseius cucumeris* evenly distributed through a bedding plant crop provided an effective method of managing thrips. Entompathogenic nematodes were found to be effective in reducing the population of fungal gnats in greenhouse crops such as poinsettia, lilies, pansies, and several herbs, reducing the need for chemicals by growers. Similar biocontrol tools were found to be effective to control lace bug (*Tingidae*) in azaleas.

The Structural IPM Interstate Pest Control Conference and other training opportunities relay the latest biological management techniques to pest control operators, managers, regulators, and industry personnel. The Structural IPM program area also promotes adoption of IPM by a wide variety of stakeholders through the HGIC.

Homeowners and the general public are supplanting traditional clientele such as farmers and growers as an audience for extension activities in rapidly urbanizing states. A venue called “Bug of the Week,” to deliver information to large audiences via the Web was explored by the IPM programmers. Each week “Bug of the Week” explores the biology of insects found in and around a home in suburban Maryland. The goal was to introduce adults and children to the wonders of biology using examples from the insect world. Concepts such as food webs, natural selection, behavior, herbivory, chemical ecology, and predator–prey interactions are introduced in an easily understandable way. The website was featured in a nationally syndicated news article first published in the *Baltimore Sun*.

Over 90 million U.S. households have a yard, the combined acreage of lawns and gardens ranging from 6.9 to 12.1 million ha (USDA-NASS, National Gardening Association). Seven of the top ten pesticides used in the home and garden sector are herbicides. Unlike most pesticides, herbicide use on home grounds appears to be increasing. Rates of herbicide active ingredient use are comparable to those in agricultural settings, but the risk of misuse and human exposure may be greater in the home and garden sector (Matheny et al. 2009). Maryland has taken considerable efforts to train master gardeners who in turn train end-users on proper use of pesticides in lawns and gardens as well as reducing their use.

3.2.5 Massachusetts IPM Program

The Massachusetts IPM program played an instrumental role in developing a nationally accepted Logic Model for planning, designing, implementing, and evaluating IPM programs (Fig. 3.1). Similar materials for IPM programs in apples and

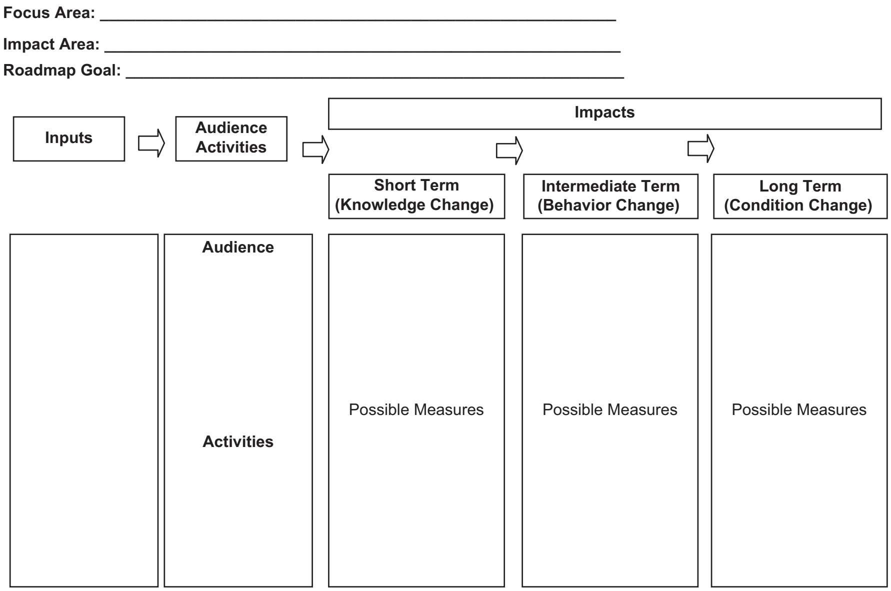

Fig. 3.1 Template of a Logic Model for planning, designing, implementing, and evaluating IPM programs.

peaches, developed in Massachusetts, were used widely in other fruit-producing states to implement cost-share practices through the NRCS. The program also has a positive reputation for effective quantification of IPM successes and programming needs through various evaluation tools (Hollingsworth and Coli 2001).

In cranberries, the Massachusetts IPM Project focused on the development of low-cost alternative pest management strategies that can be implemented by growers. A promising alternative is the use of a flood after harvest. On several grower bogs, team members studied the usefulness of a 3- or 4-week fall flood to manage cranberry fruitworm (*Acrobasis vaccinii*), bristly dewberry (*Rubus hispidus*), and *Phytophthora* root rot. Data indicated that a 4-week flood may be necessary to suppress dewberry populations, although cranberry fruitworm experienced 100 % mortality for either a 3- or 4-week flood.

In greenhouse IPM, the predatory mite *Neoseiulus cucumeris* was found effective to control western flower thrips (*Frankliniella occidentalis*). A 2003 survey of Massachusetts greenhouse growers indicated that many more growers are implementing IPM practices promoted by the UMass program. Behavioral changes documented include replacement of worn sprayer nozzles and proper calibration, use of insect growth regulators rather than broad-spectrum pesticides, better weed control, and use of disease diagnostic test kits. A major effort has gone into studying a number of different biological control agents, either small, nonstinging parasitic wasps, or nematodes that attack key pests of greenhouse crops. According to a survey reported in 2005, these and other nontoxic pest management materials (e.g., beneficial fungi, microbial pesticides, insecticidal soaps, predatory mites, etc.) went up by 68 % in New England greenhouses.

In-depth training in aspects of IPM for schools, daycare centers, and school-age childcare facilities was provided. The training sessions focused on cultural controls rather than pesticides, and also emphasized use of low-risk compounds such as baits and gels. Over 95 % indicated that they would adopt the practices described.

Pumpkin growers who participated in an IPM and crop management project reported that better timing of needed sprays through improved monitoring, in addition to crop rotation and timely harvest saved time and achieved better control of bacterial wilt. Growers who participated in a biointensive sweet corn project reported an increase in clean marketable corn without tip damage. Adequate control of both corn earworm and European corn borer was achieved using a combination of foliar sprays of Bt and direct silk application of corn oil mixed with Bt. The "Zea-Later Oil Applicator" developed at UMass enables growers to utilize this tactic. The corn IPM program developed a video titled *Farmers and Their Ecological Sweet Corn Production Practices*. Ecological practices in this video included monitoring for corn pests, hairy vetch as a cover crop, spraying Bt for European corn borer, banding herbicide applications, *Trichogramma ostriniae* for corn borer, and using the "Zea-Later Oil Applicator" for corn earworm. All practices have been key elements of the UMass Biotintensive Sweet Corn IPM project for many years.

A novel "attract and kill" system for the apple maggot fly was developed by the IPM program. A nonsticky sphere trap impregnated with a reduced-risk insecticide, and baited with odor lures and feeding stimulant was effective at controlling maggot flies at a level comparable to that achieved by insecticide spraying. Populations of the predatory mite *Typhlodromus pyri* became established in commercial orchards after they were released and were reported to have spread to nearby plots that did not receive releases.

Plum curculio is a key direct pest of apples and other tree fruits in major eastern and central US fruit-growing regions. Normally, 3–4 organophosphate insecticide sprays are directed at this pest from the petal fall period to 3 weeks postpetal fall. Commercial orchard studies indicated that odor-baited traps could be used to monitor the entry of curculios into commercial orchards. Cylindrically shaped traps baited with the synthetic fruit odors benzaldehyde, ethyl isovalerate, or limonene, in combination with synthetic sex pheromones were shown to be effective when deployed in perimeter-row trees.

Massachusetts fruit pathologists, in cooperation with colleagues at the Hudson Valley Lab of Cornell University refined their understanding of the epidemiology of summer diseases. Surveying orchard borders for alternative hosts of flyspeck (a summer apple disease caused by *Zygophiala jamaicensis*) including efforts to assess inoculum potential based on border plant composition and distance to orchard borders containing wild hosts of the organism, as well as block elevation and exposure and other abiotic factors, has been shown to be a useful tool in predicting flyspeck risk. Apple growers were very responsive to these new approaches.

A SARE-funded regional project demonstrated the potential value of mating disruption for the grape berry moth (*Endopiza viteana*), as well as the utility of leaf petiole analysis for determining vine nutritional needs. It also compared satellite-based weather data to on-the-ground weather stations, optimal vine balance range for vineyards, and use of reflective mulches to improve fruit ripening in southern New England.

In cooperation with Red Tomato, a Massachusetts-based, nonprofit marketing organization, scientists at the University of Massachusetts, Cornell University, and the IPM Institute of North America, Madison, Wisconsin, successfully developed the most advanced IPM protocol for ecological apple production in the United States to market apples produced by 12 northeastern growers to major outlets. The "Eco-Apple" project has succeeded in developing a recognizable brand for locally grown fruit that fills a niche between "organic" and "conventional" produce and is proving to be a financial benefit for New England and New York farmers.

3.2.6 New Hampshire IPM Program

New Hampshire has a clean record of pesticides never having been detected in groundwater. The IPM program takes pride in maintaining this record and minimizing the risk of any other negative health or environmental impacts from pesticide use. Unlike farms in large agricultural states, NH farms are small, diversified, and scattered. Large-scale scouting programs run by extension are therefore not feasible. Methods of disseminating IPM information are designed to assist having the growers themselves or their employees perform IPM functions.

With the appearance and spread of West Nile Virus (WNV), New Hampshire IPM focused some effort on applying IPM information to this emerging problem. IPM-oriented WNV information packets (including mosquito management and repellant safety information) were distributed to the town offices throughout the state. Information was also distributed via radio, newspapers, and the cooperative extension's website. Another publication aimed to serve homeowners was titled "Think Before You Buy Pesticides." Mosquito management became an important New Hampshire problem in 2005, due to a number of cases of Eastern Equine Encephalitis (EEE) in humans. The IPM coordinator compiled an EEE fact sheet that was used in town meetings as citizens considered mosquito control articles on town warrants. He also participated in radio and television coverage.

NH apple growers saved over $ 250 per hectare on spraying since 1981, compared to pre-IPM years (1978–1980). The incidence of pest injury on fruit was reduced by 7 %, compared to pre-IPM levels. Extensive surveys were carried out to develop IPM strategies for corn rootworm. As a result of IPM-related information on corn rootworm published as fact sheets, mailed to all producers in the state, growers were able to prevent needless insecticide treatment on field corn, which is grown on 6,072 ha. Growers used this simplified fact sheet for counting rootworm populations themselves and no longer depended on a pesticide salesperson for advice (this was important, inasmuch as most of the rootworm insecticide advertising was based on populations in the Midwest, which are 10 to 28 times higher than those in NH).

Collaborative IPM workshops are organized with Vermont and Maine. IPM workshops are considered to be more effective when delivered as "hands-on" learning, rather than a traditional lecture format. Greenhouse IPM training sessions included: (1) use of virus detection kits; (2) the pour-through method of soil pH measurement; (3) aphid identification with microscopes and hand lenses; and (4) diagnosing live plants with disease problems. The day also included sessions on thrips survival, biological control agents, and grower experiences with new approaches.

In general, some of the IPM strategies found to be effective are preventive measures, monitoring, and control. Examples include rotation (for control of corn rootworm; *Diabrotica virgifera virgifera*), eliminating weeds under greenhouse benches (alternate hosts of pests), using red sticky spheres to monitor apple maggot populations, and using insect-killing fungi to control foliar greenhouse insects. A fruit pest telephone hotline updates callers on conditions during the growing season.

3.2.7 New Jersey IPM Program

The IPM program in New Jersey encompasses production agriculture in the areas of blueberries, field crops, nurseries, tree fruit, and vegetables. In addition, research conducted by university personnel helped to increase the adoption of IPM. In the northeastern United States, the vast array of arthropod pests in tree fruits are managed using mating disrupters, traps, beneficials, and other biological and cultural-based tactics (MacHardy 2000). New Jersey was one of the early adopters of mating disruption systems for oriental fruit moth in peaches (Agnello et al. 2009). In certain years, pesticide use in tree fruit was reduced by 60 % representing a reduction of three to five sprays per orchard. Programs included arthropod and disease monitoring, nematode detection, and fertility monitoring. Implementation of the program positively affected over 47 % of the New Jersey's tree fruit acreage. Pesticide use in tree fruit was reduced between 50 and 80 % for oriental fruit moth control and because of that brought about significant savings to growers. Grower use of environmental models for apple scab and summer disease control optimized fruit quality and also reduced fungicide use. Growers learned the importance of regular orchard monitoring, helping to prevent pest resistance to pesticides, and optimizing the use of pest management resources.

In blueberry production, growers participated in USDA/NRCS EQIP cost-sharing programs for IPM. New pest management programs were utilized using new reduced risk materials and practices. Growers managing blueberry maggot (*Rhagoletis mendax*) under IPM methods reduced insecticide use from 6 to 1–2 applications (66 %). Using the results from a USDA/RAMP project, growers following this program had between 45 and 58 % lower amounts of insecticides applied than growers using standard programs. Overall, growers who practiced IPM at high levels, used from 6.7–8.9 kg ai of pesticide per hectare, whereas conventional growers treating on a pure calendar schedule, used up to 38 kg ai/ha. The average grower using IPM practices saved about $ 250/ha.

The vegetable IPM program was able to affect more acreage through the use of a website that tracks weekly European corn borer and corn earworm population changes in the state. This program has been so successful that it has been linked to a similar network maintained for the Mid-Atlantic states. A GPS blacklight monitoring program was implemented to monitor corn earworm and European corn borer population development. Control options for these two pests in sweet corn are based on the data generated by this system. The information developed was delivered via weekly printed and electronic newsletters and a weekly updated website that graphed the changes detected by the system. This was a well-accepted program in the state. Growers in the vegetable IPM program received more timely information that resulted in less pesticide use. As a result of the program conducted in greenhouses, growers were better able to manage pests and reduce insecticide and fungicide use because of the scouting program provided by the greenhouse IPM program. An estimated 48 % savings was realized in pesticide and nutrient costs as a result of program activities.

In nonagricultural programs, the landscape IPM program which utilizes a mentoring program for landscape professionals, the use of IPM contracts and the offering of numerous educational programs has been successful. As a result, 79 % of the acreage was under an IPM contract developed by the program and resulted in a 42 % drop in conventional pesticide use with an associated increase in the use of materials such as horticultural oils and insecticide soaps.

In addition, program staff conducted studies to document IPM practices in a variety of crops. These studies included monitoring for invasive species such as *Copitarsia* spp. and the brown marmorated stink bug surveys, stink bug and thrips monitoring in tomatoes, and the use of biological control in high tunnel tomato production. These and other efforts by the program affected 12,146 ha of New Jersey's vegetables. The program reached a wide audience through its weekly newsletter.

New Jersey also developed a school IPM program due to growing interest in the state. It was developed by coordinated efforts from Rutgers Cooperative Extension, the New Jersey Environmental Federation, the New Jersey Department of Environmental Protection, and the state's pest control operator industry (PCO). The information developed by the IPM program in the state was provided to growers, private consultants, industry representatives, government people, and the public at large via printed and electronic newsletters (which provided information on pest occurrences, weather information, and control options) and websites.

3.2.8 New York IPM Program

The mission of the New York State IPM Program is to develop and deliver sustainable methods to manage pests that are capable of producing economic damage and that pose minimal risks to human health and the environment. Some of the highlights of the program include a methodology to assess the environmental impact of pesticides. The model, termed the Environmental Impact Quotient (EIQ), takes into consideration various factors such as toxicity and environmental attributes of pesticides to come up with a risk factor of using a pesticide in a given situation (Kovach et al. 1992). This model has gained national and international acceptance as a credible method to quantify the impact and success of IPM programs. Brimner et al. (2005) used this model to quantify the impact of herbicide-resistant canola in Canada and documented that it reduced the environmental impact of herbicides used by 37%, compared to conventional canola. In Australia, 64% reduction in environmental impact was calculated by using Bt cotton when compared to conventional cotton, based on the EIQ model (Knox et al. 2006).

The school IPM program developed by the New York IPM program and the IPM Institute of North America also gained national attention and trainers subsequently have been asked to provide workshops in several underserved areas of the country and its territories. As a result of sustained efforts of the state's IPM program, vegetable farmers are trained to adopt environmentally sound farming practices (Shelton et al. 1987); this led to the identification of agricultural products as "IPM-Grown." Such a distinction was considered to be a significant marketing strategy to gain consumer awareness. Growers had to adhere to a documented set of IPM practices required of suppliers following major distribution companies that set IPM standards for their produce. Major distribution companies carried this idea to a national and international level with guidance from the IPM Institute of North America.

IPM educational efforts cover a broad range of commodities including vineyards, fruits, vegetables, ornamentals, row-crops, livestock, turfgrasses, and Christmas trees. Web-based information was considered to be useful. School IPM topics of interest included management of mice, mites, grubs, lice, stinging insects, ants, termites, and weeds in athletic fields, as well as policy design and development.

In grapes, an electronic newsletter helped schedule spray timings or reduce sprays by providing near real-time information on weather, pest outbreaks, and scouting information. Applied research on using microbials to suppress ornamental diseases led to the development of new IPM activities in greenhouse IPM.

Lepidopterous pests such as the European corn borer, which overwinters in New York, the corn earworm, and fall armyworm (*Spodoptera frugiperda*) pose a threat to sweet corn growers. High infestation levels at harvest by one or more of these pests can lead to total marketable crop losses. A monitoring system that included a network of pheromone traps for each of the three pests helped farmers to understand their flight patterns, and the arrival time and numbers of the migratory pests. Extension field staff, crop consultants, and farmers collaborated to set up and monitor the traps. Weekly counts are reported to an IPM staff-person who collates and posts the data, along with interpretation and scouting and threshold recommendations, on email listservs and web pages that can be accessed by farmers and their advisors. This was a well-received IPM practice and positively affected farmer success, improved adoption of IPM practices, and reduced risk to the environment through fewer insecticide applications.

In tree fruits, insect infestation can result in rejection of entire truckloads resulting in huge monetary losses for the grower. Many growers respond to such economic risks by resorting to a spray program that may not be necessary if proper IPM strategies are employed. In orchards, pheromone traps are successfully used to monitor adult moth flight information. The trap data are used to identify peak flights on each farm and observe the variability among farms in insect pressure for each species. Insecticides are applied with spray timing based on trap information and degree-day model predictions. Ultimately these practices result in cost-savings for the grower.

Weather-based pest risk models in other high-value crops such as onions and potatoes helped reduce calendar-based sprays significantly. The Network for Environment and Weather Awareness (NEWA) was developed to address such needs and can be accessed freely by growers. NEWA provides IPM forecasts to growers in New York developed from research in plant disease epidemiology and arthropod pest phenology. NEWA has expanded to include cooperative agreements with groups in several other northeastern states. The pest predictions are made available to those states based on their own local instrumentation.

An IPM education program to teach sound pest management decision making and to improve soybean profitability using IPM principles has also been well received. The model for the program is the Tactical Agriculture, or TAg Team Program, which is a season-long, on-farm, IPM and ICM (Integrated Crop Management) educational program for field crop producers. This program played a key role in communicating with farmers about the potential arrival of Asian soybean rust (*Phakopsora pachyrhizi*), its identification, and management. Improved management of pests through combinations of tactics helped mitigate the risks to soybean production in New York.

3.2.9 Pennsylvania IPM Program

The Pennsylvania IPM Program (PAIPM), a collaboration between Penn State University and the Pennsylvania Department of Agriculture, has evolved into a well-recognized program both nationally and internationally. PAIPM promotes and provides information for all types of IPM, but realizing that extension specialists and county educators carry out IPM implementation for the major crops in the state, PAIPM activities focus on emerging needs not met by traditional programs: urban IPM, conservation programs, Web-based decision support tools, and serving under-represented groups such as the Hispanic population and the Amish/Mennonite community. PAIPM pays special attention to regulations and markets that can change a producer's behavior and IPM strategies are designed to take advantage of these factors. On the regulatory side, federal and state incentives, cost-share programs, and insurance programs that reward IPM practices are taken into consideration. There is also a conscientious effort to reduce pesticide use based on the Food Quality Protection Act. On the marketing side, certain large grocery chains and nongovernmental organizations offer growers who use IPM entry into niche markets.

Both regulatory and marketplace incentives require informed citizens. The state IPM program invests in public education about IPM through media, cooperative extension, and other avenues. One of the several successful efforts in Pennsylvania is the IPM in schools program (Pennsylvania State University 2012). This program, based on a memorandum of understanding among university IPM programs and the Pennsylvania Departments of Agriculture, Education, and Health, provides education and information about the management of pests on school grounds, and includes IPM in the newly established academic programs for Pennsylvania public schools. Over one million school children learn about IPM on an annual basis. Topics such as Overview of IPM, Environment and Ecology, Teaching Standards, Identification and Management, Insect Biology, Weed Biology, Vertebrate Biology, Tactics, Issues, Concepts of IPM, and Use of IPM in Specific Environments were considered to be useful. For the general public, the use of a trendy mobile unit to display IPM to the public, and other conventional methods were employed successfully. Because a vast majority of the public in the state is not involved in agriculture, such exhibits serve as an effective method of outreach.

In service to agriculture, the Pennsylvania IPM program has effectively supported various educational tools for its outreach efforts, including computer-based troubleshooting systems for growers, information dissemination using websites and listservs, PAPipe (http://pa-pipe.zedxinc.com), and a weather-based surveillance system that produces up-to-date maps of pest development across the state. This website is used by growers to determine threats from insects, diseases, and weeds in field and horticultural crops.

IPM adoption in sweet corn eliminated unnecessary sprays based on proper pest identification, and timely applications (Orzolek et al. 1995). Pennsylvania is among the top states in greenhouse production. A serious challenge faced by greenhouse growers is the management of insects and mites due to phasing out of several effective pesticides as part of the Food Quality Protection Act. Increasingly, growers depend upon the greenhouse IPM program to manage their pests. Manuals on the use of biocontrol agents to manage pests such as aphids, fungus gnats (*Bradysia* spp.) two-spotted spider mites (*Tetranychus urticae*), whiteflies, and others were considered useful. Based on this publication, greenhouse vegetable growers eventually established a successful IPM/biocontrol system to replace traditional pesticides. Master gardener volunteers are also actively trained in IPM.

Tree fruit growers across Pennsylvania participated in a demonstration involving the use of mating disrupters to control peach tree borer (PTB; *Synanthedon exitiosa*), lesser peach tree borer (LPTB; *Synanthedon pictipes*), and oriental fruit moth (OFM; *Grapholita molesta*). PTB and LPTB contribute to tree decline resulting in lower production, whereas OFM bore into shoots and fruit. Fruit feeding from these pests makes peaches unmarketable. While using this tactic, peach orchard blocks were monitored on a weekly basis from April through September using pheromone traps. Comparisons of trap catches of PTB, LPTB, and OFM were made between treated and nontreated blocks. The growers involved with the demonstration were able to avoid insecticide sprays in mating disruption blocks compared to control blocks. It also demonstrated that mating disruption can eliminate one or two late-season sprays for LPTB and PTB, and can reduce insecticide sprays for OFM.

A four-year USDA-funded project to develop and evaluate, on a regional scale, reduced-risk IPM program was also established in Pennsylvania. About 84% of the pesticides applied to apples and peaches were organophosphates, but IPM programs based on reduced-risk pesticides are equally effective at producing saleable fruit and could reduce the pesticide load applied into the environment. Newer compounds are much more active and applied at lower rates. These materials coupled with pheromone mating disruption and increases in biological control, also helped reduce the number of applications. According to the Environmental Impact Quotient developed at Cornell University, the environmental impact of reduced-risk IPM programs is 5.3 times safer than the programs they replaced.

Such programs, however, can be significantly more expensive for growers (79 and 85 % more costly in apples and peaches, respectively). To offset some of these costs, the program was successful in establishing cost-share programs with the state's NRCS through the Agriculture Management Assistance (AMA) program, and the Environmental Quality Incentives Program. Substantial amounts of support funds were channeled to various commodities such as tree fruit to meet the higher costs of using reduced risk pesticides discussed above (Brewer et al. 2009).

A major investment in urban IPM, especially for underserved communities in Philadelphia and elsewhere, addresses IPM needs in multifamily housing, daycare centers, and schools. Spanish-speaking IPM staff addresses Latino community needs.

3.2.10 Rhode Island IPM Program

The Rhode Island IPM Program has a national reputation for its Classical Biological Control Program for developing viable biocontrol strategies, especially to manage invasive weeds. The state also has Fruit and Ornamental Horticulture IPM programs designed to minimize dependence upon pesticides.

The Classical Biological Control Program was instrumental in releasing agents against purple loosestrife and cypress spurge. In 1994 the University of Rhode Island became involved in biological control of purple loosestrife (*Lythrum salicaria*) at a zoo where this invasive weed affected the growth of native wetland plants, and hand-pulling efforts were unsuccessful. From 1994 to 1996 three species of insects were released: *Galerucella calmariensis, Galerucella pusilla,*and *Hylobius transversovittatus*. By 2000, a sharp decline in the loosestrife density and a resurgence of native plants was noticed. Subsequently, *Galerucella* spp. have been released throughout the state, providing effective control of purple loosestrife (Blossey et al. 2001).

In 1995, five species of *Aphthona* beetles were released to control cypress spurge (*Euphorbia cyparissias*) at two locations in Rhode Island. Based upon successful control at initial release sites, these insect control agents have been distributed throughout the state. The University of Rhode Island researchers also discovered, evaluated, and released biocontrol agents of lily leaf beetle (*Lilioceris lilii*). These parasitoids are now widely distributed in New England and Ontario, Canada. Other biocontrol implementation programs include hemlock woolly adelgid (*Adelges tsugae*), birch leafminer (*Fenusa pusilla*), black swallow-wort (*Cynanchum louiseae*), and common reed (*Phragmites australis*; Tewksbury et al. 2002). Birch leafminer (*Fenusa pusilla*) was a serious threat to birch trees throughout the northeast and midwestern states. University of Rhode Island researchers in collaboration with cooperators at the Agricultural Research Service (USDA-ARS) in New Jersey, Rhode Island, and Massachusetts were able to successfully control this pest by releasing a parasitoid *Lathrolestes nigricollis* (Fig. 3.2).

Fig. 3.2 *Lathrolestes nigricollis*, a parasitoid, on a leaf damaged by birch leafminer. (Photo credit: R.A. Casagrande)

The Apple IPM program has resulted in substantially reduced pesticide use in orchards. Information is provided via traditional grower meetings (occasionally with Massachusetts), site visits, and web-based recommendations. Orchards are scouted on a weekly basis by growers with the assistance of an IPM scout. In various years, growers in Rhode Island were able to reduce annual fungicide use by 17 to 30 %, insecticides by 35 to 67 %, and miticides use has been reduced by 37 to 85 % of the recommended applications in "Northeast Recommends."

In the landscape arena, the program worked closely with the Rhode Island Nursery/Landscape Association and saw their membership adopt recommendations for plant selection and management practices. The landscape program used a variety of means including annual educational meetings, demonstration gardens, newspaper articles, articles in the trade newsletter, and site visits. A publication "Sustainable Trees and Shrubs" provides clientele throughout Southern New England with information on noninvasive insect- and disease-resistant ornamental plants.

3.2.11 Vermont IPM Program

Vermont is a very rural state and agriculture is essential to the vitality of its communities. For a state with diversified crops and small farms, the Vermont IPM Program has successfully established a sound IPM program despite funding and personnel limitations. The program focuses IPM priorities and needs that are identified through participatory assessment methods conducted in the state and region.

The Vermont IPM Program includes: Apple, Berry & Vegetable, Field Crops, Greenhouse, and Consumer Horticulture. All the programs are collaborative, involving a combination of growers/farmers, gardeners, IPM consultants, extension personnel, and researchers within Vermont and the region. The objectives of the program includes incorporation of new IPM techniques into farm operations, improvement in the use of IPM practices, and reduced or minimized pesticide use (Garcia et al. 2005).

In apples, the IPM program typically includes: orchard visits and one-on-one interactions to provide site-specific information; workshops, meetings, farm tours; The Vermont Apple Newsletter; IPM Alerts; the Vermont Apple IPM Focus website for apple IPM education and information; and applied IPM research addressing the priorities and needs as defined by the apple industry in Vermont and the region. Evaluation surveys indicate that the IPM program presents relevant and timely IPM information (>95 %). A similar percentage report that the IPM program improved their IPM practices and reduced or minimized pesticide use.

In field crops, major goals are to provide crop consultants with information on IPM techniques for assessing the northern and western corn rootworm incidence and damage. This information was used by the consultants to make recommendations to their farmer clientele. The information is also useful for clientele to make decisions for the following year. Sticky traps were used for evaluating adult corn rootworm beetles. During the growing season, farmers are updated weekly on corn pest problems via the "Vermont Forage Report" published in eight newspapers around the state and also posted on the Web. Through workshop training, herbicide use in corn was reduced through use of cover crops, crop rotations, and mechanical weed control as methods to reduce weed pressure.

In greenhouse IPM, the primary goal is to educate growers about IPM and alternative nonchemical approaches to pest management. The key IPM technologies promoted include accurate pest and disease identification, regular scouting, maintenance of accurate records of pest populations and management actions, effective spray application methods, lifecycles of pests and beneficials, and biological control. To implement this, hands-on IPM workshops were made available for growers in the tri-state area (Maine, Vermont, and New Hampshire). Use of biological control is a major focus of these workshops, and includes practical tips on how and when to use them effectively. The hands-on format is considered to be an excellent means of disseminating practical information about IPM implementation. Growers consider the hands-on approach of the program to be useful. "Thripsnet," an internet listserv links growers and scientists involved with thrips research and management is being maintained. "Greengrower," an internet listserv linking greenhouse growers throughout the tri-state region has also been maintained. Through programming efforts, growers improved their ability to diagnose major pest problems. This enabled growers to use fewer pesticides, and the ones they do use are more effectively timed.

In vegetables, the IPM program trained growers in the identification of pests and diseases, in the economic thresholds for these pests, and to manage these pests and diseases using IPM management strategies. This training helped the farmers to tailor IPM strategies for their own farms concentrating on cultural, biological, and low toxicity pesticide options that safeguard both the farmworker's health and the environment. In several instances, the recommendation was to not control the pest with a pesticide because the economic threshold had not been reached. The University of Vermont Plant Diagnostic Clinic is a valuable resource for vegetable and berry farmers to send samples for specific information on IPM strategies based on diagnosis of the problem.

Vermont IPM also addresses a widespread problem associated with homeowner use of pesticides. Consumers are often quick to resort to general-purpose pesticides when dealing with unknown pests in their landscapes and gardens. Pesticides are often used by this group unnecessarily. Homeowners need science-based IPM information to address their pest identification and pest management questions. Trained master gardeners have the potential to make a difference because of their interests and ability to work closely with homeowners. Each year, the IPM program trained master gardeners over 14 weeks in all aspects of IPM including pest identification, IPM techniques, and safe pesticide use. After finishing the course, the participants volunteer 40 h to receive their "Master Gardener Certificate." Several of these certified master gardeners work with the Vermont public answering IPM questions. During the growing season, the Master Gardener Helpline received 3,400 phone calls with 90 % directly pertaining to IPM basics and principles including pest identification, pest management using cultural methods, and pest management using a pesticide. A subset of these home gardeners (50 people) were contacted at the end of the season and asked whether they learned about IPM at the time of the call and how they had managed the pest about which they requested information from the Helpline. All respondents (100 %) said they learned about IPM practices at the time of the call. Eighty percent indicated they had used only a cultural practice to manage the pest; 5 % indicated they had used a pesticide to control the pest; and 15 % indicated they had used a combination of a pesticide and a cultural practice as a result of the IPM information supplied by the Helpline staff.

3.2.12 West Virginia IPM Program

West Virginia is also considered to be a small farm state with diversified agricultural operations such as poultry and livestock, tree fruits, pasture and hayfields, row crops, turfgrasses, small fruits, and vegetables. The demand for locally grown produce and the proximity of the state to large cosmopolitan cities has recently provided an impetus for many small farms to expand. Similar to some of the other states in the northeastern United States, funding and personnel shortages have limited the scope of IPM programming in the state.

In vegetables, several field research and demonstration plots evaluated and demonstrated alternative methods to manage weeds. The results of these studies were useful for organic vegetable producers who depend on nonchemical means to achieve weed control. Field studies indicated that plastic mulch was most effective for weed management and yields in nonirrigated peppers, whereas hand cultivation resulted in the highest yields in irrigated peppers. Treatments evaluated also included straw mulch, corn gluten, and vinegar. Vinegar (> 10 % acetic acid) was partially effective to control weeds in potato, if applied twice during the growing season.

Fig. 3.3 Banded application of atrazine in corn reduced its use by 50 % compared to broadcast application without affecting crop yield. (Photo credit: R.S. Chandran)

A symposium entitled "Herbicide Tolerant Crops and Their Role in the Future" with reputed invited speakers served as an introduction to genetically engineered crops in West Virginia. As a follow-up, demonstrations were conducted to evaluate genetically modified herbicide (glyphosate) tolerant corn as a tool to manage weeds and to determine profitability. Growers embraced this technology due to cost savings and simplicity in weed management. IPM benefits included reduced pesticide loads, especially certain residual herbicides such as atrazine, and use of reduced-risk pesticides. Fact sheets were published warning growers not to depend on this technology due to risks of resistance development. However, a few suspected events of herbicide-resistant weeds were noted in corn-growing areas of the state about eight years later.

The current emphasis in agronomic Crops IPM is to reduce herbicide use in corn by banded application as opposed to conventional broadcast application (Fig. 3.3). A long-term (5-yr) demonstration is ongoing at a grower location apart from several other farm-scale demonstrations. Pre-emergence herbicides in field corn are reduced by 50 % using this strategy. This strategy may also provide other services to the ecosystem such as reduced soil erosion and nutrient runoff, provide habitat for beneficial insects, increase biodiversity levels in the field, and an increase in the levels of carbon sequestration (Chandran et al. 2011). Yield data have been encouraging for the adoption of this practice so far, but buildup of weed seed bank is however a concern.

A pilot project funded by the IPM program demonstrated the feasibility of using meat goats to graze on brushy invasive plants such as multiflora rose (*Rosa multiflora*) and autumn olive (*Elaeagnus umbellata*) in pastures. Such weeds can cause significant reductions in Appalachian pasture productivity. Small ruminants such as goats and sheep are known to utilize these plants, preferring them over most native plants. These animals also have the potential to fetch additional income to the farmer. Based on the success of this project a Conservation Innovation Grant was funded to investigate the feasibility of launching a cost-share program with NRCS to include small ruminants in pastures to manage invasive brush. The participating farmers of the project purchase animals required to manage invasive brush in the pasture and the project matched their expenses towards supplies to contain and manage the animals. NRCS subsequently included biocontrol of invasive plants in pastures as a statewide cost-share practice standard in their Environmental Quality Incentive Program.

Commercial orchardists face challenges due to increased costs for IPM and concerns over the use of high-risk pesticides. Incentives to the grower to adopt the use of reduced-risk pesticides, pheromone mating disruption, and to continue other advanced IPM practices are expected to help keep production costs down while providing healthful produce to the consumer in an environmentally benign manner. In order to encourage the use of reduced-risk pesticides and other advanced IPM practices in orchards, the NRCS was approached to offer a cost-share program through their Environmental Quality Incentive Program. The cost-share program (which lasted for a period of three years) provided financial incentives to growers to adopt up to three levels of IPM in commercial orchards starting with the 2008 growing season. This program reduced pesticide use in West Virginia orchards significantly. Pheromone traps are usually provided to apple growers in the state to monitor insect pest levels in orchards. Remote weather stations were installed in the two major apple-growing regions of West Virginia and recommendations made to spray were based on weather data. A demonstration showed that bubble wrap mulch was effective for both weed control and reduction of bruising, thus enhancing yield for apples to be processed. Other demonstrations proved that reduced (1/4 normal use rate) rates of 2,4-D along with glyphosate was as effective as the standard use rate of 2,4-D in the tank mixture to control perennial weeds in orchards.

Demonstrations were carried out on home lawns to demonstrate the effects of long-term IPM practices on weed populations in home lawns. The participants were provided with the necessary information in a step-by-step manner to establish a healthy lawn thereby reducing herbicides for weed control. Studies also demonstrated turf established under suboptimal soil conditions were more prone to pests and that the addition of composts during turfgrass establishment enhanced fertility and physical and chemical properties resulting in a healthier and more resilient turf leading to lower amounts of pesticide usage (Chandran 2006; Mandal et al. 2013).

Organic vegetable production in the state is gaining momentum especially with home gardeners. Disease management remains a challenge to the growers. Recurrently appearing diseases such as early blight of tomato and potato causes significant loss in years with wet spring and summer. Inoculum reduction through removal of infected plant debris in the fall, use of certified healthy seeds, and organically acceptable products proved useful as an IPM approach for controlling early blight. Production practice that minimizes leaf wetness hours is also being explored in the IPM research for minimizing loss from early blight. Demonstrations at the WVU organic farm effectively disseminated IPM initiatives to the end-users. A quarterly IPM newsletter published by WVU Extension has also been used as a conduit to encourage growers about IPM (htttp//www.anr.ext.wvu.edu/pests/publications).

Aquatic weeds limit the productivity of small ponds used for aquaculture in West Virginia. Use of biocontrol agents has not been explored much in the state. The IPM program carried out demonstrations in 2002 to show the usefulness of a biocontrol agent—grass carp—to manage aquatic weeds. The system was monitored and concluded to be effective for weed control. Consequently, two vendors were approved by the state to sell grass carp throughout the state. Six years later, an increase of more than 400 % in grass carp sales was reported.

Publications such as “Field Crops Pest Management Guide” and “Spray Bulletin Guide for Commercial Tree Fruit Growers” are made available to growers through the collaborative efforts of pest management specialists in the region. The State Department of Agriculture is actively involved in school IPM. Other state-funded activities include a gypsy moth (*Lymantria dispar*) monitoring and spray program and using biocontrol agents to manage purple loosestrife and hemlock woolly adelgid.

3.3 Future Directions for Northeast IPM

One of the striking features of IPM in the northeast states is the similarity of efforts based on crops or clientele served. Clearly every state in the region is productive and resourceful based on their program outcomes. However, duplication of efforts was noted in several instances. Systematic streamlining of efforts and regionwide programming may call for more efficient use of resources. Although larger states and universities have unique strengths based on personnel or infrastructure to cater to crops or clientele groups relevant to the entire region, smaller states may be able to contribute to the overall mission of IPM based on their assets and unique end-user needs. Programming logistics for major crops could be applicable to all the states on a regional basis so that available resources may be used to implement IPM programs in the field. There is a tendency towards investing more resources towards urban and community-level IPM programming efforts, however, such efforts should not come at the expense of IPM in agriculture, the original target audience of this discipline. Programming efforts and funding sources to cater to the needs of such diverse clientele vary. Proper direction and balanced decision-making processes will ensure the continued success of IPM in the region. Multistate collaboration and frequent communication will also help address such duplication of efforts.

Another common theme that influenced the implementation of IPM by growers in the region is profitability. Due to global competition, growers are forced to adopt the most cost-effective method to manage pests in their crops. Costs associated with the environment or other indirect long-term sustainability issues do not typically influence these decisions. The affordability of IPM is therefore an important prerequisite for grower adoption. For example, with the recent outbreak of brown marmorated stink bug in the region, the primary concern was crop loss. All stakeholders, including IPM practioners, sought the most effective tools made available to growers. This entailed the use of highly effective broad-spectrum insecticides at the risk of killing beneficial insects and negating years of IPM practices in orchards. Such crisis situations can challenge the survival of IPM. Carefully thought-out plans to mitigate such risks should be in place before the problem arises. Much will also depend on the industry and university researchers to deploy effective IPM-oriented tools in the event of such pest outbreaks in the future.

Web-based technologies can bring IPM to a new level of effectiveness and collaboration. The northeast is leading this effort but will require seamless cooperation among states and improved collaboration. The rapidly growing organic sector, demand for local produce, the increasing interest in community supported agriculture, and the growing nontraditional farming operations managed by women and immigrant minority populations will require new IPM research and outreach to match the needs of these farms.

Federal programs to support funding for conservation incentives are mainly administered by USDA/NRCS. Better rapport between NRCS officials at the state level and the respective IPM coordinators will be useful to enhance this process. Organizational differences as well as factors that affect state- and local-level decision making were considered by IPM coordinators as obstacles for consistent IPM programming efforts through NRCS.

Integrated pest management priorities in the northeastern United States have been dynamic, and their implementation experienced varying trends during recent years. The major driving force appears to be profitability at all levels, including institutional-level expectations to remain competitive at the programmer-level and grower/consumer-level expectations to remain competitive at the market-level. The broader scope and purpose of IPM could be lost under such circumstances. Devising a mechanism to rectify such conflicting forces can be challenging yet fruitful in the long term. A successful IPM approach not only requires a knowledgeable practitioner, but it also requires an informed consumer (Govindasamy et al. 1998). Consumers choosing IPM-utilized products are a powerful market incentive for practitioners to adopt more IPM. Consumer education from formal public school instruction to adult education will result in positive feedback to our farmers who practice IPM. In addition, informed citizens will be more responsive in the political arena when issues of environmental protection and human health share commonalities with IPM. The pesticide industry will also play a crucial role in successful IPM implementation in the future.

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Chapter 4
Emerging Issues in Integrated Pest Management Implementation and Adoption in the North Central USA

Thomas W. Sappington

Contents

Abstract There is a long tradition of integrated pest management (IPM) in the North Central region of the USA. IPM is difficult to define precisely, and it means different things to different people. But in general it is a philosophy based on multiple tactics to prevent a population from building up to unacceptable damaging levels. If preventive tactics are determined or projected to be inadequate, then a rescue tactic is applied. There are a number of constraints on adoption of IPM by growers. The growth in farm size has put a premium on efficiency, whereas IPM can demand extra effort and time on the part of the grower. The introduction of Bt

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corn and glyphosate-resistant crops have fit right in with a grower's desire to be more efficient, and in many respects these transgenic tools are highly compatible with IPM strategies. For example, Bt corn is often looked upon as a glorified form of host plant resistance, which is true in many respects. But there are also some differences when looked at in an IPM implementation context. The big issue confronting many North Central growers is that overuse of transgenic products has led to problems with weed and insect resistance in some key pests. To illustrate many of the issues involved, two contrasting case studies of insect pests of corn are presented. Area-wide suppression of the European corn borer by lepidopteran active Bt corn has been a spectacular success story, and so far resistance has not developed despite continuing high selection pressure. In contrast, the other major insect pest of corn, the western corn rootworm, has developed field resistance to Cry3Bb1 Bt corn. Though not yet present in all areas of the North Central states, the problem seems to be spreading geographically. In response, many entomologists are calling for a return to IPM in an effort to manage the fallout, slow the spread, and prevent resistance developing in other traits or pyramids containing Cry3Bb1. But a common reaction so far has been to layer multiple chemical insecticide tactics on top of Bt-traited corn. This "kitchen sink" approach is going to be a challenge to curtail, given the current high commodity price of corn and growers' heightened desire to protect yield.

Keywords Integrated pest management · Insect resistance management · Transgenic crops · Corn · Soybeans · European corn borer · Western corn rootworm · Bt resistance · Herbicide resistant weeds

4.1 Introduction

The North Central region of the USA, also called the Midwest, comprises an area running from roughly the foot of the Rocky Mountains in the west (~105° longitude) to the Appalachian Mountains in the east, and from the border with Canada in the north to about 38° latitude in the South. Annual rainfall is generally abundant and reliable in the east, but declines gradually toward the west, with a reciprocal increase in row crops being grown under center-pivot irrigation. A number of agricultural crops are produced in the North Central region, including corn, soybeans, alfalfa, wheat, sugar beets, potatoes, sorghum, sunflowers, vegetables, fruits, and more. However, much of the region is dominated by corn and soybean production, and it is often referred to as the Corn Belt. The last 10–15 years have been a time of dramatic changes in pest management methods and economic drivers in corn and soybean systems in particular. Given the ongoing uncertainty and fluidity of responses of the corn and soybean agricultural community to these changes, along with the overwhelming dominance of corn and soybean cropping systems in much of the Midwest landscape, this chapter will focus mainly on these two crops.

Integrated Pest Management (IPM) is a paradigm accepted by almost all professionals, including those in academia, government, industry, and independent consulting businesses, tasked with providing solutions, guidance, or advice to growers on how to manage pests attacking their crops (Hammond et al. 2006; Zalucki et al. 2009). But IPM means different things to different people. There are many, many definitions of IPM (Kogan 1998; Buhler et al. 2000; Hammond et al. 2006; Gray 2011), which are not all simply different ways of saying the same thing. The array of definitions reflects in part the wide-range of attitudes and expectations for IPM as a philosophy and practice, which depend on the focus, orientation, goals, and interests (sometimes conflicting) of various proponents or practitioners (Zalucki et al. 2009) . It is also a reflection of how difficult it can be to synthesize a particular set of goals into a concise, easily digestible, meaningful statement. Most definitions of IPM, in a cropping system context, tend to reflect an overarching goal to manage pest populations (mainly insects, weeds, and pathogens) in a way that is effective in protecting the crop but with as little negative input and disruption to the environment as possible. Application of chemical pesticides to protect a crop, despite their relative ease of use and efficacy in killing the target pests, can cause serious problems for the grower, the environment, and society if overused or used unwisely (Gray and Steffey 2007). These effects—e.g., pest resistance, secondary pest release or resurgence, destruction or sub-lethal effects on non-target organisms, residues on foods, contamination of water (Gray and Steffey 2007)—are well-known and acknowledged by almost everyone, including (and maybe especially) growers, and most agree in principle it would be ideal if the need for chemical input for crop protection could be reduced somehow. This is particularly relevant to the Corn Belt, where pesticide detection in waterways is especially high (Hamerschlag 2007). Hence, the goal of IPM implementation in most people's minds, as encapsulated by Castle and Naranjo (2009), boils down to 'spray as little as you possibly can'.

The best combination of tactics for realizing the overarching goal of IPM on a particular real-world farm is situation dependent. The generalized strategy of achieving IPM is first to avoid pest populations of damaging proportions through tactics such as enhancement of natural controls, host plant resistance, and cultural practices (such as tillage, rotation). If these preventive tactics are observed or projected to be inadequate, therapeutic (curative, rescue) measures are taken to quickly suppress the pest population, usually via the use of a pesticide (Pedigo 1994; Kogan 1998). Thus, IPM philosophy promotes the use of multiple tactics for pest population avoidance or suppression, with use of chemical pesticides only when needed and only when other methods are not projected to do an adequate job of controlling the pest at a reasonable cost under given circumstances (Kogan 1998; WSSA 2012a). Furthermore, IPM philosophy recognizes that the optimal choice of management options in a given situation depends on a thorough knowledge of the biology and ecology of the pest involved, including its life history, population dynamics, and the form and consequences of its interactions with other components of its environment (Kogan 1998; Frisvold and Reeves 2010). Relevant knowledge will be any that facilitates accurate predictions of the impact of the pest population on the crop in a given field, including background knowledge of the organisms involved along with real-time assessment of pest population status, and prediction of the consequences of implementing any contemplated management option. It is obvious that effective implementation of IPM is heavily knowledge-dependent (Heinemann et al. 1992; Pedigo 2007; Castle and Naranjo 2009), and the potential factors worthy of knowledgeable consideration when making a management decision are never ending, leading quickly to complexities of daunting proportions. The art of IPM is to reduce the complexity of decision making to workable dimensions by identifying and focusing on key essentials for the situation at hand.

Implementation of IPM ultimately resides with the grower (Buhler et al. 2000; Cullen et al. 2008; Zalucki et al. 2009), and the grower has many motivations that militate against embracing complexity in management decisions. The grower always wants to get a decision right, in terms of it being the most cost-effective while minimizing economic risk (Zalucki et al. 2009). But in reality, he/she usually has limited time and resources to throw into obtaining the information necessary to ensure an optimal decision. Whether implied or explicit, most definitions of IPM recognize that the methods used, the decisions made, and the results achieved must be economically viable for the grower in the short-term. Otherwise, the grower will not be around to reap the benefits of long-term strategies (Sanyal et al. 2008). This central constraint is enshrined in the concepts of "Economic Damage", "Economic Injury Level", and "Economic Threshold", cornerstones of assessing the need and timing of actions to reduce a pest population, usually by chemical treatment, before the cost of the action becomes greater than the value of the crop lost if no action is taken (Stern et al. 1959; Pedigo 1994, 2007). Implementation of IPM requires effort and potential input costs on the part of the grower, as well as the acceptance of economic risk and uncertainty that comes with decisions made while juggling a multitude of complexities. The motivation to simplify and/or reduce the risk of economic loss by sticking with conventional, fast-acting, "proven" tactics like chemical treatment is often very strong (Hammond et al. 2006).

4.2 Research and Development of Integrated Pest Management Systems in the North Central States

Key roles of researchers devoted to IPM are to obtain the thorough background knowledge about the key pests of a particular cropping system necessary to develop management options, and to develop reliable, inexpensive, user-friendly sampling procedures to assess the current demographic status and trajectory of a pest population (Pedigo 1994). The said knowledge of the pest and the ability to predict population trajectories must include background and real-time knowledge of other pests of all classes attacking the crop, beneficial organisms impacting populations of the primary and secondary pests, the crop itself, and how they all interact. Such a task is too big of course for any one person to tackle, so scientists tend to specialize on one aspect of this tangled web or another. This compartmentalization by specialty is unavoidable, and has been necessary to achieve the great progress over the last several decades in developing background knowledge and population assessment/

prediction methodology for a large number of pests in various cropping systems. The great challenge is merging this knowledge and methodology into a robust, integrated (the "I" in IPM) strategy of pest management for a given crop that is attractive to and easily implemented by a grower (Castle and Naranjo 2009).

4.2.1 Education

During decision-making, the grower is thinking holistically, because he/she is managing the entire farm at once and must make timely decisions on all aspects of crop production, each of which has ripple effects on other aspects of the operation (Heinemann et al. 1992; Long 2006). Growers operate in a milieu characterized by integrated decision making, and most naturally understand and appreciate the philosophy of Integrated Pest Management—but to embrace an IPM-inspired methodology, it must be reliable (not too risky), cost-effective, and time-effective. Extension scientists have the difficult but rewarding role of translating the basic knowledge and methodology developed by themselves and other non-extension scientists into a form that is practical and relevant to the grower. Conversely, their contact with growers and intimate knowledge of their concerns and constraints help alert other researchers to the knowledge gaps that are in need of filling, and serves to keep research grounded in the realm of realistic future application.

Up to now, most IPM-based options for growers have been developed separately by class—entomology, weed science, plant pathology—and by pest species within a class (Kogan 1998). Ehler (2006) points out that this approach constrains implementation of IPM because it does not provide integration across classes. While true in a narrow sense, this lack of integration across disciplines is not due to lack of interest, but to the complexity and intractability of the task itself. In my experience, extension scientists in the North Central states are extremely knowledgeable about the entire farm operation, and strive diligently to make recommendations on a holistic basis. Frequent encounters with farmer groups in Q&A sessions simply do not allow them to make their recommendations in a completely compartmentalized way. Those of us non-extension scientists who specialize in a discipline, such as entomology, are regularly reminded of the larger constraints and needs of the grower at technical meetings where we gather to share research results and exchange ideas. The desire to integrate pest management across disciplines is nearly universal, and is reflected in the 2009 launch of a Doctor of Plant Health (DPH) graduate program at the University of Nebraska (http://dph.unl.edu/) (Hein and McGovern 2010). The DPH program is designed to parallel other health practitioner degrees such as the MD or DVM, where the goal is to prevent, diagnose, and manage health problems. In the case of DPH, the patient is the crop. Perhaps caring for the patient is another way of describing the goal of IPM? The DPH curriculum includes coursework in plant pathology, entomology, weed science, plant science, and soil science, as well as internships, diagnostic training, and research methodology practicum.

In turn, extension scientists in the North Central states have been promoting and explaining the principles and advantages of IPM, and the types of management practices consistent with IPM, to the grower and society for many years. Many, perhaps most, growers in the Corn Belt are college educated, and the professors teaching courses in agronomy, entomology, weed science, and plant pathology over the last 35 years have almost all stressed, and continue to stress, the importance and value of an IPM approach in dealing with pests (Kogan 1998). Consequently, there are few farmers indeed who are not at least rudimentarily familiar with IPM as the ideal.

Specifics of current pest management recommendations are available from extension scientists through an array of avenues. Large budget cuts to universities in the North Central region over the last several years have hit most extension programs hard, reducing the ability for fewer and fewer professionals to meet with growers face to face. The response has been an accelerated turn to electronic media to provide timely information to growers. Most universities provide updated literature on pest management through documents available on their extension websites, with links to relevant publications in other states imparting added value. In addition, pod casts, training videos, webinars, and use of social media such as Twitter and Facebook are now commonplace methods of communication and extension outreach at most universities. The array of information available is impressive, ranging from basic biology and ecology of pest and beneficial organisms, to scouting procedures and treatment thresholds, to pest identification guides, to control options and their proper timing, and much more. A survey in Iowa indicated that the primary source of information on corn and soybean production for >90% of growers is from private-sector crop advisors, and that >80% of the crop advisors receive their information from Iowa State University. This reflects the effectiveness of the university's long-held philosophy of training the trainer (Wintersteen 2007).

4.2.2 Grower Adoption

Serious pest management challenges that have arisen recently in the North Central region, such as development of western corn rootworm, *Diabrotica virgifera virgifera*, resistance to transgenic Bt corn (Gassmann et al. 2011, 2012; Gassmann 2012; Gray 2012) and development of weed resistance to glyphosate (Legleiter and Bradley 2008; Green and Owen 2011; Tranel et al. 2011), now confront growers relying on simplified management strategies made possible over the last decade and a half by biotech crops. As a result, there is a growing dismay at the apparent abandonment of IPM practices, and a rising call for growers and consultants to return to IPM basics (Gray and Steffey 2007; Gray 2011; Steffey and Gray 2008; Gassmann 2012; Porter et al. 2012). For example, the confirmation of field resistance in western corn rootworm to corn expressing the Cry3Bb1 Bt toxin (Gassmann et al. 2011) has led to a widespread increase in use of soil and aerial insecticides layered on top of Bt-traited corn, even in locations where Bt resistance has not been observed (see Sect. 4.3.5.2). This led to an open letter to EPA from 22 corn entomologists (Porter et al. 2012) indicating that in their best judgment field resistance in the rootworm is real (it was being denied or downplayed in some quarters), and that an IPM approach is needed to slow its spread and to slow evolution of resistance to this (in new locations) and other Bt toxins.

4.2.2.1 Scouting and Consultants

In addition to university sources, many growers obtain information and advice from seed dealers and custom applicators. Complimentary scouting and recommendations are often offered as part of a bundled package of other products and services (Hammond et al. 2006). This can be a valuable resource for the grower, and facilitates IPM-compatible decisions by providing real-time information on pest incidence and abundance in the grower's fields. A potential problem, however, is the conflict of interest inherent in such a relationship where recommended pest control actions are provided by an agribusiness that profits from recommendations to treat (Ehler and Bottrell 2000). Offsetting this bias to some extent, is that the agribusiness must keep the customer satisfied, and questionable advice to treat may backfire with the loss of the customer's future business. For the same reason, however, the approach of the agribusiness consultant may be conservative, to avoid the risk of crop loss due to a decision not to control a pest (Czapar et al. 1997; Hammond et al. 2006). The potential conflict of interest is not lost on the grower (Long 2006). Less than a third of Wisconsin growers surveyed indicated complementary scouting influenced their decision to hire a custom applicator of herbicides (Hammond et al. 2006). Another recent survey asked Wisconsin farmers whom they would like to conduct rootworm scouting on their farm: preferences were for self (or family), university extension agent, independent consultant, or Co-op agronomist, while representatives of pesticide or seed companies ranked among the least preferred (Cullen et al. 2008).

Independent crop consulting services provide a means for the grower to monitor crop pests and beneficial insects via trained objective observers, who are committed to providing recommendations based on the best interests of the grower (Bechinski 1994; Jones 2007). Such services often explicitly espouse a commitment to the principles of IPM, and are common in the North Central states: for example, a quick internet search for independent services providing pest scouting revealed 29 in Iowa, 73 in Nebraska, and 30 in Wisconsin. These services vary in size from an individual to those with several regional offices and customers in more than one state. Although the majority of farmers probably do not contract with independent consultants, the fact that such enterprises continue to flourish in the North Central region indicates a recognized need by many farmers of the value of obtaining help in monitoring in-season status of pests and in integrating pest management with their entire farming operation.

4.2.2.2 Practicalities Affecting Implementation

In response to the criticism of reliance on the biotech crop “silver bullet” approach to pest management, it is increasingly common to hear the claim that IPM was never really adopted much by growers in row crops of the North Central region in the past anyway (Onstad et al. 2011). There is some validity to this claim if what is meant by IPM is integrated management across classes of pests, across multiple pests within a class, and use of biocontrol agents (Ehler 2006). However, IPM adoption is not an all or nothing binary choice, but instead takes place along a continuum of choices (Kogan 1998; Hollingsworth and Coli 2001; Cullen et al. 2008; Puente et al. 2011). For example, most growers adopt weed and insect IPM components more readily than community-level or ecosystem-level components (Puente et al. 2011). Components of the IPM philosophy historically have been adopted to greater or lesser degree, mainly in the following ways: avoiding damaging pest populations using cultural methods and host plant resistance when appropriate; using insecticide only when necessary based on scouting for insect pest (or damage) incidence and pest abundance; using models to project pest development and population trends; using more selective chemistries when possible; rotating chemistries to avoid resistance development; and careful targeting, timing, and placement of treatments to limit negative impact on natural enemies (Heinemann et al. 1992; Cullen et al. 2008; Castle and Naranjo 2009). Though the approach to management of pests by the vast majority farmers in the North Central region cannot be described as “complete IPM”, the benefits of lower-level adoption are not trivial.

Nor is even a partial, low-level adoption of IPM a trivial undertaking by the grower and it should not be disparaged. There are a number of difficulties and constraints commonly faced by a grower in implementing IPM-compatible tactics. In general, applying an IPM tactic or strategy requires sufficient background and real-time knowledge of pest demography and implementation procedures, which may be out of reach or intimidating for a grower (Castle and Naranjo 2009). In some instances, sampling schemes may be too complicated or expensive even for a consultant to employ, making use of economic thresholds and injury levels impractical (Ehler and Bottrell 2000). Use of thresholds are particularly problematic for weed pests because of the difficulty in reliably estimating density (Swanton et al. 1999; Buhler et al. 2000), a psychological concern for crop appearance (Czapar et al. 1997, Swanton et al. 2008), the necessity of dealing with multiple weed species (Sanyal et al. 2008), and the dynamic nature of thresholds because they depend on relative phenologies of both the weed and the crop (Swanton et al. 2008).

The trend of increasing farm size and the amount of hectares that must be managed has put a premium on efficiency, and growers are looking for ways to simplify operations, not complicate them (Ehler 2006; Gray 2006; Green and Owen 2011). Thus, the time required to implement an IPM strategy is a serious consideration for a grower (Fernandez-Cornejo et al. 2002; Hammond et al. 2006; Cullen et al. 2008; Sanyal et al. 2008). The constraint of efficiency can be mitigated by hiring crop consultants to undertake time-consuming tasks such as pest monitoring (see Sect. 4.2.2.1). But the added monetary outlay can be an obstacle, and willingness to hire a consultant will depend on the grower's assessment of cost-effectiveness, perceived financial risk of doing nothing, and cash flow (Hammond et al. 2006; Cullen et al. 2008). The survey by Hammond et al. (2006), revealed that the degree to which Wisconsin farmers practiced IPM was greater among cash-grain than dairy operations, and increased with increasing farm size. The latter pattern may reflect the greater resources available to larger farmers through economies of scale, and perhaps a greater emphasis on economic optimization of pest management (Hammond et al. 2006).

Adoption of alternative tactics, such as pesticide rotation/diversification or using an insecticide with greater selectivity, will meet with grower reluctance if the grower is not convinced it will improve, or at least not harm, profitability. This is especially true if the new method complicates his/her crop-production practices, if it depends on precise timing for effectiveness, or if there is any doubt about efficacy (Swanton et al. 2008; Castle and Naranjo 2009; Green and Owen 2011). Translating concern for preserving natural enemies or a philosophical desire to employ other biologically-based approaches from feel-good platitudes into a foregoing of or change in insecticide use, depends on a fair certainty of their ability to satisfactorily impact the pest populations of concern, a certainty that is seldom established or that is not trusted by the grower (Hollingsworth and Coli 2001; Cullen et al. 2008; Zalucki et al. 2009).

4.3 Transgenic Crops: Everything Changes (Except for Some Things)

The introduction of transgenic corn and soybeans has revolutionized the way both insect and weed pests are being managed in the North Central USA (Duke 2011; Frisvold and Reeves 2011). The ongoing trend of consolidation of acreage into larger and larger farms has increased the desire of growers to have simple, effective pest control options because of the tight time-windows large acreages impose on in-season management (Green and Owen 2011; Green 2012). In the past, application of chemical pesticides filled this role because they were the simplest, fastest-acting pest control option available to the grower (Pilcher and Rice 1998). Now transgenic crops fulfill this role for many pests. Bt corn and glyphosate resistant soybeans and corn are highly effective in managing certain key pests, and have simplified management considerably. Bt corn allowed high-level control of destructive insect pests previously difficult to manage, and because it represented a prophylactic pest avoidance tactic, it did not require the time or expense of scouting (Pilcher and Rice 1998). In an early survey, growers saw the biggest advantage to the advent of these technologies as a way to reduce insecticide input into the environment (41 %) and exposure of farm workers (21 %), while increased yield was most important to only 20 % of respondents (Pilcher and Rice 1998). Although simplification of operations was not one of their choices in the survey, the results do show that yield is not the lone consideration of a farmer—quality of life matters too.

Transgenic herbicide-resistant (primarily glyphosate) soybeans were even more rapidly adopted than Bt corn, again because of the simplification of weed management made possible by this technology (Dill et al. 2008; Frisvold and Reeves 2010; Duke 2011; Green and Owen 2011; Green 2012). The option of a single herbicide with broad-spectrum activity on basically all weed species, yet with no damaging effects on the crop plants, was a boon beyond measure to growers with little time to spare for weed management (Duke 2011; Green 2012). More recently, adoption of transgenic glyphosate-resistant corn has become common, simplifying weed management in that crop as well, and thus for the entire production system if it is a corn-soybean system typical of the North Central region (Hurley et al. 2009; Duke 2011).

In the North Central region, the percent hectarage of corn treated with insecticides and the amount of active ingredient applied per treated hectare did not change much between 1996, when European corn borer targeting Bt-corn was first commercialized, and 2005 (Fig. 4.2). This lack of change probably reflects the general lack of attempts by growers to control this pest with conventional insecticides, despite chronic yield losses, due to the difficulties involved in proper timing to ensure efficacy (see Sect. 4.3.5.1). However, a large decrease in insecticide use in corn is evident from 2005 to 2010, probably due to the introduction of very effective rootworm-targeting Bt varieties beginning in 2003. Farmers in the North Central region growing continuous (i.e., non-rotated) corn cannot ignore this ubiquitous and damaging pest without risking grievous losses, and before the adoption of Bt corn that could provide protection, soil insecticides were routinely applied at planting, usually prophylactically (see Sect. 4.3.5.2). Bt varieties targeting corn rootworms provided such good protection that soil insecticides could be safely abandoned. Almost all cornfields must be protected against weeds, and the percent corn hectarage treated with herbicides has not declined from consistently high levels since the introduction of glyphosate-resistant varieties (Fig. 4.1). However, the amount of herbicide active ingredient applied per treated hectare declined substantially through 2005 (Fig. 4.2). It increased some between 2005 and 2010, perhaps reflecting increasing pressure from weeds that have become resistant to glyphosate, but it is still much reduced compared to pre-transgenic days.

Silver bullets have come and gone in the past, most spectacularly the use of cyclodienes and other organochlorine insecticides to control insect pests in row crops. First reactions to the development of these insecticides back in the 1940s and 50s were almost giddy, because insect scourges could now be suppressed easily, quickly, and cheaply. But resistant pests developed within only a few years (Siegfried et al. 2007; Pittendrigh et al. 2008), and these chemistries were very hard on non-target organisms, including vertebrates. The introduction of IPM as a more rational approach to crop protection (Stern et al. 1959) , was largely an outgrowth of this situation (Kogan 1998). The quick embrace of transgenic crops in the late 1990s and early 2000s was reminiscent of the quick embrace of organochlorines in that earlier era (Obrycki et al. 2001). But this time it was different, because Bt toxins have a narrow spectrum of activity and Bt corn has little or no negative impact on beneficial or nontarget organisms (Marvier et al. 2007; Lövei et al. 2009), although some natural enemy populations may decrease in response to decreased prey den-

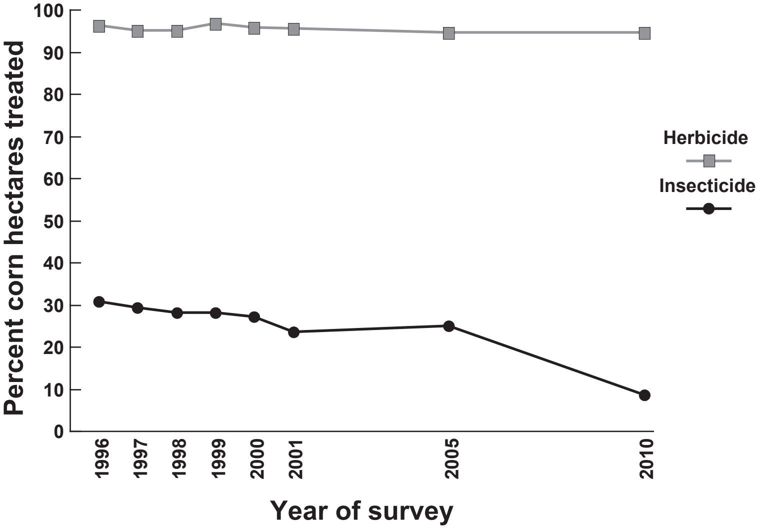

Fig. 4.1 Trends in percent of corn hectares treated with herbicide or insecticide in the North Central region of the USA. (Data based on USDA Agricultural Resource Management Surveys from the USDA Economic Research Service website http://www.ers.usda.gov/data-products/arms-farm-financial-and-crop-production-practices/tailored-reports.aspx, updated Nov 27, 2012. Data for the USDA Farm Production Regions of the Corn Belt (Iowa, Missouri, Illinois, Indiana, Ohio), Northern Plains (North Dakota, South Dakota, Nebraska, Kansas), and Great Lakes States (Minnesota, Wisconsin, Michigan) were weighted by total corn hectares planted in each and summed to represent the North Central region.)

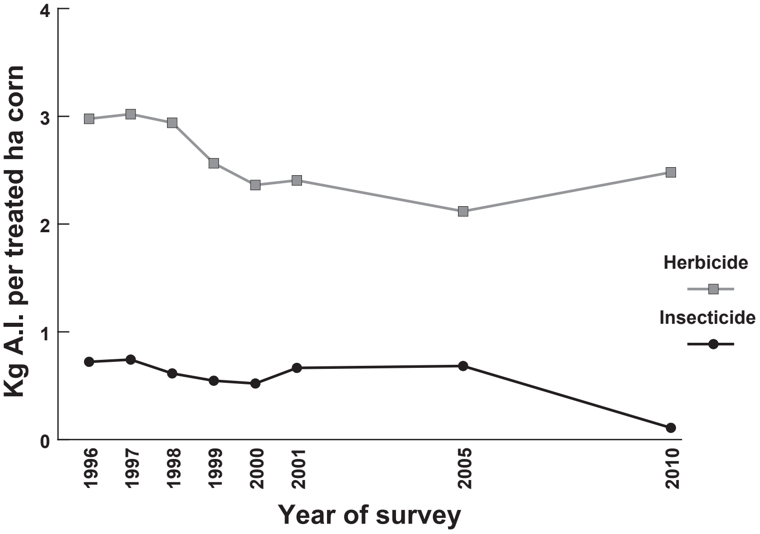

Fig. 4.2 Trends in kg of active ingredient (A.I.) per hectare of corn treated with herbicide or insecticide in the North Central region of the USA. (Data from same sources, and compiled in the same manner as described for Fig. 4.1.)

sity (Lundgren et al. 2009c). And herbicide resistant crops allowed a near total shift to use of glyphosate, making adoption of conservation tillage much more practical (Frisvold and Reeves 2010, Duke 2011).

4.3.1 The Threat of Resistance Development in the Pest

So it was different—but then it was not different. As with previous silver bullet tactics, the shadow hanging over transgenic crops, like a shoe waiting to drop, has been that pests have a maddening way of evolving resistance to control tactics. And the fastest way to induce resistance in a pest population is to hit it over and over again with the same mortality factor (Frisvold and Reeves 2010; Duke 2011; Green and Owen 2011). Glyphosate-resistant weeds, and resistance to certain Bt toxins have begun to emerge among some pests. Early cautions came aplenty from the academic community that growers should continue attacking pests with a variety of tactics to slow the development of resistance (Kogan 1998). Corn Belt growers themselves recognized that the likelihood of resistance developing to Bt crops was high and that it was an unfavorable outcome worth taking proactive steps to avoid (Pilcher and Rice 1998). Resistance of weeds to conventional herbicides was becoming an increasingly difficult problem for growers to overcome (Duke 2011), so they were not oblivious to the threat to glyphosate. But their acute and growing problem of weed resistance to the old herbicides made them even more receptive to adopting the new technology as a lone tool.

The U.S. Environmental Protection Agency (EPA) saw the promised reduction of insecticide input into the environment made possible by Bt crops as an important development for the well-being of the American public (EPA 1998; Glaser and Matten 2003; Tabashnik and Gould 2012). In consequence, it imposed an obligation on companies registering crops with plant-incorporated protectants to require implementation of insect resistance management (IRM) plans by purchasers of their seed. The goal was to prevent the premature loss of this environmentally-friendly technology through overuse and the resulting development of pest resistance. EPA does not impose IRM on other pesticides or herbicide-resistant transgenic crops in part because it has no philosophical interest in prolonging or increasing pesticide input into the environment, but there are other reasons as well (see Frisvold and Reeves 2010). From the farmer's perspective, IRM for Bt corn has meant planting a prescribed minimum percentage of their hectares (20 % in the North Central region) to non-Bt corn. Although rotation or diversification of control tactics to slow evolution of pest resistance is one of the fundamental tenets of an IPM approach (Onstad 2008; Frisvold and Reeves 2011), this has not been a formal part of EPA-prescribed IRM strategies for Bt corn to this point.

IRM is logically a component under the umbrella of IPM (McGaughey and Whalon 1992; Onstad 2008; Frisvold and Reeves 2010; Onstad et al. 2011). A natural source of tension between the two, however, is in their time horizons. IPM is generally about short- to medium-term management goals on a farm, often focused on one or two growing seasons, while IRM is implemented with a view to the long-term maintenance of a management tool for the benefit of the entire farming community (Glaser and Matten 2003; Frisvold and Reeves 2011). Some farmers have been disillusioned by the appearance of an insect pest population resistant to Bt on their farm despite following all the IRM rules. It is especially galling when they know a neighbor has been less diligent, and reaped greater short-term profits because of their choice not to cooperate. The problem is the high mobility of insect pests, which can result in fast spread of resistance from a distant location. Growers are more accustomed to dealing with weed resistance, where preventive measures taken in their fields can have a direct impact on the time it takes for resistance to manifest on their farm (Frisvold and Reeves 2011). Resistance in weeds can spread of course through seeds (Llewellyn and Pannell 2009), but distances and rate tend to be lower than that of insects, and the seed bank ensures that susceptible weeds will make up part of the population in a field for several years (Buhler et al. 2000). Expecting that planting a Bt refuge protects that field from resistant insects is unrealistic, but the foiled expectation may harm IRM efforts and credibility in the future.

4.3.2 Factors Conspiring Against Multi-tactic IPM Implementation

The unparalleled control and simplicity of transgenic crops have largely replaced the more complicated IPM-compatible multi-tactic strategies of the not-so-distant past. Additional, sociological factors have further accelerated this change in paradigm (Gray and Steffey 2007; Gray and Onstad 2008) . The new market for corn as a biofuel crop has helped spur a significant rise in corn prices. With increased corn prices, more hectares are being planted to corn, increasing the number of fields no longer being rotated to soybeans. Thus soybean prices have risen as well in response to the drop in supply. As crop value rises, the economic injury level for any pest attacking that crop is lowered—less damage is necessary to justify spending more to protect yield (Pedigo 1994, 2007; Tollefson 2008). This has led to what M. E. Gray refers to as an insurance mentality in protecting the crop, or “Insurance Pest Management” instead of “Integrated Pest Management” (Gray 2011). The realized value of a prophylactic measure taken to protect a crop from a certain pest, like planting a Bt variety, depends on the realized pest pressure in-season. But if the pressure is perceived or projected to be likely, based on experience, the grower accepts a known cost of protection up front in the form of the technology fee paid for transgenic seed, to avoid the risk of greater costs later—this is the nature of insurance. Even if scouting for the pest followed by a rescue treatment makes it possible to avoid greater costs and reap the benefit of increased profit in years of low pest pressure, the prophylactic tactic is simpler and time efficient, by itself of intangible value to a grower. The grower’s tolerance of risk influences willingness to forgo the planting of transgenic seed. In the case of weeds, which require management every year because of the presence of the seed bank in the soil (Buhler et al. 2000), purchase of herbicide tolerant varieties reflects more the adoption of a glyphosate-based system than an insurance mentality.

4.3.3 Bt Corn: Glorified Host Plant Resistance?

Although the switch to an insurance pest management mentality for insects is evident, the use of prophylactic measures to avoid pest presence or build-up is not necessarily incompatible with IPM in itself (WSSA 2012a). For example, conventional host plant resistance to an insect or plant pathogen is essentially a prophylactic tactic, because resistant seed is purchased and planted in advance of in-season knowledge of pest abundance (Gould 1998). But it has long been a respected and valued IPM tool for avoiding insect pests, because it eliminates or reduces the need for in-season therapeutic insecticide treatments (Pedigo 1994; Teetes 2007). Many look upon transgenic insect protection as simply a glorified form of host plant resistance, but with the genetic protection introduced through biotechnological means rather than through conventional sexual breeding (Gould 1998; Teetes 2007; Gray 2011; Onstad et al. 2011). Modeling suggests that the optimal strategy for a grower may be to plant Bt corn prophylactically, rather than based on a threshold (Crowder et al. 2006).

In many fundamental respects, transgenic and conventional host plant resistance are the same, but in a practical IPM context they differ in some important ways. Growers can usually purchase resistant cultivars at little or no extra cost compared to susceptible varieties (Teetes 2007). In the case of transgenic crops, growers pay a significant premium, or technology fee, for the trait which must be factored into the value of the protection it provides (Hyde et al. 1999). Both types of resistant crop are highly compatible with other components of an IPM program, such as biological control or cultural tactics like crop rotation (Teetes 2007) . However, a Bt crop tends to differ in the very high level of protection it affords against the target pest, making other components of IPM against that pest seem superfluous—i.e., its effectiveness leaves nothing to integrate. Conventional resistance is usually species-specific. While not as broad-spectrum as most insecticides, Bt crops often have activity or partial activity against other phylogenetically-related pests. This is usually considered a bonus, because the plant is protected against damage from an array of secondary pests that by themselves normally would not warrant the cost of an insecticide treatment. The downside is the possibility of affecting phylogenetically-related species that are not pests. Though so far such effects have been nonexistent or negligible (Marvier et al. 2007; Lövei et al. 2009), the possibility still requires extensive testing of each new toxin before registration, something that has seldom been a concern for varieties with conventionally-derived host plant resistance (but see Dogramaci et al. 2005; Ballmann et al. 2012; Ghising et al. 2012).

4.3.4 Lessons from Conventional Host Plant Resistance

Nevertheless, the history of conventional host plant resistance as a management tool is instructive for managing transgenically-derived resistance traits (Gould 1998). For example, for many decades, wheat has been bred to produce varieties resistant to key pests such as aphids, *Schizaphis graminum*, and Hessian fly, *Mayetiola destructor* (Porter et al. 1997; Ratcliffe et al. 2000; Onstad and Knolhoff 2008).

The usual pattern is that a variety with a new pest-resistance gene provides protection for a few years until a new insect biotype evolves resistance, followed by release of cultivars with a newly developed resistance trait (Smith 1989; Porter et al. 2000). Soybeans in the North Central region historically have been relatively free of serious insect pests. This changed in 2000 with the introduction of the soybean aphid, *Aphis glycines*, from Asia, a pest that can cause serious damage (Ragsdale et al. 2011). IPM strategies including promotion of natural enemies and economic thresholds for therapeutic chemical treatment have been developed and are being implemented across the North Central region (Ragsdale et al. 2007, 2011). In addition, soybean varieties with very effective resistance to soybean aphids conferred by several *rag* genes have been developed, and are now an important part of the IPM toolbox against this pest (Hill et al. 2004, 2006; Wiarda et al. 2012). However, biotypes of resistant aphids have been reported in some North Central states (Kim et al. 2008; Hill et al. 2010, 2012; Michel et al. 2011). It is obvious that evolution of soybean aphid biotypes to defeat host plant resistance will be fast, and the need for more resistance genes is being felt already (Michel et al. 2011). The lesson is clear for the transgenic host plant resistance in corn we call Bt.

The kind of arms race that develops in the effort to stay ahead of Hessian fly and aphid biotypes that overcome host plant resistance is a type of "pest control treadmill". It is similar in principle to the "pesticide treadmill", where a new chemistry is used heavily until resistance evolves in the pest, followed by release of a new pesticide which takes the place of the old one (Kogan 1998; Buhler et al. 2000; Onstad 2008; WSSA 2012b). Essentially, a pest control treadmill is a type of coevolutionary arms race (Goeschl and Swanson 2001; Mitchell and Onstad 2008), but with humans directly manipulating the response on the domesticated plant side (genetics or toxin), while deploying the selection pressure on the pest side. Growers tend to accept such treadmills as a normal part of doing business, and, though inefficient from an objective point of view, it has been a viable strategy to date (Onstad 2008; Mitchell and Onstad 2008). Many assume it will be no different in the case of insect or weed resistance to transgenic crops (WSSA 2012c). But the difference now is that a transgenics treadmill will be much harder to sustain. Biotech crops take an exceptionally long time to develop and register—an average of 12 years for corn and 16 years for soybean from 2008–2012, with 5.5 years needed to proceed through the regulatory process alone (McDougall 2011; Fuglie et al. 2012). For weeds, the situation is even worse, because herbicides with new modes of action must be developed along with a complementary transgenic herbicide-resistant crop (Green 2012). There is not necessarily going to be an effective alternative trait always waiting in the wings when a popular transgenic tool begins to falter (Green and Owen 2011).

4.3.5 A Tale of Two Targets: Contrasting Cases of the Two Biggest Insect Pests of Corn

The two most costly insect pests of corn in the North Central region are the European corn borer, *Ostrinia nubilalis* (Lepidoptera: Crambidae), and the western corn rootworm, *Diabrotica virgifera virgifera* (Coleoptera: Chrysomelidae). Both species have life history characteristics that make them difficult to manage, and were the subjects of extensive IPM-inspired research for many years. They are now the main targets in the North Central region of transgenic Bt corn expressing genes for various Bt toxins. These toxins have a fairly narrow range of activity against some Lepidoptera (e.g., Cry1Ab, Cry1F) or Coleoptera (e.g., Cry3Bb1, Cry34/35Ab1, mCry3Aa), and are thus consistent with the IPM goal of selectivity (Rice 2004). Hybrids containing these or other Bt genes have been enthusiastically adopted by growers, beginning with commercial release of European corn borer-targeting Bt corn in 1996 (Pilcher and Rice 1998), and western corn rootworm-targeting Bt corn in 2003 (Vaughn et al. 2005).

The fates of these two systems have been quite different.

4.3.5.1 European Corn Borer

European corn borer was historically difficult to control with a therapeutic insecticide treatment, because of the need for accurate timing of insecticide treatments to ensure larval exposure before they tunneled into the stalk and were safe from any insecticide treatment (Heinemann et al. 1992; Mason et al. 1996). Economic thresholds were developed based on egg mass sampling, but sampling is labor intensive and even well-timed sprays provide only partial protection, sometimes requiring a second spray (Calvin et al. 1986; Bode and Calvin 1990; Sorenson et al. 1995; Mason et al. 1996). A novel strategy of adult control by sampling and treating aggregation areas in grassy field borders can be effective in protecting the field (Showers et al. 1980; Derrick and Showers 1991), but logistical constraints and the potential impact on nontarget organisms in the grass, despite evidence this was not a problem (Whitford and Showers 1987, 1988; Whitford et al. 1987), discouraged adoption.

Difficulties and risks that come with relying solely on chemical rescue treatments as a pest control strategy were strong incentives to develop pest avoidance tactics. Much research effort was put into improving pest avoidance options through use of biological agents, host-plant resistance, and cultural measures (Lewis et al. 2001; Ma and Subedi 2005). Good progress was made in breeding corn lines with resistance or tolerance to corn borer feeding (e.g., Barry et al. 1983; Guthrie et al. 1989), although no hybrid was immune from attack (Revilla et al. 2007). Biological control with predators, parasitoids and pathogens was extensively explored, and some agents showed promise (Bing and Lewis 1991; Hoffmann et al. 2002; Wright et al. 2002), but no routine method was adopted for implementation in a field corn IPM program in the USA mainly because of economic limitations. Nevertheless, natural infection by the microsporidian *Nosema pyrausta* has had a significant impact on damping corn borer population growth (Lewis et al. 2009), and generalist predators attacking egg masses may have the same effect (Phoopholo et al. 2001). Parasitoids have had some effect on European corn borer populations in the eastern U.S. (Sked and Calvin 2005), but seem not to have much impact in the Corn Belt (Andow et al. 1995; Phoopholo et al. 2001).

Crop rotation is not of direct value to European corn borer IPM programs, because adults emerging in the spring disperse from the natal field, often several or many km distant, before laying eggs in a different location (Reardon et al. 2006; Dorhout et al. 2008; Kim et al. 2011). Thus, the infestation of a given field is the result of egg-laying immigrants that emerged and flew in from somewhere else, so even the complete absence of an infestation in a field planted to soybeans one year has no effect on infestation levels in that field rotated to corn the next year. For the same reason, tilling corn stubble in the fall to kill overwintering larvae will not protect that field from infestation the following spring, despite the high mortality it imposes and a persistent belief among growers of its efficacy (Pilcher and Rice 1998). Because of female preference for taller corn in the spring generation and for pollinating corn in the summer generation (in two-generation regions), planting date can be manipulated to avoid relative attractiveness to ovipositing females during one or the other time window. But avoidance of one generation by planting early or late usually increases attractiveness to females of the other generation (Pilcher and Rice 2001). In the end, despite chronic losses to this ubiquitous pest, most farmers gave up trying to manage it beyond early harvest to minimize ear drop from tunneling in the ear shank, and employing irrelevant and ineffective tactics such as crop rotation and destroying crop residue (Rice and Ostlie 1997; Pilcher and Rice 1998).

The introduction of Bt corn targeting European corn borer suddenly made it possible for many growers to protect their fields from this pest. Efficacy is close to 100 % (Graeber et al. 1999; Archer et al. 2001; Ma and Subedi 2005), and many growers began to see for the first time just how much yield they had been losing every year to the corn borer (Pilcher et al. 2002). There has been no sign so far of European corn borer populations developing resistance to Bt corn. A possible reason is that alleles conferring resistance appear to be uncommon in natural populations, as indicated by several screening trials (Andow et al. 1998, 2000; Bourguet et al. 2003, 2005; Tabashnik et al. 2003; Stodola et al. 2006; Siegfried et al. 2007; Engels et al. 2010). Nevertheless, resistant laboratory strains have been selected (Chaufaux et al. 2001; Alves et al. 2006; Lopez et al. 2010a, b), and monitoring for field resistance continues. Secondly, the preventive high dose/refuge IRM strategy (Ostlie et al. 1997; Gould 1998; Andow and Ives 2002; Bourguet et al. 2005; Qiao et al. 2008; Tabashnik et al. 2009) required by EPA appears to have been successful in delaying resistance to the Cry1Ab Bt toxin in European corn borer (Tabashnik et al. 2003, 2008). The trend now is toward deploying a lower percentage of refuge in a seed mixture with Bt seed, with inherent trade-offs in possible, still unknown, effects on rate of resistance development (Onstad et al. 2011).

The continued effectiveness and high adoption of Bt corn in the North Central states has led to a documented areawide suppression of European corn borer populations (Hutchison et al. 2010). The level of suppression is such that even those growers who do not plant Bt corn now benefit more economically from the rarity of the pest in the landscape than those who pay a premium for the transgenic seed (Hutchison et al. 2010). Despite the rarity of the pest, and despite the technology fee paid for the trait, growers have shown a reluctance to reduce planting of corn borer targeting Bt corn (Gray 2011). This may reflect reductions in government crop insurance premiums for those planting Bt hybrids, risk aversion, and a growing shortage of high-yielding non-Bt corn hybrids (Gray 2011; Onstad et al. 2011). As long as resistance to Bt corn does not develop, continued planting of Bt corn with European corn borer targeting traits despite little or no pest pressure, while unnecessary, is not of itself a problem since there are virtually no negative environmental impacts. The concern, however, is that regional suppression substantially increases the risk of resistance evolution under continued selection pressure when density of the susceptible population drops below a certain threshold (Caprio 2001; Ives et al. 2011). In the North Central states, European corn borer populations are currently at historically low levels, but they are not on the immediate verge of disappearing. Relaxing selection pressure by planting non-Bt corn in the absence of significant pest pressure would clearly reduce risk of resistance.

4.3.5.2 Western Corn Rootworm

The western corn rootworm was originally an inhabitant of the Great Plains, but it began expanding its range eastward beginning in the mid 1940s and had crossed the Corn Belt by 1980 (Gray et al. 2009; Meinke et al. 2009). It has one generation per year and overwinters as a diapausing egg in the soil. Larvae feed on roots and are the main damaging stage, although adults in high densities during pollination can cause damage by feeding on silks. It has a narrow host range, including a few grasses, but its main host is corn (Oyediran et al. 2004). Because of its univoltinism and strong preference for corn, historically the western corn rootworm has not been a pest in first-year corn following rotation from soybeans or other crops. This is true also of the northern corn rootworm, *Diabrotica barberi*, which is also a serious pest through most of the Corn Belt and shares many life history traits in common with the western corn rootworm, except that it is not invasive. Thus, crop rotation is generally a very effective way of protecting corn from the rootworm complex. However, the western corn rootworm developed rotation resistance in east central Illinois in the 1990s (Levine et al. 2002; Gray et al. 2009; Miller et al. 2009), apparently through a loss in fidelity to cornfields for oviposition (Mabry and Spencer 2003). Rotation resistance subsequently spread to parts of surrounding states before stalling out in the mid 2000s (Gray et al. 2009). The northern corn rootworm also evolved rotation resistance, but by a different mechanism: extended diapause, where eggs remain in diapause for two or more years (Krysan et al. 1986; Levine et al. 1992; French et al. 2012). Although natural enemies of rootworms exist, there has been little success in enhancing population control in the USA (see Gray et al. 2009). However, the impact of predators on rootworm eggs and larvae seems to be greater than previously thought, and cultural management options for enhancing them are being explored (Lundgren et al. 2009a, b; Lundgren and Fergen 2010, 2011).

Many growers in the North Central region prefer to plant continuous corn for various reasons, and they must take other measures to protect their crop from this ubiquitous pest. Because it is a soil-inhabiting insect, it is especially difficult to monitor rootworm larval populations, making economic thresholds to guide decisions on rescue insecticide treatments impractical (Chandler et al. 2008). Instead, thresholds of adults were developed to guide decisions on soil insecticide treatment the following year (Pruess et al. 1974; Foster et al. 1982; Steffey et al. 1982; Stamm et al. 1985). Foster et al. (1986) found that use of a static economic threshold in this scheme was not always reliable, and their analysis led to the conclusion that a prophylactic soil insecticide in continuous corn was the optimal strategy, something most growers were doing anyway (Turpin 1977).

In Nebraska, western corn rootworm populations became resistant to organochlorine soil insecticides in the early 1960s (Ball and Weekman 1962). Earlier trials had shown that aerial sprays of adults seemed to be effective in reducing lodging the next year (Hill et al. 1948), and growers with resistant populations turned to this tactic. Later research confirmed that aerial sprays of rootworm adults could protect a field against rootworm damage, and economic thresholds of adults were developed (Pruess et al. 1974). By 1995, western corn rootworm populations in areas of Nebraska relying heavily on adult sprays had become resistant to carbamate and organophosphate insecticides (Meinke et al. 1998). An areawide program of adult control to suppress rootworm populations was begun in 1997 in 5 locations across the North Central states and Texas. The concept was to sample and treat adult populations over threshold with a semio-chemical bait containing a feeding stimulant and laced with carbaryl insecticide (Chandler 1998). Adult mortality from bait sprays was high, but the level of protection from larval damage this provided fields the next year was not dramatic and varied by location (French et al. 2007; Chandler et al. 2008). Nevertheless, it performed as well as prophylactic insecticide treatments and reduced insecticide input by up to 20-fold (Chandler et al. 2008). A potentially serious obstacle to implementation of such a program was detection of quickly developing resistance in the adults to both the feeding stimulant and the carbaryl within the areawide managed fields (Zhu et al. 2001; Siegfried et al. 2004).

Against this background of resistance evolution by western corn rootworm to a wide variety of control tactics, Bt corn expressing the Cry3Bb1 toxin was introduced in 2003, and was adopted quickly by growers. Rootworm Bt corn provided a number of significant benefits to growers including much better control of larvae than soil insecticides, and a simplification of the production system (Rice 2004). For example, growers could remove insecticide application equipment from the planter, which they did to an extent that manufacturers of planters made design changes reflecting that abandonment. The discontinuance of routine soil insecticide application raised the possibility of damage by other secondary and sporadic pests like wireworms and grubs (Rice 2004), but this has been addressed by applying seed treatments with neonicotinoids (imidacloprid, thiamethoxam, clothianidin) to provide systemic protection of the plant (Tiwari and Youngman 2011). All Bt corn seed sold in the USA is now treated with neonicotinoid insecticide, and has been for several years (Mullin et al. 2005; Magalhaes et al. 2007).

The IRM program mandated by EPA (EPA 2005) was very similar to that already in place for European corn borer, despite recommendations by a Scientific Advisory Panel to make the refuge size 50 % instead of 20 % (EPA 2002; Tabashnik and

Gould 2012) . The main reason for the panel's recommendation was that Cry3Bb1 is considered a low-moderate dose event, making the potential rate of evolution of resistance faster for rootworms than corn borers, and thus requiring a larger refuge to prolong its effectiveness (Tabashnik and Gould 2012). The more recently commercialized Bt varieties with different toxins (Cry 34/35Ab and mCry3A) also are not high-dose (Hibbard et al. 2010, 2011), so the same reasoning applies (Tabashnik and Gould 2012) . Presumably the decision to go with a 20 % refuge was based in part on a concern for farmer compliance with planting the mandated refuge. Refuge compliance is being removed from the table in the North Central states by a trend toward approval and marketing of seed mixtures of Bt and non-Bt, or refuge in the bag, which come with lower refuge requirements (5–10 %) (Onstad et al. 2011). The rationale for the 5 % refuges in seed mixtures is that they apply to pyramids of two different Cry toxins with presumed different modes of action, which should slow evolution of resistance (Zhao et al. 2003; Gould et al. 2006). Pyramids, however, are not as effective in delaying resistance if one of the toxins has already been partially compromised (e.g., Cry3Bb1), or even exposed to selection as a single trait (e.g., Cry34/35 and mCry3A) (Onstad and Meinke 2010; Frisvold and Reeves 2011; Porter et al. 2012; Tabashnik and Gould 2012).

Field resistance of western corn rootworm to Cry3Bb1 Bt corn was not long in coming, and has been confirmed in Iowa and Illinois (Gassmann et al. 2011; 2012, Gassmann 2012; Gray 2012), with several other states reporting damage that is likely from the same cause (Porter et al. 2012). Initial responses were muted, based on the assumption that it was only a few fields having problems. But as the problem became more widespread and farmer awareness grew, the question of how to advise growers—those with a problem, and those who wanted to prevent one in their fields—became acute. Messages have been mixed depending on the source, causing a great deal of confusion among growers, and there is an ongoing effort to come to agreement on a unified message among those advising them.

The academic community has been consistently urging a return to IPM basics, especially including not relying on a single control tactic year after year (Porter et al. 2012; Gassmann et al. 2012; Gassmann 2012). The majority of fields with confirmed resistance had been planted to continuous corn with the same Bt trait for three years or more (Gassmann et al. 2011). The first recommendation to growers is to reduce selection pressure for resistance by rotating to another crop, such as soybeans. Even in areas of previous rotation-resistance problems, the incidence of damage to first-year non-Bt corn has decreased, and seems to no longer be as much of an issue. The reason for the decline in rotation resistance frequency, as well as the stalling out of its initial spread from Illinois (Gray et al. 2009), is probably because of a proclivity of growers to plant rootworm Bt corn even in rotated fields, either to protect against the rotation resistant variant, or because of a lack of elite high-yielding non-Bt hybrids (Onstad et al. 2011; Porter et al. 2012). This practice would reduce the selective advantage to rotation resistant phenotypes in rotated fields, because mortality would be as high as among rotation susceptible phenotypes. So, in principle, rotation should be a good option in most of the North Central region. However, the current high commodity price of corn works against the viability of this option, because the incentive to grow more corn is very high. Even if a farmer is receptive to rotating, his/her landlord or banker may not allow it. Farmers who raise corn primarily to feed their own livestock also may not have the realistic option to rotate.

High commodity prices also work against IPM in another way. Growers are anxious to do everything they can to protect yield. A cornerstone of IPM is to diversify and use multiple control tactics, rotating the tactics to avoid constant selection pressure. In a perverse twist of fate, growers are receiving recommendations from several quarters to use multiple tactics, but all at once all the time. This "kitchen sink" approach is quickly becoming the new norm for western corn rootworm control. It involves a layering of redundant control tactics on top of one another to make up for any loss of control by the Bt toxin, even in locations where no loss of Bt corn efficacy has been observed. Thus, it is common now for a farmer to plant rootworm Bt seed coated with a neonicotinoid insecticide along with an in-furrow soil insecticide, followed later in the season by aerial insecticide applications for adult beetle control, all in the absence of scouting and thresholds to guide decisions. The substantial decline in insecticide use in corn from 2005 to 2010 in the North Central region (Fig. 4.2), one of the most important benefits of Bt corn to society, is undoubtedly on the way to being reversed in the new atmosphere of resistance and layered "insurance" treatments. The grower's anxiety to protect yield is often expressed as, "I can't afford not to treat". There are not as many chemical insecticides available today as in the past, and new ones are not being developed. The concern of course is that through massive overuse, we will burn through all the control tools we have.

Although industry is concerned about losing Bt products to resistance, their immediate concern is to suppress rootworm populations in their customers' fields. The grower buys a product and expects it to work. The closer an industry rep or consultant is to the grower, the greater the incentive to make input-heavy recommendations. Managing the population is the first concern, of both the grower and those who directly advise him/her. And with high commodity prices, the less inclined the grower will be to accept any risk of yield loss, the more receptive he/she will be to advice to spend a little more on "insurance" treatments. The impulse to layer a soil insecticide on top of Bt-trait protection was being encountered among some growers by public-sector entomologists as early as 2007, even before resistance was suspected (Cullen 2008; Steffey and Gray 2007) . Extension entomologists are fighting an uphill battle to promote IPM under such conditions.

There is a difference in approach to cleaning up a mess in a failed field and managing other fields so that a new resistance hotspot does not develop. If a field has failed because of Bt resistance, it may be a good idea to throw the kitchen sink at the local rootworm population if crop rotation is not an option, but only in the short-term. For both the short and long-term, if the grower wants a transgenic option (or feels there is no viable non-Bt option because of unavailability or lower yield potential; Onstad et al. 2011; Porter et al. 2012), it is important that he/she rotate Bt traits or use a pyramid of traits with different modes of action. Promoting this strategy to customers may be a hard pill to swallow for a company worried about trait-loyalty and maintaining market-share, and this is an action further down their lists of recommended "best management practices" than it is on the list of academic IPM-compatible recommendations. But at least it is on the list.

4.4 Conclusions

> …and your sons and your daughters shall prophesy, your old men shall dream dreams, your young men shall see visions… (Joel 2:28)

There are many other issues and complexities to deal with in this crisis, but the relevance to the future of IPM is clear, as is the relevance of IPM to mitigating the crisis. The motivation for applying multiple IPM tactics in corn has been declining since the introduction of Bt varieties. The same is true for applying multiple IPM tactics for weed management since the introduction of glyphosate-tolerant varieties. As in the case of rootworm Bt corn, the ease, efficiency, and efficacy gained by adopting a glyphosate-based weed management system made possible by transgenic glyphosate-resistant soybeans and corn created a “perfect storm” for evolution of weed resistance (Green and Owen 2011). But in the midst of these crises, it is important to remember that the problem is not the technologies themselves, but the quintessentially human instinct to strive for efficiency and to simplify complicated systems. It is the same overwhelming compulsion that accompanies every new silver bullet. In fact, that is what makes them appear to be silver bullets, because we want one so badly. We dream dreams. “This time it will be different”, which it always is, but then again not really. Or we think, “IPM (or IRM or both) is a luxury I can’t afford”, “I can’t afford not to treat”, “Of course it will become resistant, but so what? By then they’ll have a new product to take its place”…

But the good news is we have a way out. IPM, despite the difficulty in defining it, the different perspectives of various interest groups, and the inevitable complexities and difficulties in applying it, is such a robust idea, at least in its potentialities, that it has survived attempted usurpation by the latest silver bullets and is the true rescue strategy waiting in the wings. It is robust because it is based on universal principles. The long string of prophets warning over and over again not to rely solely on these miracle technologies have been proven right, but not to their delight. It is time for us all to get to work using IPM principles as the underlying philosophy to clean up the latest resistance messes, and to prevent new messes from springing up.

There are many other challenges facing us as well, which we will best confront in the context of applying IPM principles. There are several recently invading or approaching pests in the North Central region that we must quickly learn how to deal with, including western bean cutworm (*Striacosta albicosta*), brown marmorated stink bug (*Halyomorpha halys*), and Japanese beetle (*Popillia japonica*). Climate change, with the projected hotter, drier summers in the North Central region may be profoundly destabilizing of agroecosystems (Adamo et al. 2012). Rising CO_2 levels themselves can affect plant resistance to insect herbivores (Casteel et al. 2012). Unknown effects include desynchronization of pest and crop phenologies, and changes in pest migration patterns and overwintering ranges. Introduction of transgenic drought-tolerant crops hold out the promise of continued productivity, but will come with their own set of needed adjustments to the production system. IPM choices are being squeezed by the many factors described above, but in particular growers need access to elite non-Bt corn hybrids (Onstad et al. 2011; Porter et al. 2012) and to seed without neonicotinoid treatment if the grower does not want it. Spurious marketing and labeling of pesticides, including seed treatments, for use in improving "plant health" beyond targeting specific pests is disturbing and adds to overuse. Many of the plant species suggested for possible widespread planting as biofuel crops have a history of being invasive weeds (Raghu et al. 2006; Meyer et al. 2010; WSSA 2012c), and their use must be considered extremely carefully to avoid disastrous "escapes" and invasions. The insects that will inevitably become the key pests in biofuel monocultures are not yet known (Landis and Werling 2010; Bradshaw et al. 2010; Prasifka et al. 2011). Finally, cooperation between public-sector scientists and industry is critical to dealing with these issues in an optimal way. Despite a long history of effective collaboration, interactions have not always been ideal since the advent of biotech crops—but we are trying and communicating through a number of new initiatives, and it is getting better (Sappington et al. 2010). We are all in the same boat together, and we need IPM now more than ever.

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Chapter 5
Integrated Pest Management in the Southern United States of America: Changing Technology and Infrastructure—Implications for the Future

Charles T. Allen

Contents

Abstract This chapter provides a history of the development of integrated pest management (IPM) in the southern U.S. and discussion of the current and future status of the discipline in the South. The historical components of the chapter are organized using the eras of pest management (Newsom 1974, Perkins 1980), and

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the chapter's focus in the early years is the struggle to manage, control and finally eradicate the boll weevil from cotton. Since 1996, it has become clear that American agriculture has transitioned to another era, the era of genetically modified crops that have led to significant reductions in the IPM infrastructure. As the timeline approaches the present, the focus of the chapter is broadened to discuss many of the pest management technologies which have emerged in southern crops in recent years and the impact of their adoption on agriculture and the availability of people with applied "field specific" IPM skills in the southern U.S. The chapter concludes with a discussion of world population projections and the importance of highly efficient agricultural production systems to meet the food and fiber needs of the growing population. The importance of training and maintaining people with the knowledge and skills to manage pests in grower fields is emphasized.

Keywords Integrated pest management · Insecticides · Herbicides · Fungicides · Insects · Weeds · Plant diseases · Cotton · Corn · Soybeans · Boll weevil · Cultural control · Biological control · Host plant resistance · Chemical control

5.1 Introduction

Newsom (1974) divided the history of cotton insect management into four periods: pre-1892 –the pre-boll weevil era, 1892–1917—the early boll weevil era, 1917–1945—the calcium arsenate era, and 1945 forward—the synthetic organic insecticide era. Perkins (1980) later sub-divided the synthetic organic insecticide era. Perkins recognized 1945–1955 as the era of euphoria and the crisis of residues; 1954–1972 as the era of confusion, environmental crisis and the beginning of new directions; and 1968 forward as the era of changing paradigms (IPM). Since 1996, it has become clear that American agriculture has transitioned to another era, the era of genetically modified crops.

The history of pest management since the late 1800s is a repeated cycle of pest intensification, development of innovative and effective technology, enthusiasm and over-use of the powerful new technology, followed by the development of problems with the technology. The problems that arose that were often associated with failure of growers to integrate the tactics into multi-tactic IPM systems. The historic trend has been for producers to rely heavily on a single control tactic. Often, this has resulted in the development of environmental problems and placed powerful selection pressure on pest populations. Over-use of single tactics has led to premature evolution of resistance and failure of the pest management technology. Pest resistance, resurgence of secondary pests, and loss of natural enemies have resulted in environmental and human health impacts, and economic losses.

This chapter discusses the history of pest management in the southern United States of America (U.S.A). It focuses on our failure to integrate pest management tactics in the past and the need to do so in the future to meet the challenges of feeding and clothing a rapidly growing world population. It also discusses the evolution of

IPM programs in the era of genetically modified crops. It discusses increasing use of preventative tactics implemented on an area-wide basis and the impact of these changes on the numbers of agricultural professionals available. Finally, the chapter discusses the future consequences and perils of failing to counter the trend of the diminishing numbers of crop production professionals supporting farmers in the era of genetically modified crops.

5.2 Before Boll Weevil– Pre 1892

Cotton production in North America began about 1600 (Handy 1896). Donnell (1872) reported that the country was supplied with cloth from cotton grown in Maryland, Delaware and New Jersey during the American War of Independence. In 1796, President George Washington signed the patent for Eli Whitney's cotton gin (Donnell 1872; Linder 1954), making the production of upland cotton commercially feasible (Anonymous 1930).

Production of cotton in the American South grew rapidly during the period 1840–1860 (Trelogan 1969). By 1849, cotton was the most important agricultural export, and income from cotton sales paid for two-thirds of all US imports (Anonymous 1850; Phillips 1850; Haney et al. 1996). By 1850, 85 % of the world's cotton was produced in the American South. In 1860, America produced 2 million bales of cotton. Eighty percent of cotton spun in United Kingdom (U.K) mills came from the southern U.S. The American Civil War severely disrupted cotton production and marketing. During the war, United Kingdom mills received only two percent of their cotton fiber from southern states. The American Civil War ended in 1865 and by 1876, the cotton industry in the South had recovered sufficiently to supply 62 % of the cotton used by mills in the U.K (Anonymous 1877; Haney 2001).Westward population movement after the Civil War, aided by development of railroads, greatly expanded cotton production—especially in Texas. By the end of the 19th century, any threat to the cotton industry was a clear threat to the U.S. economy. Cotton was central to the economies of southern states which were struggling to recover from the devastation of the war (Haney 2001).

5.3 Initial Boll Weevil Years—1892–1917

It was into this milieu that the boll weevil *(Anthonomus grandis)* arrived, crossing the Rio Grande into South Texas about 1892 (Newell 1904). Yield losses in cotton fields near Brownsville and San Diego, Texas exceeded 90 % by 1894 (Townsend 1895). Moving at an average of 80–100 km per year, the weevil had infested all of the U.S. cotton belt east of the Texas High Plains by 1922 (Coad et al. 1922). Cotton yield losses during these years varied between 20 and 80 % (Worsham 1914; Lewis 1920; Isley and Baerg 1924; Thomas 1929; Coad 1930; Wagner 1999). In Georgia, Soule (1921, p. 16) spoke for the all southern U.S. cotton producing communities, "The boll weevil has disturbed our economic situation more than any other single factor since the conclusion of the Civil War; it is a pest of as great a magnitude as any which afflicted the Egyptians in the olden days."

Historically, the immigration of the boll weevil into and through the South had the most significant impact of any invasive pest in the history of the southern USA. It resulted in the establishment of entomology as a discipline and departments in southern universities. The establishment by Dr. Seaman Knapp of a boll weevil management method demonstration as one of the earliest actions of the Cooperative Extension Service substantiates the importance of boll weevil management in the founding of Extension (Frisbie 1993) (Fig. 5.1).

Initially, farmers were defenseless and the boll weevil caused extensive damage. Public sector entomologists quickly responded. Early biological observations formed the basis for cultural control tactics which limited boll weevil losses. Observations and initial cultural management suggestions were made by C.H.T. Townsend, L.O. Howard, E.A Swartz and C.L. Marlatt. This led to the development of a suite of cultural management practices, many of which were developed by F.W. Mally, W.D. Hunter, W.E. Hinds and S.A. Knapp. Mally recognized the value of earliness (Mally 1901) and stalk destruction (Walker and Niles 1971; Walker 1984; Klassen and Ridgway 2001). Hunter (1904) found that the application of fertilizer could aid in the production of an early crop, thereby avoiding severe late season boll weevil damage.

Modification of row width was recommended—first wider rows to allow greater light penetration and desiccation of boll weevil immature in squares (pre-bloom flower buds) on the ground; and later, narrow rows to promote earliness (Mally 1901; Cook 1924; Hinds 1928; Ware 1929, 1930). Government entomologists promoted a program of cultural tactics, termed the Government Method, which were incompletely adopted because stalk destruction—a key component of the strategy—was very difficult to accomplish in the era before mechanization (Helms 1977; Wagner 1980; Walker 1984; Haney 2001; Stavinoha and Woodward 2001). Newell and Paulsen (1908) proposed defoliation of the cotton crop to slow late season boll weevil losses. The development of the V-shaped stalk cutter (Anonymous 1911) aided growers in accomplishing stalk destruction. In 1922, the development of tractors equipped with power-take-off and stalk shredders greatly improved farmers' ability to destroy stalks in a timely manner (Williams 1987).

In the years before effective insecticides were available, the primary focus was on cotton varieties that could escape devastating late season boll weevil populations through early fruit production and maturation. Early spring planting of varieties selected for rapid maturation was recommended (Cook 1906, 1911; Bennett 1908). Mally's concept of a short season approach to cotton production continued to be an area of emphasis in Texas for many years (Niles 1970; Namken and Hielman 1973). Cotton breeders selected varieties for other boll weevil-resistant traits such as thickened boll walls (Harned 1910), red leaves and stems (Isley 1928) and strap-like, frego bracts which permitted light to pass through the bracts and reach the squares and bolls, inhibiting weevil damage (Jones et al. 1964; Lincoln and Waddle 1965).

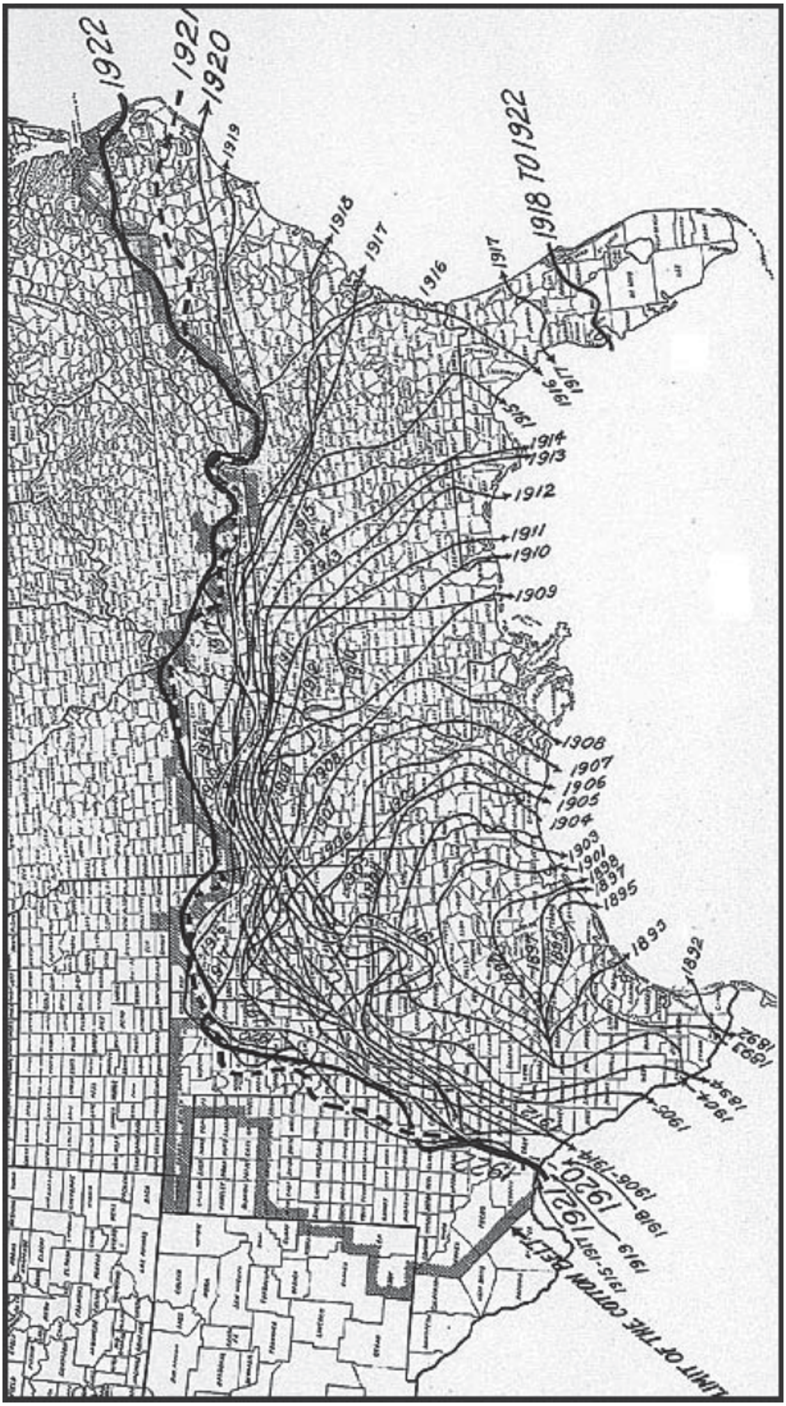

Fig. 5.1 Migration of the boll weevil across the southern USA. Coad et al. 1922

5.4 Calcium Arsenate Era—1917–1945

From the first appearance of boll weevil, various concoctions were used in attempts to poison them. Lime, ashes, sulfur, Paris green, London purple, lead arsenate and many other concoctions were used (Parencia et al. 1983; Haney et al. 1996; Haney 2001). Paris green was effective against the cotton leafworm, *Alabama argillacea*, but not boll weevil. Sulfur was effective on sucking insect pests such as tarnished plant bug, *Lygus lineolaris* and cotton fleahopper, *Pseudatomoscelis seriatus*, but once again, ineffective against the weevil (Parencia et al. 1983). In the early 1920s, calcium arsenate was found to be effective against boll weevil. And, in the 1920s, airplanes were found to be a very efficient means of applying insecticides. By 1931, aerial application of insecticides was widely accepted (Post 1924; Hinds 1926; Parencia 1978).

After the discovery of practical application methods for calcium arsenate, entomologists largely abandoned development and implementation of ecologically-based management methods and concentrated on research and extension programs involving chemical control methods (Smith et al. 1976). The Georgia State Bureau of Entomology recommended calcium arsenate treatments every 4–6 days (9–10 applications per season) to control boll weevil (Warren and Williams 1922). Farmers adopted chemical control and they too largely abandoned ecologically-based tactics to manage boll weevil and other cotton pests. Insecticide-dependent cotton production systems quickly became the principal means of protecting cotton. Isley, Baerg and Sanderson promoted use of insecticides only as necessary to supplement cultural and other management methods (Isley and Baerg 1924; Baerg et al. 1938), but dependence primarily on calcium arsenate continued for decades (Parencia 1978). Injurious populations of cotton aphid, *Aphis gossypii,* and bollworm, *Helicoverpa zea,* were associated with repeated use of calcium arsenate (Bishop 1929; Fletcher 1929; Sherman 1930; Baerg et al. 1938; Gaines 1942; Ewing and Ivy 1943). Nicotine or hydrated lime sulfur was sometimes mixed with calcium arsenate to provide control of mixed populations of cotton aphids, cotton fleahoppers, and bollweevils (Parencia et al. 1983).

In the 1920s and 1930s, Dr. Dwight Isley's work in Arkansas stood out as one of the earliest examples of what would later be called integrated pest management (IPM). An advocate of the Government Method, Isley worked to encourage farmers to integrate cultural and biological control with judicious insecticide use. He used small, early planted trap plantings of cotton to attract boll weevils which were then controlled with insecticides without disrupting natural control on whole fields. He advocated scouting and the use of economic thresholds to determine when to treat for weevils and other cotton pests. And, he showed that early-season spot-treatment of heavily infested areas of cotton fields was effective in reducing damage from boll weevils. Integrating the cultural controls espoused by the Government Method with natural biological control and insecticides, Isley was ahead of his time and laid the early foundations for IPM systems in the United States (Isley 1933; Johnson and Martin 2001; Klassen and Ridgway 2001).

5.5 Synthetic Organic Insecticide Era—1945–1996

5.5.1 Euphoria and the Crisis of Residues—1945–1955

The discovery and development of synthetic organic insecticides in the 1940s and 1950s revolutionized pest control in the Southern U.S.A. The synthetic organochlorine insecticides quickly replaced calcium arsenate on cotton (Parencia et al. 1983). BHC, aldrin, dieldrin, chordane and heptachlor were effective against boll weevils, but not against bollworms. When mixed with DDT, both weevils and worms were controlled. Toxaphene and endrin were effective against both pests. Soon, insecticides from the organophosphate class of chemistry became available and growers quickly began using them along with organochlorines to control insect pests. Methyl parathion, azinphosmethyl, demeton and EPN were some of the organophosphate insecticides used in cotton. Carbamate insecticides such as carbaryl were developed and used as well (Parencia et al. 1983).

Emulsifiable concentrate (EC) insecticide formulations were developed in 1948 (Parencia et al. 1983). EC formulations allowed farmers and aerial applicators to conveniently mix insecticides with water and apply them to crops in low-pressure, low-volume sprays. Foliar sprays were a significant improvement from both efficacy and environmental contamination standpoints over more drift-prone dust formulations. In the late 1940s and 1950s the standard approach to controlling pests became spraying weekly from squaring to near harvest (Whitcomb 1970; Newsom 1970). This approach was accepted by most entomologists of the day (Rainwater 1952; Gaines 1952, 1957; Curl and White 1952; Ewing 1952; Smith et al. 1976). The number of applications for cotton pests ranged from one or fewer per year in northern, dryland production areas to 18 or more in warmer, high-rainfall, and irrigated regions (Smith et al. 1964; Haney et al. 1996; Barker 2001; Boyd 2001). After World War II cotton became the most heavily insecticide treated crop in the U.S.A (ARS 1976; Botrell 1983). By the 1950s and 1960s, one third of the insecticides used in American agriculture were used on cotton (Brazzel et al. 1961; Knipling 1971; Perkins 1980). The majority of this insecticide use occurred in the southern U.S.A.

Overuse of synthetic organic insecticides followed the pattern seen after development and widespread adoption of calcium arsenate. The availability of highly effective insecticides generated exaggerated optimism among cotton growers in their new-found power to control pests with synthetic organic insecticides (Barducci 1972; Adkisson et al. 1982; Gould 2010; Tabashnik and Gould 2012). Grower optimism quickly led to over-use of the very effective, but largely single tactic, synthetic organic insecticide-based approach to pest control (Smith and Allen 1954; Stern 1969; Adkisson 1969, 1971, 1972; Smith and van den Bosch 1967; van den Bosch et al. 1971; Smith 1969, 1970, 1971; Doutt and Smith 1971; Newsom 1970). Unfortunately, chemical control methods were not often integrated with cultural and biological control methods, but instead supplanted them (Smith et al. 1976). Most major cotton growing areas—which were plagued with severe insect pest problems—came under a heavy blanket of insecticide (Smith et al. 1976). Optimism, over-use, and failure to integrate insecticides with ecologically-based pest management strategies were patterns which would be repeated again and again as each new technology became available. Each time, reliance on single-tactic pest management practices—even when several modes of action have been used—has been unsustainable (Stern et al. 1959; Metcalf and Luckman 1982; Persley 1996; Kogan 1998; Benedict and Ring 2004).

5.5.2 Confusion, Crisis of the Environment and Beginning of New Directions—1954–1972

Multiple concerns soon began to develop as a consequence of over-reliance on insecticides in the late 1940s and early 1950s. The confidence of cotton growers in the southern U.S.A. in insecticides as the solution to their cotton insect pest problems was shaken by the discovery of high levels of resistance to organochlorine insecticides in the boll weevil in Louisiana in 1954 (Roussel and Clower 1955) and in Texas the following year (Walker et al. 1956). Grower confidence was further weakened by the development of resistance to organochlorine insecticides (DDT) in the tobacco budworm and bollworm in the early 1960s (Brazzel 1963; Graves et al. 1963), and further loss of confidence in the system occurred with the development of organophosphate (methyl parathion) resistance in the tobacco budworm six years later in Texas (Nemec and Adkisson 1969; Ridgway and Lloyd 1983). Resistance was occurring in other pests on other crops as well. Banks grass mite, *Oligonychus pratensis,* on grain sorghum and corn became resistant to multiple miticides in the late 1960s and early 1970s on the Texas High Plains (Ward et al. 1972). By 1983, Parencia and co-workers noted that 25 insects and spider mites that attack cotton had developed resistance to organochlorine insecticides. At least one resistant pest species was found in each cotton producing state.

The increasing cost of the single-tactic approach of pest control was exacerbated by insecticide resistance, pest resurgence and secondary pest outbreaks (Smith and Allen 1954; Stern 1969; Adkisson 1972; Bottrell 1983). Control costs were an increasingly important concern and were directly related to grower over-reliance on insecticides. The National Cotton Council of America estimated the cost of insecticides and application on cotton at $260 million annually for 1970–1972 (Eichers et al. 1978). An estimated 64.1 million pounds (29.1 million kg) of insecticide were applied to control cotton insects in the United States that year (Parencia et al. 1983).

The environmental costs of the heavily insecticide-driven pest management system on cotton and other southern crops were brought into national focus with the publication of *Silent Spring* by Rachel Carson in 1962. Her book marked the beginning of the environmental movement in the United States and led to a President's Science Advisory Committee study and special report in 1963. The report found fault with a number of crop production chemicals (Smith et al. 1976). Environmental concerns led to the formation of the U.S. Environmental Protection Agency

(EPA) in 1970. EPA banned the use of DDT—the insecticide at the center of the controversy—in 1972 (Parencia et al. 1983).

It was into these tumultuous times—highlighted by public and agricultural concerns about crop protection, production costs and the environment—that the southern corn leaf blight epidemic broke in 1970. Male sterile hybrid seed corn production techniques rendered 85 % of the U.S. corn crop vulnerable to the *Bipolaris maydis* fungus. Southern corn leaf blight destroyed 15 % of U.S. corn production in 1970 (Tatum 1971; NAS 1972; Ulstrup 1972). The southern corn leaf blight epidemic further increased concerns about modern agricultural methods and the stability of the food supply.

As pest and pesticide related problems continued, experts reviewed and debated the best course of action (Perkins 1983). The approach now known as integrated pest management (IPM) was judged the most likely to succeed (NRC 1981; Bottrell 1983). Over time, the IPM approach, which relied upon a broad suite of techniques—intelligent use of cultural practices, cultivars with resistance to pests, biological control, crop monitoring (scouting), and judicious use of pesticides only when pests reached economic thresholds—was embraced by public sector crop protection specialists. Soon—with the demonstrated success of the IPM approach—farmers and consultants adopted it as well.

Modern ecologically-based IPM arose from the observations and strategies of Townsend, Howard, Schwartz, Marlatt, Mally, Hunter, Hinds, Knapp, Coad and others. Their work helped cotton growers in the years just before and shortly after the turn of the 20th century to avoid some of the destruction caused by the boll weevil. Conceptually, their work laid the foundation for the development of IPM in the U.S. Other scientists who worked on boll weevil—Isley, Baerg, Sanderson and others—further developed IPM concepts as they began integrating ecologically-based strategies with insecticide-based strategies. Crop scouting, treatment thresholds, trap crops, spot treatments and conservation of natural enemies were products of their research and extension work.

The concept of integrated control was first articulated by Smith and Allen (1954) (Smith et al. 1976). Stern et al. (1959) is widely credited with having first provided the theoretical basis and applied methodology for holistic IPM (Castle and Naranjo 2009). They developed the theoretical basis for control decisions and popularized the concepts of the economic injury level and the economic threshold. The integrated control concept was later broadened to include all pest management methods (Smith and Reynolds 1965). Still later it was extended to include management of all classes of pests—plant pathogens, insects, nematodes and weeds (Smith et al. 1976). Modern multidisciplinary IPM is developed and implemented by teams of scientists who operate with a holistic view of pest management problems and tactics. IPM teams operate most effectively when they work and think in ways that consider the agro-ecosystem and the pests within it from a broad ecological perspective. From this perspective, they are able to develop multidisciplinary management programs featuring ecologically-based solutions that address primary pest concerns without damaging systems, keeping other pests in check, causing unnecessary environmental damage, or limiting agricultural production (Smith et al. 1976).

5.5.3 Changing Paradigms—1968–1996

The period of nearly three decades—1968–1996—was a time of concentrated public and private sector investment in IPM. During this period, grower adoption of IPM provided benefits both on the farm and to society in the South and throughout the U.S.A.

Scouting services were embryonic in the 1940s and 1950s. They consisted primarily of checking to see if the insecticides that had been applied had worked. Little attention was given to thresholds, beneficial insects, resistant varieties, cultural practices, etc. As resistant insect pests evolved and insecticide costs increased, producers became more aware of the need for professionals to help them make decisions (Head 1983). State Cooperative Extension Services initial efforts to initiate IPM programs in cotton began in 1967 (Young 1983; Canerday 1983). Extension agents—deployed at the 1 to 5 county level—developed integrated pest management programs which emphasized beneficial insects, use of cultural practices, diapause and overwintering boll weevil control, individual field scouting, and use of selective insecticides only when economic thresholds were met or exceeded. Federal funding for research and extension IPM programs was begun in 1972 with the Huffaker Project—1972–1978 (Huffaker and Smith 1980). It made organizing and implementing pilot IPM programs across the cotton belt possible. Further funding in 1975 allowed for program expansion. EPA, NSF and USDA funded the 17 university Consortium for IPM, 1979–1985, and further developed state IPM research and extension efforts (Frisbie 1985a). Farmers rapidly adopted IPM programs and accepted guidance from extension agents (Young 1983). Scouted cotton acreage increased rapidly across the cotton belt (Lambert 1983; Canerday 1983).

Research teams quickly developed and improved IPM tactics and systems. Economic thresholds, monitoring methods, pest resistant crops, pest suppression systems, crop and pest modeling and forecasting and improved biological control techniques were achievements of the research efforts (Frisbie 1985a).

Extension teams provided grower funded scouting programs which informed producers about pest populations and natural enemy levels in individual fields, and informed farming communities about pest and natural enemy trends. They worked with pest management technologies (pesticides, pest resistant crop technologies, cultural controls, biological controls, etc.) and demonstrated the best use of technologies for local crop production systems. Their work emphasized integration of ecologically-based and pesticide-based technologies with goals of reducing the environmental and human health risks associated with crop production, and improving farm profits.

As a result, insecticide use began to decline (Lambert 1983; Adkisson et al. 1985) and the number of scouted cotton fields increased (Corbet 1981; Pimentel et al. 1992; Parvin et al. 1994). Participating farmers realized higher yields, lower risks and greater profits ~$333 per hectare ($135 per acre) compared with nonparticipants in Mississippi (Parvin et al. 1994).

The investment of Federal funds in state extension IPM programs had a positive impact on the crop consulting industry. In 1972 there were an estimated 61 crop consultants practicing in the entire cotton belt. By 1982 the number of practicing consultants had increased dramatically to an estimated 571. Mississippi, Texas, California and Louisiana had greater numbers of consultants than other cotton belt states. Sixty-three former extension employees were working as consultants (Head 1983). Acres scouted by consultants had grown from an estimated 401,500 (~162,481 ha) in 1972 to 2.2 million (~0.9 million ha) in 1982 (Lambert 1983). Producer support for private consultants increased from $430,000 in 1972 to ~$7 million in 1980 (Blair 1983). By 1983 a substantial portion of U.S. cotton land was regularly monitored by private, college-trained pest management consultants who offered a wide range of services including soil fertility analysis and recommendations, crop variety selection, pest advice, pesticide application and alternate control methods (Bottrell 1983). By 1983, an estimated 2.75 million hectares (6.8 million acres) of cotton were in either a private or university sponsored IPM program. The grower cost for IPM was estimated at $14.3 million per year, while the economic benefit was estimated to be greater than $133 million per year—$9.30 for every dollar invested (Smith 1983).

Fuchs et al. (1997) conducted an extensive survey of Texas producers on their adoption and use of IPM. The survey team received 1,552 responses. Sixty-four percent of growers met the definition of IPM users (pre-determined by the survey). Farmers managing 68 % of the land used survey-defined IPM practices to suppress pests. Eighty-eight percent of farmers used economic thresholds, and 84 % of acres were scouted. Fifty-one percent of acres were treated and 69 % of growers considered the impact of treatment on natural enemy populations before they applied an insecticide. Thirty-seven percent of all insecticide applications targeted boll weevil and 36 % targeted bollworms (a total of 73 % for of treatments targeting either boll weevils or bollworms). Cotton fleahopper was the target for 10 % of the insecticide treatments, while aphids were the target for 8 % and thrips were the target for 9 % of the treatments.

During its first 50 years, IPM in cotton was predominantly a field-based approach with monitoring and decision-making conducted on a field-by-field basis (Brewer and Goodell 2012). Notably, area-wide IPM also had its early roots in the struggle to manage boll weevil in the early years of the twentieth century. Mally and other early scientists were proponents of area-wide stalk destruction for boll weevil population management as a part of the suite of management tactics early farmers called the Government Method. Their concept of area-wide pest management for cotton—area-wide stalk destruction—is still mandated by state law in many southern states and is practiced to this day. Selection of cotton varieties for earliness and use of early fruiting varieties on an area-wide basis along with cultural practices to promote earliness—tactics from Mally's ecologically-based management suggestions—were major components of the IPM cotton production systems in use 60–100 years later (Adkisson et al. 1982; Walker and Niles 1971; Frisbie 1985b). The area wide management philosophy was further developed in Texas by Ewing and Parencia (1949, 1950). They developed community-wide, early-season programs to control overwintering boll weevils with the least possible disruption of natural enemies. In Arkansas, the area-wide IPM concept was the central paradigm for bollworm management communities. Initially conceived and operated by the Arkansas Cooperative Extension Service, these programs began in 1976 and by 1983 they were operational on over 32,000 hectares (80,000 acres), involving over 200 cotton producers (Cochran et al. 1985). By 1985, thirty percent of the cotton in Arkansas had IPM activities conducted through one of seven community IPM programs (Frisbie 1985b). Economic surveys indicated participating growers enjoyed benefits of 67 kg/ha (60 lbs/acre) higher lint yield and 4.2 fewer insecticide applications (Frisbie 1985b).

Area-wide boll weevil diapause control programs were conducted in many southern states in the 1960s and 1970s (Allen 2008). The largest of these was conducted on the Texas High Plains from 1963–1997. For 34 years the program prevented boll weevil infestation of the 1.3 million hectares (3.2 million acres) of cotton on the Texas High Plains (Frisbie 1985b). Economic evaluation of the program indicated it prevented the loss of 75–125 million bales of cotton and it prevented the use of 3.6–9 million kilograms (8–20 million pounds) of insecticide per year. By preventing the establishment of boll weevil on the Texas High Plains, $12-$20 million per year in increased production costs was avoided (Lacewell et al. 1974). In the end, however, the program failed due to mild winters and the establishment of 1.7 million hectares (4.2 million acres) of USDA Conservation Reserve Program grasses which served as boll weevil overwintering sites (Leser et al. 1997; Stavinoha and Woodward 2001).

In corn, crop rotation—conducted on a field-by-field basis, but adopted by producers on an area-wide basis—was effective for many years in reducing populations of western and Mexican corn rootworms. In spite of the non-chemical nature of the tactic, its widespread use exerted significant selection pressure on corn rootworms resulting in the development of western and Mexican corn rootworm biotypes which laid their eggs in non-host crops in the fall, enabling the emerging larvae to infest corn as fields were rotated back into corn production the following spring (Chandler et al. 2008).

The successes of area-wide approaches to the management of insect pests led Dr. Edward Knipling to develop the Total Population Management (TPM) concept. Following successful application of the area-wide, TPM concept in eradication of screwworm (*Cochliomya hominavorax*) from the southern U.S.A. (Klassen and Ridgway 2001), Knipling believed the concept could be used to eradicate the boll weevil (Knipling 1966, 1967, 1968). He thought that the boll weevil was a good candidate for eradication because it had one host plant throughout most of its range in the U.S.A. His success with screwworm emboldened the cotton grower leadership to accept and embrace the idea that the boll weevil could be eradicated.

Knipling, Robert Coker and J.F. McLaurin led discussions with the National Cotton Council which passed a resolution in 1958 to develop the technology to eradicate the boll weevil from U.S. cotton fields (Knipling 1956; Coker 1958). This began an intensive effort to fund USDA Agricultural Research Service (ARS) efforts to develop the biological and technical tools that would be needed for boll weevil eradication. In 1960, the U.S. Congress appropriated $1.1 million for construction of the USDA ARS Boll Weevil Research Laboratory on the campus of

Table 5.1 Critical technologies for boll weevil eradication and the periods of development

Technologies	Year(s)	Citations
Crop residue destruction	1890s–1920s	Mally 1901; Walker and Niles 1971
Short season varieties and production	1890s–1970s	Mally 1901; Walker and Niles 1971
Aerial application of insecticides	1920s	Post 1924; Hinds 1926
Mass rearing boll weevils	1950s–1960s	Vanderzant and Davich 1958; Gast and Vardell 1963
Diapause control	1950s–1960s	Brazzel 1959, 1962
Ultra-low-volume insecticide application	1960s	Hopkins and Taft 1967
Malathion (insecticide)	1960s	Burgess 1965; Hopkins and Taft 1967
Pheromone	1960s–1970s	Tumlinson et al. 1969, 1971
Trap	1970s	Leggett and Cross 1971
Mapping/trapping/data systems	1990s	El-Lissy and Moschos 1999; Allen 2008
Aircraft global positioning systems	1992	Personal Communication, R. Haldenby, 2007.

Mississippi State University. Table 5.1 provides information about the key efforts and advancements which enabled private-public partnerships to successfully conduct boll weevil eradication in the southern U.S. (Davich 1976; McKibben et al. 2001; Allen 2008).

Following the Pilot Boll Weevil Eradication Trial 1971–1973 in Louisiana, Mississippi and Alabama and the Boll Weevil Eradication Trial in northeastern North Carolina and southeastern Virginia 1978–1980, the national boll weevil eradication program began in the USA in 1983. The program began in southern North Carolina and South Carolina on the east and two years later, in California and Arizona in the west (Ridgway and Mussman 2001; Dickerson et al. 2001; Harris and Smith 2001; Clark 2001; Neal and Antilla 2001; Roof 2001; Allen 2008). It has resulted in eradication of the boll weevil from all U.S. cotton except approximately 60,000 hectares (150,000 acres) near the Rio Grande in South Texas. Boll weevil eradication programs in Mexico have eliminated the pest from the majority of cotton producing lands, including the primary production areas in northwestern Mexico. In Texas, the net cumulative economic benefit of boll weevil eradication from 1998–2010 has been $1.9 billion (McCorkle 2011).

In the southwestern U.S., a program to eradicate the pink bollworm has also been successful. Through this area-wide effort, pink bollworm has been eradicated from all cotton producing areas in Texas, New Mexico, Arizona, California and northwestern Mexico in which it was previously a significant pest (Personal communication, L. E. Smith 2012; Liesner et al. 2011). Pink bollworm programs have used a number of tactics including Bt cotton, pheromone mating disruption, insecticides and sterile insect releases (Smith et al. 2012).

Together, area-wide boll weevil and pink bollworm eradication programs have transformed IPM in southern states and have produced highly positive economic impacts for cotton growers and local economies in the region. In addition, they have greatly reduced the need for insecticides, providing significant environmental and human health benefits.

Highly effective pyrethroid insecticides became available to U.S. cotton producers in 1977 (Bierman 1983). Once again, growers developed great confidence in the new technology and their use of pyrethroid insecticides soared. On average, 8 applications per year were made on cotton in higher use areas. From one to five *Heliothis/Helicoverpa* generations were treated annually during the late 1970s and 1980s (Bacheler 1985).

By 1985—seven years after the pyrethroids became available—field-evolved resistance was reported in tobacco budworm (*Heliothis virescens)* populations in West Texas (Allen et al. 1987). Resistance was confirmed in the laboratory in both South and West Texas tobacco budworm populations (Plapp et al. 1987). During the next 10 years, pyrethroid resistance in tobacco budworm spread gradually through the South (Graves et al. 1989, 1991, 1992; Elzen 1995; Elzen et al. 1992, 1997; Hasty et al. 1997).

Insecticide resistant cotton aphids were another cause for grower concern during the late 1980s and early 1990s. During this period, widespread resistance to multiple classes of insecticides developed in the cotton aphid across much of the South (Allen et al. 1990; Hardee and O'Brien 1990; Kerns and Galor 1991; Reed and Grant 1991; Bagwell et al. 1991; Johnson and Studebaker 1991; Harris and Furr 1993; Layton et al. 1996a). A few years later, tarnished plant bug populations continued the trend. They too, developed resistance to multiple classes of insecticides (Snodgrass and Elzen 1995; Snodgrass and Scott 1996; Luttrell et al. 1998; Russell et al. 1998).

Resistance management plans were developed by research and extension entomologists with the goal of sustaining the efficacy of pyrethroid and other insecticide chemistry against tobacco budworm, cotton aphid and tarnished plant bug. They were modeled after plans developed in Australia to preserve pyrethroid efficacy against *Heliothis armigera* (Sawicki and Denholm 1987; Sawicki 1989). The plans emphasized earliness, use of field scouting and economic thresholds to determine the need for field treatment, use of alternative insecticide classes, and tank mixes of insecticides from different classes (Fuchs 1994; Bagwell 1996). Extension Service promotion of resistance management plans and widespread grower and consultant adherence to them sustained the effectiveness of pyrethroids for tobacco budworm and insecticides for cotton aphid and tarnished plant bug from the late 1980s until the mid-1990s when Bt transgenic cotton varieties and novel insecticides for cotton aphid and tarnished plant bug became available (Colburn 1994; Allen 1995; Graves et al. 1995; Bagwell et al. 1991; Bagwell 1996; Furr and Harris 1996; Layton 1994).

The suppression of natural enemies through repeated use of insecticides resulted in pest resurgence and increasing secondary pest problems. This, along with increasing insecticide resistance in primary pests, led to an escalation in insecticide use in the late 1980s and 1990s. Grower treatments were made during the same years that broad-spectrum malathion treatments were being applied to by boll weevil eradication programs. Natural enemy populations were reduced and pest management systems became unstable, resulting in severe pest outbreaks. Beet armyworm, *Spodoptera exigua,* outbreaks occurred in Alabama, Georgia, Mississippi, Florida, South Carolina and Texas during the period 1988–1998 (Sprenkel and

Austin 1996; Mascarenhas et al. 1998). Because insecticides were mostly ineffective, high control costs and significant crop loss resulted in outbreak areas (Summy et al. 1996; Sparks et al. 1996). Serious tobacco budworm outbreaks occurred as well, with similar outcomes. Cotton growers in Alabama, Mississippi and Tennessee experienced highly damaging tobacco budworm outbreaks in 1993, 1994 and 1995 (Layton et al. 1996b; Williams and Layton 1996). And, in 1991, farmers on the Texas High Plains experienced insecticide induced outbreaks of resistant cotton aphids (Leser et al. 1992).

5.6 The Era of Genetically Modified Crops—1996 to Present

5.6.1 Insect Resistant, Bt Transgenic Crops

In 1996—one year after serious beet armyworm outbreaks in Texas and tobacco budworm outbreaks in Mississippi, Alabama and Tennessee—Bt transgenic cotton and corn first became available in the U.S.A. Not surprisingly, grower adoption of Bt cotton was rapid (Benedict and Ring 2004; Luttrell et al. 2012). Adoption continued to increase for several years. By 2011, Bt cotton plantings comprised greater than 95 % of land planted to cotton in most production regions of the USA (Luttrell et al. 2012). Over 58 million hectares of Bt crops, primarily cotton and corn were planted in the U.S.A. in 2010 (James 2010).

The first year of Bt cotton use, bollworm populations caused crop damage (Carter et al. 1997; Lambert 1997; Pitts et al. 1999). Damage occurred mid-season in Texas and the Mid-South as bollworms fed on blooms and small bolls deep within the crop canopy. Pyrethroid insecticides were applied to control the worms in some fields. In general, however, in spite of minor to moderate crop losses in some areas, the Bt transgenic cotton (single protein toxin) performed well (Benedict and Ring 2004; Naranjo and Elsworth 2010; Duke 2011). Caterpillar control and resistance management were improved by the introduction of dual toxin Bt cottons in 2002 (Greenplate et al. 2002; Bacheler and Mott 2003; Catchot and Mullins 2003; Hagerty et al. 2003).

Resistance management was a part of the agreement when farmers purchased Bt seed and it was a part of the EPA label for Bt crops. EPA considered Bt proteins as plant incorporated protectants (PIPs) resulting in their being regulated. Refuges of non-Bt crops were required. The refuge requirements were based on the ability of a transgenic Bt plant to deliver a high toxin dose. EPA categorized “high dose” as toxin concentrations high enough to kill at least 99.99 % of susceptible insects in the field—survival of less than 0.01 % of larvae on Bt plants compared to larval survival on non-Bt plants (EPA 1998; Tabashnik and Gould 2012). Modeling projected that a high dose teamed with non-Bt refuge plantings which would produce adults which had not been selected for Bt resistance could forestall resistance development resulting in enhanced sustainability of the technology. In theory, for target pests in which the high dose definition is not met, refuges should be higher than those for pests in which the high dose threshold is met (Gould 1998; Carrière and Tabashnik 2001; EPA 2002; Tabashnik et al. 2004, 2008, 2009). Availability of additional non-Bt refuge introduces greater numbers of non-selected adults into the environment. Increased percentages of non-selected moths are needed to slow resistance in pests that do not meet the high dose threshold. Unfortunately, neither bollworm nor western corn rootworm, *Diabrotica virgifera*, meet the high dose threshold (Tabashnik and Gould 2012). Refuge requirements may not have been set high enough and these pests have proven problematic in Bt cotton and Bt corn (Ali et al. 2006; Luttrell et al. 2004; Porter et al. 2012; Tabashnik et al. 2008, 2009, 2010, 2012).

In cotton, one or more bollworm sprays on two gene Bt cotton have produced yield increases in recent years. These treatments are commonly made by growers in the mid-South and southeast (Greene et al. 2011; Jackson et al. 2012; Luttrell et al. 2012; Lorenz et al. 2012).

In corn, western corn rootworm caused "greater than expected damage" to Cry 3Bb1 corn in 2009. By 2011, damage to transgenic Cry 3Bb1 hybrids had been reported in Illinois, Iowa, Minnesota, Nebraska and South Dakota. Field-evolved resistance in western corn rootworm is believed to be the reason for the damage (Gassmann et al. 2011). In 2012, the North Central Coordinating Committee NCCC46, consisting of entomologists from land grant institutions and USDA-ARS, wrote a letter pointing out the need for more effective refuge requirements to preserve the effectiveness of the Bt toxins against western corn rootworm (Porter et al. 2012).

In spite of the inability of Bt cotton to completely control higher populations of bollworm in some locations, the technology has transformed pest management on cotton in the South. Target pests have been brought under almost complete control. And secondary pest outbreaks that in the past developed due to use of insecticides against primary pests and the resulting loss of natural enemies—have been almost completely eliminated (Turnipseed et al. 2001; Shelton et al. 2002; Naranjo and Ellsworth 2003; Head and Dively 2004). Insecticide applications have been reduced by 50–60 % by the combination of Bt cotton, boll weevil eradication and other advances since 1996 (Roush and Shelton 1997; Chilcutt and Johnson 2004; Naranjo 2011). A compilation of the Beltwide Cotton Conference, cotton insect loss estimates from southern states Table 5.2, demonstrates how insect losses have been reduced. State losses to insects for the period 1980–1995 averaged 7.51 %, while average losses for the period 1996–2011 averaged 5.17 %; losses after 1996 were reduced by 31 %. Similarly, the number of insecticide applications for the period 1986–1996 averaged 5.61 applications per hectare, compared to an average of 2.98 insect applications per hectare for the period 1996–2011. After 1996, insecticide applications were reduced by 47 % (Hamer 1981; Head 1982–1998; Williams 1999–2012).

An analysis by the National Center for Food and Agriculture Policy concluded that quantity of insecticide active ingredient applied to cotton in the USA declined from 0.41 kg/ha in 1995 (the year before the commercial introduction of Bt crops) to 0.13 kg/ha in 2000, a 68 % reduction (Carpenter et al. 2004). In China and India even greater reductions in pesticide use have been seen since Bt cotton became

Table 5.2 State average losses to insects and insecticide applications on cotton before the Bt cotton became available in 1996 compared with the years since 1996 when Bt cotton was widely used. (Sources: Hamer 1981; Head 1982–1998; Williams 1999–2012)

Year	% Loss	No. Appl.	Year	% Loss	No. Appl.
1980	8.73	NA	1996	6.61	3.97
1981	10.49	NA	1997	9.42	4.05
1982	NA	NA	1998	7.98	4.3
1983	6.80	NA	1999	7.66	2.94
1984	6.90	NA	2000	9.26	3.61
1985	7.01	NA	2001	4.53	2.28
1986	7.76	4.6	2002	4.61	3.14
1987	5.89	5.5	2003	4.16	2.97
1988	6.87	5.2	2004	4.18	2.96
1989	9.22	6.7	2005	4.47	3.02
1990	6.41	4.2	2006	2.95	2.29
1991	5.63	4.6	2007	3.62	2.79
1992	6.90	5.8	2008	3.80	2.15
1993	6.88	5.8	2009	2.58	2.11
1994	6.03	5.2	2010	3.91	2.45
1995	11.08	8.5	2011	3.03	2.69
Average	*7.51*	*5.61*	*Average*	*5.17*	*2.98*

NA—not available

available (Duke 2011). Commercialization of Bt crops worldwide has led to a reduction of 140 million kg of insecticide active ingredient on cotton and a 352 million kg reduction of insecticide active ingredient use on all crops between 1996 and 2008 (Brookes and Barfoot 2010; Naranjo 2011). The reduction in pesticide use has provided significant environmental and human health benefits (Yu et al. 2011).

Reduced pesticide use due to elimination and suppression of key cotton pests—boll weevil eradication and the use of transgenic Bt cotton—has had overwhelmingly positive impacts on cotton production economics and the environment. But negative impacts have occurred as well. In the reduced insecticide environment, the pest status of sucking bugs has increased, resulting in an increase in insecticide treatments needed to control them. The emergence of stink bugs in the southeast (Greene and Herzog 1999; Roof and Bauer 2002; Steede et al. 2003; Ottens et al. 2005; Greene et al. 2005) and tarnished plant bugs in the mid-South (Luttrell et al. 1998; Johnson et al. 2001; Layton et al. 2003) have required field monitoring and multiple, timely applications of insecticides. Even with the increased treatment for sucking bugs, the total insecticide load on cotton has been greatly reduced by Bt cotton and boll weevil eradication. In addition to insecticide reduction, the adoption of Bt transgenic crops is estimated to have saved 125 million liters of fuel and avoided emission of 344 million kg of CO_2 worldwide (Brookes and Barfoot 2010).

Negative effects of Bt crops on natural enemies have been reported. But comprehensive studies have documented that Bt proteins do not pose direct hazards to natural enemies (Gould 1998; Benedict and Altman 2001; Naranjo 2011). Bt crops rely less on insecticides, allowing farmers to take greater advantage of natural enemies

(Head et al. 2001; Benedict and Ring 2004; Naranjo 2011). Natural enemy populations are typically higher in untreated Bt cotton than in non-Bt cotton treated with insecticides (Marvier et al. 2007; Wolfenbarger et al. 2008; Naranjo 2009, 2011). Production systems which include pest resistant cultivars and maintain effective natural enemy populations have greater sustainability because of the increased pest mortality from natural enemies. Bt transgenic systems allow predators and parasites to respond naturally—in a density dependent manner—to the presence (or increase) of pest populations (Benedict and Ring 2004). Mortality due to natural enemies reduces selection pressure on Bt insecticidal proteins, slowing the development of pest resistance to Bt cotton (Van Emden 1991; Carrière and Tabashnik 2001).

The impact of Bt crops on non-target organisms has been thoroughly examined. The world literature on the subject was summarized by Yu et al. (2011). They found that Bt crops do not cause apparent, unexpected, detrimental effects on non-target organisms or their ecological functions. Bt proteins do not accumulate in soils (Head and Dively 2004). Since Bt protein toxins are only toxic to one or two insect orders, their action is much more targeted than most insecticides (de Maagd et al. 1999). The proteins kill some major crop pests, but they cause little or no harm to most other organisms—including humans (Mendelsohn et al. 2003; National Research Council 2010).

5.6.2 Nematodes and Thrips

For a number of years, treatments for nematodes and thrips have been preventative and area-wide in many areas of the southern US cotton belt. Aldicarb (Temik 15G) was the product of choice for both pest complexes and performed well for many years. A USDA-NAPIAP study in 1993 concluded that aldicarb was the single most valuable pesticide for U.S. cotton growers (Anonymous 1993). Bayer CropScience announced in the fall of 2010 that the marketing of aldicarb would end in the USA in 2014 and EPA declared that its use on all crops would end no later than August 2018. At the farm-level, however, aldicarb was unavailable for the 2011 and 2012 seasons. Without aldicarb, cotton vulnerability and losses to nematodes and thrips were expected to increase and widespread use of preventative seed-treatment and in-furrow, at-planting treatments to control these pests was expected to continue, involving multiple products for nematode and thrips control (Siders 2011).

Following the loss of aldicarb, cotton grower use of seed treatment and in-furrow pesticides continued the preventative and areawide use pattern seen previously when aldicarb was available. Seed treatment and in-furrow treatments to control nematodes, primarily southern root-knot nematode, *Meloidogyne incognita,* and reniform nematode, *Rotylenchus renniformis;* and thrips, predominantly tobacco thrips, *Frankliniella fusca* in most of the cotton belt, and western flower thrips, *Frankliniella occidentalis* in West Texas. Nationally, some 950,000 bales of cotton per year are lost to nematodes (Davis 2011; Blasingame 1999–2010) and thrips losses have averaged 121,094 bales per year since 2000 (Williams 2001–2012). Annual cotton yield losses to nematodes in the U.S.A. range from two to seven percent of the crop (Haygood et al. 2012). Based on losses at these levels, the $7.2 billion dollar 2011 cotton crop (NASS 2012) in the U.S.A. suffered losses from nematodes between $144 million to $504 million. And, thrips losses in the U.S.A. averaged $30.8 million per year (Williams 2001–2012; NASS 2012). Nematode and thrips losses occurred primarily in the southern USA.

Management to reduce losses from root-knot and renniform nematodes has evolved, post-aldicarb, to an increasingly integrated approach. Improved laboratory methods using PCR to quantitatively determine the number of renniform nematodes in soil samples has the potential to reduce the lab time and the cost of evaluating nematode infestation levels (Showmaker et al. 2012). Multi-temporal remote sensing technologies with information delivery via the internet can provide cotton growers with information on the degree of renniform nematode infestation in fields—without the necessity of taking or processing soil samples (Palacharla et al. 2012). Systems using various methods including digital elevation modeling, soil electrical conductivity, normalized difference vegetative index, yield maps and geographic information system referenced nematode sampling have been developed allowing growers to specifically target areas of infested fields which can respond to fumigation treatment. The use of fumigants has increased in recent years (Overstreet et al. 2011, 2012; Allen et al. 2012; Haygood et al. 2012; Norton et al. 2012). In addition, cotton growers are using other nematode management techniques such as nematode tolerant varieties (Anderson et al. 2011; Wheeler et al. 2012) and rotating to non-host crops such as peanuts and grain sorghum (Overstreet and Kirkpatrick 2011). Highly nematode resistant cotton lines have been identified and work is underway to develop elite, nematode resistant varieties (Davis 2011; Nichols 2012).

To minimize losses from thrips, growers across the south are increasingly adopting preventative seed-treatment and in-furrow insecticides (Akin et al. 2011, 2012; Griffin et al. 2012; Nino and Kerns 2010; Herbert et al. 2012; Roberts et al. 2012). In most cases, foliar sprays have not increased yields of cotton which has been protected with in-furrow or seed-treatment thrips control insecticides. But, when thrips infestations are high or early season growing conditions are wet and/or cool, foliar thrips treatments can increase cotton yields (Roberts 2012; Akin et al. 2011, 2012). It is not uncommon for producers to make foliar applications for thrips control at specific growth stages, or with herbicide applications; regardless of thrips numbers or damage potential (Akin et al. 2011, 2012). The consensus of extension entomologists in the South is that foliar sprays following seed treatment or in-furrow insecticide applications should only be made on the basis of the presence thrips above treatment thresholds (Akin et al. 2011, 2012; Roberts et al. 2012). Thrips resistant cotton lines have been identified and breeding for resistant varieties is on-going (Arnold et al. 2010).

Trends for nematode and thrips management have been, and very likely will continue to be preventative and area-wide.

5.6.3 Innovations in Managing Mycotoxins and Plant Diseases

5.6.3.1 Mycotoxins

In recent years plant pathologists and crop protection specialists have made a number of significant advances in the management of long-unsolved plant disease/mycotoxin issues affecting agriculture in the southern U.S.A. The development of technology which has allowed farmers to reduce aflatoxins in corn, peanut, and cotton seed has been critically important in their ability grow these crops profitably and produce crops which can be safely consumed by humans and animals.

Aflatoxins—a group of mycotoxins which are very important in the southern USA—are extremely toxic compounds produced by some biotypes of *Aspergillus* section *flavi* and *A. parasiticus*. These ubiquitous fungi infect many crops (Diener et al. 1987; Cotty 1994). They have been problematic in the hot, humid growing conditions typically present in the South. Hot years with low rainfall often result in aflatoxin contamination in corn and other crops.

Aflatoxins are considered among the world's most serious food safety problems. They were first identified in the 1960s following the death of a large number of turkeys in Britain. Scientists studying that incident found high levels of aflatoxins in imported peanut meal used in the turkey feed (Robens 2008). The presence of aflatoxins in human food causes both acute and chronic effects—aflatoxicoses—ranging from immune system suppression, to growth retardation, and cancer. Human deaths can result from acute poisoning (Gong et al. 2002; Wild and Turner 2002). Occasional outbreaks of aflatoxin poisoning in humans has occurred in Africa. In 1966–1967 and 2004, outbreaks of aflatoxin poisoning in Uganda and Kenya, respectively, caused human illness and death. In both instances, consumption of highly contaminated corn—which was produced during drought years and stored improperly—was identified as the cause. Those affected developed jaundice, after which the mortality rate was high (Probst et al. 2007). High concentrations of aflatoxin in human food have been positively associated with the incidence of liver cancer (Wild and Hall 2000). In the U.S.A., health risks to humans, livestock and wildlife, and the reduced profitability of contaminated crops have strongly motivated farmers to prevent the formation of aflatoxins in the field (Park et al. 1988).

Many countries have implemented regulations which limit the concentration of aflatoxins allowable in food and feeds (Haumann 1995). In the U.S.A., the U.S. Food and Drug Administration (FDA) limits aflatoxins in food or feed in interstate commerce to 20 ppb and in milk to 0.5 ppb (Brown et al. 1991; Gourma and Bullerman 1995). Crops containing over 100–300 ppb cannot be legally fed to animals in the U.S.A. (FDA 2012).

Economic losses to farmers who have produced aflatoxin contaminated corn (or other commodities) are high. Monitoring, research and lost sales are estimated at between $0.5 and $1.5 billion annually (Robens and Cardwell 2003; Bruns and Abbas 2006). During a drought in 1998, losses from inability to market aflatoxin

Table 5.3 USDA-ARS funding for aflatoxin research 1982–2006

Year	USDA-ARS Funding for Aflatoxin Research
1982	$ 3.2 million
1989	$ 3.7 million
1998	$ 8.4 million
2006	$ 12 million

Source: Robens 2008

contaminated corn in Texas, Arkansas, Mississippi and Louisiana were estimated at $85 million (Williams et al. 2003; Abbas et al. 2002, 2006).

Following widespread aflatoxin contamination of crops in the U.S. Corn Belt in 1988, commodity groups pushed for additional funding for research (Cole and Cotty 1990; Robens et al. 1990). This resulted in the formation of the Multi-crop Aflatoxin Working Group, composed of land grant university and USDA scientists to address the aflatoxin problem in cotton, corn, peanuts and tree nuts (Robens et al. 1990). Stakeholder groups provided multi-crop funds and USDA-ARS funding for aflatoxin research was increased. multi-crop funds totaled $750,000 in 2007. That year 28 research/extension projects were funded—ten on corn, nine on peanut, four on cotton seed, and four on tree nuts. USDA –ARS funding for aflatoxin research was increased 3.75 fold from 1982 to 2006 (Robens 2008) (Table 5.3).

Cultural practices such as manipulation of planting dates to avoid heat/water stress during kernel filling (Abbas et al. 2007), manipulation of harvest dates (Bock and Cotty 1999), improving irrigation practices (Russell et al. 1976), improving harvest methods (Russell et al. 1981), and improving storage practices (Batson et al. 1997) have been shown to reduce aflatoxin contamination of agricultural products. Furrow-diking fields was a specific irrigation method which reduced aflatoxin in southeastern U.S.A. peanut, cotton and corn fields (Nuti et al. 2007). And, prevention of root infection by the peanut root nematode was shown to reduce aflatoxin contamination in peanut (Timper and Holbrook 2007).

Infestation by insect pests can increase the levels of mycotoxins—primarily aflatoxins and fumonosins (from *Fusarium* spp.). Insects carry fungal spores and cause damage which permits entry of the fungus. One of the positive benefits of Bt corn has been a reduction of insect damage and lower aflatoxin and fumonosin contamination (Benedict et al. 1998; Munkvold et al. 1999; Dowd 2001; Bakan et al. 2002; Williams et al. 2002; Hammond et al. 2003; Williams et al. 2004; Wiatrack et al. 2005; Bruns and Abbas 2006). Planting of Bt corn has resulted in an estimated $23 million per year benefit from reduced aflatoxin and fumonosin contamination of the crop (Wu 2006).

Competitive displacement of toxicogenic fungi is a novel biocontrol strategy to reduce aflatoxin contamination. This IPM strategy was pioneered by USDA-ARS scientists and strongly supported by grower groups and agricultural business partners (Cotty et al. 2007; Robens 2008). Public sector research scientists found that certain lines of *A. flavus* do not produce aflatoxin. They theorized that atoxigenic strains could be used to competitively displace and exclude the naturally present aflatoxin producing strains. After collecting and characterizing more than 10,000 isolates of the fungus (Cotty 1994), a competitive, atoxigenic line was selected—AF36. It could be produced simply on wheat seed, was stable in storage, was stable when applied to fields and could remain dormant until conditions became conducive for growth of the fungus. It was easy to use and easy to transport (Cotty et al. 2007). When applied to fields contaminated with toxigenic strains of the fungus, relatively small quantities of atoxigenic strains were found to shift the composition of *A. flavus* communities without increasing either the quantity of the fungus on the crop or the amount of the crop infected. A single application of 11.1 kg/ha (10 lbs./acre) of colonized wheat seed can produce significant shifts in *A. flavus* communities. A single application has been demonstrated to change *A. flavus* from 1–2 % atoxigenic strains to 80 % atoxigenic strains (Cotty et al. 2007). K-49, another atoxigenic *A. flavus* strain isolated from corn kernels in Mississippi, has been shown to reduce aflatoxin contamination of crops by 67–94 % (Abbas et al. 2006). Aflagard®, a third atoxigenic *A. flavus* strain, developed and labeled through research funding by the National Peanut Research Center has shown positive results as well (Dorner 2004).

AF36 was first registered for use in the U.S.A. through an Experimental Use Permit in 1996. It received EPA Section 3 Federal Registration for use in Texas and Arizona in 2003 and was labeled for use in California in 2004 (Cotty et al. 2007). It was soon discovered that AF36 treatment could positively impact ratios of atoxigenic to aflatoxin producing *A. flavus* strains for multiple years. Evidence suggests that inoculation of fields with multiple atoxigenic strains can lead to more complex and stable fungal communities and provide resistance to re-establishment of strains capable of producing aflatoxins.

Timing the application of atoxigenic strains to coincide with conditions that favor fungal establishment is an important component in suppressing aflatoxin development in crops. Use of atoxigenic strains of *A. flavus* is an effective tactic for reducing aflatoxin production in peanut, corn and cotton (Degola et al. 2011).

Public sector development and ownership of atoxigenic *A. flavus* lines has helped assure that the technology will continue to be available to farmers at a reasonable cost (Cotty et al. 2007). Because of the long term and area-wide effects of the atoxigenic strain technology (Cotty et al. 2007) and its current use by southern corn farmers throughout affected corn-producing regions, the use of atoxigenic fungi to competitively displace toxigenic strains is another example of a preventative, area-wide IPM tactic.

Corn lines have been discovered which have resistance to *A. flavus* infection (Warner et al. 1992; Campbell and White 1995; Scott and Zummo 1998). However, their poor agronomic quality has rendered them of little commercial value (Brown et al. 1999). Two resistant lines have been released by USDA-ARS in cooperation with the Mississippi Agricultural and Forestry Experiment Station as sources of resistance to aflatoxin in corn breeding programs. In field tests they have been reliable sources of high levels of resistance (Williams and Windham 2012). Genetic and molecular analysis and mapping suggest multiple mechanisms are involved in the aflatoxin defense systems (Kelley et al. 2012). Work to characterize the proteins which confer resistance (Baker et al. 2009; Brown et al. 2010) and development of markers to facilitate transfer of the genes coding for them (Brown et al. 2010) is on-going. Resistance-associated proteins in *A. flavus* resistant plants are expected to contribute to the development of aflatoxin-resistant corn lines and aid in the development of other *A. flavus* resistant crops (Brown et al. 2010).

Currently, cultural practices and biocontrol (use of competitive atoxigenic fungal strains) are reducing the levels of aflatoxin contamination in previously affected crops. The effort to develop elite, aflatoxin-resistant cultivars is expected to add to the suite of tactics that can be integrated into aflatoxin management programs. Resistant cultivars are eventually expected to further reduce aflatoxin contamination of crops in the southern U.S.A. The currently available tactics and those under development for reducing aflatoxin contamination are preventative. Growers have adopted the available tactics for aflatoxin prevention on an areawide basis and it is expected that they will adopt aflatoxin resistant cultivars on an areawide basis as well.

5.6.3.2 Verticillium Wilt

Verticillium wilt, caused by the fungus *Verticillium dahlia,* is a destructive disease that damages cotton plantings in irrigated and high rainfall regions of the South. *V. dahlia* is a soil-borne pathogen which causes damage to the plant vascular system resulting in plant wilting, defoliation and crop yield and quality losses (Wang et al. 2008). Some 1.5 million bales of cotton are lost annually to the disease (Bell 1992). While tolerance to the disease is available in certain commercially available cultivars (Cano-Rios and Davis 1981; Wheeler and Woodward 2011), high levels of resistance to the fungus is known in Sea Island and Pima S-7 cultivars (Wang et al. 2008; Bolek et al. 2005). Genetic and molecular techniques are being used to map and isolate the genes conferring resistance to reduce verticillium wilt either through conventional breeding or transgenic techniques (Bolek et al. 2005; Wang et al. 2008). As with aflatoxin resistance, cultivars with high levels of verticillium wilt resistance are eventually expected to greatly reduce damage from this disease. Tolerant cotton varieties are currently being used preventatively and resistant varieties are expected to be used in a similar manner when they become available. Currently in cotton growing areas affected with verticillium wilt, varieties conferring tolerance are used on an area-wide basis. When resistant varieties become available, it is expected that they too will be used area-wide.

5.6.3.3 Cotton Root Rot

Cotton root rot, caused by the fungus *Phymatotrichopsis omnivorum*, is another important disease of cotton in the South. This soil-borne pathogen causes plant vascular damage, premature defoliation and loss of yield and quality on certain alkaline soils in Texas, other southwestern states and Mexico. Some 1.5 million acres (648,000 hectares) of cotton in Texas are affected annually and, in spite of farmers' use of crop rotation and other cultural practices, losses are estimated at $29 million per year in Texas (G. D. Morgan. 2011. Unpublished Report, p. 5).

In 2009 field fungicide screening trials conducted by Texas A&M AgriLife Extension Service identified an effective fungicide treatment, flutriafol (Isakeit et al. 2012). Field tests were conducted to determine appropriate application methods and use rates. The fungicide effectively controls cotton root rot when it is applied to the soil, near the seed at planting. A Section 18 Emergency Exemption label allowed use of the product on of some 275,000 acres (111,000 hectares) of cotton in Texas in 2012. For the first time in 150 years, Texas cotton farmers have an effective, preventative treatment for managing destructive cotton root rot in cotton fields. The development of flutriafol for cotton root rot control by public sector plant protection specialists has resulted in area-wide use of the technology in root rot prone areas. Public sector plant protection specialists are working to develop the techniques and information to allow use of the product on other root rot prone crops such as grapes and tree fruits in the southern U.S.A.

5.6.4 Herbicide Tolerant Crops

The era of weed management with synthetic herbicides began with the introduction of 2,4-D in the early 1950s and herbicide use increased rapidly through the 1960s (Timmons 2005). Herbicide treated farm land in the increased from 30 million ha (90 million acres) in 1962 to 87 million ha (215 million acres) by the mid-2000s (Timmons 2005; Gianessi and Reigner 2007). The combination of herbicides and tillage made it possible for farmers to control weeds that were not previously controlled by tillage alone. Concerns about the possibility of herbicide resistance were first realized when common groundsel became resistant to triazine herbicides in Washington state in 1968 (Ryan 1970; Ross and Lambi 1999; Hager and Sprague 2000).

Prior to the introduction of herbicide tolerant crops, weed control strategies included a pre-plant-incorporated (PPI) or pre-emergence (PRE) herbicide or both to prevent weed germination and establishment. These applications were followed by post-emergence (POST) or post-directed (PDS) treatments to control weeds growing after crop emergence (Price et al. 2011). Use of these systems required a comparatively higher level of knowledge and skill than has been required since the advent of herbicide tolerant crops (HTCs). Before HTCs, farmers had to carefully select among a range of herbicide active ingredients and carefully manage herbicide application rates and timing. In addition, they had to integrate chemical and non-chemical practices to control weeds without damaging the crop (Mortensen et al. 2012). Prior to the release of glyphosate resistant soybeans, weed control in soybeans was typically a two pass system that utilized a PRE herbicide for grass and limited broadleaf weed control followed by a selective POST herbicide application (Price et al. 2011). Nonselective herbicides such as glyphosate were rarely used for weed control after crop emergence (Duke 2011).

Since its commercial introduction in 1974, glyphosate has become the dominant herbicide worldwide. It is a highly effective, broad-spectrum herbicide, yet it is toxicologically and environmentally safe. It is relatively slow acting and translocates well, allowing it to be transported through plants before transport systems are affected. Glyphosate is the only herbicide that targets the 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) enzyme required for production of aromatic amino acids (Duke and Powles 2008; Schönbrunn et al. 2001). It is considered the world's most important herbicide (Powles 2008). Until recently there were relatively few reports of weedy plant species which had evolved resistance to glyphosate (Powles 2008). In the 1990s Monsanto considered there was very low risk of the evolution of glyphosate resistant weeds (Bradshaw et al. 1997; Owen 2011).

In 1996, glyphosate-resistant (GR) soybeans were commercially introduced, soon followed by the introduction of GR cotton and corn cultivars (Young 2006; Webster and Nichols 2012). All three glyphosate resistant crops (GRCs) were very popular and widely adopted because of the utility, reliability and ease of application of broad-spectrum glyphosate (Duke and Powles 2008). The low perceived threat of weed resistance to glyphosate was the rationale for release of the technology without an integrated weed management (IWM) plan to reduce selection pressure on glyphosate and delay resistance development. IWM requirements were not mandated or generally promoted by weed scientists (Bonny 2011). Resistance management practices were not viewed as being economical and were not readily used by farmers (Webster and Sosnoskie 2010). Two factors were cited by farmers as reasons they did not adopt IWM practices to manage weed resistance to glyphosate. They believed resistance management practices would be futile and they believed new technologies would be developed to solve resistance problems (Webster and Sosnoskie 2010). Even with the higher cost of GRC seed, the technology simplified and generally lowered the costs associated with weed management (Duke 2011). Farmer use of GR cotton in the U.S.A. grew to over 70% of the total farmland planted to cotton in less than ten years (Price et al. 2011).

One immediate effect of widespread farmer adoption of GRCs was a significant expansion in the use of glyphosate and a reduction in the use of other herbicide modes of action (Givens et al. 2009a).Twenty percent of the land planted to soybeans on U.S. farmland was treated with glyphosate in 1995. By 2006, 96% of U.S. soybeans received glyphosate treatments (Bonny 2011). Use of other herbicides declined. Imazethapyr was used on 44% of U.S. soybeans in 1995, but on only three percent of U.S. soybean plantings by 2006 (Bonny 2011). The US patent for glyphosate expired in 2000. Afterward, generic glyphosate was marketed, competition was fierce and glyphosate became significantly less expensive (Bonny 2011). Chemical/seed companies increasingly consolidated and it became more difficult for farmers to find high-yielding varieties/hybrids which did not include transgenic herbicide-resistant traits (Mortensen et al. 2012). The increasing use of glyphosate in U.S. agriculture is shown in Table 5.4.

Expansion of conservation tillage was one of the significant benefits of the availability of GRCs and cheap, effective glyphosate. Glyphosate's broad spectrum of activity gave growers the capacity and confidence to eliminate primary tillage and

Table 5.4 Tons of glyphosate used in US agriculture

Year	Agricultural Use of Glyphosate (metric tons)
1987	2.9
1997	14.8
1999	29.0
2003	53.5
2007	75.3

Sources: Aspelin and Grube 1999; Donaldson et al. 2002; Kiely et al. 2004; Grube et al. 2011

cultivation as weed management tools (Givens et al. 2009b). Their ability to use glyphosate in POST applications to control weeds in GRCs facilitated extensive adoption of conservation tillage in several crops, but especially in cotton. By 2000, more than 44 million ha (109 million acres) of US cropland had been converted to conservation tillage (Sandretto 2001). Price et al. (2011) reported 46 million ha (114 million acres) of farmland in the USA were farmed using conservation tillage by 2010.

Conservation tillage has been thought of primarily as a method of reducing soil erosion by wind and water (Le Bissonnais 1990; Baumhardt and Lascano 1996; Truman et al. 2005). However, there are many other benefits including: increased organic matter at the soil surface (Rasmussen and Collins 1991; Reeves 1994, 1997; Truman et al. 2003), increased diversity and numbers of soil organisms (Kemper and Derpsch 1981; Rasmussen and Collins 1991; Bruce et al. 1992; Heisler 1998; Lupwayi et al. 2001; Kladivko 2001; Holland 2002; Riley et al. 2005; Brévault et al. 2007), reduced runoff (Reeves 1994, 1997; Truman et al. 2003; Banerjee et al. 2009), improved water infiltration (Kemper and Derpsch 1981; Bruce et al. 1992; Truman et al. 2003; Banerjee et al. 2009), improved soil surface sediment, improved soil aggregate stability, reduced soil crust formation (Bruce et al. 1992; Banerjee et al. 2009), reduced chemical runoff (Banerjee et al. 2009), improved water availability and water holding capacity (Hudson 1994; Reeves 1994, 1997; Kaspar et al. 2001), improved biological control of insect pests (Stinner and House 1990; Hammond and Stinner 1999; Kromp 1999), increased carbon sequestration (Baker and Saxton 2007) and reduced carbon emissions (Brookes and Barfoot 2006). Because of the numerous benefits of conservation tillage, it is a fundamental component of agricultural sustainability (Price et al. 2011).

Conservation tillage generally produces greater economic returns and lower production costs compared with conventional systems (Raper et al. 1994; Smart and Bradford 1999). Some of the savings are in lower fuel costs, reduced labor costs, and lower machinery inputs (Lithourgidis et al. 2006). In southern U.S. cotton production, the costs of no-till and strip tillage systems were lower than or equal to conventional tillage systems (Schwab et al. 2002). Yields of no-till corn and soybean tended to be greater in conservation tillage than in conventional tillage in the south and west regions of the U.S.A., but similar in the central U.S.A. In the northern U.S.A. and Canada, no-till systems produced lower yields (DeFelice et al. 2006). Economic analyses indicate that conservation tillage systems are not riskier than conventional tillage systems, even in the short term (Baker and Saxton 2007).

The high level of grower adoption of available GRCs and their reliance on glyphosate alone or with very limited use of alternative weed control practices resulted in high selection pressure on weeds to evolve resistance to glyphosate and led to the development of highly problematic, glyphosate-resistant weeds (Duke 2011; Bonny 2011). In southern cotton-growing states, the most serious glyphosate-resistant weed threat is from Palmer amaranth, *Amaranthus palmeri* (Heap 2007; Culpepper et al. 2006; Culpepper et al. 2007). Since the first confirmed case of glyphosate resistant Palmer amaranth in Georgia in 2005, resistant biotypes have been reported in Alabama, Arkansas, Florida, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee and Texas (Culpepper et al. 2006; Norsworthy et al. 2008; Steckel et al. 2008; Nichols et al. 2009; Dotray et al. 2012). In addition, glyphosate resistant populations of common waterhemp, *Amaranthus rudis,* are present in several southern states (Light et al. 2010). As of 2009, glyphosate resistant *Amaranthus* species infested 1.2 million hectares (3 million acres) of farmland in the U.S.A. (Heap 2009; Light et al. 2010). Along with resistant *Amaranthus sp*., glyphosate resistant populations of Italian ryegrass, *Lolium multiflorum,* have been identified in Mississippi, Louisiana, Arkansas, and North Carolina (Bond et al. 2012); glyphosate resistant populations of horseweed, *Conyza canadensis,* occur in many southern states. The problem of glyphosate resistant weeds became severe enough in 2010 to motivate hearings in the U.S. Congress to assess whether additional government oversight was needed to address the problem of herbicide resistant weeds (US House Committee on Oversight and Government Reform 2010).

In the wake of grower overuse of glyphosate on GRCs, extension and research weed scientists are working to promote broad-based, multi-tactic IWM systems for weed management (Mortensen et al. 2012; Bonny 2011; Harrington et al. 2009). They advocate increased research, alternating herbicide modes of action, alternating crops, use of cover crops and judicious use of tillage (Culpepper et al. 2010; Culpepper et al. 2011; DeVore et al. 2011; Price et al. 2011; Mortensen et al. 2012). Southern farmers are increasingly using residual PRE herbicides (Steckel 2012). The chemical/seed industry response is to develop and release crops resistant to multiple broad-spectrum herbicides (Carpenter and Gianessi 2010; Feng et al. 2010; Green and Owen 2011; Adler 2011; Duke and Powles 2008; Gerwick 2010; Mortensen et al. 2012). However, the herbicide resistant crops being developed and released are tolerant to herbicides with modes of action that have been used for decades (Duke 2011). In order to achieve more sustainable systems, farmers must reduce selection pressure on any single control tactic or herbicide through use of multiple tactics. As a part of this strategy they must utilize herbicide programs which rely on products with different modes of action (Powles 2008; Duke and Powles 2009; Dotray et al. 2012; Mortensen et al. 2012).

GR weeds demonstrate the vulnerability of widely-used systems that are dependent on a single weed control technology. That critical fault now threatens the sustainability of conservation tillage (Culpepper et al. 2006; Price et al. 2011). Declining farmland in conservation tillage is inevitable unless integrated, effective weed control strategies which include crop and herbicide rotation, and use of cover crops are quickly developed and deployed (Price et al. 2011). GR weeds are making tillage more desirable as an additional management tool in weed control systems which utilize herbicide-resistant crops (Duke and Powles 2008).

In spite of the "as-needed" nature of foliar glyphosate use on GRCs, the pre-plant decision to plant a GRC, their widespread use, and the intensive use of glyphosate on GRCs have many of the characteristics of area-wide, and preventative pest management approaches (Duke 2011; Price et al. 2011). Rapid adoption by American farmers of conservation tillage—primarily due to the availability of the effective GRC/glyphosate weed management system—demonstrates the increasingly area-wide nature of modern farming systems (Powles 2008; Price et al. 2011; Bonny 2011; Webster and Nichols 2012).

5.7 World Agricultural Challenges and Status

5.7.1 Challenges—World Population Growth

Earth's human population reached 7 billion persons in 2011 (James 2011). There is an urgent need to increase the world food and fiber supply as the population is projected to increase by one billion people every 10–12 years through 2050 (Kang 2005). By the mid- 21st Century, farmers will be challenged to feed and clothe another 4 billion people. The future security of the food supply will depend on science developing technology and IPM practitioners integrating it intelligently into production systems which maximize its effectiveness and longevity. The resulting integrated, multi-tactic systems will enable crop producers to grow crops efficiently and sustainably (Christou et al. 2006). Multi-disciplinary systems approaches will be needed (Kang 2005) and local IPM practitioners to aid farmers in adoption of the best IPM tactics for their farms will be essential. Teams of agricultural specialists will be critically important in helping farmers to meet the increasing needs of the human population while minimizing environmental degradation.

5.7.2 Current Status—Genetically Modified Crops

For the U.S., 2012 was the 17th year of commercialization of genetically modified crops. Worldwide, biotech crops were planted on 160 million hectares in 2011, up 12 million hectares (8 %) from 2010. Worldwide, adoption of the technology had increased from 1.7 million hectares in 1996 to 160 million hectares in 2011, making genetically modified crops the most quickly adopted crop technology in the history of modern agriculture (James 2011).

Global economic gains at the farm level of approximately US$78 billion were generated by genetically modified crops during the last fifteen years. Forty percent of these gains were from reduced production costs (reduced pesticide use, less labor, less tillage) and 60 % from yield gains (276 million tons) (James 2011).

From the environmental perspective, by 2010, worldwide reductions in fossil fuel and pesticide use because of widespread adoption of genetically modified crops resulted in a 1.7 billion kg reduction of CO2 emissions. In addition, increased use of conservation tillage led to an additional 17.6 billion kg of CO_2 sequestered by the soil by 2010 (James 2011; Brookes and Barfoot 2012).

5.7.3 Changes in IPM Systems

During the first 50 years of IPM, tactics were predominantly applied at the individual field level (Brewer and Goodell 2012). Field-based IPM was effective in encouraging IPM adoption, improving pest management and minimizing adverse environmental effects associated with pesticide use. The adoption of ecologically-based cultural practices, biological control, pest scouting and economic thresholds brought about reduced pesticide use, lower risks to human health and less environmental pollution (Harris 2001; Smith et al. 2002; Benedict and Ring 2004; Brewer and Goodell 2012).

Evolution of IPM systems has occurred since the early 1960s. Ecologically-based systems with as-needed insecticide applications based on scouting and economic thresholds have evolved to increasingly preventative systems implemented on a field-by-field basis. These field-based systems have been adopted on such a wide scale that they have, in effect, become area-wide IPM systems. The successes of boll weevil and pink bollworm eradication programs (Personal communication, L. E. Smith, 2012; Allen 2008) and the adoption of pest/herbicide resistant crops have had large, area-wide impacts and have dramatically changed IPM in field crops. Other authors have recognized widely adopted Bt technology as area-wide IPM (Carrière et al. 2003; Adamczyk and Hubbard 2006; Naranjo 2011; Hutchison et al. 2010). Other tactics such as the use of seed treatments, disease resistant varieties, atoxigenic *A. flavus* strains for biological control of aflatoxins, etc. exemplify the continuing evolution of agriculture in the U.S.A. in the direction of preventative and area-wide IPM systems. Weed control systems also have elements of area-wide impacts due to area-wide planting of GRC seed and areawide, repeated use of glyphosate (Duke 2011; Price et al. 2011). And, widespread adoption of transgenic weed control technology has supported area-wide adoption of conservation tillage practices (Powles 2008; Price et al. 2011; Bonny 2011; Webster and Nichols 2012).

Time savings have been one of the benefits of farmer adoption of transgenic, herbicide tolerant crops on their farms (Bonny 2011). Many southern farmers have invested the time they save by farming GRCs into increasing the land they farmed. Farms across the region have expanded, farmers have parked or sold plows and the large tractors used to pull them, and invested in large, efficient sprayers.

5.7.4 Impact of Changing IPM Systems on Infrastructure Supporting Crop Production

The author's initial notion that the IPM infrastructure supporting agricultural producers had changed significantly, was the result of considerations of the changes which have occurred in the Lower Rio Grande Valley (LRGV) of Texas. The area is convenient for study because it is relatively small (3 counties) and is isolated from other production regions. The author collaborated in this case-study with John Norman, IPM Agent-retired and current crop consultant with 37 years' experience in IPM in the LRGV (Personal communication, J. Norman 2012). The case study compared resources available to growers in 1980 to those available in 2012. In 1980 the Texas Agricultural Research and Extension Center and the USDA Kika de la Garza Subtropical Research Center were fully staffed and conducting extensive agricultural research and extension programming including significant work related to IPM. In 2012, the USDA facility was closed and the land grant Research and Extension Center is operating at reduced strength. In 1980 there were 35–40 local chemical/seed company field men scouting crops and assisting producers—in 2012 there were 12. In 1980 there were about 18 crop consultants working in the LRGV—in 2012 there were five. In 1980 there were thirty or more aerial spraying services—in 2012 there were five.

The LRGV case-study suggested that the infrastructure supporting farmers had significantly diminished over the last 30 years. It was the basis for the hypothesis that the change from major-pest driven, field-specific IPM to increasingly preventative, area-wide IPM has led to a decrease in the resources supporting field-specific IPM across the southern U.S.A.

Information on the numbers of crop consultants was obtained though state regulatory agency licensing records. Data were available for Louisiana and Arkansas. For Louisiana, records of licensed agricultural consultants were available from 2005 to 2011 (CPARD 2012). In 2005 there were 282 licensed consultants in Louisiana and by 2011 there were 183—a 35 % reduction. In Arkansas, similar records were available from the Arkansas State Plant Board (2012). There were 343 licensed agricultural consultants in Arkansas in 2006, and 248 licensed consultants by 2012—a reduction of 28 %. The author conducted a survey of southern state extension entomologists in September of 2012. Twenty-eight surveys were sent and 15 were returned. Forty-seven percent of the respondents indicated that fewer consultants were working in their area or state compared with five years ago while 53 % said the number of consultants in their area or state had not changed. None of the respondents indicated that the number of consultants had increased. Averaged across respondents, the number of consultants reported had decreased nine percent in the last five years.

The 2012 CPARD database, a repository of pesticide applicator information from states in the U.S.A., was used to answer the question, "Have crop production system changes affected numbers of licensed commercial pesticide applicators?" Data for Alabama, Arkansas, Florida, Georgia, Louisiana, Missouri, North Carolina, Oklahoma, South Carolina, Tennessee, Texas and Virginia were available for the period 2005–2011. In 2005 there were 14,703 registered commercial applicators operating in those states. By 2011 there were 13,684—a reduction of 6.9 % in six years (CPARD 2012). Texas data, provided by Texas Department of Agriculture (2012) provided a comparison over a longer window of time. In 2000 there were 2,482 licensed applicators in the crop protection category. In 2011 there were 1,745—a 30 % reduction during eleven years (Texas Department of Agriculture 2012).

Florida, Georgia, Louisiana, South Carolina, Tennessee, Texas and Virginia have separate licensing categories for commercial aerial applicators. There were 1,588 aerial applicators licensed in these states in 2005. By 2011 there were 1,413—an 11% reduction in six years (CPARD 2012). Texas Department of Agriculture (2012) records from 2000 to 2011 showed 746 commercial aerial applicators in 2000, and 543 licensed aerial applicators in 2011—a 27 % reduction in eleven years. The 2012 extension survey was further indicative of changes in numbers aerial applicators. Forty-seven percent of respondents indicated there were fewer aerial applicators compared with five years ago. Fifty-three percent said the numbers of aerial applicators was unchanged over the last five years. None of the respondents indicated that the number of aerial applicators had increased. The average of survey respondents' estimates indicated an 11 % reduction in aerial applicators in the last five years.

Extension resources supporting growers are also on the decline. Extension survey respondents unanimously reported that there were fewer extension personnel working on cotton now compared with five years ago. The average reduction in personnel reported in the 2012 survey was 33 % over the last five years. In Texas, the number of IPM Agents and Extension Entomologists has decreased 45 % during the last 20 years (Personal communication, J. Thomas 2012).

5.8 The Future—Challenges and Consequences

The sustainability of the highly successful technologies which have delivered the impressive benefits documented in this chapter (and many others which were not discussed) is dependent on our ability to use technologies wisely. History has repeatedly demonstrated our ability to develop powerful pest protection technologies, adopt them rapidly and use them exclusively with remarkable impacts on pests and farm economies. And, history has repeatedly documented our over-use of new technologies, followed by resistance and other problems within a few years. Again and again we have underestimated the impact of selection pressure on pests. In our enthusiasm to embrace the new technology, we have often failed to integrate other management practices which might have been used to reduce selection pressure, shortening the effective life of valuable technologies. Failure to integrate tactics has prevented us from developing sustainable systems consisting of broad suites of tactics which would reduce selection pressure on any single tactic. The number of technologies man can exploit to manage pests is limited. We can ill afford to continue to overuse them and, in so doing, strongly select for pests which can survive them—resulting in pest resistance and premature failure of the technology. Well trained, and effective public sector plant protection specialists are sorely needed to work with and educate farmers about the importance of using integrated tactics for managing pests.

The recent failure of systems involving GRCs has forced farmers to partially or completely revert to crop management systems that were in place prior to the introduction of genetically modified crops in 1996. Use of residual herbicides and tillage are on the increase in resistant weed-affected areas of the South. As a result, growers and society stand to lose many of the benefits of conservation tillage. Growers who expanded their farms based on the effectiveness of GRC-based systems and the time savings they have provided may find that they must now farm less land. They may have to reinvest in large tractors and plows and are likely to face economic losses.

The failure of transgenic insect resistant crop technology may have even more dire consequences. The human and equipment resources which would be needed to allow growers to revert to the field-specific pest management systems in use prior to the introduction of genetically modified crops are not available. Gone are the days when farmers had sufficient numbers of consultants, extension personnel, pesticide applicators –both aerial and ground—aircraft and other resources to conduct the field-specific IPM in the manner it was conducted prior to 1996. Colleges are no longer training sufficient numbers of students in field-specific IPM. Academic departments with crop protection emphasis have evolved and now emphasize molecular and genetic approaches to IPM. Several years would be needed for colleges to hire faculty with field-specific IPM experience and skills, and begin to train the numbers of students needed by farmers to enable them to transition back to field-specific IPM as it was conducted prior to 1996. In the meantime, losses would mount and the preventative use of foliar insecticides would increase. As has happened with the development of glyphosate resistant weeds—economic, human health and environmental costs would escalate. In the absence sufficient numbers of crop protection specialists, and with high commodity prices associated with the increased demand stimulated by a growing world population; the likely farmer response would be to revert to weekly foliar insecticide applications to protect their valuable crops from damaging insect pests. Under this scenario, pest management systems would revert to the preventative spray technology of the 1940s and 1950s, and—reminiscent of the current conservation tillage situation—the advances of the last 60 years would be lost. Under this scenario, agricultural production may become stagnant.

Since the boll weevil crossed the Rio Grande, public sector research and extension scientists with USDA and land grant universities have led the way—developing and testing new pest control technologies and educating farmers. Extension agents and specialists have guided farmers in the adoption of new management strategies and integrated technologies to help them be successful. Eradication programs, and transgenic and other technologies have greatly improved agriculture, but much more remains to be done. Highly effective, single tactic IPM technologies have produced great benefits for American agriculture and the public but are unsustainable if they are not integrated broadly in systems to reduce selection pressure on pests. Use of diverse pest management tactics—which include ecologically-based IPM and resistance management strategies—are critical to the long-term stewardship of transgenic and other preventative, area-wide technologies. Integration of components and concepts into effective IPM programs has been historically achieved at the local (county) level by public sector research and extension personnel. Multiple tactic integrated systems of this kind are rarely developed or promoted by the chemical/seed industry because they do not produce corporate profits in the short term. And, they are not often conceived of or deployed initially by consultants whose focus is managing pests in farmer's fields on a week to week basis. The work of development, testing and deployment of integrated IPM systems is most often accomplished by public sector agricultural professionals. Without integration of technologies into multi-tactic IPM systems, transgenic and other areawide technologies can be expected to fail within a few years.

Public sector agricultural research and extension work -developing and demonstrating IPM and other farming technologies, and providing farmers with the opportunities to learn from unbiased information sources is critically important at this point in history. The growing human population, risks of pest resistance, and diminished private sector infrastructure supporting farmers highlight the need for highly efficient crop production systems and increased support for farmers. Numbers of private consultants are driven by grower demand, but government can and should rebuild public sector crop production and crop protection capabilities within USDA and the land grant universities. American agriculture must be highly efficient if it is to keep pace with the world's increasing demands. It is doubtful that American farmers can achieve and maintain this level of efficiency without robust research and extension programs. The need for public sector research and extension is as great now as at any time in the past—and funding for these critical services has not kept pace.

American agriculture is held in high regard world-wide. Without strong research and extension programs, our ability to produce at present levels and increase production to provide for the billions of people expected in a few short years is in jeopardy. Change—pest resistance, new and improved technologies, etc.—must be expected. Outstanding technologies, promoted and adopted with a short-term profit perspective will quickly fail. Without government investment in research and extension programs (USDA and land grant universities) the balanced, unbiased, public-sector voice will become increasingly silent, to the peril of American and southern farmers, and the world's ever-growing human population.

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Chapter 6
Integrated Pest Management: Fruit Production in the Western United States

Kelly A. Grogan

Contents

Abstract Integrated Pest Management (IPM) has a long history in the western United States. Among fruit producers, IPM adoption has been uneven. In cases such as codling moth control on apple and pear crops and wine grape production in general, IPM adoption has occurred on a large scale. In cases such as stone fruits and citrus, while some growers have adopted IPM, adoption is not as widespread as it could be. Research and extension play crucial roles in the development and implementation of IPM since individual growers do not have the time, resources, or risk-absorbing ability to experiment with and develop such complex management programs. Additionally, successful implementation often requires cooperation across states and crops. Perhaps most importantly, IPM implementation requires a

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large impetus to motivate adoption. Such an impetus could include legislation, pest resistance to the currently used pesticide, or public pressure.

Keywords Biological control · Fruit · Integrated pest management · Western United States

6.1 Introduction

This chapter addresses the adoption of integrated pest management (IPM) in the western region of the United States. Since the University of California is a leading force in the development and diffusion of IPM practices in the western region, their definition of IPM is worth noting:

> Integrated pest management (IPM) is an ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties. Pesticides are used only after monitoring indicates they are needed according to established guidelines, and treatments are made with the goal of removing only the target organism. Pest control materials are selected and applied in a manner that minimizes risks to human health, beneficial and nontarget organisms, and the environment. (UC Integrated Pest Management 2011)

From the definition, it is apparent that IPM, as envisioned by the University of California, is a complex management program that combines various control methods in an effort to reduce negative effects both in the field and off.

Integrated pest management (IPM) in the context of fruit production in the western United States is particularly interesting. Much of the early work on IPM was done in the western region, particularly in California. Additionally, many fruits are tree crops where habitat is available for both the pest and predators or parasitoids of the pest year-round. This potentially creates more complicated pest management issues, but also allows for establishment of beneficial insect populations. While both of these factors positively affect the potential for IPM adoption, adoption has been higher and more successful for some crops than others. It will be demonstrated that IPM adoption is most prevalent when there is a large motivation for adoption including pesticide resistance issues or legislative changes and when there is active research and extension activities to aid in the transition.

This chapter briefly discusses the history and adoption of IPM in general, and then discusses several case studies that display the spectrum of successes and failures of IPM. The chapter will conclude with a discussion of factors that contribute to success.

6.2 History of IPM

Since the early days of agriculture, pests have been damaging crops, and humans have been devising methods with which to control the pests. Early methods included the use of beneficial insects. As early as 300 BC, citrus growers in China used

Oecophylla smaragdina, an ant species, to control caterpillars in their groves. They placed ants' nests, taken from wild trees, in their groves and connected the nests to the trees with bamboo (Hajek 2004).

By the 1800s, pest control had evolved to include substances that are toxic to or that repel pests. Such substances include as red pepper, sulfur, tobacco, and quick lime. Synthetic pesticides developed in the first half of the twentieth century as chemical production flourished during and between the two world wars. Such synthetic pesticides included the infamous dichlorodiphenyltrichloroethane (DDT) in 1939 as well as organophosphates (OPs) and methyl carbamates. However, secondary pest outbreaks and effects on non-target organisms soon made the negative effects of these chemical controls apparent (Smith and Kennedy 2002).

The concept of integrated pest management (IPM) emerged in the late 1950s and 1960s with early work done by entomologists within the University of California system (Stern et al. 1959; van den Bosch and Stern 1962) . This system of pest management considers the farm to be an agroecosystem and emphasizes the use of cultural and biological control whenever technically and economically feasible (Smith and Kennedy 2002) . Researchers who were already working on biological control of crop pests at the University of California, Riverside and Berkeley campuses were particularly interested in IPM, and research on the topic flourished at these western region campuses (Kogan 1998).

While research on IPM has been extensive, adoption has been limited in the United States (Epstein and Bassein 2003; Fuglie and Kascak 2001). Several factors contribute to the limited extent of adoption, and largely revolve around time constraints and narrowly focused interests. Implementation of integrated pest management takes considerable time that farmers often do not have and pest control advisors who advise many farmers are simply not present on any farm for enough time or frequently enough to adequately monitor pests and implement IPM. Lastly, some researchers specialize in only one component of IPM, preventing a full integration of control methods (Ehler 2006).

Tree crops such as the majority of fruit crops are unique from row crops in that the crops are present year-round albeit without fruit present the entire time. The continuous presence of the trees implies that habitat for both pests and beneficial insects exist continuously. This may make pests more problematic, but it also allows for better conservation of natural enemies because their habitat is not lost after harvest. This puts tree crops in a position for the development of strong IPM practices.

Despite the western region origins of IPM and the ecological potential of IPM in tree crops, adoption of IPM among fruit growers in the western U.S. has not been uniform. As will be demonstrated in the discussion that follows, when there are strong economic, social, and/or environmental incentives to adopt IPM, growers tend to do so. With weak or moderate incentives, the transition does occur. IPM adoption is also hindered when support from researchers and extension agents is lacking.

6.3 Measurement Issues

Before moving on to case studies of IPM implementation, it is important to recognize that measuring rates of adoption is somewhat problematic. Many components make up an IPM program for any individual pest and an ideal program will vary from grower to grower based on local conditions. With such specificity, it is impossible to perfectly label each grower's program as IPM or not. Instead various proxies are used including reduced use of toxic pesticides, reduced use of all pesticides, or adoption of individual methods that are included among possible IPM methods. These proxies however, can be misleading because they are only a small component of the larger pest management program utilized by a grower.

A study by the U.S. Government Accounting Office (2001) illustrates this point with a study of pesticide use in the U.S. Using data from 1992 to 2000, they calculate trends in use using various metrics. Overall pesticide use during this period remained the same, which might suggest that growers are not adopting IPM. However, if one considers the fact that the replacement of a broad-spectrum pesticide that controls multiple pests with selective controls might require a selective pesticide for each pest, constant pesticide use may not preclude adoption of IPM.

This study also analyzed the use of the riskiest class of pesticides including OPs, carbamates, and carcinogenic ingredients. They found that the use of these pesticides declined by 14 % between 1992 and 2000, but that 40 % of pesticides applied, by weight, still falls in this class of pesticides. While this decline could be attributed to adoption of IPM for the sake of transitioning to a more sound pest management system, the actual motivating factors for the reduced use of these pesticides include regulations that prevent the use of some of these pesticides, the development of cheaper alternatives, pest resistance lowering efficacy, and the introduction of genetically modified organisms that are no longer susceptible to the pest (U.S. GAO 2001).

According the U.S. GAO (2001), by 2000, 70 % of growers in the U.S. had adopted IPM. However, their metric for qualification as IPM is lenient. The United States Department of Agriculture (USDA) uses four categories of controls: prevention, avoidance, monitoring, and suppression. A grower's pest control is considered IPM if (s)he uses at least one practice considered as an IPM practice in three of the four categories of controls. The grower can use other controls that are not considered IPM practices, including the use of high-risk pesticides and still be categorized as having adopting IPM. The U.S. GAO report utilized this classification system to determine the percentage of growers utilizing IPM.

Since objective metrics for IPM adoption are problematic, it is not surprising that subjective measures can also be misleading. Shennan et al. (2001) interviewed citrus, broccoli, corn, grape, and tomato growers in California, asking them to rate their degree of IPM implementation as well as asking them to describe their pest management programs for specific pests. When asked to rate their IPM implementation as None, Minimum, Medium, High, or Organic, 41 % classified themselves as Minimum, 31 % as Medium, 16 % as High, and 7 and 5 % as None or Organic,

Table 6.1 Hectares, weight, and value of production in the Western United States, 2010. (Sources: United States Department of Agriculture 2011, 2012)

	Hectares	Production (1,000 tons)	Value ($ 1,000s)
Alaska	0	0	0
Arizona	5,949	106[a]	40,278
California	585,256	14,037[a]	8,155,402
Colorado	1,538	19	25,460
Hawaii	1,172[b]	25[b]	22,531
Idaho	2,149	41	24,804
Montana	295	2	4,026
Nevada	0	0	0
New Mexico	0	0	0
Oregon	27,539	405	398,772
Utah	2,711	23	13,248[c]
Washington	125,210	3,759	2,349,704[c]
Wyoming	0	0	0

[a] Excludes tangerines and mandarins. Data unavailable due to the small number of growers in the state

[b] Excludes pineapple. Data unavailable due to the small number of growers in the state

[c] Excludes apricots. Data unavailable due to the small number of growers in the state

respectively. When the researchers analyzed management of specific pests, 59 % of growers fell in the Minimum category, 17 % in medium, 12 % in None, 5 % in High, and 6 % in Organic. Growers tended to rate themselves as having a higher level of IPM adoption than their actual practices indicated.

A good measure of IPM adoption would vary by crop and location since possible management programs will vary along these lines as well. The measure would consider the grower's entire pest management program, and would rank growers along a spectrum of adoption instead of being a binary measure.

The following sections will discuss cases where adoption has been low and where it has been high, keeping in mind that "adoption" is a loose term and can vary depending on the metrics used.

6.4 Western Fruit Production

Thirteen states make up the western region of the United States: Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. Four of these states (Alaska, Nevada, New Mexico, and Wyoming) do not have commercial fruit production. Of the remaining nine states, California, Washington, and Oregon have the largest amount of fruit production by acreage, volume, and value. Table 6.1 contains the acreage, volume, and value of fruit production by state for the western region in 2010. Fruits produced include several types of citrus, apples, several types of berries, avocados, bananas, cherries, stone fruit, figs, guavas, and papayas.

6.5 Struggles with IPM Implementation

I begin with the cases where IPM adoption has been impeded, so that they can serve as a point of comparison for the success stories discussed in Sect. 6.6. Three cases will be discussed: organophosphate use on stone fruit in California, control of fire blight, blossom blast, and russetting on pears in California, and control of California red scale and cottony cushion scale in California citrus.

6.5.1 Stone Fruit Growers and Organophosphates

In California in the 1990s, concerns grew over contamination of surface water with OPs. Dormant season applications of OPs made by almond and stone fruit growers were major contributors to OP runoff. The growers' dormant season coincides with the rainy season, so applications were frequently washed off into surface water. While moving away from OP applications, growers had an opportunity to transition to IPM. Indeed, both the University of California Statewide Integrated Pest Management Project (UCIPM) and the Biologically Integrated Orchard System (BIOS) worked closely with almond growers to promote alternative controls. However, little effort was applied to stone fruit growers. Use of OPs on almond and stone fruit fields declined between 1994 and 2000, but OPs were largely replaced by pyrethroids (Epstein and Bassein 2003). While pyrethroids are less toxic than OPs, they have high toxicity towards aquatic organisms (Environmental Protection Agency 2012). On almond orchards, some growers transitioned to sustainable practices and no longer applied conventional pesticides. However, on stone fruit orchards, no such transition occurred (Epstein and Bassein 2003). Since the development of an IPM program is complex, it is not surprising that the stone fruit growers simply replaced one pesticide with another similar pesticide. Any individual grower has little incentive to experiment with and develop an IPM approach when a chemical substitute is readily available. However, larger organizations like UCIPM and BIOS have the capacity to do such work and then disseminate results to growers, as occurred with almond growers.

6.5.2 Pear Growers and Pseudomonas fluorescens

Pear growers face three potential pathogens: *Erwinia amylovora* which causes fire blight, *Pseudomonas syringae* which causes blossom blast, and several bacteria that produce acetic acid which cause russetting. To control these pests, growers traditionally apply antibiotics. The University of California and the Pear Advisory Board developed a program utilizing *Pseudomonas fluorescens* which could potentially substitute for antibiotics in the control of the three aforementioned pathogens. In 1998, *P. fluorescens* was applied to 29 % of California pear acreage, which is relatively high usage for a microbial control agent. However, use declined in subsequent years due to lacking quality of the microbial control agent (Epstein and Bassein 2003).

While the use of *P. fluorescens* was relatively widespread, on some fields its use was not as intended. Growers with the highest rates of antibiotic use were more likely to adopt *P. fluorescens*, and on average, growers who applied *P. fluorescens* used it in addition to the antibiotic regimen instead of reducing antibiotic use (Epstein and Bassein 2003). It is not entirely surprising that growers with high rates of antibiotic use would be more likely to try *P. fluorescens*. These growers are likely applying high rates because of high incidence of the pathogens and might feel that they need an additional tool to control the pathogens. The failure of this control likely results from researchers not considering all levels of pathogen pressure. A different approach may be needed for cases with high incidence of the pathogens. This highlights one of the challenges of IPM: a program that controls a given pest under a certain set of conditions may not provide adequate control in other settings. The lack of quality product also highlights a challenge of IPM. If IPM practices do not meet or exceed the standards and efficacy of the products they are replacing, growers have no incentive to adopt the inferior practices.

6.5.3 Citrus Growers and California Red and Cottony Cushion Scales

California citrus growers have a long history of using biological control. Despite this history, use of biological control has faced several impediments including climate, introduction of new pesticides, and the use of pesticides by neighboring growers.

Likely the oldest active use of biological control that is still used today involves the control of cottony cushion scale, *Icerya purchasi*. This pest was an invasive species that arrived in California in 1868, posing a large threat to the citrus industry. Since this introduction was prior to the development of contemporary pesticides, the growers' best option was biological control by the scale's predators and/or parasitoids from its country of origin. The vedalia beetle, *Rodolia cardinalis*, was introduced in 1888 and quickly suppressed scale populations across the entire growing region to economically acceptable levels (Doutt 1964; Caltagirone and Doutt 1989; Grafton-Cardwell and Gu 2003).

The beetle can provide sufficient control of the scale, eliminating the need for any chemical control, so long as its populations are not reduced. Since its introduction there have been several periods when new pesticides have suppressed beetle populations, leading to outbreaks of cottony cushion scale. Not surprisingly, the introduction of OPs and carbamates caused the first outbreak of cottony cushion scale. However, the beetle is quite adaptable and largely built up resistance to these pesticides such that outbreaks only occurred after multiple applications of these pesticides (Grafton-Cardwell and Gu 2003).

OPs were predominantly used to control California red scale, *Aonidiella aurantii*, and citrus thrips, *Scirtothrips citri*. In the 1980s, citrus thrips developed resistance to OP controls and in the 1990s, California red scale was also developing resistance to the OP controls. New pesticides, including insect growth regulators (IGRs), were developed and registered to address these resistance problems (Grafton-Cardwell and Gu 2003). Insect growth regulators are often considered to be compatible with an IPM program because they usually have a narrow range of toxicity. However, in the case of the vedalia beetle, the newly developed IGRs, buprofezin and pyriproxyfen, used to control California red scale as well as cyfluthrin, used to control citrus thrips, proved toxic to the beetle. There were large outbreaks of cottony cushion scale in the San Joaquin Valley region of California during the 1998 and 1999 growing seasons (Grafton-Cardwell 1999). Despite the IGRs' toxicity to the vedalia beetle, growers are still applying them although generally in alternating years, with an OP application being used in years when the IGR is not applied. The IGRs are highly effective at controlling California red scale, so secondary effects are overshadowed by the benefits (Morse et al. 2007).

While IGRs are one possible method for controlling California red scale, growers also have the option of utilizing *Aphytis melinus*, a parasitic wasp that provides control of California red scale by laying its eggs in the scale. The wasp is produced commercially, so growers can purchase it and release it in their fields. Such releases are relatively inexpensive, but the use of certain pesticides used to control California red scale and other pests are toxic to the wasp (Fake et al. 2008; O'Connell et al. 2010; UC Integrated Pest Management 2003). Reliance on the wasp potentially requires altering pest control methods for other pests in order to conserve the wasp.

Climatic factors impede but do not necessarily prevent reliance on the wasp in the San Joaquin Valley. Three other citrus growing regions do not face these impediments (Hoffmann and Kennett 1985; Kennett and Hoffmann 1985; Luck 1995; Yu and Luck 1988). A 2010 survey of California citrus growers asked growers about the presence of natural enemies, including *A. melinus*, and their pest control methods used for four major pests, including California red scale. Among respondents, 51.3 % did not know whether or not *A. melinus* was present in their fields during the growing season. Growers in the Interior region were the most knowledgeable about *A. melinus* with 44 % responding that they did not know whether or not *A. melinus* was present, while growers in the Coastal-Intermediate region were least knowledgeable with 53.1 % responding that they did not know if the wasp was present. Over all the regions, 11.4 % of growers relied entirely on *A. melinus* for red scale control with the percentage of growers relying on the wasp lowest in the San Joaquin Valley; 6.8 % of growers relied entirely on the wasp in this region. Growers with a higher level of education and growers with a higher expected crop value per hectare were more likely to rely mostly or entirely on the wasp (Grogan and Goodhue 2012a). The effect of education is not surprising given the knowledge that one must possess to effectively use *A. melinus* and to effectively control other pests while conserving the wasp.

While lack of knowledge is most likely a contributing factor that limits the use of *A. melinus* as a control of California red scale, neighboring growers can also impede a grower's use of *A. melinus*. The use of pesticides that are toxic to *A. melinus* on neighboring fields decreases the probability that a grower reports *A. melinus* present and increases the probability that (s)he applies a chemical control for California red scale. These effects occur due to pesticides on both citrus and non-citrus fields

(Grogan and Goodhue 2012b). Since *A. melinus* moves freely between fields and parasitizes scale pests found on both citrus and non-citrus fields (UC Integrated Pest Management 2003), pesticide use on neighboring fields appears to lower regional populations of *A. melinus*.

While neighboring use affects whether or not a grower applies a chemical control, among growers applying a chemical control for California red scale, neighboring growers' decisions do not affect what type of control is applied. That is to say that if neighbors are applying a highly toxic pesticide, the citrus grower is not more likely to apply a highly toxic pesticide. Growers are willing to differ from their neighbors in terms of pest control, but growers located in areas where high levels of pesticides toxic to *A. melinus* are used will have a more challenging time making use of *A. melinus* (Grogan and Goodhue 2012b).

This citrus grower case study points out several implications for IPM implementation. First, implementation of IPM for a given pest, such as the cottony cushion scale, can be impeded by changes to management practices used for other pests or for management practices introduced to control new invasive pests. This creates the need for a constantly evolving IPM program. Just as all pests on a grower's field must be considered for successful IPM, all growers within pest and beneficial insect population ranges must be considered as well. Coordination among growers, as will be shown throughout Sect. 6.6 can improve the success of pest control programs and can lessen negative effects on beneficial insects. Lastly, lack of knowledge about components of IPM, such as beneficial insects, prevents growers' use of biologically-based IPM.

6.6 IPM Implementation Successes

While IPM implementation has met with limited success in some situations, in other situations, implementation has resulted in widespread adoption and strong control of the targeted pest(s). This section will discuss a variety of IPM programs implemented for grape, pear, and apple growers in the western U.S.

6.6.1 Grape Growers and IPM

In recent years, there has been growing public concern about the environmental effects of wine production in California. Concerns include water use and water quality, habitat conversion for production, invasive species, erosion, congestion and noise, and labor and health concerns. To address these concerns and to promote more sustainable production, several regional growers' associations formed.

At the state level, the Sustainable Winegrowing Program (SWP) began in 2001 to promote sustainable practices from "ground to bottle." Practices concerning pest management, water and energy use, labor practices, wine quality, community issues, and other topics are outlined in their *Code of Sustainable Winegrowing Practices: Self-Assessment Workbook (2nd edition)*. SWP puts on workshops where growers assess their practices as well as receive information about sustainable practices. By 2006, assessments covered about 33 % of wine-grape acreage and 53 % of wine production for the entire state. Scores for those growers assessed between 2004 and 2006 were about 8 % higher than assessments made between 2002 and 2004, suggesting improvement in practices such as pest management (Broome and Warner 2008).

Smaller regional programs also exist. In 1994, the Robert Mondavi Winery began the Central Coast Natural Vineyard Team, now the Central Coast Vineyard Team (CCVT). Its goals were two-fold: increase wine quality in the region, and increase the industry's sustainability in the region. To promote and assess sustainability, the program uses a Positive Points System, where participants answer 152 questions, receiving points for each question, weighted by the particular issue's sustainability impact on the region (Broome and Warner 2008). IPM adoption is one component of the program's sustainability focus. Through demonstrations and research, CCVT promotes the use of biological control and the use of reduced risk pest control methods (Central Coast Vineyard Team 2010) .

By 2007, CCVT had about 300 members representing almost 25,000 ha of wine grape production. About 750 assessments had been done, with some members repeating assessments in multiple years. On average, assessment scores increased by about 50 points out of a possible 1,000 between 1996 and 2006. While this average is a modest increase, almost 10 % of 166 growers who repeated assessments increased by at least 300 points and all but 13 of the repeat assessments increased in points (Broome and Warner 2008). While increases may be slow, they are occurring for many growers.

In addition to the points system, CCVT launched a third party certification in 2008. Growers who attain 75 % of the possible points in the Positive Points System can become certified and label their bottles with the Sustainability in Practice (SIP) Certification label. Currently, 350,000 cases of wine are certified by SIP (Sustainability in Practice (SIP) Certification Program 2012). While this program is still new, the establishment of this label may enable growers to receive a price premium for their wines, potentially encouraging other growers to adopt sustainable practices including IPM.

In the Lodi, California winemaking region, all growers producing more than 25 tons of wine grapes annually must belong to the Lodi Winegrape Commission (LWC). LWC was established in 1991 by a grower vote, and levies a tax of 0.45 % of the grape production value. Revenue goes towards promotion of the region's wines, research, and grower outreach. In 1998, LWC developed the *Lodi Winegrowers Workbook: A Self Assessment of Integrated Farming Practices*. The workbook provides information to growers about sustainable practices and provides materials for growers to develop a plan for sustainable management (Broome and Warner 2008).

Like CCVT, LWC has created a third party label that growers can use if they meet the qualifications for certification. The standards for production were determined by a team including growers, vintners, vineyard consultants, a wildlife biologist, and University of California farm advisors and scientists. One of the areas required for certification is the use of IPM. To assess the grower's pest management, they use a pesticide environmental impact model that considers risks to workers, consumers, aquatic invertebrates, birds, bees, and natural enemies of the pests. Since the creation of the certification in 2005, certified hectares have increased from about 590 to more than 8,050 in 2010 (Lodi Winegrape Commission n.d.).

The creation of third-party certifications such as those of CCVT and LWC help to ensure a more objective evaluation of grower practices than things like assessment workbooks or self-reported levels of adoption. As these two programs develop and spread, there is potential for better monitoring of adoption, and there is also potential for growers and winemakers to capture higher prices due to the eco-label. Organic labels have not yielded price premiums for growers (Delmas and Grant 2010), but broader-based labels that include all aspects of sustainability may yield the elusive price premium. Such price premiums, however, will depend on how clearly the general public understands what is implied by the label.

While third-party certification and labeling is an option for products like wine where consumers generally spend some time reading the product's label, they may have less potential for products like fresh-fruit where consumers do not generally look at the small sticker on the product. Labeling could have larger potential for processed fruit products such as juices or dried fruit.

6.6.2 California Pear Growers and IPM

Codling moth, *Cydia pomonella* L, control in pear orchards in the western United States is a prime example of IPM success. The codling moth, a major pest of both apples and pears, was introduced to California in 1872. In the early 1900s, growers relied on lead arsenate and other stomach poisons to control the moth. In the 1950s, growers transitioned to DDT and other chlorinated hydrocarbons. In the late 1950s until recently, growers relied on azinphos-methyl (AZM), other organophosphates, and carbamates. By the 1970s, growers were applying fourteen pesticides to control 30 different pests, with limited success to due increasing pesticide resistance (Weddle et al. 2009).

Faced with rising control costs and rising pest damage, pear growers from the Sacramento River area requested help from the University of California Cooperative Extension (UCCE) with regards to pest monitoring. The UCCE/USDA Smith-Lever Cooperative Pear IPM Project (UCPIPM) began in 1973 to address this request. The project developed monitoring techniques and economic thresholds. Initially, the project spanned 1,389 ha but had expanded to 2,866 ha by 1977. Growers still relied on AZM, but only made applications when codling moth populations exceeded threshold levels (Weddle et al. 2009).

Despite these efforts, the codling moth developed increasing resistance to AZM and pyrethroids in the 1980s, leading to increased application rates and more resistance. In 1989, pheromone mating disruption was used experimentally on an apple and pear orchard in the Sacramento Delta (Weddle et al. 2009). In 1991, Pacific

Biocontrol developed a dispenser to dispense a synthetic pheromone mixture, with an active ingredient that was registered in California in 1992 (Weddle et al. 2009; Calkins and Faust 2003).

Preliminary work with pheromones suggested that they could be an effective management tool when codling moth populations were low. However, they were not as effective for high codling moth populations or along field borders. This prompted the Randall Island Project, an area-wide project, initiated in 1993 and funded by the California Pear Advisory Board and the Pear Pest Management Fund, to determine if better control was possible when large areas of land were managed cooperatively. The project also sought to increase the use of natural enemies in pear IPM and minimize resistance problems. The collaborative project included a diverse group of stakeholders including University of California researchers, UCCE agents, five growers from the Sacramento area, fruit processors, and pest control advisors. The project managed 308 contiguous hectares in the Sacramento Delta (Weddle et al. 2009).

Although the project sought to minimize the use of AZM, in most cases at least one application of AZM or parathion-methyl was required to lower population levels to a level at which pheromones could provide adequate control over the course of the growing season. Even though chemical pesticides were still in use, fewer applications were required and use decreased by 70–80 %. Over the 7-year study period, resistance lessened when AZM applications were kept at a minimum and alternated with parathion-methyl. By 1999, codling moth damage was reduced to at most 0.2 % when pheromones were combined with a properly timed application of AZM or parathion-methyl. Within the project's area, field edge effects were largely non-existent except in cases where the edge bordered open areas (Weddle et al. 2009).

By 2001, 90 % of the pear acreage in the Sacramento River region had adopted pheromones as a method of control for codling moth (Weddle et al. 2009). Growers who had been applying 14 high-risk pesticides, now apply only 5–6 organic or low-risk pesticides. Figure 6.1 illustrates AZM and pheromone use from 1990 to 2010. A sharp drop in AZM use occurs in the late 1990s. Cost effectiveness was a large contributing factor to the decline in AZM use and pheromone adoption. The use of pheromones costs about $ 271 per hectare, coinciding with the cost of about three conventional pesticide applications (Calkins and Faust 2003). Since growers were applying more than three pesticide applications, the use of pheromones was an appealing option. Pest control advisors with previous training in IPM were also a contributing factor to the adoption of this technique (Weddle et al. 2009).

While the Randall Island Project centered on one region, pear growers across the state of California have high rates of IPM adoption, likely due to the success of the Randall Island project. 97 % of pear growers monitor for pests using pheromone traps, and 91 % use pheromones for mating disruption of key pests. Over the past 12 years, pear farmers have decreased their use of organophosphates and carbamates by 91 %. More than 70 % of pear growers consider pesticide residue periods and impacts on aquatic invertebrates, beneficial insects, mammals, and water quality (California Pear Advisory Board 2011).

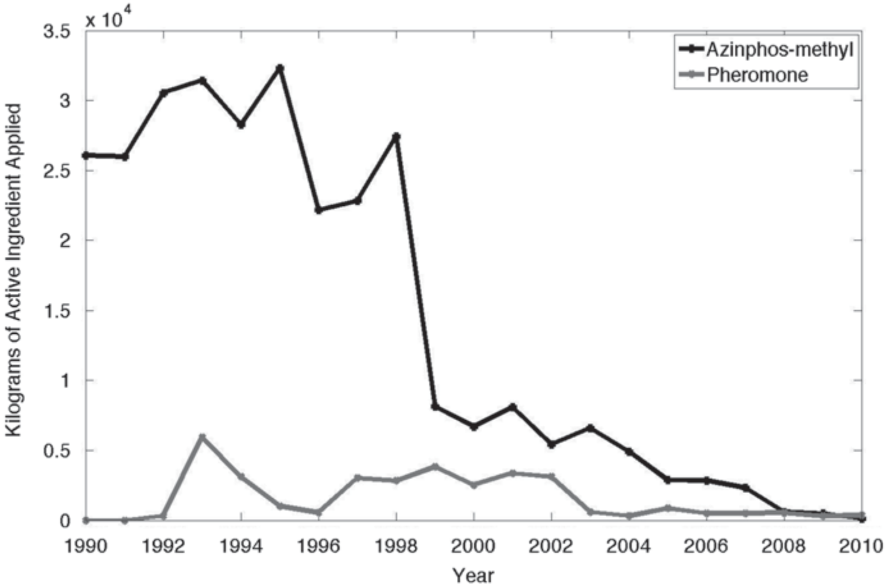

Fig. 6.1 Azinphos-methyl and Pheromone Use (Kilograms of Active Ingredient) on Pear Orchards in California. With widespread adoption of pheromone use, azinphos-methyl use on pear orchards in California declined sharply. (Source: California Department of Pesticide Regulation Pesticide Use Reporting Data, 1990–2010 (California Department of Pesticide Regulation 2010))

6.6.3 WashingtonTree Fruit Growers and IPM

Codling moth, being a pest of both apples and pears, has been a troublesome pest for apple growers and much work has been done to develop an IPM program for apple growers. In Washington, the Washington Tree Fruit Commission funded 2 years of the Pest Management Transition Program (PMTP), designed to help growers transition to IPM after the Environmental Protection Agency's decision to phase out AZM. Following these 2 years, the USDA's Specialty Crop Block Grant Program funded two more years of the Apple IPM Transition Project (AIPMTP), largely a continuation of the PMTP (Brunner 2011).

The PMTP focused in Implementation Units (IUs), consisting of growers and consultants. In total, the project included 136 IUs, spanning more than 38,040 ha of apple orchards. This covered about 55 % of Washington's apple hectares. These IUs committed to learning IPM methods to replace AZM and other chemical controls and shared their experiences with others. Most learning was done through the AIPMTP (previously PMTP) Handbook. In addition to distributing this handbook to IUs, PMTP/AIPMTP distributed it to the entire industry, posted the handbook online, and created a Spanish language version to spread IPM information as thoroughly as possible (Brunner 2011).

In addition to the handbook, the project included a variety of interactive learning tools. Field days educated growers about monitoring, calibrating sprayers, and implementing biological control. A Pest Management Fruit School was delivered both in person and remotely, reaching 183 participants. The school educated growers about the transition to new forms of pest control, allowing them to move away from organophosphates. In addition to formal training sessions, researchers involved with the project met with 30 individual growers and organizations to learn about their concerns, their current knowledge, and how best to communicate information to farm workers (Brunner 2011).

Extensive surveying was another component of the project. Surveys were delivered in 2008 and 2010 to both growers and pest control consultants. The survey results illustrated concerns about the AZM phase out. In both years of the survey, 91 % of growers agreed that codling moth control costs would increase after the phase-out. Among consultants, 98 and 93 % agreed with this statement in 2008 and 2010, respectively, showing that at least among consultants, some experienced increased optimism. In both years, 68 % of growers agreed that codling moth control would be more difficult after the phase-out, and about half of the respondents agreed that effective AZM replacements existed (Brunner 2011). The latter response is particularly interesting because mating disruption has been shown to provide better control in most circumstances than AZM, for which resistance has been a problem.

While growers were pessimistic about transitioning, 50 and 59 % reported decreases in organophosphate use for codling moth control in the 3 years prior to 2008 and 2010, respectively. For consultants, those numbers are 35 and 75 %, representing a large increase in the number who decreased organophosphate use. By 2010, 24 % of growers had already stopped using AZM and 65 % were reducing their use of AZM. Only 8 % reported not reducing AZM use (Brunner 2010).

In addition to efforts to implement IPM for codling moth control among apple growers, efforts in Washington have taken place to promote IPM for a variety of pests for growers of apple, cherry, pear, and stone fruits. Implementation of IPM has become more complex in recent years due to legislation, new methods, increased knowledge about pest and natural enemy biology, invasive pests, and increases in pests that previously were only secondary pests. The Food Quality Protection Act of 1996 affected several pesticides that had previously been important for Washington tree fruit growers. In its aftermath, new pesticides have been developed, but these new pesticides tend to have shorter residue periods. The timing of a pesticide with a long residue period is less critical than the timing of these newer pesticides with short residue periods. To aid growers using these newer pesticides, researchers at the Washington State University Tree Fruit and Extension Center have developed a decision tool for growers (Jones et al. 2010).

In 2005, legislation expanded Washington's weather station network to create AgWeatherNet (AWN). AWN consists of 132 weather stations that transmit data to a central server. The Decision Aid System (DAS) combines these data with models developed for 10 insect pests, four diseases, and one postharvest skin disorder. Users can also enter data from their own stations to be combined with the models. In addition to using AWN data, the system uses forecasts from the National Oceanic and Atmospheric Administration. The system then provides localized management recommendations to growers for the next 1–10 days, including recommendations about sampling, applications, and critical times to avoid sprays to conserve natural enemy populations. It can also provide recommendations for organic growers (Jones et al. 2010).

After implementation in April 2007, about 259 users logged in at least 10 times by 2008. In a survey of users, almost half were at least 50 years old, indicating that the internet platform was not necessarily limiting use among older growers who may be less familiar or less comfortable with internet and computer use. About two-thirds of users had at least a college degree. The state average is only 30 %, suggesting that users are more educated than the average population. Just over half of users learned about DAS through industry meetings, while about a quarter learned about it from a friend, colleague, employer, or supervisor. Respondents reported using DAS data on 2,888 orchards and 101,209 ha. The state contains about 3,000 orchards spanning 87,180 ha. The reported numbers are high because some hectares and orchards had multiple users reporting the same fields, and this overlap could not be distinguished from unique observations. Users predominantly grew apples (98.4 %), followed by cherries (80.3 %), pears (58.3 %), and stone fruits (34.6 %). Many growers produce multiple kinds of tree fruits (Jones et al. 2010).

Almost 20 % of users reported that DAS had a “very large impact” on their management decisions, while about 58 % indicated that it “somewhat” affected their decisions. About 80 % indicated that DAS affected them by altering their timing of control methods, and about 65 % indicated that it helped to clarify their scheduling (Jones et al. 2010).

Washington fruit growers highlight several facets of IPM implementation. First, growers may be pessimistic about changes, particularly legislatively mandated changes, even when effective alternatives exist; change is not always a welcome entity. Second, IPM is highly complex, particularly when multiple pest species must be managed simultaneously. Tools like DAS simplify decisions by keeping track of pest and beneficial insect populations through weather modeling so that growers do not need to spend their time calculating life cycle events or sampling at times when sampling is not necessary. It also simplifies the need to consider natural enemies of all pests when thinking about control of a particular pest because the system will provide the necessary warnings about unintended negative effects.

6.6.4 Pear and Apple Growers and Codling Moth IPM

While many IPM programs focus on one crop, there are some pests than damage more than one crop, and IPM practices used to control the pest are applicable across crops. This is the case with codling moth. At the same time that pear growers in the Sacramento River region were experimenting with area-wide management and apple growers in Washington were developing an IPM program, apple and pear growers throughout California, Oregon, and Washington were working together as part of the codling moth area-wide projects (CAMP). These projects, funded by the USDA, ran from 1994 to 2000, and included researchers from Washington State University, Oregon State University, University of California-Berkeley, the Washington State Tree Fruit Research commission, fruit packinghouses, farm supply companies, the USDA's Agricultural Research Service, and growers (Calkins and Faust 2003).

CAMP had several objectives including demonstrating the efficacy of mating disruption for codling moth control when used on a large spatial scale, developing non-chemical control of major fruit pests, assisting growers with a transition from their previous pest control methods that relied heavily on chemical control to IPM, developing monitoring techniques and threshold population levels, and improving the general public's perception of the environmental impact of fruit production. To accomplish these objectives, they created 5 sites, including the Randall Island Project discussed in Sect. 6.6.2. The sites ranged in size from 120 ha at a site in southern Oregon to 440 ha at a site near Chelan, Washington (Calkins and Faust 2003).

This project used extensive monitoring to accurately determine the effects of the control methods on both the pest and natural enemy populations. They sampled for codling moth, oblique banded leafroller (*Choristoneaura rosaceana*), leafroller (*Pandemis* sp), white apple leafhopper (*Typhlocyba pomaria* McAtee), aphids, pear psylla (*Psylla pyricola* Foerster), leafminers, and leafminer and leafhopper parasite rates. While many growers were initially hesitant to participate, as pesticide use decreased significantly, more growers joined the program, and additional sites were added. The range of sites expanded into Colorado (Calkins and Faust 2003).

At the start of CAMP, growers in Oroville, WA applied up to six applications to control codling moths with damage rates between 5 and 8 %. By 1999, growers were using 0.7 sprays and damage rates were less than 0.2 % in most areas. Prior to CAMP, only 400 ha were under mating disruption in Washington. By 2000, 40,000 ha were under mating disruption. This 100-fold increase was in large part due to the example created by CAMP (Calkins and Faust 2003).

CAMP is a prime example of a case where IPM implementation was quite successful. The key features of its success were a need for new methods due to growing pesticide resistance, a large team of collaborators drawing from the entire production chain as well as researchers, and a participant base that covered all relevant growers spanning three and eventually four states and two crops. In addition, word of mouth networks spread the news of the success of the program, helping to get more growers involved. In the case of codling moth control, and likely many other pests, the more growers who are involved and coordinated, the more successful the program will be for all involved. Getting past the collective action problem can be a large hurdle, but the CAMP project was able to overcome that hurdle.

6.7 Discussion and Conclusions

These case studies highlight certain features of successful IPM implementation. First, all successful programs had a large impetus for change: legislation, resistance, or public pressure. Transitioning to IPM is time-intensive and risky. A transition will not occur without a strong motivating factor.

Second, research and extension are paramount. The development of an IPM program is complex and requires experimentation and time to develop. Individual growers are understandably reluctant to experiment on their own and likely do not have the time to invest in the kind of research necessary for a successful program. All of the successful IPM projects discussed had great involvement from university and industry researchers and extension agents. Such entities have the time and resources to develop IPM programs and have the ability to absorb the risk of a particular program failing. In the case of stone fruit growers transitioning away from organophosphates, without targeted extension, the growers simply substituted one pesticide for another instead of re-working their entire pest management plans to focus on IPM. When legislation requires eliminating pesticides, a simple one-at-a-time one-for-one substitution will meet legislative requirements but will most likely not result in optimal pest management decisions.

Third, a broad scope is required for superior implementation. In the case of codling moth control, IPM is most successful when used on all crop land. This entails multiple states and two different crops. Without cooperation across political and agronomic boundaries, IPM implementation would have struggled from edge effects. Since many growers receive information through growers associations and crop advisory boards, control may end up splintered by crop instead of encompassing all relevant crops. Care must be taken to ensure that all relevant stakeholders are involved with implementation.

Fourth, IPM is situation-specific and must constantly evolve as conditions change. Some controls work best within certain pest population ranges and pest and beneficial insect populations will vary across space due to environmental and climatic variation. This prevents the possibility of a one size fits all program. Additionally, new invasive pests and shifting levels of historical pest populations create new combinations of pests, requiring constant modification of the IPM program. Tools like DAS can help alleviate some of these problems by utilizing local weather data that is continuously updated so that growers can time applications based on their area's conditions for that particular growing season.

Despite the challenges inherent in IPM, some of the large successes that have occurred in the western U.S. suggest that these challenges can be overcome with creative tools, collaborative effort, and a willingness to try new methods. If legislation continues to restrict pesticide options and if pesticide resistance continues to be problematic, IPM adoption will likely increase to address these issues. The creation of third-party certification and labeling may also create further incentives for IPM adoption if growers can capture a price premium for using sustainable methods.

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Chapter 7
The Impact of Integrated Pest Management Programs on Pesticide Use in California, USA

Lynn Epstein and Minghua Zhang

Contents

Abstract Integrated Pest Management (IPM) is often promoted to farmers as a method that can provide the most economical, sustained disease and pest control, but promoted to the public as a method to reduce agricultural pesticide use. California has a public infrastructure for supporting IPM research and implementation, largely through the University of California IPM program. California's Department

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of Pesticide Regulation's Pesticide Use Reports provide a system to track pesticide use state-wide. In practice, IPM in California is extremely pesticide-dependent, particularly in weed control and in agricultural production systems that rely on soil fumigation, such as strawberries. During our study period between 1993 and 2010, California had a decrease in use of 88 % of the highly-used pesticides listed for regulatory concern for human health. However, most of these pesticides were replaced with other chemicals rather than with non-chemical methods. We feature several case studies that illustrate key issues in California IPM: the limited progress in meeting Montreal Protocol guidelines for methyl bromide phase-out due to critical use exemptions for strawberry producers; a successful IPM program to decrease use of dormant-season organophosphates that are important water pollutants; the increase in use of neonicotinoid insecticides, which might have a role in the current bee colony collapse disorder; and the limited use of all of the commercialized microbial biocontrol agents except for *Bacillus thuringiensis*.

Keywords Agriculture · Biological control · Fumigants · Fungicides · Herbicides · Insecticides · Methyl bromide

7.1 Trends in Agricultural Pesticide Use in California from 1993 to 2010

7.1.1 Monitoring Pesticide Use with the California Pesticide Use Reports

Here we show trends in agricultural pesticide use from the California Pesticide Use Reports (PUR) database, an extensive pesticide reporting system that started in 1990 and achieved reasonable data quality in 1993 (Epstein 2006). According to California law, (http://www.cdpr.ca.gov/docs/legbills/calcode/subchpte.htm#pur), all commercial agricultural pesticide use in California must be reported weekly to county agricultural commissioners, who then forward the data to the California Department of Pesticide Regulation (DPR). Pesticide applications to schools and day care facilities, parks, golf courses, cemeteries, rangeland, pastures, and along roadside and railroad rights-of-way are also reported but on a monthly basis, as are postharvest pesticide treatments of agricultural commodities and pesticide treatments in poultry and fish production and in some livestock applications. Home-and-garden use and most industrial and institutional use are exempt from reporting. Each PUR record contains information on the following: a grower identification code with an indication of whether a grower or a commercial pest control operator filed the report; the crop treated; the number of acres of the crop that the grower planted; the grower's identification of the particular field treated (the site location identification); the geographic location (township, range and section) of the treated field to within a square mile (2.59 km^2); the county code; the application date; the active ingredient; the number of acres (or other units, 1acre = 0.405 ha) treated; the pounds (1 pound = 0.45 kg) of active ingredient applied; the pesticide product used; the formulation; the pounds of product applied; and application method (by air or on the ground).

Individual records and summaries of the PUR are available from DPR (http://www.cdpr.ca.gov/docs/pur/purmain.htm). The California Healthy Schools Act of 2000 established specific right-to-know requirements for pesticide use in public schools (Barnes et al. 2012). Although there are errors in the PUR that can be addressed in a variety of ways (Epstein et al. 2001; Epstein 2006), the PUR remains the most comprehensive pesticide use reporting system in the world.

7.1.2 General Trend of Decreasing Use of Chemicals of Regulatory Concern

Table 7.1 shows trends in the mass of major agricultural pesticides of major regulatory concern that were applied in California between 1993 and 2010. The table includes data for 48 compounds that were applied in relatively large quantities in agriculture (i.e., more than 10,000 kg in either 1993 or 2000), and that appear on at least one of five lists: the California State Proposition 65 (CP65) list of reproductive toxins; either the CP65 carcinogen list or the U.S. EPA B2 probable carcinogen list; the U.S. Food Quality Protection Act list of organophosphates and carbamates; the DPR groundwater protection program list of compounds; and the DPR toxic air contaminants list as of 2010. Of the 49 compounds in Table 7.1, 43 (88 %) have declined in use, and have been at least partially replaced by materials of lesser regulatory concern. Nonetheless, only three (benomyl, cacodylic acid, and cyanazine) of the 43 compounds with declining use, or 7 %, are no longer in use, while others are still used extensively. Two (methyl bromide and metam sodium), or 5 % of the 43 compounds, have current annual use (averaged over the 2008–2010 period) of 2.2 and 4.4 million kg, respectively, while another 42 % have annual use in the 10^5 kg range and 37 % have annual use in the 10^4 kg range. Thus, despite use reduction these pesticides remain of considerable regulatory concern.

The U.S. Food Quality Protection Act has been an important driver of changes in organophosphate (OP) and carbamate usage in California and in the U.S. (Van Steenwyk and Zalom 2005). In the U.S., OP use declined from approximately 59 million kg in 1980 to 38 million kg in 1990, and then vacillated around this level until 2001 (Grube et al. 2011). Starting in 2002, OP use declined further to 15 million kg in 2007. As suggested in Table 7.1, OP use has declined in multiple crops in California. PUR data has been used to show declining use of OPs in pears (Weddle et al. 2009). In Sect. 7.3.1 we discuss data on declines in OP use in dormant almond and stone fruit orchards in California. Zhang and Zhang (2011) used PUR data to show a declining use of the most toxic miticides by California winegrape growers.

California has avoided certain environmental issues by never registering some of the pesticides that are commonly used in the rest of the U.S. In 2007, the herbicide acetochlor was the 5th ranked most commonly used agricultural pesticide in the U.S. (Grube et al. 2011). However, acetochlor is on the CP65 known carcinogen list, and is not registered in California.

Table 7.1 Trends in use of the main pesticides of regulatory interest that were used in agriculture in California between 1993 and 2010[a].

Agricultural use	Compound[b]	Annual average applications, kg			Linear regressions, 1993[c]–2010, if $R^2>0.50$		Risk groups[b]
		1993–1995	2008–2010	% change	Slope, kg/yr	R^2	
Defoliant	s, s,s-Tributyl phosphorotrithioate	4.2×10^5	6.2×10^3	−99	-2.7×10^4	0.91	N, A
Fumigant	*Chloropicrin*	1.1×10^6	2.6×10^6	*+130*	1.0×10^5	0.96	A
Fumigant	*1,3-Dichloropropene*	7.1×10^4	3.7×10^6	*+5120*	2.7×10^5	0.86	C, A
Fumigant	*Metam potassium*	0	2.2×10^6	*(new)*	2.3×10^{5}[c]	0.88[c]	A
Fumigant	Metam sodium	5.3×10^6	4.4×10^6	−17	–	–	R, C, A
Fumigant	Methyl bromide	7.5×10^6	2.3×10^6	−69	-3.8×10^5	0.85	R, A
Fungicide	Benomyl	1.4×10^5	2.8×10^1	−100	-9.6×10^3	0.59	R
Fungicide	Captan	2.8×10^5	1.7×10^5	−40	–	–	C, A
Fungicide	Chlorothalonil	4.7×10^5	3.4×10^5	−28	–	–	C
Fungicide	Iprodione	2.6×10^5	1.3×10^5	−51	-9.8×10^3	0.69	C
Fungicide	Mancozeb	2.6×10^5	2.1×10^5	−20	–	–	C, A
Fungicide	Maneb	5.2×10^5	2.9×10^4	−45	–	–	C, A
Fungicide	Myclobutanil	7.3×10^4	2.8×10^4	−61	–	–	R
Fungicide	*Propamocarb HCl*	0	4.8×10^4	*(new)*	–	–	N
Fungicide	Thiophanate methyl	6.0×10^4	4.2×10^4	−30	–	–	R
Herbicide	2,4-D	3.3×10^5	2.6×10^5	−21	–	–	A
Herbicide	Acephate	1.8×10^5	6.0×10^4	−67	-8.7×10^3	0.88	N
Herbicide	Atrazine	2.0×10^4	1.2×10^4	−41	–	–	W
Herbicide	Bromacil	6.5×10^4	2.9×10^4	−56	–	–	W
Herbicide	Bromoxynil	5.7×10^4	3.8×10^4	−34	-2.0×10^3	0.55	R
Herbicide	Cacodylic acid	2.8×10^4	6.9	−100	-1.8×10^3	0.70	C
Herbicide	Cyanazine	2.6×10^5	0	−100	-1.8×10^4	0.74	R
Herbicide	Diuron	5.3×10^5	2.9×10^5	−45	–	–	C, W
Herbicide	EPTC	3.3×10^5	5.4×10^4	−83	-1.9×10^4	0.87	R, N
Herbicide	Molinate	6.8×10^5	3.6×10^3	−99	-4.7×10^4	0.96	R, N
Herbicide	Norflurazon	7.4×10^4	2.2×10^4	−70	–	–	W
Herbicide	Oryzalin	3.1×10^5	2.6×10^5	−15	–	–	C
Herbicide	Propyzamide	5.3×10^4	3.5×10^4	−35	–	–	C

Table 7.1 (continued)

Agricultural use	Compound[b]	Annual average applications, kg			Linear regressions, 1993[c]–2010, if $R^2>0.50$		Risk groups[b]
		1993–1995	2008–2010	% change	Slope, kg/yr	R^2	
Herbicide	Simazine	4.3×10^5	1.9×10^5	−57	-1.5×10^4	0.87	W
Herbicide	Thiobencarb	1.9×10^5	1.2×10^5	−36	–	–	N
Herbicide	Trifluralin	6.3×10^5	2.5×10^5	−60	–	–	A
Insecticide	*Bensulide*	2.9×10^4	1.1×10^5	*+286*	5.6×10^3	0.76	N
Insecticide	Carbaryl	3.8×10^5	5.6×10^4	−85	-2.3×10^4	0.85	R, C, N, A
Insecticide	Chlorpyrifos	1.4×10^6	5.9×10^5	−57	-5.2×10^4	0.75	N
Insecticide	Diazinon	6.2×10^5	7.9×10^4	−87	-3.6×10^4	0.94	N
Insecticide	Dimethoate	2.9×10^5	1.1×10^5	−61	-1.1×10^4	0.84	N
Insecticide	Endosulfan	1.6×10^5	2.1×10^4	−87	-8.6×10^3	0.79	A
Insecticide	Malathion	3.5×10^5	2.4×10^5	−33	-9.0×10^3	0.66	N
Insecticide	Methamidophos	1.8×10^5	7.8×10^3	−96	-1.1×10^4	0.71	N
Insecticide	Methidathion	1.7×10^5	2.2×10^4	−87	-1.0×10^4	0.80	N, A
Insecticide	Methomyl	3.3×10^5	1.1×10^5	−68	-1.7×10^4	0.81	N
Insecticide	Naled	2.1×10^5	7.7×10^4	−63	–	–	N
Insecticide	Oxydemeton-methyl	5.5×10^4	3.8×10^4	−31	–	–	R, N
Insecticide	Phosmet	1.1×10^5	8.9×10^4	−16	–	–	N
Insecticide	Propargite	8.3×10^5	1.6×10^5	−81	-4.7×10^4	0.93	R, C
Insecticide/nematicide	Aldicarb	1.3×10^5	2.6×10^4	−79	-9.7×10^3	0.51	N
Insecticide/nematicide	Carbofuran	1.2×10^5	3.9×10^3	−97	-8.7×10^3	0.87	N
Insecticide/nematicide	*Oxamyl*	3.2×10^4	4.0×10^4	*+25*	–	–	N
Plant growth regulator	Ethephon	4.3×10^5	1.3×10^5	−69	-1.9×10^4	0.83	N

[a] Data are from the California Department of Pesticide Regulation's (DPR) http://www.cdpr.ca.gov/docs/pur/purmain.htm. Pesticide Use Reports. Only compounds of regulatory interest that were applied in a total quantity greater than 10,000 kg in either 1993 or 2010 are included. Compounds in which the quantity is greater (> 110 %) in the 2008–2010 annual average than in the 1993–1995 annual average are highlighted in italic

[b] *R,* listed in California state Proposition 65 (CP65) as known to have reproductive toxicity; *C,* listed as either a U.S. EPA B2 carcinogen or in the CP65 as causing cancer; *N,* organophosphate and carbamates that are cholinesterase-inhibitors, and targeted by the U.S. Food Quality Protection Act; *W,* listed in the California DPR groundwater protection list, part a; *A,* listed as a California DPR's toxic air contaminant

[c] Slopes and R^2 for metam potassium were based on 2000 (first use) to 2010

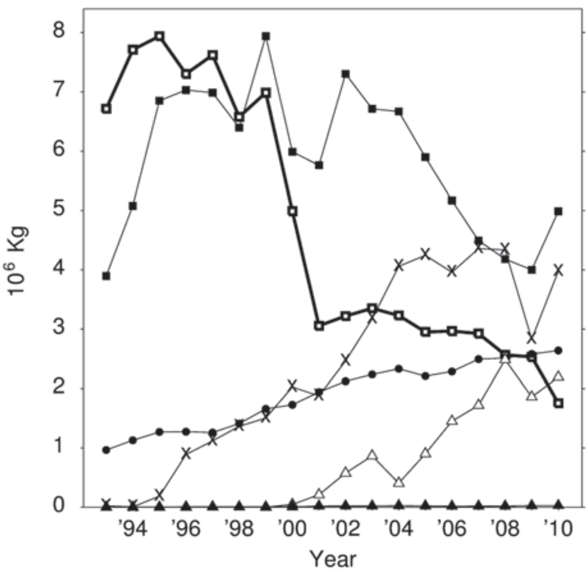

Fig. 7.1 Mass in millions of kg of agricultural fumigants used in California between 1993 and 2010. The data show the partial replacement of methyl bromide (□, thicker line) with 1,3-dichloropropene (X), chloropicrin (●), metam potassium (potassium n-methyldithiocarbamate) (Δ) and dazomet (▲); metam sodium (■) has been used throughout the period. Data are from the California Department of Pesticide Regulation's Pesticide Use Reports. http://www.cdpr.ca.gov/docs/pur/purmain.htm

7.1.3 An Example of Replacement of One Chemical with Others

The Methyl Bromide "Phase-Out" and its Replacements in California. Despite the extensive literature on substitution or reduction of chemical use with IPM, in practice, there are many more examples of replacement of one chemical for another. In Fig. 7.1, we show data for fumigants applied in California from 1993 to 2010. Because methyl bromide that is released into the atmosphere from fumigation ultimately decreases UV protection by the upper ozone layer, the Montreal Protocol and subsequent international agreements mandated the global phase-out of methyl bromide as an agricultural fumigant starting in the early 1990s (Grahl 1992). Many countries around the world have ceased its use (Schafer 1999). The U.S. phase-out strategy called for freezing the yearly amounts used from 1993 to 1998 at 1991 levels (~25,500 metric tons $=2.5\times10^7$ kg for "total consumption", = production + imports − exports), a 25 % reduction from that baseline between 1999 and 2000, a 50 % reduction from baseline during 2001–2002, a 70 % reduction from baseline during 2003–2004, and a complete phase-out by 2005 except for allowable exemptions, such as the critical use exemptions that the Montreal Protocol Parties accept. The U.S. nominated critical use exemptions at 39 % of baseline in 2005 and was authorized at 37 %; the nominations and slightly lower authorizations have declined yearly, to a 12.7 % nomination in 2010, and a 1.7 % nomination in 2014. As shown in Fig. 7.1 and Table 7.1, methyl bromide use declined by 69 % during the 1993–2010 study period ($R^2=0.85$) . However, California is far from a phase-out with 1.8 million kg of methyl bromide applied in 2010. In addition, methyl bromide declines (slope $=-3.8\times10^5$ kg/year) have been accompanied by an increase in the use of four other fumigants as methyl bromide replacements: 1,3-dichloropropene (slope = 2.7×10^5 kg/year; $R^2 = 0.86$); metam potassium (slope = 2.3×10^5 kg/year starting with its registration in 2000; $R^2 = 0.88$); dazomet (slope = 2.3×10^5 kg/year; $R^2 = 0.76$;); and chloropicrin (slope = 1×10^5 kg/year; $R^2 = 0.96$). All of the alternatives have their own exposure toxicity risks and all fumigants generate toxic volatile organic compounds. Although metam sodium can be used as a methyl bromide replacement, overall, it had a modest (17 %) decline in use between the 1993–1995 and the 2008–2010 periods. We note that the mechanism of pesticidal activity of three methyl bromide replacements (metam sodium, metam potassium and dazomet) are similar in that they depend on the release of methyl-isothiocyanate (MITC) during breakdown. Methyl iodide (iodomethane) was registered briefly in California in 2010 as a methyl bromide replacement, but was then removed from the market by its manufacturer.

There are many contributing factors for both the continued use of methyl bromide and, to the extent that it has been replaced with other fumigants, its replacements. In California, many crops (e.g., strawberries, stone fruits, nuts, grapes, peppers, and carrots), strawberry plant nurseries and the ornamental industry rely on pre-plant fumigation of the soil to kill pathogens and nematodes. Indeed, the California Department of Food and Agriculture (CDFA) Nursery Stock Nematode Control Program requires that tree, strawberry and grapevine nurseries produce nematode-free crops, which is difficult to achieve without fumigants. At the same time, fumigant use is constrained by regulations of the U.S. Environmental Protection Agency and the California Department of Pesticide Regulation (DPR), which require buffer zones, township caps (generally the amount that can be applied in a 93 km^2 area), and low emissions in California's Air Quality Non-Attainment Areas. The majority of California's major agricultural areas have been declared as federal non-attainment areas and are subject to California regulations to reduce emissions from fumigant pesticides; these areas include the entire San Joaquin Valley, Ventura County, the South Coast and Southeast desert (which includes the Coachella Valley), and the Sacramento Metropolitan area (Goodell et al. 2011). Township caps are particularly limiting for applications of 1,3-dichloropropene (1,3-D), which is on California's Proposition 65 carcinogen list. Although the DPR suspended use of 1,3-D in 1990 when it was detected above air quality standards in Merced County, it allowed 1,3-D applications to begin again in 1994, subject to regulation. Carpenter et al. (2001) estimated that township caps would limit the permits for 1,3-D in 47 townships, particularly in the strawberry-producing counties of Monterey and Ventura. Consistent with these caps, the use of 1,3-D has been flat between 2004 and 2010 (slope = 0, $R^2 = 0.16$) (Fig. 7.1).

Methyl bromide has been the foundation of soil-borne pathogen, nematode and weed control in California strawberry fruit production fields for the past 50 years (Schneider et al. 2003; Wilhelm and Paulus 1980) . University of California (UC) researchers were instrumental in the research and development of agricultural fumigants. Initially, Wilhelm and Koch (1956) used chloropicrin to control the fungal pathogen *Verticillium dahliae* in strawberry. Then, methyl bromide was added because it augmented the fungicidal properties of chloropicrin and also controlled weeds (Wilhelm and Paulus 1980). Importantly, a combined application of methyl bromide + chloropicrin provides a poorly understood growth promotion to strawberry (Wilhelm and Paulus 1980; Larson and Shaw 1995) and annual plants (Duniway 2002). The most common speculation about this activity of methyl bromide + chloropicrin is that in addition to killing well-characterized pathogens it also kills a highly variable array of organisms that are either difficult to culture (Johnson et al. 1962) or that are non-lethal root 'nibblers.' However, growth promotion might occur via a nutritional mechanism (Millhouse and Munnecke 1979) or one that affects microbial and enzymatic functions in soil (Stromberger et al. 2005). Regardless, contemporary strawberry production has been developed with methyl bromide fumigation. In California, strawberry fruit production increased from 38 metric tonnes per ha in 1972 to 150 metric tonnes per ha in 2010. Particularly in the major south and central coastal production areas, strawberries are produced year after year with no rotation. While the yield increases occurred by optimizing cultivars and cropping practices, "conventional" fields were all pre-plant methyl bromide/chloropicrin-fumigated.

Historically and currently, most of the methyl bromide fumigation in the U.S. is in soil for strawberry fruit production. In 2011, California growers produced 2.57 billion pounds (1.17 billion kg) of strawberries, accounting for 89% (USDA 2011) of U.S. production (California Department of Food and Agriculture 2013). The U.S. Department of Agriculture (USDA) lists the following as registered methyl bromide alternatives: 1,3-D; chloropicrin; dazomet; dimethyl disulfide; metam sodium; the herbicide terbacil (with minor use in California); 1,3-D + chloropicrin; 1,3-D + chloropicrin + metam sodium; and metam sodium + chloropicrin (http://www.epa.gov/ozone/mbr/alts.html#***). Critical use exemptions are allowed when "(i) … lack of availability of methyl bromide … would result in a significant market disruption; and (ii) there are no technically and economically feasible alternatives or substitutes available to the user that are acceptable from the standpoint of environment and public health and are suitable to the crops and circumstances of the nomination." The 2014 U.S. critical use nomination exemption includes 415,607 kg methyl bromide (94 % of the entire U.S. nomination) for fumigation of soil for strawberry fruit production in California. The nomination was based on an application from the California Strawberry Commission, a private commodity group that works closely with UC researchers. The nomination argues for methyl bromide treatment of 16 % of the strawberry fruit acreage for the following reasons: the 1,3-D caps limit the availability of that fumigant; iodomethane may not be accepted by consumers (and indeed is not available as of 2012); and two currently relatively minor pathogens, *Macrophomina phaseolina* and *Fusarium oxysporum* (Koike 2008; Koike et al. 2009) are not adequately controlled by the methyl bromide alternatives. In the nomination, the U.S. is focused on maintaining the yields and the profit margins achieved in a methyl bromide-system.

Interestingly, in contrast to predictions (Goodhue et al. 2005), the years of declining methyl bromide use have been years of increasing California strawberry yields, acreage, exports, revenue and market share (Mayfield and Norman 2012). Gareau and DuPuis (2009) argue that U.S.-backed policies of granting Montreal Protocol exemptions based on claimed economic losses to California growers is incompatible with meeting public health goals for protection of the ozone layer in the upper atmosphere. We contend that using methyl bromide as the standard—with its attendant control of soil-borne pathogens, weeds, and nematodes, and its plant growth promotion—reduces IPM into an Integrated Pesticide Management system that will ultimately inhibit the development of a fully sustainable agriculture that considers all of the environmental and health externalities.

Several fumigation and non-fumigation alternatives for California strawberries are in the testing stage. There have been advancements in fumigation tarps, which allow lower application rates (Fennimore and Ajwa 2011). Two non-fumigation methods are currently being tested: (1) steam, which is currently energy intensive but may become more efficient after further equipment modifications (Samtani et al. 2012); and (2) "anaerobic soil disinfestation," which has combined solarization (Morgan et al. 1991) with the addition of organic amendments. The combination of carbon source addition, soil saturation, and a plastic tarp helps generate higher temperatures, and generates temporary anaerobiosis and fungitoxic compounds. The anaerobic disinfestation of strawberry soil reduces pathogens but not weeds (Daugovish et al. 2011) and results in strawberry yields similar to fumigated treatments (Shennan et al. 2011). While rotation is the classic method to control plant disease and is used in organic strawberry production, because land costs are high and operating profit margins on strawberries are estimated currently at 17 % (http://www.epa.gov/ozone/mbr/CUN2014/2014CUNStrawberryFruit.pdf), conventional strawberry growers in California will not adopt rotation at this time.

7.1.4 Examples of Increased Use of Compounds that Have or Might Have Adverse Agricultural or Health Consequences

During the 50-year history of IPM (Stern et al. 1959), California agriculture has intensified with more monoculture, less rotation and larger acreages of plantings—factors that tend to increase pesticide use. As indicated above, many of the older materials of regulatory concern (Table 7.1) have decreased in use. For example, use of the organophosphate chlorpyrifos, which is targeted by the Food Quality Protection Act, declined between the 1993–1995 and the 2008–2010 periods by 57 % ($R^2 = 0.75$). Nonetheless, even though chlorpyrifos is an important water pollutant in California (Bailey et al. 2000), with use at 5.9×10^5 kg/year during the 2008–2010 period, it remains a highly used insecticide and miticide particularly on almonds, oranges, walnuts, alfalfa, wine grapes, and broccoli. Human health concerns about chloropyrifos remain (Rauh et al. 2012). Using a combination of PUR data, and historical amphibian survey data, Davidson (2004) found a significant association between applications of cholinesterase inhibiting pesticides (mostly organophosphates and carbamates) and downwind declines in multiple frog species in California.

Although chloropyrifos and the other organophosphate and carbamates have declined in use, they have been largely replaced by newer materials, which are often toxic to pests at lower masses, albeit with less mammalian toxicity. For example, neonicotinoid use has increased between 1993 and 2010 (Fig. 7.2), and may be involved in colony collapse disorder of honeybees (Henry et al. 2012; Isawa et al.

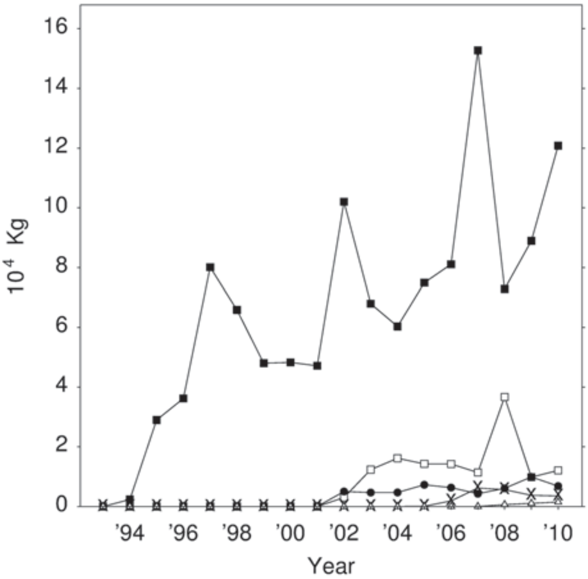

Fig. 7.2 Mass in 10^4 kg of neonicotinoids, a new class of insecticides and miticides, that were applied in California between 1993 and 2010, based on the California Department of Pesticide Regulation's Pesticide Use Reports <http://www.cdpr.ca.gov/docs/pur/purmain.htm>. The neonicotinoids have been implicated as a possible cause of colony collapse disorder in bees and include imidacloprid (■), acetamiprid (□), thiamethoxam (●), dinotefuran (X), and clothianidin (Δ)

2004; Schneider et al. 2012; Whitehorn et al. 2012). Honeybees are highly sensitive to numerous newer insecticides that have low mammalian toxicity (Casida 2012). In addition to neonicotioids such as imidacloprid (Isawa et al. 2004), examples of insecticides with high honeybee toxicity include the reduced-risk spinosad ($LD_{50}=3$ ng/g) and the pyrethroid deltamethrin ($LD_{50}=23$ ng/g) (Casida 2012).

7.1.4.1 Pesticide Resistance

The herbicide glyphosate has been the most-used pesticidal active ingredient in U.S. agriculture since 2001 (Grube et al. 2011). While it is not the dominant pesticide in California, glyphosate is currently the most extensively used herbicide in California by weight. Pesticide Use Report data on glyphosate use in California (Fig. 7.3) indicates an average increase of 1×10^5 kg/year ($R^2=0.89$) for the 1993–2010 period (Fig. 7.3). In contrast to the 17 herbicides of regulatory concern listed in Table 7.1, glyphosate is relatively free of environmental and health concerns. Although as discussed later, since California has relatively few genetically modified crops, the increase in glyphosate use is due to its low cost (it was off-patent in 2000), efficacy, and safety (Duke and Powles 2008). Two apparent consequences of increased glyphosate use are changes in the distribution of weed species and the emergence of herbicide resistance. In California, glyphosate-resistant strains have emerged in the following species: Italian ryegrass (*Lolium multiflorum*) (Jasieniuk et al. 2008); rigid ryegrass (*Lolium rigidum*); hairy fleabane (*Conyza bonariensis*); feral, genetically-modified glyphosate-resistant canola (Munier et al. 2012); jungle rice (*Echinochloa colona)* (Alarcón-Reverte et al. 2013); Palmer amaranth (*Amaranthus palmeri*); and horseweed (*Conyza bonariensis*) (Hanson et al. 2009). In the case of

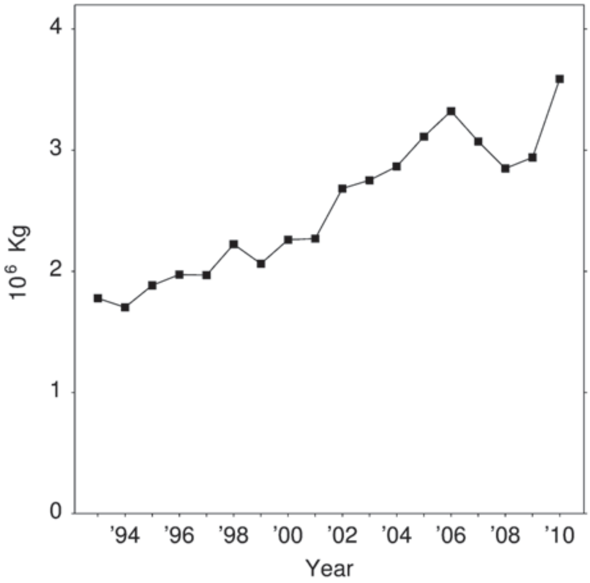

Fig. 7.3 Mass in millions kg of the herbicide glyphosate that was applied in California between 1993 and 2010, based on from the California Department of Pesticide Regulation's Pesticide Use Reports. <http://www.cdpr.ca.gov/docs/pur/purmain.htm>

glyphosate-resistant horseweed, the resistant strain has a greater impact on young grapevine growth than the glyphosate-susceptible strain (Alcorta et al. 2011). The International Survey of Herbicide Resistant Weeds lists 26 herbicide-resistant biotypes in California (http://www.weedscience.org).

Insecticide resistance (Zalom et al. 2005) and fungicide resistance (McGrath 2012) are also critical issues in California agriculture. UC IPM-recommended strategies for stalling fungicide resistance are based on recommendations of the Fungicide Resistance Action Committee (http://www.frac.info), which focuses on resistance avoidance by using products which vary in the fungal target site. Consequently, the UC IPM recommendations primarily involve alternation of fungicides with different modes of action. There are two ramifications of this recommendation. First, it tends to continue use of compounds of greatest regulatory concern, partly because these compounds often have multiple-sites of action and consequently are less likely to select for resistance. Second, the recommendations do not provide a strategy for avoiding selection of multi-drug resistant strains, which often have a mutation in a cellular pump that exports multiple drugs (Kretschmer et al. 2009).

7.1.4.2 Emergence of Secondary Pests After Pesticide Applications

There are many cases in which use of a pesticidal product ultimately results in a previously secondary pest becoming a primary problem (Kennedy 2008). In California in 1889, the vedalia beetle, *Rodolia cardinalis*, was imported and successfully introduced into citrus orchards as a biocontrol for the cottony cushion scale, *Icerya purchasi*, (Mills and Daane 2005). However, use of compounds in the newer classes of insect growth regulators, neonicotinoids, and pyrethroids can kill the vedalia beetle, which led to scale outbreaks (Grafton-Cardwell and Gu 2003).

7.1.4.3 Additional Comments on Pesticide Externalities

Externalities (economic impacts from pesticide use that are not paid for by either the manufacturer or the grower) are often complex issues that are difficult to assess and quantify (Devine and Furlong 2007; Leach and Mumford 2008; Waterfield and Zilberman 2012). Pimentel (2009) estimates that $ 10 billion/year in pesticide control saves approximately $ 40 billion in U.S. crops, but generates $ 9 billion in environmental and public health externalities with the following major annual costs: ground water contamination, $ 2 billion; public health, $ 1.1 billion; pesticide resistance in pests, $ 1.5 billion; crop losses caused by pesticides, $ 1.1 billion; and bird losses due to pesticides, $ 2.2 billion. We provide a few examples of toxicities from relatively low levels of contamination on aquacultural and agricultural productivity. Some insecticides, herbicides and fungicides are extremely toxic to fish, such as deltamethrin ($LC_{50} \approx 1$ ppb), the herbicide trifluralin ($LC_{50} = 88$ ppb), and the fungicide captan ($LC_{50} \leq 0.3$ ppm) (Casida 2012) . Fox et al. (2007) found that residues of the organophosphate insecticide methyl parathion inhibited nitrogen-fixing bacteria and estimated that alfalfa yields could be reduced by one-third by residues. Although the organically-acceptable copper is considered a safe fungicide and bactericide because it has low mammalian toxicity, it accumulates in topsoil and is toxic to beneficial microorganisms and sensitive crops (Epstein and Bassein 2001). Based on the individual PUR records, they estimated that during the 6-year study period from 1993 to 1998, a walnut orchard with the mean copper application would acquire 28 mg per kg dry weight soil in the upper 15 cm of soil and that 125 km^2 of walnut orchards (17 % of the area planted with walnuts in California) would acquire 50 mg copper per kg dry weight in the upper 15 cm of soil in the 6-year period. Although several soil factors affect toxicity, the following mg copper per kg soil are considered inhibitory to the following: beneficial mycorrhizal fungi, 34; soil respiration, 50; earthworms, 80–110; and copper-sensitive crops, 100–150. Consequently, the externalities of pesticides may be underestimated.

7.2 IPM and Pesticide Use

7.2.1 An Overview of IPM Infrastructure in California

The University of California Statewide (UC) IPM program defines IPM as “an ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties. Pesticides are used only after monitoring indicates they are needed according to established guidelines, and treatments are made with the goal of removing only the target organism. Pest control materials are selected and applied in a manner that minimizes risks to human health, beneficial and nontarget organisms, and the environment." (http://www.ipm.ucdavis.edu/GENERAL/ipmdefinition.html).

Historically, the UC has been a leader in IPM research, particularly in facilitating the development of predatory insect populations that naturally control insect pests (Stern et al. 1959). IPM has been broadly embraced, particularly in California, as a strategy for both optimizing and minimizing pesticide use (Brewer and Goodell 2012). However, a U.S. Government Accounting Office (GAO) report stated that "a survey of 50 state IPM coordinators indicated that, of the 45 respondents, 20 believed that the IPM initiative is primarily intended to reduce pesticide use, 23 did not, and 2 were undecided" (US GAO 2001). Regardless, in practice, IPM often degenerates into "Integrated Pesticide Management" (Ehler 2006), with IPM providing a rationalization for pesticide use (Zalucki et al. 2009).

The most influential program supporting IPM adoption in California is institutionally housed at the UC Statewide Integrated Pest Management Program. The Statewide IPM Program was essentially formed by the state legislature in 1979 with the appropriation of funds (Zalom 1996). The stated goals of the program are to: "reduce the pesticide load in the environment; increase the predictability and thereby the effectiveness of pest control techniques; develop pest control programs that are economically, environmentally and socially acceptable; marshal agencies and disciplines into integrated pest management program; and increase the utilization of natural pest controls."

Currently the program maintains a web site (http://www.ipm.ucdavis.edu/) with extensive information on the following main topics: agricultural, urban, and wildland pests and their control; information on exotic and invasive pests; annotated image galleries of weeds and beneficial insects; degree-day calculators and links to weather data; links to pest and plant models; and links to pesticide information. UC IPM produces comprehensive print and digital pesticide application information and IPM manuals for growers and pest control advisors. Information for growers, pest management professionals and pesticide applicators is also available through workshops, events and online training programs. The journal *California Agriculture* (http://californiaagriculture.ucanr.org/) has peer-reviewed articles, many of which focus on IPM (Brodt et al. 2007; Epstein et al. 2000).

The broader University of California Division of Agricultural and Natural Resources (ANR) has academic researchers at the UC Davis in the College of Agricultural and Environmental Sciences and the School of Veterinary Medicine, the UC Riverside College of Natural and Agricultural Sciences, and the UC Berkeley College of Natural Resources. These departments often have UC Co-operative Extension specialists, some of whom focus on IPM to varying extents. ANR also has nine Research and Extension Centers throughout the state, primarily in agricultural areas. ANR also has 57 local offices with UC Co-operative Extension farm advisors, many of whom perform at least some IPM research and/or outreach; about 11, all with Ph.D. or M.S. degrees, have specific IPM responsibilities. Mullen et al.

(2003) estimated that the UC spent $ 26.2 million in 1997 (in year 2000 $) on pest management, amounting to about 35 % of its agricultural research budget.

On the state level, the California Department of Pesticide Regulation (DPR) also promotes IPM (Barnes et al. 2012). Under California law, pest control advisors (PCAs) must be licensed by DPR. Licenses require passing an exam on IPM, and taking continuing education on IPM. UC ANR's *IPM in Practice: Principles and Methods of Integrated Pest Management*, 2nd ed. is the official study guide for the PCA exam (www.ucanr.edu/IPMpractice). In practice, many but not all pest management professionals sell pesticides and have an economic conflict of interest between pesticide sales and promoting minimum use. However, although Brodt et al. (2007) found that independent PCAs on cotton in California in 2000 communicated more with growers than their product supplier-counterparts, most of their on-the-ground treatment recommendations were similar. Growers and pesticide companies both interact with the broader UC ANR community in multiple ways. The California Marketing Act of 1937 enabled growers to form commodity groups that can collect revenue based on sales of that commodity. The commodity boards sponsor both marketing and research; commodity grants to UC ANR are generally exempt from overhead charges. Comparative pesticide efficacy trials are frequently conducted by UC ANR personnel.

7.2.2 IPM and Pesticide Use

California and U.S. agriculture are pesticide-dependent. In 2007, the U.S. spent 32 % of the total world's expenditures for pesticides, with 38 % of world's expenditures on herbicides (which includes plant growth regulators), 39 % of world's expenditures on insecticides/miticides, 15 % of world expenditures on fungicides, and 25 % of world expenditures on "other" pesticides (which includes nematicides, fumigants, sulfur, petroleum oils and some other products) (Grube et al. 2011). Agriculture accounted for 72 % for the U.S. expenditures in herbicides, 46 % of the insecticides/miticides, 78 % of the fungicides and 67 % of the "other pesticides." (Grube et al. 2011). Use of agricultural fungicides and bactericides in California from 1993 to 2000 is discussed in Epstein and Bassein (2003).

While, theoretically, genetic modification could substantially reduce broadcast applications of insecticides and fungicides into the environment, in practice, it has had little effect in California. As of 2012, there were relatively few genetically modified plants in commercial California agriculture. Of the three crops that dominate the U.S. genetically modified market (soybeans, corn and cotton), in 2011, California produced less than 0.04 % of all the soybeans produced in the U.S., 0.2 % of the corn, and 8.6 % of the cotton (http://www.usda.gov/nass/PUBS/TODAYRPT/crop0912.pdf). However, in 2011, 41 % of California's cotton was American Pima, which has historically been difficult to genetically modify. Of the upland cotton, between 2000 and 2010 in California, the percentage that was herbicide-tolerant increased from 21 to 64 %. Herbicide-tolerance simplifies weed management by allowing greater flexibility in when herbicides can be applied, and, particularly in less-till situations, can ultimately result in less fossil fuel use for plowing, and less soil erosion from bare-fields. However, herbicide-tolerance has not reduced herbicide use in the U.S. (Benbrook 2012) and seems unlikely to do so in the future. In contrast to herbicide tolerance, the percentage of cotton that produced the *Bacillus thuringiensis* (Bt) toxin (with or without herbicide tolerance) only increased from 7 to 27 % (http://www.ers.udsa.gov). Factors that affect the relative lack of adoption of Bt-cotton include the following: the higher cost of genetically modified seed; the lack of economically important lepidopteran pests in some areas of the San Joaquin Valley; the current efficacious control of the (Bt-sensitive) pink bollworm (*Pectinophora gossypiella*) by a California Department of Food and Agriculture and grower IPM program that includes monitoring, sterile release, crop destruction and occasional pheromone treatments; and, in some parts of southern California, lepidopteran pressure that is so high that insecticidal applications have to be made regardless of the Bt toxin in the genetically modified cotton. In those areas in which Bt-cotton is grown, it may have benefits in reduction of insecticide applications (Epstein and Bassein 2003). The Bt toxin in cotton and corn in the U.S. has reduced insecticide use (Benbrook 2012).

In an economic analysis of pesticide use reduction by IPM programs in California, Mullen et al. (2005) concluded that IPM programs had saved over $ 1 billion in pesticide costs for almonds, cotton, oranges and processing tomatoes since 1970. Their "first approximation" was that a benefit-cost ratio for investments in agricultural research and in pest management were both 6:1, although in specific case studies in pest management in almond, cotton, orange and processing tomato, the benefit:cost ratios were estimated as 5.5:1, 4.4:1, 0.4:1, and 2.8:1 (Mullen et al. 2003).

IPM can reduce pesticide use and costs without compromising yield in some circumstances (for examples, see Hendricks 1995; Flint et al. 1993; Pretty 2005; Swezey et al. 2007). Trumble and colleagues (Trumble et al. 1997; Reitz et al. 1999) reduced a "calendar application" program of nine applications of the organophosphate methomyl and the pyrethroid permethrin per season on celery (*Apium graveolens*) in California to a program with scouting and application of "biorational" insecticides only when pests were at threshold levels. Yields were similar in the chemical and IPM treatments, and greater than in the untreated controls, but grower costs were $ 250/ha less in the IPM than in the chemically-intensive program.

California does have IPM success stories. Graebner et al. (1984) describe a voluntary collective of citrus growers in the Fillmore, California area from 1922 to 2003 in a grower cooperative that operated an insectary that produced more than 20 species of beneficial insects and mites. In addition to supplying as many as a half-million predatory and parasitic insects per day, for a maximum of 250 growers farming over 3,000 ha, the growers agreed to adhere to a collective strategy for pest control. Initially, the growers replaced the use of cyanide gas, and continued to use biocontrol instead of chemicals. According to the Los Angeles Times, "In recent years, only about 2 % of the acreage in the district has required chemical treatment, according to district officials." (http://articles.latimes.com/2003/aug/10/local/me-insect10). As a result of the economic downturn in Valencia oranges and the replacement of citrus orchards with more profitable crops, the Fillmore insectary was closed in 2003 after more than 80 years of successful biocontrol.

Fig. 7.4 An IPM success story: pear IPM in California, USA. Codling moths (*Cydia pomonella)* are a major pest on pears. **a**) A mature codling moth larva, typically 13–19 mm in length. **b**) A male and female codling moth adult, typically 8 mm long. **c**) The codling moth damage, just around the calyx of a pear and internally, is caused by larval feeding and excrement; some mechanical injury is also present on the pear. **d**) University of California North Coast Area IPM Advisor Lucia Varela instructs agricultural workers about identification of insects and their damage on pears. **e**) UCCE staff member Jim Benson hanging an experimental pheromone "puffer" dispenser used in an area-wide codling moth mating disruption project in Lake County, California. The success of the pear IPM program to switch growers from an organophosphate insecticide-dependent control to a more sustainable IPM control program that includes use of pheromones for mating disruption has depended upon multiple factors: publically-funded research and extension by the University of California; the implementation of an area-wide program so that treated orchards were not bordered by untreated orchards; grower participation and collaboration; and careful attention to the development of cost-effective pheromone technology that can be distributed efficiently in orchards with relatively low labor costs. Photos are courtesy of the University of California Statewide IPM Program

Weddle et al. (2009) describe IPM programs to control insects in pears in California from the 1960s to the present. As in the rest of the United States, insect control in the 1960s was highly dependent on chlorinated hydrocarbons, organophosphates and carbamates. As a result of UC-IPM programs and grower alliances (Varela and Elkins 2008) current arthropod IPM in California pears can be classified as efficacious, relatively low input, and biologically intensive. Typical current practices in California pears include the following: regular use of a mating disruption pheromone for codling moth (Fig. 7.4); occasional use of insect growth regulators for leafrollers and codling moth; lime sulfur, particularly for mite control in organic orchards; the natural product abamectin for mite and psylla control; and mineral oil for suppression of psylla, mites and codling moth. In Sect. 7.3.1, we summarize data from the Pesticide Use Reports about phasing out organophosphates on almond and stone fruit orchards during the winter rainy season, the period when pesticides most readily are transported by run-off into surface water.

Integrated pest control is challenged by numerous factors that do not tend to reduce pesticide use or risk: (1) in the U.S. many consumers demand cosmetically perfect fresh fruits and vegetables (Castle et al. 2009); (2) there have been repeated introductions of invasive species unaccompanied by their natural enemies; (3) growers often treat so that they will be able to sell to a wide range of potential export markets, each of which may have different standards (Castle et al. 2009); (4) standards of "best management practice" for farm managers and recommendations of pest control advisors may focus on protection from worst-case scenarios; and (5) IPM strategies generally have to be justified to individual growers based on economic arguments, while the benefits of the IPM often require regional participation, and the benefits, at least partly, accrue to the broader farming community and the public (Brewer and Goodell 2012). While some studies show that, IPM reduces pesticide use in the U.S. (e.g., Mullen et al. 2005), others show the opposite (e.g., Maupin and Norton 2010). As the latter study points out, comparisons between different studies on this point are difficult due to differences in definitions of "IPM" and the multitude of external factors which influence pesticide applications by individuals. Nonetheless, Maupin and Norton (2010) concluded that, on average, IPM strategies in the U.S. from 1996 to 2005 led to slightly increased pesticide spending and kilograms of active ingredient per hectare.

Using literature reviews and telephone interviews, Epstein sought examples in which a researcher thought that an IPM program in California during the 1990s had resulted in reduced use of pesticides and that the PUR data supported the contention (Epstein and Bassein 2003). There were a few examples with insecticides (Epstein et al. 2000; Epstein et al. 2001), primarily with organophosphates that are mentioned in this chapter. Epstein and Bassein (2003) examined two pathosystems in which anecdotal and/or survey data supported a reduction in fungicide use but the PUR data indicated there had been relatively consistent fungicide use.. Diseases on grapevine provide useful case studies of pathogen management in California because there are a large number of growers and acreage; in 1995, there were 6,181 vineyards and a total of 1,645 and 1,343 km^2 of wine and non-wine grapes, respectively. In addition, one can make reasonable predictions on why applications were made, based on the active ingredient and the time of applications. The assumption is often made that participating growers in an IPM program are representative of the grower community and, specifically, as people that are interested in IPM, they are not more pesticide-intensive than the rest of the grower community. However, comparisons of the distribution of farm size of UC IPM grapevine survey respondents and PUR "acre planted" per grower ID suggested that the participants in UC IPM programs are not random samples. Similarly, comparisons of PUR and survey data suggested that IPM program participants may be more pesticide-intensive than the grower community. Theoretically, replacement of a historically-used "one size fits all" "calendar spray" pesticide program with an "environmentally driven" program could reduce pesticide use, particularly in years with lower disease pressure. However, this assumes a relative homogeneity of grower programs with the majority of growers currently using the higher-frequency “calendar spray” program. In addition, there is the assumption that if there are growers that currently use less than recommended pesticide dosage by an environmentally-driven program, that they would not increase their use. The study period from 1993 to 2000 included multiple years before the introduction of an environmentally-driven program that extended the recommended interval between applications when temperatures were sub-optimal for the pathogen that causes powdery mildew (Gubler et al. 1999). The analysis of PUR data indicated that while there were subset of growers who appear to use the calendar spray model, and consequently, could reduce their fungicide use, the majority of growers appeared to have a schedule that was less than would be recommended by the environmentally-driven model. While these growers might conceivably have better disease control if they adopted the environmentally-driven model, if all growers adopted the environmentally-driven model, there would be a net increase of fungicide use in California grapevines. Consequently, the data suggested that widespread adoption of the IPM program would increase fungicide use (Epstein and Bassein 2003).

The second example (Epstein and Bassein 2003) involves control of Botrytis bunch rot in grapevines with either fungicides or a non-chemical cultural practice of selective leaf removal; leaf removal increases air flow, decreases the hours that berries are wet, and consequently makes the environment less conducive for fungal infection. Leaf removal was implemented in the higher value, wine grape-growing areas on the California coast in the 1990s largely because it improves fruit quality by increasing sunlight on the berries. Based on anecdotal reports, the media stated that growers’ adoption of leaf removal resulted in decreased fungicide use. However, analysis of PUR records indicated that the use of fungicides used to control bunch rot on wine grapes on the coast vacillated yearly but was overall stable between 1992 and 1997, the time period during which both UC IPM survey data and anecdotal reports indicated that leaf removal was increasing. Overall, the data suggest that growers’ control programs are more heterogeneous than often implied in the pest control literature, and that while some growers reduced their chemical control programs, others increased their control programs. In section 7.3.2, we discuss a third example in which growers added the biological control agent *Pseudomonas fluorescens* to a chemical control program instead of replacing the chemical control.

7.3 Two Case Studies in IPM in California based on the Pesticide Use Reports

7.3.1 The Reduction of Organophosphates (OP) in Dormant Almond and Stone Fruit Orchards during the California Rainy Season

Pesticide contamination of surface water and groundwater in California, and in the U.S., are well documented externalities of pesticide use (Gilliom et al. 2006; Starner and Goh 2012). In the early 1970s, UC entomologists introduced the practice of

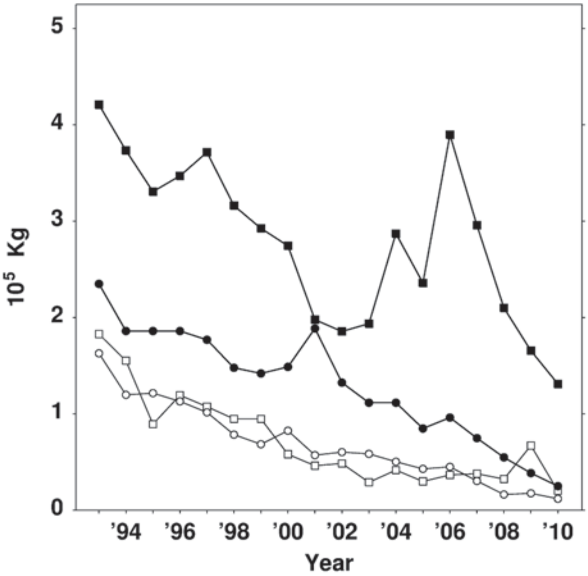

Fig. 7.5 Mass in 10^5 kg of organophosphates (OP) applied in California orchards between 1993 and 2010 on almond and stone fruit (peaches, nectarines, prune, & plum) orchards either during the dormant season (10 December of the previous year to 20 March of the indicated year) or annually. Total annual on almond (■ thicker line), dormant-season on almond (□), total annual on stone fruits (● thicker line), dormant-season on stone fruit (○). OP include acephate, azinphos-methyl, bensulide, chlorpyrifos, ddvp, diazinon, dimethoate, disulfoton, ethephon, fenamiphos, malathion, methamidophos, methidathion, methyl parathion, naled, oxydemeton-methyl, phorate, phosmet, propetamphos, s, s,s-tributyl phosphorotrithioate, temephos, and tetrachlorvinphos

an OP insecticide application during the dormant season in almond orchards as an environmentally-preferred practice (Rice et al. 1972). Environmental advantages of a dormant-season vs. in-season OP application include the following: one dormant season application can replace multiple in-season applications; there are fewer adverse affects on beneficial arthropods during the dormant period, workers are less likely to be in the field at this time and consequently there is less human exposure to pesticides; and there is no exposure of fruit to potential residues. However, in California, the dormant season is also the rainy season, and when deciduous tree crops lack leaf cover, pesticides more readily run-off into surface water. Consequently, the resultant water pollution from dormant-season OP use on both almond and stone fruits has resulted in violations of the Federal Clean Water Act. During the 1990s, in response to food safety groups, regulatory agencies began to critically examine the health and environmental effects of OPs. The UC Statewide IPM program and the Biologically Integrated Orchard Systems (BIOS), a coalition of public and private groups, promoted the replacement of OPs on almonds during the rainy season with alternative practices. There was also a much smaller research and extension effort in stone fruits, which share many of the same pests with almonds. Figure 7.5 shows the mass of OPs applied between 1993 and 2010 during the rainy season and during the entire year on almonds and on stone fruit. The data show excellent progress in reduction of dormant season OPs during the rainy season on almond (slope $= -7.4 \times 10^3$ kg/yr, $R^2 = 0.72$) and on stone fruit (nectarine, peach, plum, and prune) (slope $= -7.5 \times 10^3$ kg/yr, $R^2 = 0.93$). The percentage of mass of OPs that were used in the dormant season versus annually decreased from 43 % in the 1993 to 1994 period to an average of 17 % in the 2003–2010 period in almond, and from 67 to 45 % in stone fruits. Using PUR records in a way that allowed reconstruction of individual grower practices between 1992 and 2000, Epstein and Bassein (2003) showed that the reductions in OPs in stone fruits were primarily due to replacement with pyrethroids. However, in almonds, in which there was a more sustained UC IPM education and extension program, more of the OP applications were replaced with either no treatment (presumably due to monitoring and a decision not to treat) or the use of a "sustainable" alternative: the biocontrol agent *Bacillus thuringiensis* at bloom time; or oil without an insecticide during the dormant season. Despite the decline in the dormant season OPs, almond growers had a spike in use of in-season OPs around 2006; this was probably due to: (1) increased pest pressure from the San Jose scale, the navel orangeworm, and ants; and (2) expectations of a good price (http://www.cdpr.ca.gov/docs/pur/pur06rep/06com.htm#trendscom). Almond prices went from \$ 2/kg in 2001 up to \$ 5.73/kg in 2005 and then down to \$ 3.22 in 2008.

7.3.2 Microbial Biopesticides

The DPR requires reporting of applications of microbial biological control agents. There is a vast literature on application of microbes as biocontrol agents with multiple journals that focus on the topic, for example, *BioControl* (Springer), *Biological Control* (Elsevier), and *BioControl Science and Technology* (Taylor & Francis). Biocontrol has been a popular area of research within the USDA and the academic community for multiple reasons: microbial biocontrol is viewed as "environmentally friendly;" the application of biocontrol agents fits in with the "magic bullet" chemical paradigm of pathogen and pest control; commodity groups can use the lack of efficacy of a biocontrol agent as part of a rationale for a U.S. Sect. 18 emergency pesticide exemption; and microbial biocontrol agents are patentable (Saenz de Cabezon et al. 2010). Nonetheless, reproducible efficacy in the field has been problematic for many agents. *Bacillus thuringiensis*, the producer of *Bt*-toxin, has been uniquely successful in achieving widespread adoption in commercial agriculture, as is evident in aggregate data from 22 registered strains (Fig. 7.6a). During the 1993–2010 study period, the most popular strains have changed; genetically engineered *Bt* have been registered, but their use is limited, and they are not allowed in organic agriculture.

Besides *Bt*, 23 other microbial biological control products have been registered in California, and the most successful are shown in Figs. 7.6a and b; Figure 7.6b shows the eight (other than *Bt*) that were applied in the greatest quantity. The data show that new biocontrol agents are often tried by growers, but not

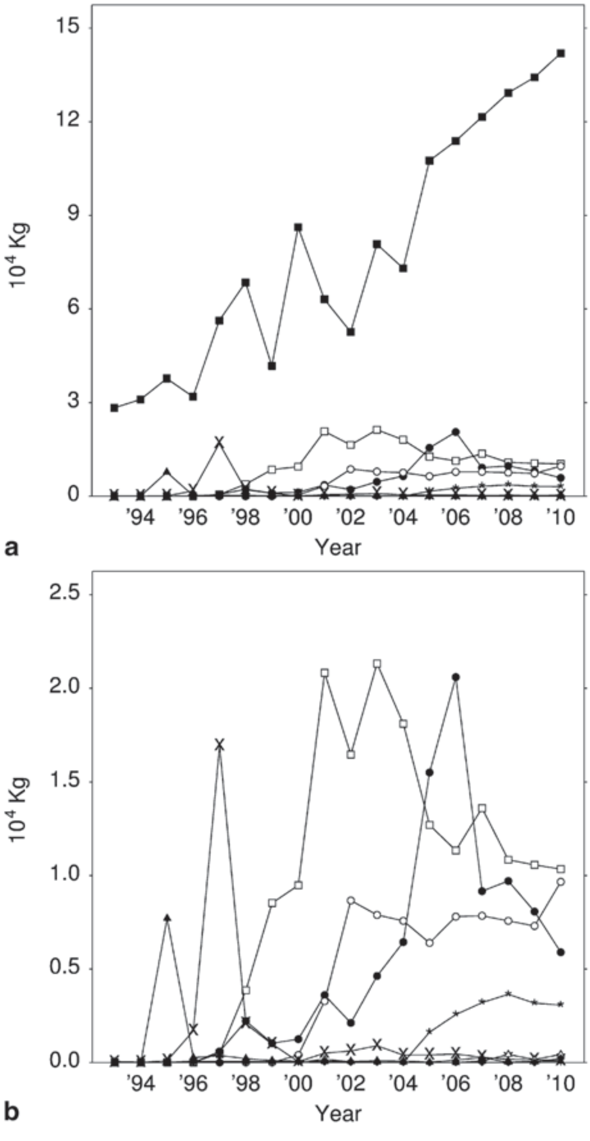

Fig. 7.6. Mass in 10^4 kg of the microbial biocontrol agents that were applied in California between 1993 and 2010, based on data from the California Department of Pesticide Regulation's Pesticide Use Reports <http://www.cdpr.ca.gov/docs/pur/purmain.htm>. Only those agents in which more than 500 kg was applied during the entire study period are included. The microbes listed here are *Bacillus thuringiensis* (■), *Myrothecium verrucaria* (□)*, Bacillus sphaericus* (●)*, Bacillus subtilis* (○)*, Pseudomonas fluorescens* (X)*, Bacillus pumilus* (*)*, Agrobacterium radiobacter* (▲)*, Gliocladium virens* (Δ),and *Trichoderma harzianum* (♦). **a**) All agents are included; use of *B. thuringiensis* (■) dwarfs all others. **b**) All of the indicated agents except *B. thuringiensis* are shown on a scale 1/6th that of **a**)

necessarily continued. In Fig. 7.6b, a peak of use occurred in 1995 for *Agrobacterium radiobacter* (▲), a bacterium isolated for crown gall control that is applied to roots before transplanting, but lacks the competitive ability to colonize and persist on roots. Use of *Pseudomonas fluorescens* (X) peaked in 1997. Although use of the nematocidal (and herbicidal) preparation of killed cells of the plant pathogenic fungus *Myrothecium verrucaria* with its fermentation products from axenic culture (□), was greater in 2001 through 2004, it has had more sustained use. The bacterium

Bacillus sphaericus (●) is formulated as a larvicide for aqueous applications for killing Diptera (flies, mosquitoes, midges, and gnats); and its use appears to have peaked in 2006.

The organic agricultural markets in California are expanding rapidly (Klonsky 2012), and this expansion is providing opportunities for use of the approved biopesticides. In the last 10 year period, organic production went from 0.5 % of California farmgate sales to its current 3 %. California produces two-thirds of the U.S. organic vegetables and over one-half of the organic fruit (Klonsky 2012). Some of the more recent products represented by the agents shown in Fig. 7.6 that have been marketed for organic agriculture and greenhouse production are from Agraquest, which was acquired by Bayer CropScience in 2012: a fungicide with *Bacillus subtilis* (○), and two fungicides with *Bacillus pumilus* (*). The two other biopesticides in Fig. 7.6b are *Trichoderma harzianum* (*) (BioWorks, Inc) and *Gliocladium virens* (Δ) (Certis). Several new commercial products have been registered and promoted since 2010.

Results of comparative tests of efficacy for microbial biocontrol agents for disease control are published by the American Phytopathological Society Plant Disease Management Reports (http://www.plantmanagementnetwork.org/pub/trial/pdmr/). Historically, except for *B. thuringiensis*, the microbial biocontrol market has been challenged by a lack of reliable, high efficacy in the field. California's largely hot, dry growing season reduces the survival of the biocontrol strains on aerial plant surfaces. Broadcast applications of microbes to soil rarely effect the composition of the soil microbial community. Pre-colonization of transplants or seeds with microbes that are adapted for survival and biocontrol activity on the particular plant host/soil environment could theoretically enable protection of crops from soil-borne pathogens. However, it remains to be demonstrated whether any of the newer agents will rise to the remarkable level of safety, efficacy, and multiple-target specificity of *B. thuringiensis.*

The biocontrol agent *P. fluorescens* A506 'Blight Ban' (Fig. 7.6, denoted by X) provides an interesting case study on IPM and biocontrol. In 1996 a UC research and extension program introduced *P. fluorescens* A506 for application in pear orchards as a substitute for antibiotics; the project was supported by the California growers' Pear Advisory Board. Three diseases of pears can be controlled with either the antibiotic streptomycin or with *P. fluorescens* A506: fire blight, caused by *Erwinia amylovora*; blossom blast, caused by ice-nucleating strains of *P. syringae*; and russetting, caused by various indole acetic acid producing bacteria. *P. fluorescens* can be used with or without antibiotics; indeed it can be tank mixed with streptomycin, which can even be used by organic growers. Epstein and Bassein (2003) used the PUR grower identification codes to reconstruct individual pear grower's pathogen control programs in order to determine whether growers that started to use a *P. fluorescens* used the agent instead of, or in addition to, chemical control. The 89 pear growers in the targeted IPM program that could be tracked over the 4 year period from 1995–1998 were selected for analysis. Growers with the most intensive antibiotic use in 1995 were more likely to use *P. fluorescens* in the later years ($P = 0.012$ by logistic regression). Of the growers in 1995 that used the median number or less, of applications of antibiotics, only 17 % used *P. fluorescens* in 1997 and 1998 whereas 60 % of the more intensive antibiotic users used *P. fluorescens.* Thus, the most intensive pesticide users were most likely to try the biocontrol alternative, but they did not decrease their antibiotic use. That is, the biocontrol was used most by those that wanted to intensify their disease control program.

7.4 Conclusions

1. According to the UC Statewide IPM program (http://www.ipm.ucdavis.edu/) "Integrated Pest Management is an ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, and modification of cultural practices. Pesticides are used only after monitoring indicates they are needed, and pest control materials are selected and applied in a manner that minimizes risks to humans, non-target organisms, and the environment." While the definition describes a laudable goal, common contemporary practice of pest management is highly pesticide-dependent and is prescribed based on factors such as comparative costs to the grower of the array of legal chemical choices, perceived efficacy of the products, and potential financial consequences to the grower from product use or lack of use. IPM could reduce pesticide use or risk if there were more incentives for growers to do so. As practiced, IPM is primarily a strategy for management of individual pests.
2. Overall, the UC IPM program has been highly successful in helping growers to decrease use of the organophosphate and carbamate pesticides targeted by the U.S. Food Quality Protection Act, partly by recommending products that have lower mammalian toxicity. Growers in California are willing to try new products.
3. The University of California (UC) and the UC Statewide IPM program has played a critical role in providing research and extension on IPM to California growers. Economic analyses have demonstrated that the research and extension have been a good investment for both the growers and the public. However, more, and not less, public funding is needed to assure that California agriculture in the twenty-first century promotes both truly integrated pest management and sustainable agriculture. Goals for achieving IPM need to be better integrated with goals for sustainability including: maintenance of crop biodiversity; the inclusion of diverse genetic resistance to pests and pathogens in crops; the stoppage of the loss, contamination, and salinization of groundwater and soil; and achieving an energetically sustainable agriculture in which the total calories from the crops exceeds the energy applied as inputs.

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Chapter 8
Experiences with Integrated Weed Management and Pesticide Use in the Canadian Prairies

Julia Y. Leeson and Hugh J. Beckie

Contents

Abstract The majority of field crops grown in Canada are grown in the three Prairie Provinces, Alberta, Saskatchewan, and Manitoba. The most commonly used pesticides in this area are herbicides, indicating an opportunity for integrated weed management (IWM) to significantly increase the sustainability of farming systems. Much research has been done investigating the feasibility of various individual

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IWM practices in the Canadian Prairies. Extension efforts to communicate this information are generally carried out by the provincial government and industry. Two major changes have occurred in management systems since the 1990s: the adoption of zero (no)-tillage and herbicide-resistant (HR) canola (*Brassica napus* L.). While it has been shown that herbicide use can be reduced under zero-tillage, our data indicated that producers using zero-tillage tend to also use a greater amount of herbicides. Glyphosate- and imidazolinone-HR canola had lower environmental impact than non-HR canola in the 1990s; however, glufosinate-HR canola had a similar herbicide use to non-HR canola in the 1990s. The adoption of other IWM strategies focusing on competitive crops, crop rotations and preventative management has not been well documented. Our data shows that the adoption rates vary among provinces, possibly due to differing regional priorities. The adoption rate of most practises could be increased, particularly in the areas of crop competiveness and sanitation. Given the increasing threat of HR weeds, it is important to be able to convey to producers the benefits of adopting IWM practices on their farms.

Keywords Integrated weed management · Herbicide · Canada · Herbicide resistance · Genetically-modified crops · Herbicide-resistant crops · No-tillage

8.1 Introduction

8.1.1 *Agriculture and Pesticide Use in Canada and the Prairie Provinces*

The majority of the field crops in Canada are grown in the three Prairie Provinces, Alberta, Saskatchewan and Manitoba. In 2011, this area included 28.8 million ha of field crops, representing over 81 % of the field crop acreage in Canada (Statistics Canada 2012). While a large proportion of this area is hay crops (4.6 million ha), the main crops produced were annuals: spring wheat (including durum), canola, barley, oats, lentils, dry peas, and flax.

The majority of the land base receiving pesticide inputs in Canada is located in the Prairie Provinces (Statistics Canada 2012): 86, 78, and 89 % of the area receiving herbicides, insecticides and fungicides, respectively, in Canada are located in these provinces.

In Canada, the majority of pesticides applied are herbicides (Statistics Canada 2012). In 2010, 26.7 million ha received herbicides; 3.1 million ha received insecticides; 5.5 million ha received fungicides. In the three Prairie Provinces, 23.0 million ha had herbicide applications, while only 2.4 and 4.9 million ha received insecticide and fungicide applications, respectively. The reported use of pesticides has increased since 2005. In the Prairie Provinces, 21.4 million ha received herbicides in 2005.

Most of the area treated with herbicides is planted to annual crops (Agriculture and Agri-Food Canada 2012). Approximately 86 % of the area in spring cereals and pulses, and 93 % of the area in oilseeds in the Prairie Provinces received herbicides in 2006. However, only 10 % of the area in hay crops had an application of herbicide in 2006. The area that is certified organic is relatively low in comparison to area not receiving herbicides. In 2005, there were 0.49 million ha of certified organic land in the Prairie Provinces (including land in transition; Macey 2006).

Given that the Prairie Provinces are the major agricultural region in Canada and that the majority of pesticides applied are herbicides, this chapter will focus on Integrated Weed Management (IWM) in the Canadian Prairie Provinces.

8.1.2 Integrated Weed Management in Research and Extension

There has been much research done investigating the feasibility of various individual IWM practices and systems in Canada (see Nazarko et al. 2005; Blackshaw et al. 2008, for reviews). In general, research into IWM practices saw resurgence in the 1990s, and continued to be the focus of many projects through the 2000s. The interest centered on the reduction of herbicide use for environmental and economic reasons, and later, delaying the development of herbicide resistant (HR) weed biotypes.

Extension is usually delivered at a provincial or regional scale, with the provincial departments of agriculture playing the major role. Producers are able to access information from provincial websites, publications, and extension staff. Typically, there are also large conferences and trade shows held each year in each province directly targeting producers. As delaying weed resistance to their products is in the best interest of chemical companies, the private sector is also a source for the latest IWM information.

A survey of Alberta farmers in 2009 indicated that the main source of weed management advice was the Crop Protection Guide, a provincial publication used by 60 % of respondents (Neeser et al. 2013). Other government resources were used less frequently. Local agricultural field men were consulted by just over 20 % of respondents, and 10 % called the AgInfo Centre. Private industry also had a large influence on producers. Advice from dealers of agricultural products was sought by just under 60 % of respondents. Hired crop consultants were used by about 15 % of producers, and advice was sought from custom sprayers by just under 10 % of producers. Web-based services were used by 8 % of respondents, and herbicide decision-support software was used by less than 5 % of producers.

8.1.3 Measuring Success

There has been little organized effort to directly measure the adoption of IWM practices in Canada. However, information has been summarized in this chapter from three main sources: Canadian Census of Agriculture, Farm Environmental Management Survey, and Prairie Weed Management Surveys.

Information on farm management practices are collected every five years in the Canadian Census of Agriculture (Statistics Canada 2012). This information tends to be general, but allows us to track major shifts in agronomic practices such as tillage systems and total pesticide use.

The Farm Environmental Management Survey is a national survey conducted every five years by Statistics Canada. The first survey was conducted in 2001 (Korol 2004). These surveys collect more detailed information than the census, but do not provide any information at the field level.

An extensive weed survey program conducted since the 1970s in the Canadian Prairie provinces includes the regular collection of detailed management data for the major annual crops grow in each province. The most recent data available are surveys conducted in 1995 and 2003 in Saskatchewan, 1997 and 2002 in Manitoba, and 1997 and 2001 in Alberta. The majority of the data is collected on a field basis, including detailed information on cropping history, pesticides used, and rates. In the 1997 Manitoba survey, producers were also asked about the use of specific IWM practices on their farms. This question was repeated in all provinces in the surveys conducted in the 2000s, allowing for an assessment of the adoption rate of these practices.

8.2 Major Changes in Management Systems Since the 1990s

8.2.1 Tillage

Over the past 20 years, zero-tillage has been rapidly adopted by producers in the Canadian Prairies (Fig. 8.1). This change in management was driven by a desire to conserve soil quality and soil moisture as well as increase economic returns on the farm (Zentner et al. 2002). The relatively quick adoption in Saskatchewan and Alberta versus Manitoba may be attributable to the presence of relatively drier areas in those two provinces. Much of the IWM literature considers the change to zero-tillage to be detrimental to IWM as the option to use tillage as an alternative weed control measure is removed. However, zero-tillage can also be seen as part of an IWM system, able to aid in the control of weeds. For example, weeds left on the surface have a higher mortality rate, and the residue can suppress weed growth (Blackshaw et al. 2008).

Tillage may be used for reasons other than weed control, such as residue removal and seedbed preparation. To address this issue, the Prairie Weed Management Surveys specifically asked producers if they used tillage for weed control. In general, the results are highly correlated with the adoption rate of zero-tillage, indicating that most producers who used tillage were doing so, at least in part, to control weeds (Fig. 8.2). In 2003, 39 % of Saskatchewan producers used tillage for weed control; down from 91 % in 1995. Tillage was more commonly used for weed control in Alberta (68 %) and Manitoba (74 %) in 2001 and 2002, respectively. There was no significant change in Manitoba from 1997 to 2001. The majority of the producers reported tilling for weed control in the fall or spring. However, post-seeding tillage

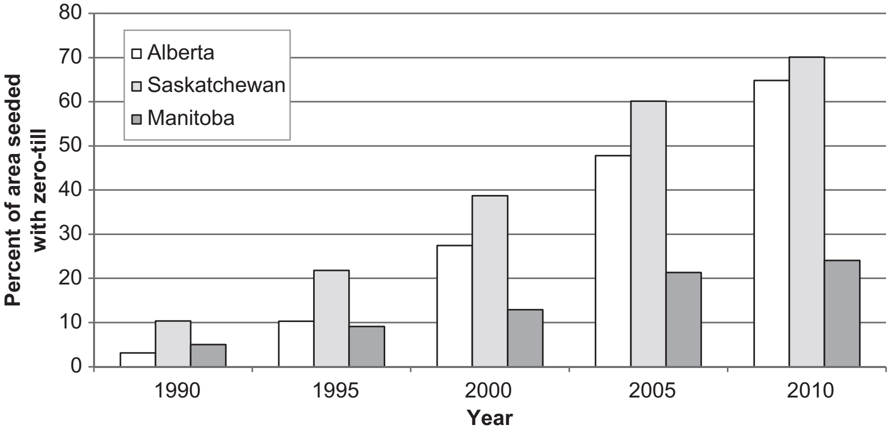

Fig. 8.1 Rapid increase in area seeded with zero-tillage in Prairie Provinces from 1990 to 2010 (Statistics Canada 2012)

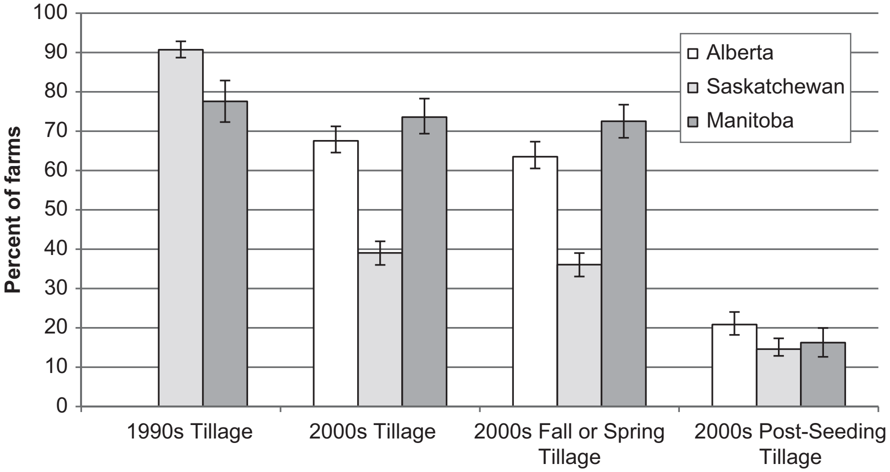

Fig. 8.2 Use of tillage for weed control at any time in the 1990s and 2000s and at specific times in the 2000s based on data from Prairie Weed Management Surveys. The shortest unbiased 95% confidence limits for the proportions are shown (Sokal and Rohlf 1995)

was used on 15 to 21% of farms in the 2001–03 Prairie Weed Management Survey. Tillage at this time could still allow the fields to be classified as seeded with zero-till.

Data from the Prairie Weed Management Surveys in 2001–2003, indicate that the actual amount of herbicide active ingredient was highest in the zero-tillage system (Fig. 8.3a). The high disturbance zero-tillage seeding system used slightly less herbicide than the zero-tillage system and the minimum tillage and high tillage systems used a similar amount of herbicide active ingredient. The extra active ingredi-

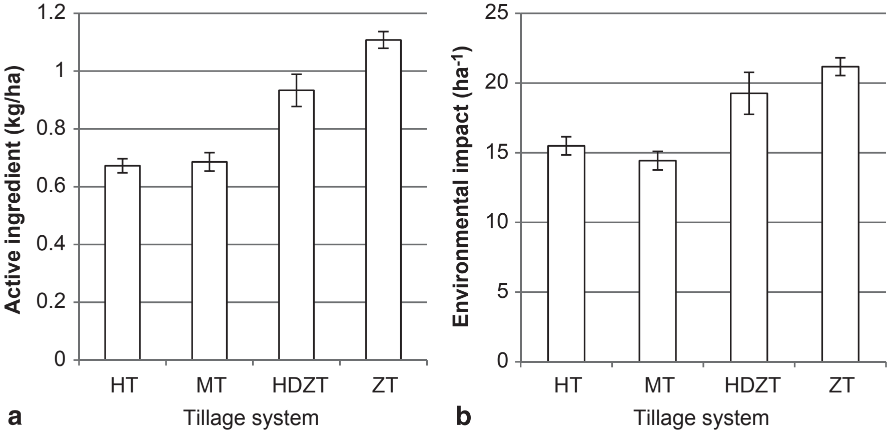

Fig. 8.3 Impact of tillage system (HT-high tillage, MT-minimum tillage, HDZT-high disturbance seeding zero-tillage, ZT- zero tillage) on herbicide use in terms of **a)** active ingredient and **b)** environmental impact based on data from the 2000s Prairie Weed Management Surveys. Environmental impact is calculated based on Kovach et al. 2012. Standard errors are shown

ent used in the no-tillage systems can be attributed to increased usage of herbicides at each application window, particularly in the spring prior to crop emergence (Leeson and Thomas 2009). The greater amount of active ingredient applied resulted in a higher environmental impact (environmental impact quotient x application rate of an active ingredient) in the zero-tillage and high disturbance zero-tillage seeding systems than the minimum tillage and high tillage systems (Fig. 8.3b). The lack of significant difference in environmental impact between zero-tillage and high disturbance zero-tillage seeding systems as opposed to the actual amount of herbicide active ingredient indicated that the two systems rely on products with different environmental impact quotients.

Despite the current situation where the adoption of zero-tillage is correlated with higher herbicide use, research indicates that herbicide quantities can successfully be reduced when incorporating zero-tillage into an IWM system (Blackshaw et al. 2005a, b).

8.2.2 Herbicide-Resistant Crops

Another major change in crop production in the Canadian Prairies is the adoption of HR canola since its introduction in 1995 (Figs. 8.4 and 8.5). Almost all the canola acreage in Canada has been converted to HR crops within 15 years of their introduction. Unlike the change in tillage practices the adoption of HR canola varieties was primarily driven by the need for better weed control to provide the producer with a greater economic return.

Data from the Weed Management Surveys indicate that the total active ingredient applied to each of the main cereal crops did not change from the 1990s to early

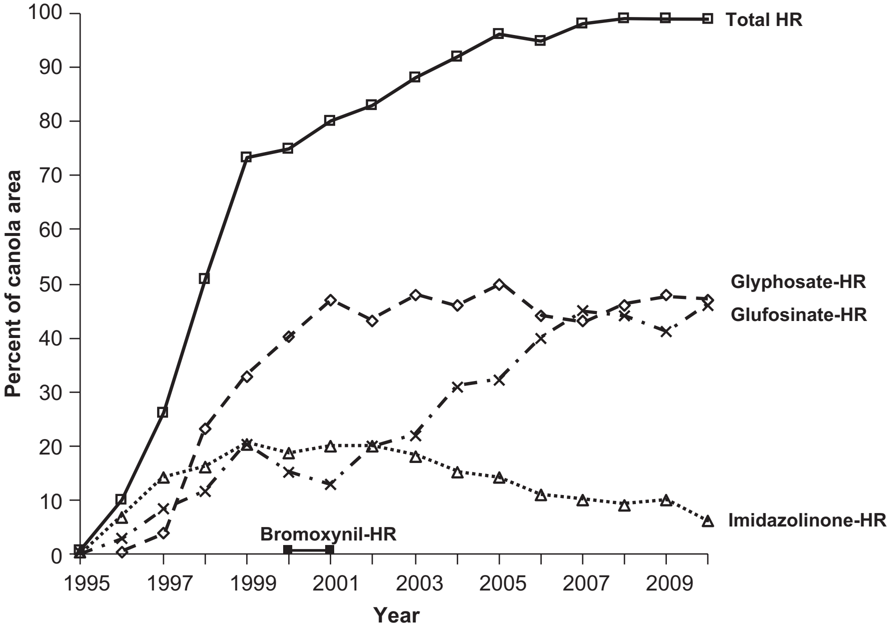

Fig. 8.4. Adoption of HR canola in Canada. (adapted from Beckie et al. 2011)

Fig. 8.5. Genetically-modified herbicide-resistant canola (*Brassica napus* L.) fields are common in the Canadian Prairie Provinces

2000s (Fig. 8.6a). Additionally, the amount of active ingredient applied to glyphosate- and glufosinate-HR canola was similar to that applied to non-HR canola in the 1990s. The amount of active ingredient applied to these three types of canola was similar to barley, but more than spring wheat and oats. The amount of active

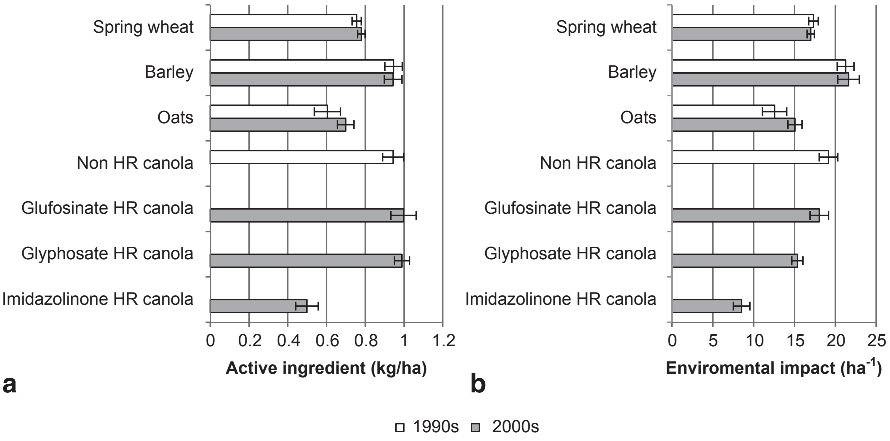

Fig. 8.6 Impact of crop on herbicide use in terms of **a)** active ingredient and **b)** environmental impact based on data from the Prairie Weed Management Surveys. Environmental impact is calculated based on Kovach et al. 2012. Standard errors are shown

ingredient applied to imidazolinone-HR canola was much less than the other canola types and the cereal crops with the exception of oats in the 1990s.

The environmental impact of herbicides applied to oats has increased from the 1990s survey to the 2000s survey, while the environmental impact of herbicide applied to other cereals remained similar (Fig. 8.6b). Glyphosate- and imidazolinone-HR canola had lower environmental impact than non-HR canola in the 1990s, while glufosinate-HR canola had a similar environmental impact.

8.3 Competitive Crops

8.3.1 Selection of Competitive Crops

Giving the crop a competitive advantage over the weeds will decrease the need for chemical weed control. One of the simplest ways to achieve this is to include competitive crops in rotation. The use of competitive crops for weed control as reported by producers differs significantly by province, being most common in Manitoba (79 %), then Saskatchewan (69 %) followed by Alberta (62 %) (Fig. 8.7). No significant difference was observed in the percentage of producers in Manitoba reporting using competitive crops in rotation in 1997 and 2002. These percentages do not necessarily reflect the frequency with which competitive crops are being incorporated into rotations, only when producers are doing so specifically for weed control. The most competitive annual crops grown on the Prairies are rye > oats > barley > wheat (Blackshaw et al. 2002a). While the acreage of rye is generally low, the remaining three crops are the most commonly grown cereals. In the 2000s, just over 65 % of

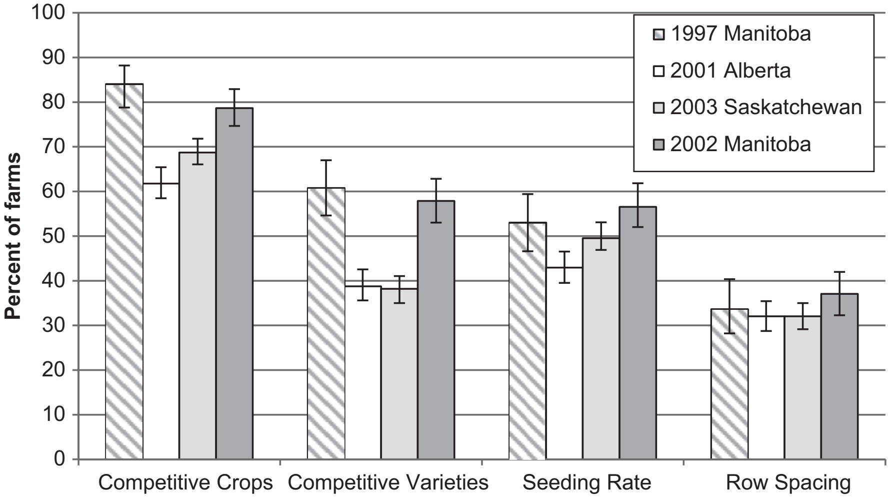

Fig. 8.7 Percentage of farms in the Prairie Weed Management Surveys that chose to increase the competitive ability of crops to help manage weeds through selection of crop type, selection of variety, increasing seeding rate or adjusting row spacing. The shortest unbiased 95 % confidence limits for the proportions are shown (Sokal and Rohlf 1995)

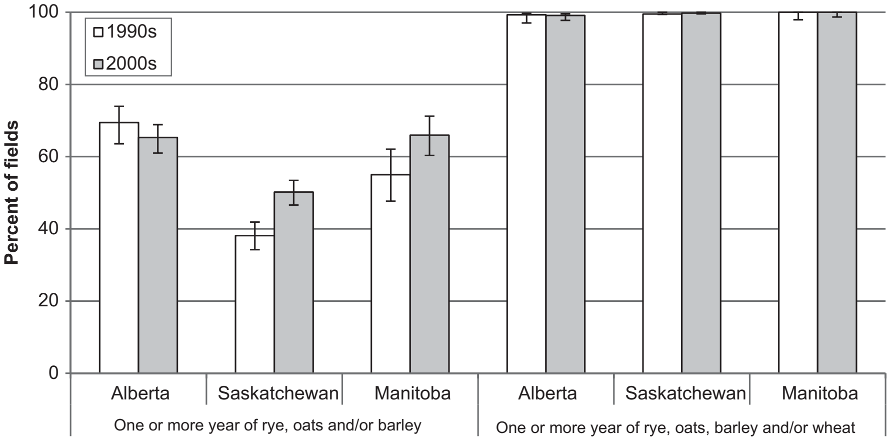

Fig. 8.8 Inclusion of top competitive crops in a six-year cropping rotation based on data from Prairie Weed Management Surveys. The shortest unbiased 95 % confidence limits for the proportions are shown (Sokal and Rohlf 1995)

producers in Alberta and Manitoba included barley, oat or rye in a six-year rotation (Fig. 8.8). In 2001 in Saskatchewan, these crops were less commonly planted—only included in 50 % of the fields; however, this percentage was a significant increase since the 1995 survey. This change may be correlated to the increase in zero-tillage, allowing the reduction of summer fallow in Saskatchewan. Almost all of the producers grew at least one of the top four most competitive crops at least once in a six-year rotation.

8.3.2 Selection of Competitive Varieties

There is a large range in competitiveness among varieties of the same crop. Research has identified varieties of wheat, barley, field pea and canola that are able to suppress weeds significantly better than other varieties of the same species (Harker et al. 2003; Hucl 1998; Huel and Hucl 1996; O'Donovan et al. 2000, 2005; Watson et al. 2006; Zand and Beckie 2002). Hybrid canola varieties can outcompete wheat and possibly barley (Blackshaw et al. 2008). Producers are more aware of this option in Manitoba where 58 % of producers selected competitive varieties to help with weed management (Fig. 8.7). In Alberta and Saskatchewan, just fewer than 40 % chose to plant competitive varieties for weed control. No significant difference was observed in the percentage of producers in Manitoba reporting the use of competitive varieties in 1997 and 2002.

8.3.3 Increased Seeding Rate

Research in the Prairie Provinces has demonstrated that increased crop seeding rates may contribute to weed suppression in field pea (Townley-Smith and Wright 1994); barley (O'Donovan et al. 1999, 2000, 2001), wheat (Blackshaw et al. 1999, 2000b) and canola (Linde 2001). Increasing seeding rate was most commonly used as a weed control method in Manitoba, where 57 % of producers used it on their farms; 50 % of Saskatchewan producers and 43 % of Alberta producers used increased seeding rates for weed control (Fig. 8.7). There was no significant change in the use of increased seeding rates in Manitoba between survey years.

8.3.4 Row Spacing

Like increasing seeding rate, narrow row spacing is an opportunity to increase crop density and therefore increase crop competitiveness by increasing the speed of canopy closure. Research in the Canadian Prairies has shown that decreasing row spacing has the potential to increase yield and suppress weeds (Kirkland 1993); however, increased seeding rate is more effective (Stevenson and Wright 1996). This is reflected in the less frequent use of narrow row spacing in comparison to increased seeding rate in the Prairie Weed Management Survey (Fig. 8.7). Adjusting row spacing was practised equally across the Prairies on 32 to 37 % of the farms. This practice may be expected to become less common as narrow row spacing may not be practical in some direct-seeding operations due to residue management issues and new equipment is only available with relatively wide row spacing.

8.3.5 Precision Fertilizer Placement and Timing

Several studies have shown that placement of fertilizer so that it is accessible by the crop rather than weeds is a beneficial IWM practice (Blackshaw et al. 2000a, b, 2004, Kirkland and Beckie 1998). Producers have also been encouraged to adopt these practices to prevent nutrient loss and therefore potential contamination of surface and groundwater as part of the National Environmental Farm Planning Initiative. In 2001, in Manitoba 26 % and Alberta 28 % of fertilizer applications were broadcast (Korol 2004). At the same time, only 9 % of fertilizer applications were broadcast in Saskatchewan. There has been little change in how fertilizers are applied in Canada from 2001 to 2006 (MacKay and Hewitt 2010). Blackshaw et al. (2008) report a 50 % decrease in amount of surface-broadcast nitrogen fertilizer in the Prairies from 2002 to 2008.

Timing of fertilizer applications also impacts the availability of the nutrients to weeds. Various Canadian studies have shown that spring-applied fertilizer reduces weed problems (Blackshaw et al. 2002b, 2005a, b). In the 2000s Prairie Weed Management survey, the area receiving fall fertilizers varied greatly among provinces: 41 % in Manitoba in 2002, 25 % in Alberta in 2001, and 3 % in Saskatchewan in 2003 (data not shown). This may reflect the differential adoption of zero-tillage in the provinces. Blackshaw et al. (2008) reported a 40 % reduction in the amount of fall-applied fertilizer in the Prairies from 2002 to 2008.

8.4 Rotations

8.4.1 Crop Rotation

Crop rotation is the key to slowing the adaption of weeds. Planting a number of different crops increases the ability to vary seeding dates and herbicides. Based on the 2000s Weed Management Survey, the majority of producers use crop rotation to control weeds on their farms. In Alberta, 90 % of producers reported using this practice and 92 % of producers in Saskatchewan reported rotating crops for weed control (data not shown). The frequency of this practice was higher in Manitoba, with 99 % of respondents rotating crops for weed control in 2002, not significantly different than that reported in 1997. In 2010, Alberta producers ranked crop rotation as their most important weed management tool, surpassing herbicides (Neeser et al. 2013) .

The complexity of crop rotations can be evaluated based on a six-year cropping history. Overall, the participants in the 2000s Prairie Weed Management Surveys reported growing 66 different crops or crop mixes (including fallow). Very few

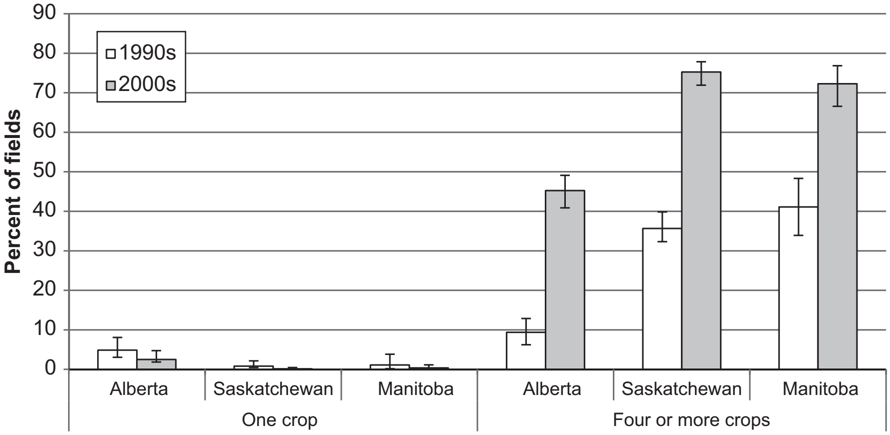

Fig. 8.9 Number of different crops included in a six-year cropping rotation based on data from Prairie Weed Management Surveys. The shortest unbiased 95 % confidence limits for the proportions are shown (Sokal and Rohlf 1995)

producers only grew one crop during this time (<1 % in Saskatchewan and Manitoba, 3 % in Alberta; Fig. 8.9). This percentage has not significantly changed since the 1990s surveys. Rotational diversity was greater in Saskatchewan and Manitoba, where approximately three-quarters of producers had four or more crops; in Alberta, only 45 % of respondents had four or more different crops in the six-year rotation. This has increased significantly in all provinces since the 1990s, when 36 and 41 % of fields in Saskatchewan and Manitoba, respectively, had four different crops, but only 9 % of fields in Alberta had four different crops in a six-year rotation.

Despite the relatively high diversity of crops included in the six-year cropping history, the majority of crops grown were either annual cereals or annual broadleaves (Fig. 8.10). In the 2000s, 22 % of the fields in Alberta and 16 % of the fields in Saskatchewan only had annual cereals planted in the six-year cropping sequence. In Manitoba, this was the case in only 2 % of the fields. In 1997, Alberta had fewer fields with only annual cereal crops (9 %), while Saskatchewan had more (33 %), and Manitoba did not significantly change.

Crops with different life cycles allow the implementation of greater diversity. A 1992 survey of Saskatchewan and Manitoba producers indicated that 83 % of the producers observed weed control benefits in annual crops grown after forages (Entz et al. 1995). However, it is still relatively uncommon for producers in any province to include fall-seeded crops (2 % of fields in Alberta and Saskatchewan, and 6 % in Manitoba) in rotation with annual crops (Fig. 8.10). While there was no change from the 1990s in Alberta and Saskatchewan, the use of fall-seeded crops in rotation in Manitoba increased from 1 % in 1997. There were significantly more fields with perennial crops in rotation with annuals in Albertain 2001 (10 %) in comparison to 1997 (4 %); however, this practice remained uncommon in the 2000s in Saskatchewan (3%) and Manitoba (5 %).

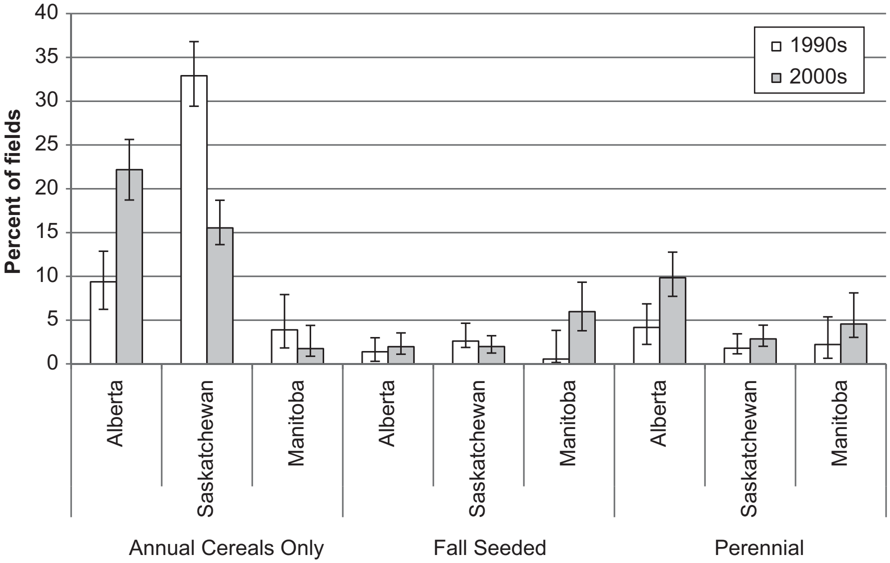

Fig. 8.10 Number of crop types included in a six-year cropping rotation based on data from Prairie Weed Management Surveys. The shortest unbiased 95 % confidence limits for the proportions are shown (Sokal and Rohlf 1995)

8.4.2 Seeding Date

While crop rotation facilitates varied seeding dates, adjusting to an early or late seeding date for a particular crop may help control weed flushes. The percentage of producers reporting varying seeding dates did not differ significantly among provinces, ranging from 29 % in Alberta to 34 % in Saskatchewan and Manitoba (data not shown). There was no significant change in the use of varied seeding dates in Manitoba between survey years. The relatively high percentage of farms using varied seeding dates in comparison to those using fall- seeded or perennial crops indicates that most of these producers are varying the seeding dates within the normal time frame when spring annual crops are planted.

8.4.3 Herbicide Rotation

In 2002 most producers in Manitoba reported rotating of herbicide groups (defined by site of action) to delay or manage the development of HR weeds (90 %; Fig. 8.11). By contrast, only 77 % of producers in 2001 in Alberta and 68 % of producers in 2003 in Saskatchewan rotated herbicides. This difference may be attributable to the earlier development of HR weeds in Manitoba and greater extension efforts. Among producers who rotated herbicides, there was no difference between provinces in the

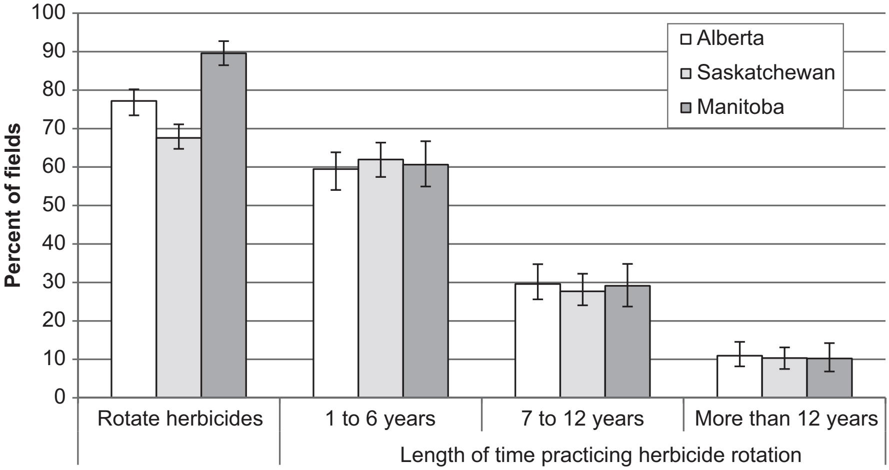

Fig. 8.11 Rotation of herbicide groups to delay or manage the development of herbicide-resistant weeds based on data from Prairie Weed Management Surveys. The shortest unbiased 95 % confidence limits for the proportions are shown (Sokal and Rohlf 1995)

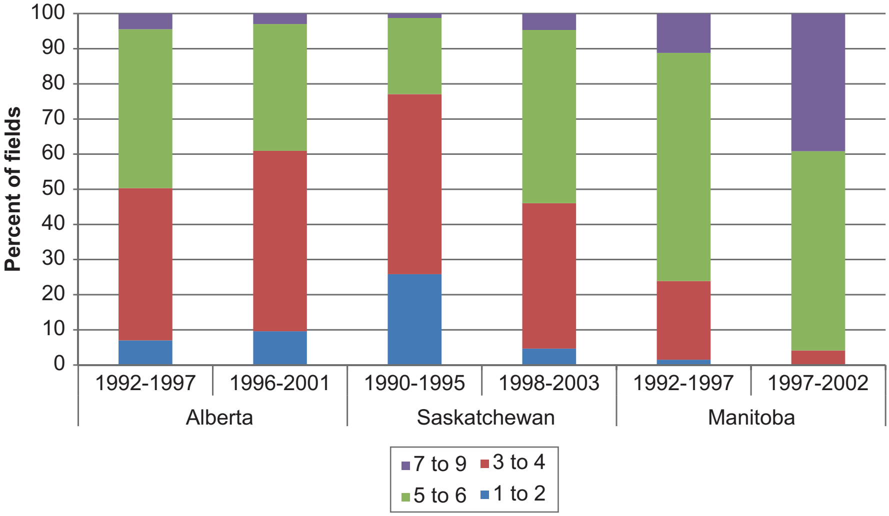

Fig. 8.12 Number of different herbicide groups applied to a field in a six-year period based on data from Prairie Weed Management Surveys

length of time that herbicide rotations had been used on their farms. Most producers adopted this practice relatively recently at the time of the survey (approximately 60 % had started in the previous six years).

The complexity of herbicide rotations varied between provinces, but has generally increased over time (Fig. 8.12). Fields in Saskatchewan often only had one

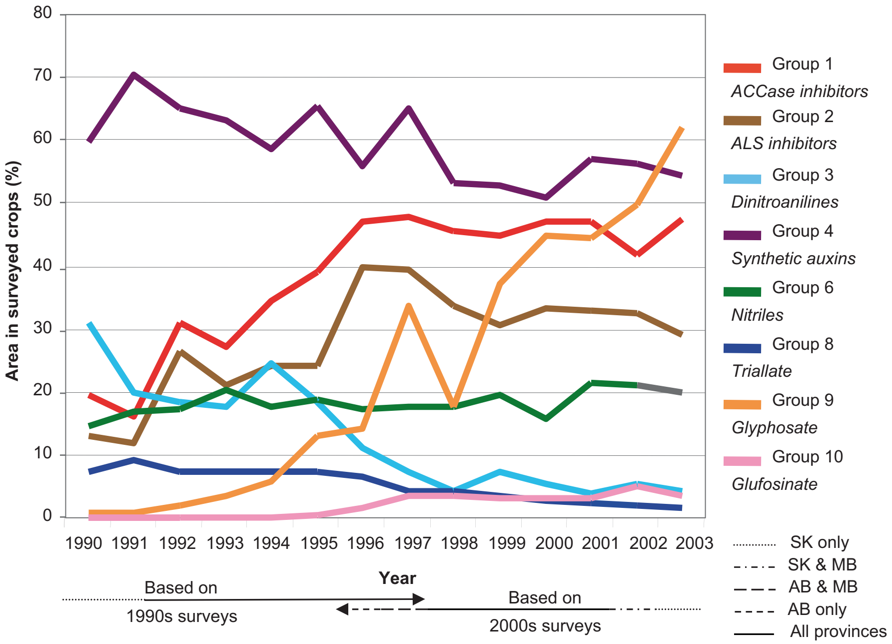

Fig. 8.13 Herbicide group use based on data from Prairie Weed Management Surveys

or two herbicide groups applied in a six-year period from 1990 to 1995; however, the situation improved greatly from 1998 to 2003 when only 5 % of Saskatchewan fields had only one or two herbicides applied. This low level of herbicide rotation occurred in less than 10 % of Alberta fields, and did not occur in the most recent survey of Manitoba. Manitoba producers also rarely only used three or four herbicide groups within a six-year period (4 % of fields); however, this was common in Saskatchewan and Alberta (41 to 51 % of fields). In the most recent surveys of Alberta and Saskatchewan, it was still relatively uncommon to use seven or more groups (3 to 5 %); however, 39 % of Manitoba fields had seven or more herbicide groups applied within a six-year period. The number of different herbicide groups applied was greater in the more recent surveys in both Manitoba and Saskatchewan, likely, in part, because of the increased use of Group 9 (glyphosate) products (Fig. 8.13). In Saskatchewan, there was also large increase in the use on Group 1 and 2 products between the two surveys.

The increased acreage to which glyphosate is being applied is a concern, as it indicated that back-to-back use of this product is occurring (Fig. 8.13). In Manitoba and Alberta, 23 to 24 % of producers applied glyphosate four or more times in six years based on the most recent surveys (data not shown). In Saskatchewan, 63 % of producers applied glyphosate four or more times in six years, and 23 % of producers applied glyphosate seven or more times from 1998 to 2003 (data not shown). In 2012, the first glyphosate-resistant weed species, kochia [*Kochia scoparia* (L.) Schrad.], was found in the Prairie Provinces.

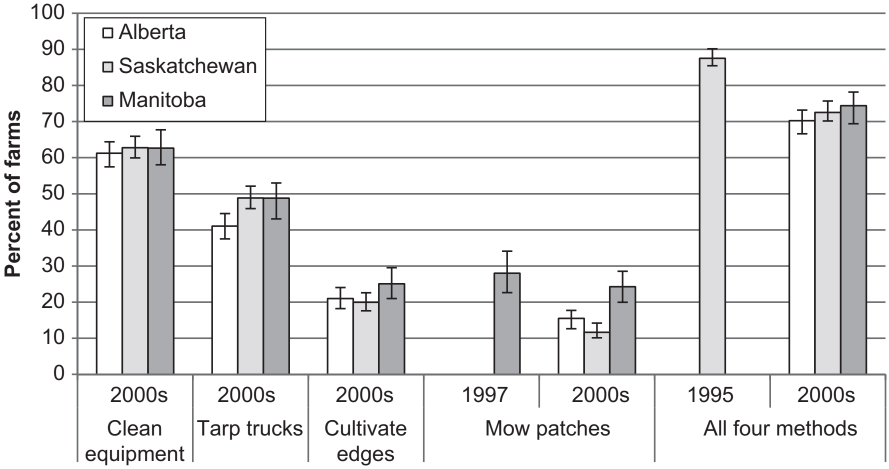

Fig. 8.14 Most common sanitation techniques used based on data from Prairie Weed Management Surveys. The shortest unbiased 95 % confidence limits for the proportions are shown (Sokal and Rohlf 1995)

8.5 Sanitation

A goal of IWM is to limit the introduction and spread of new weeds (Kelner and Derkson 1996). This can be achieved by using weed sanitation techniques, such as cleaning harvesting and tillage equipment, tarping grain trucks, mowing or spraying ditches or uncontrolled weed patches. While these practices are promoted in extension literature, the benefits of many of these practices are difficult to directly quantify, and thus have not been the focus of much research. An exception is a study in conjunction with the 1990s surveys indicating that consistent use of weed sanitation decreased likelihood of development of weed resistance (Légère et al. 2000).

The 2000s Prairie Farm Management survey indicated that cleaning equipment was the most common sanitation method practised by just over 60 % of the producers (Fig. 8.14). Tarping trucks was practised by just under half of the producers in Saskatchewan and Manitoba, and slightly less common in Alberta. Cultivating edges was practised by about 20 % of producers. Mowing weed patches was less common, except in Manitoba, where 24 % of producers used this practice. This was not a significant change since 1997 when 28 % of producers reported this practice as useful. The use of hand-weeding was relatively uncommon in all provinces, used by 8 to 11 % of producers in the 2000s Prairie Farm Management survey (data not shown).

Overall, sanitation practices have become less important to producers than in the 1990s (Fig. 8.14). At that time, 88 % of Saskatchewan producers reported using weed sanitation to help control weeds, i.e., cleaning harvesting and tillage equipment, tarping grain trucks, mowing or spraying ditches or uncontrolled weed patches. Only 73 % of producers from Saskatchewan reported using at least one of these four practices on their farm in 2003.

A sanitation technique which has received some attention from the research community is chaff collection (Shirtliffe and Entz 2005; Stumborg 2004). Despite research emphasizing the potential of chaff collection as a weed management technique, it has significantly decreased in popularity from 1997 in Manitoba when 16 % of producers found it useful to 2001 when only 6 % found it to be a useful practice (Prairie Weed Management Surveys, data not shown). This practice was also rarely used in Saskatchewan in 2003 (8 %) and Alberta in 2001 (7 %).

8.6 Scouting and Thresholds

The concept of scouting and thresholds is a fundamental part of integrated pest management. Only applying herbicide when necessary is economically and environmentally beneficial. Additionally, skipping applications of herbicides can help delay resistance. However, the use of thresholds was ranked as the fourth most important factor for determining whether to apply herbicide in Prairie Provinces in 2001, used by only 11 % of producers (Korol 2004). The majority of producers applied herbicides based on crop growth stage (53 %). In contrast, 17 % chose to apply herbicides at the first sign of weeds, indicating that scouting was performed, but thresholds were not considered. Sixteen percent of producers relied on regional monitoring to determine whether to apply herbicides and 3 % applied herbicides based on calendar dates.

8.7 Summary/Conclusions

Producers in the Canadian Prairies have shown that they are willing to change their weed management strategies when beneficial as illustrated by the rapid adoption of zero-tillage and HR crops. Based on data presented here, there is opportunity to increase the levels of adoption of most IWM practices. Producers must be made aware of the potential of these practices not only to reduce pesticide use, but also to delay resistance. Further efforts must be made to convey the importance of diversifying operations in the face of the increasing development of HR weeds.

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Chapter 9
Implementation and Adoption of Integrated Pest Management in Canada: Insects

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Abstract Canada is one of the largest agricultural producers and exporters in the world, and agricultural production systems are as varied as might be expected in such a vast country with many different regions, soil types and climates. In this Chapter we present general background information on Canada and its agricultural insect pests followed by a discussion of pesticide use and the current situation regarding integrated pest management (IPM). Regulations, and roles and responsibilities of the various levels of government, universities, commodity organizations and private companies in research, development and extension, are discussed. Finally, four case studies are presented to illustrate the status of IPM for the cabbage maggot, *Delia radicum*, in vegetable brassicas, the wheat midge, *Sitodiplosis mosellana,* in wheat, and various insect pests in apples and grapes. These studies of IPM in very different production systems provide insight into the challenges of establishing robust integrated insect management approaches and the parameters required for successful IPM. The wheat midge IPM program for example, has been adopted widely, largely because the insect can be identified with confidence, and most key components for successful IPM are in place. These include cultural practices, an early-warning system, degree-day models and economic thresholds. In contrast, management of the cabbage maggot is challenging and IPM systems remain rudimentary. Despite a strong theoretical understanding of its ecology, species identification is difficult and unreliable, there are few economic thresholds and limited control options. In summary, it is clear that the development and extension of IPM programs for insect pests in agriculture is a priority in Canada.

Keywords Canada · Integrated pest management · Apple IPM · Wheat midge · *Sitodiplosis mosellana* · Cabbage maggot · *Delia radicum*

9.1 Introduction

Canada is a vast country (land: 9,984,670 km^2, water: 891,163 km^2), inhabited by 33 million people (Vincent 2011) and framed by the Atlantic, Pacific and Arctic Oceans (Fig. 9.1). Much of the Canadian landscape is forest, lakes, rivers and tundra, but there are areas in each province with suitable land and either a maritime or a rather temperate continental climate which allow agricultural production. Some areas located in southern Quebec, Ontario and British Columbia have relatively intense and diverse agricultural industries. Average winter and summer high and low temperatures, precipitation, number of frost-free days, soil types and other parameters relevant to agricultural production vary from region to region. Politically, Canada is divided into ten provinces and three territories with a central federal government headquartered in Ottawa, Ontario (Fig. 9.1).

Fig. 9.1 Map of Canada showing provinces and territories. (*N.B.* is New Brunswick, *P.E.I.* is Prince Edward Island and *Sask.* is Saskatchewan)

The origins of many of our insect pests are uncertain (Morris 1983) but a large proportion are invasive alien species introduced over the last 200 years in soil used as ship's ballast, in packing straw and on plants and animals (Lindroth 1957) and more recently through the global movement of humans and their goods. Several species invade periodically from more southerly sources. An example is the diamondback moth *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), which reaches outbreak levels in canola (*Brassica napus* L. and *B. rapaoleifera* (DeCandolle) Metzger), and vegetable brassicas in some years. Many native species reach pest status under favorable conditions including grasshoppers (*Melanoplus* spp. (Orthoptera: Acrididae)), the apple maggot (*Rhagoletis pomonella* (Walsh) (Diptera: Tephritidae)) and the Colorado potato beetle (*Leptinotarsa decemlineata* Say (Coleoptera: Chrysomelidae)).

No comprehensive text exists on the history of integrated pest management (IPM) in Canada although Riegert (1980) discussed the development of economic entomology in the three Prairie Provinces and British Columbia. IPM in Canada followed a path similar to that of many other countries (see Kogan 1998; Walter 2003 and references therein, Brewer and Goodell 2012). Canadians have been at the forefront of the development of "integrated control" since the 1940s, with pioneering research in Nova Scotia by A.D. Pickett and associates from Agriculture and Agri-Food Canada (AAFC) (Figs. 9.2a and 9.2b). The insecticidal properties

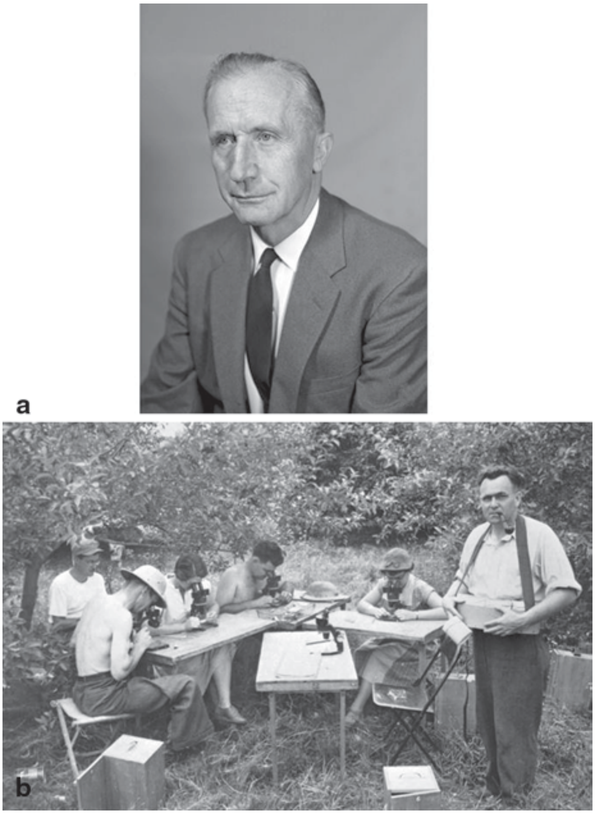


Fig. 9.2 **a)** A.D. Pickett, Entomologist, AAFC-Kentville, Nova Scotia, Canada. **b)** Staff from AAFC-Kentville, Nova Scotia, Canada identifying samples in the field (L to R – C. M. Phillips, Dr. A. W. MacPhee, H. J. Herbert, K. H. Sanford, E. J. Armstrong, and F. T. Lord, ca. 1950) (copyright ©1986. Catalogue number: A52-61/1986 E, AAFC. All rights reserved)

of DDT were recognized in 1939 and this insecticide dominated insect control in Canada and much of the world for the next 25 years. Spider mites became a problem in apple orchards in Nova Scotia only after DDT was used for spider mite control (McEwen and Stephenson 1979), and studies on the fauna of apple orchards in Nova Scotia were initiated in 1943 to determine the long term effect of the indiscriminate use of broad-spectrum spray chemicals on insects in the orchard environment (Pickett and Patterson 1953; MacLellan 1986). The development of IPM for agricultural insect control in Canada has continued to be a focus since that time.

In terms of pesticide use in Canada, there is no coordinated national collection of data on the use of insecticides or any other pesticides. However, during the development of an agri-environmental indicator for risk of contamination of water by pesticides, data were collected for use between 1986 and 2006 (Cessna et al. 2010). The amount of pesticide applied to Canadian cropland during that period, remained relatively constant, ranging between 29.7 and 35.4 million kg annually. In 2006, approximately 84 % of pesticides was applied in the Prairie region of Canada, specifically the provinces of Saskatchewan, Alberta and Manitoba. Ninety-four percent of all pesticides applied in Canada in 2006 were herbicides (Cessna et al. 2010). Insecticides accounted for just 2 %, although the relative proportions of herbicides, fungicides and insecticides varied by province (Cessna et al. 2010). Pesticide use data and information about IPM approaches used for the production of three crops (apple, carrot, grape) were collected in a pilot survey commissioned by AAFC following the 2005 growing season. Although the survey provided excellent information for a snap shot of practices in the given crops, the pilot also demonstrated that the survey was not a feasible approach to track pesticide use and pest management practices for specific crops over time.

Some individual provinces collect data to assist in the development and tracking of policy objectives related to pesticide use and reduction. For example, "Food Systems 2002" (FS2002) was a program established in Ontario in 1987, with the explicit goal of reducing pesticides in food production by 50% by 2002. FS2002 consisted of various components, including research, education, field delivery and pesticide use surveys conducted every 5 years (Appleby and Murphy 2003). Between 1983 and 1998, FS2002 reported a reduction in pesticide use of 38.4%, primarily on large acreage field crops like corn and soybeans, and measured as tonnes of active ingredient. This reduction was attributed to the increased use of integrated pest management, as well as availability of new low volume products and formulations, improved spray technology, changes in cropping patterns, education and the use of genetically modified crops (Appleby and Murphy 2003). The province of Quebec initiated a similar program, Stratégie Phytosanitaire, several years ago (Stratégie Phytosanitaire 2012). This program has been renewed, with the goal of reducing pesticide use in the province by 25% between 2011–2021. According to the original Stratégie Phytosanitaire, from 1995 to 2002, average pesticide use in Quebec (on a per hectare basis) was reduced by 35.7%.

The approach we have taken in this Chapter is to first discuss the current situation regarding IPM in Canada in general, including regulations, and roles and responsibilities in research, development and extension. This is followed by four case studies of the status of IPM for Canadian agricultural insect pests in apples, grapes, vegetable brassicas and wheat. Apples were chosen partly because of their place in the history of integrated control, and because IPM in apples is more truly "integrated" with inclusion of several key insect pests as well as diseases. By contrast, the viticulture case study presents a very different situation, a reflection in part of the relative immaturity of the grape industry in Canada. The third example describes management of the wheat midge (*Sitodiplosis mosellana*, (Géhin) (Diptera: Cecidomyiidae)), where again a successful IPM program has been developed for this key insect pest in wheat. Finally, *Delia radicum* (L.) (Diptera: Anthomyiidae), the cabbage maggot, is discussed in relation to vegetable brassicas. The cabbage maggot illustrates a situation where there is a strong understanding of the pest biology and ecology, but its application in a practical IPM system remains elusive and current control methods largely preventative. We examine the details of each case in the context of implementation and the availability of key components of an IPM program, including knowledge of pest biology and ecology, monitoring tools, taxonomy, thresholds and control strategies. While this Chapter deals with insect pests, we recognize that IPM refers to all pests, including plant pathogens and weeds.

9.2 Current Situation

9.2.1 Roles and Responsibilities in IPM

Agriculture was established as a shared federal—provincial responsibility in Canada via Section VI: Distribution of Legislative Powers, of the Constitution Act of 1867. Over time, the provinces have had a predominant role in agricultural outreach and extension activities pertinent to regional and local conditions and needs, while the federal government has taken on leadership roles in research and development, international markets and trade, food safety and inspection, and business risk management for growers. The Pest Control Products Act (PCPA), which governs the import, registration for sale, and conditions for use of pesticides, is administered by the federal health department's Pest Management Regulatory Agency (PMRA) (Health Canada 2012a). The storage, transport, sale and use of pesticide products, including commercial applicator licencing, are governed via provincial legislation, allowing provinces to institute further restrictions on pesticide use within their borders, should they so choose. Education for safe use of pesticides is also a provincial responsibility.

Agriculture and Agri-Food Canada (AAFC), the federal agriculture department, delivers programming to enhance the sector's capacity for innovation and competitiveness in international markets, in an environmentally sustainable manner. Integrated pest management is a key to sustainable agriculture, and thus is represented across a range of programs delivered by AAFC or jointly with the Canadian provinces within the context of a comprehensive agricultural policy framework (Cass and Kora 2012). Federally supported IPM research takes place at twenty AAFC research centres located across Canada, with teams of researchers active in biological pest control, pest identification and biology, behavior, forecasting, cultural and mechanical pest and weed management methods, resistant variety development, discovery and development of biopesticides and semiochemicals, and integrated systems approaches to pest management to reduce reliance on chemical-based control (AAFC 2012). Some specific examples are provided in the case studies below.

In addition, AAFC has in place two federal technology transfer programs which specifically support integrated pest management implementation: the Minor Use Pesticides Program (MUPP) (MUPP 2011) and the Pesticide Risk Reduction Program (PRRP) (PRRP 2011). The MUPP, modeled on the successful USDA IR-4 Project (IR-4 2012), complements minor use work carried out at the provincial level. Within this program, regulatory data generation trials are conducted and submission packages are assembled and submitted to PMRA to make new pest management product uses available for Canadian growers of small acreage and specialty (i.e., "minor") crops, thereby expanding the options available to growers. The PRRP works with industry stakeholders and experts to develop and transfer integrated management strategies to address priority pest management issues, and supports IPM implementation projects which develop, validate and/or demonstrate and communicate new IPM tools and approaches. The PRRP also conducts data generation trials and provides regulatory support to facilitate the development and registration of biopesticides, important tools in the IPM tool-box.

Areas of joint federal—provincial activity include applied research, forecasting and monitoring, Environmental Farm Plans (EFPs) and Beneficial Management Practices (BMPs) adoption programs. Under the EFP and BMP programs, Canadian producers have accessed incentive payments for adoption of a number of BMPs pertinent to IPM including development of farm-scale IPM plans, use of biological control agents, and adoption of designated pest management approaches posing a lower risk to humans and environment.

Canadian provinces have assumed the lead in areas of applied research, grower education, awareness-raising regarding new approaches and best management practices, and certain IPM program elements such as pest monitoring and risk advisories, and pest management recommendations. Provinces provide extension services in different ways across the country; some but not all provinces have employees on staff to provide traditional in-field extension services. Most Canadian provinces have comprehensive resource websites where growers can access information relevant to pest management in their operations; many also offer telephone hotline services or pest advisories and alerts.

Experts at Canadian universities conduct research into aspects of IPM; some also provide grower training. Academics are included in advisory groups through which they provide policy advice to federal and provincial governments related to IPM planning and programming. Several Canadian academic institutions are particularly active in the area of agricultural IPM, such as the University of Guelph (Ontario), Dalhousie University (Nova Scotia), Macdonald Campus of McGill University (Quebec), the University of Saskatchewan (Saskatchewan), Simon Fraser University and Kwantlen College (British Columbia).

In addition to governmental and academic IPM activities, many commodity organizations in Canada take a proactive approach to provide their members with support and guidance in implementing IPM systems in their agricultural operations. The Canadian Nursery and Landscape Association (C.N.L.A. 2012), the Canadian Horticulture Council (C.H.C. 2012), Saskatchewan Pulse Growers (S.P.G. 2012), the Canola Council of Canada (C.C.C. 2012), and Flowers Canada Growers (F.C.G. 2012) are examples of industry organizations which have put an emphasis on IPM and have made tools and information available to their member growers.

9.2.2 Methods in IPM Extension in Use in Canada

In general, the trend over the past several years has shifted toward mass communication of information via websites, e-mail and phone advisories, and recently, applications which can be accessed via smartphones. Most provinces use a combination of approaches to inform and educate growers about pest risks and advances in IPM.

Some examples of different approaches in use across the country include:

- extension services based upon on-line and winter-time training opportunities (workshops, conferences) complemented by in-season mass communications, and in-person advice delivered by crop/extension specialists at field days and grower meetings;
- information for growers provided mainly through mass communication approaches and grower hotlines/communication centers;
- delivery of extension services through a third party organization and consultants, (e.g., Perennia (2012) in Nova Scotia, Agri-Trend (2012) in the Prairie provinces, E.S. Cropconsult (2012) in British Columbia);
- delivery via grower agri-environmental advisory clubs (e.g., Quebec's "Clubs-conseils en agro-environnemental", groups of producers based in the various regions of the province which hire extension specialists with provincial funding).

Some services are provided free of charge by provincial governments (e.g., publications, pest information, and management recommendations) or by governmental and industry partnerships (e.g., on-line pest risk advisories and weather data), and some are available on a fee for service basis from various companies.

Specific farmer participatory training exercises are used in some provinces to accelerate the adoption of new IPM techniques and systems (e.g., Lygus plant bugs in strawberry, (AAFC PRR06-880 (2012)), grape IPM (AAFC PRR07-590 (2011b)), and demonstration of "Contans", a biofungicide containing *Coniothyrium minitans* (AAFC BP108-030 (2011a)), and on-line information modules (e.g., Ontario Crop IPM 2009)), webinars, crop pest diagnostic days (e.g., Manitoba (2012)), field tours, and other outreach events contribute to informing growers of new approaches in pest management.

9.2.3 Drivers for IPM Adoption in Canadian Agriculture

As in other OECD countries, a number of circumstances are combining to drive an increase in awareness and adoption of IPM in Canadian agriculture (OECD 2012). Markets are beginning to respond to consumer concerns over environmental sustainability in agricultural systems and chemical pesticides used in food production. Some specialized markets now require that growers comply with certain standards of production, which has given rise to a need for sophisticated record-keeping systems. Major buyers/processors can and do play an important role in driving the actual production practices of growers, including pest management practices. In Canada, this influence on growers' IPM practices is exemplified by the case of a potato IPM program (Potato IPM 2012) developed via a collaborative effort of the growers (as represented by the CHC potato council), a major potato buyer and processor (McCain's), and an end user (McDonald's). The voluntary program is centered on a survey of IPM practices which growers complete to assess their position on an IPM continuum.

The province of Quebec has renewed its “Stratégie Phytosanitaire” for the period 2011–2021. The stated goal of the strategy is to reduce risks to human health and to the environment associated with pesticide use in agriculture in the province by 25 % by 2021 in comparison with an average of pesticide use during the reference years 2006–2008 (Stratégie Phytosanitaire 2012). Farmers in the province will be provided training and better access to reduced risk pest management tools and decision support systems such as “SAgE pesticides” (SAgE Pesticides 2012), a system for selection of pesticides taking into account potential impact on health and environment. At the same time, growers will be provided with incentives to adopt IPM systems approaches. It can be anticipated that these measures will have a positive impact on adoption of IPM within Quebec.

In Canada, growers are interested in reducing their reliance on expensive chemical inputs to the extent possible, and in reducing exposure of workers on their farms to potentially harmful compounds. Certain older pesticides are being lost from the pest management tool-box as a result of regulatory re-evaluation, while the usefulness of some pesticides is being compromised due to a rise in pest population resistance to the active ingredients. Growers are forced to deal with new pest threats due to invasive alien species, e.g., *Drosophila suzukii* (Matsumura) (Diptera: Drosophilidae), and changes in pest biology or behavior as a result of climate change. These issues all demand long term, robust, systems-based and sustainable solutions.

At the same time that growers are being faced with these pressures, accessibility to IPM information via a number of channels has been greatly enhanced, as discussed above. Elements of IPM infrastructure such as reliable and timely weather data, degree-day forecasts, incorporation of specific geographic and soil information, and refined economic thresholds which take into account natural enemy numbers are becoming more readily available to growers through online and smart phone applications. The ease with which growers can customize IPM information to their own operations is a major factor in determining their success in adopting IPM practices. Together, these factors can be expected to combine to drive change along the IPM continuum toward the use of more integrated, systems based management approaches by Canadian growers.

9.3 Case Studies

9.3.1 IPM in Apple Orchards and Vineyards in Canada

9.3.1.1 Background and Context

It is useful to consider IPM in apple and grape production together given the issues which the two production systems have in common: in both cases fruit are produced by perennial plants planted in rows; production is relatively intensive in terms of plant density, labor and economic value per hectare; both apples and

Fig. 9.3 Apple orchard in bloom, Frelighsburg, Quebec, Canada (photo credit Charles Vincent)

grapes are grown for fresh and processed markets. As well, the rigor of Canadian winters is a major factor restricting the choice of cultivars, fungal diseases are major concerns and drivers of IPM programs, and the timing of IPM interventions can be guided by phenological crop stages.

By contrast, there are major differences between apple orchards (Fig. 9.3) and vineyards which have implications for IPM approaches. Apple trees over-bloom and, after fruit set, fruitlets fall to the ground in June, leaving just one or two fruits per cluster. On grape vines, the number of berries per cluster is frequently >60, with small berries appearing continually throughout the season, and with very few berries dropped to the ground prior to reaching maturity. Apple trees have definite growth whereas vines exhibit indefinite growth, offering a continuous supply of tender tissues to arthropod pests throughout the season. Most apples produced in Canada are aimed at the fresh market and, consequently, tolerance for cosmetic damage is very low. Most grapes grown in Canada are transformed into wine, and thus a certain amount of direct damage to grapes can be tolerated. Apple orchards and vineyards share very few pest species. Finally, from a research and knowledge perspective, a great deal more information has been published over the past decades concerning arthropods of apple orchards (several thousand), while ca. 1,000 articles have been published in viticultural entomology since 1972. As a consequence, radically different research and IPM programs have been developed to service the pomological and the viticultural industries.

9.3.1.2 IPM in Apple Orchards

The principles on which IPM programs for tree fruits rely have been reviewed in Aluja et al. (2009). In Canada, at least 30 arthropod species attack apple orchards (Vincent and Rancourt 1992; Chouinard et al. 2000). As these species can vary in absolute and relative numbers across Canada, optimal IPM programs are tailored to meet specific regional needs. For instance, the plum curculio (*Conotrachelus nenuphar* Herbst (Coleoptera: Curculionidae)) is present in Nova Scotia, Quebec and Ontario, but absent in British Columbia (Vincent et al. 1999; Leskey et al. 2009). In Quebec and Ontario, it is a major pest that requires insecticidal treatments. Similarly, due to wet climate, the pressure exerted by apple scab (*Venturia inaequalis* (Cke) Wint.) in eastern Canada is much greater than in British Columbia, where apple production regions, particularly in the Okanagan Valley, enjoy a drier climate. Conversely, the codling moth (*Cydia pomonella* L. (Lepidoptera: Tortricidae)) is an example of a pest which has been handled differently in different regions of Canada (it is a key pest in the Okanagan Valley but seldom a problem in eastern Canada). The climate and other factors in the Okanagan apple production region have allowed the successful application of an area-wide approach to codling moth management involving sterile insect release. On the other hand, Ontario, Quebec and Nova Scotia reported that this pest continued to have widespread, yearly occurrence with high pest pressure (AAFC 2009b), and resistance to insecticides has been reported in some pest populations.

Alternatives to Insecticides Throughout the years, numerous research projects yielded information frequently formatted as research articles or technical bulletins. This information has been blended into optimal apple IPM programs which have, for the past decades, been based upon chemical pesticides. However, the need for alternatives to the use of insecticides for many of the reasons identified earlier in this chapter including consumer awareness of environmental issues and legal restrictions on the use of some insecticides is clear. In particular, the regulatory phase out of azinphos-methyl (a broad spectrum insecticide widely used in apple IPM programs) in 2010 presented challenges for apple producers. In preparation for this, the Pest Management Regulatory Agency (PMRA) and AAFC's Pest Management Centre implemented strategies to ensure adequate reduced risk alternative products were brought forward for Canadian registration, and that IPM approaches and alternative tools be added to the tool-box where possible. As a result of these efforts, 24 new minor use submissions of alternative products were made, novel pest monitoring tools were developed and projects demonstrating the use of all of these IPM tools were supported (Sethi 2011).

Numerous soft alternatives have been investigated or developed in Canada. For example, AAFC's Pest Risk Reduction Program funded a research project to support the use of *Lathrolestes ensator* Brauns (Hymenoptera: Ichneumonidae), a larval parasitoid of the European apple sawfly (*Hoplocampa testudinea* Klug (Hymenoptera: Tenthredinidae)) (Fig. 9.4) (Vincent et al. 2001, 2013). Virosoft CP4, a baculovirus-based biopesticide (Lacey et al., 2008), has been developed through a partnership between Biotepp Inc. (Mont-St-Hilaire, Quebec) and AAFC (Vincent et al. 2007). Mating disruption techniques (i.e., saturation of the atmosphere by sex pheromones) are commercially available. Persistence of insecticidal activity of novel encapsulated formulations of *Bacillus thuringiensis* var. *kurstaki* has been determined in field trials against the oblique banded leafroller (*Choristoneura rosaceana* Harris (Lepidoptera: Tortricidae)) (Côté et al. 2001). The Okanagan-Kootenay

Fig. 9.4 **a)** Adult European apple sawfly, *Hoplocampa testudinea*, on apple flower (photo credit Leo-Guy Simard), **b)** European apple sawfly, *Hoplocampa testudinea,* damage on apples (photo credit Julien Saguez)

Sterile Insect Release (OKSIR) program has successfully kept codling moth below problematic levels for a number of years through an integrated approach consisting of: mandatory area-wide control application of sterile insects or mating disruption; surveillance via pheromone traps and visual inspections; enforcement, and; grower education. Between 1991 and 2008, the amount of organophosphate insecticide used per hectare was reduced by 93 % (OKSIR 2012).

Few alternative methods have the potential to impact several organisms belonging to different classes (Vincent et al. 2003). Noteworthy exceptions are apple leaf shredding, which can impact both apple scab and the spotted tentiform leafminer, (*Phyllonorycter blancardella* (Fabr.) (Lepidoptera: Gracillariidae)) (Vincent et al. 2004), and cellulose sheeting, which can impact weeds, the European apple sawfly and the plum curculio (Benoit et al. 2006). Other physical methods such as perimeter trapping of apple maggot adults have been researched with some success (Bostanian et al. 1999).

While the use of insecticides remains the only feasible approach in some cases, the use of a border spray strategy may dramatically reduce the quantities of insecticides recommended compared to full orchard treatment. An example is the plum curculio, where a border row strategy using products targeting the adults can reduce insecticide use by up to 60 % (Vincent et al. 1997, 1999). Such savings are achieved at the cost of increased labor, i.e., frequent monitoring of fresh oviposition scars. Likewise, border row strategies have been developed in Ontario for the codling moth and the apple maggot (Trimble and Solymar 1997). However these strategies need further verification when applied to the use of newer, reduced-risk products (AAFC PRR09-020 2011c). Although some insecticides have been used each year for ca. 50 years, little resistance has been documented so far in Canadian orchards, with the exception of the spotted tentiform leafminer in Ontario (Pree et al. 1986), and the oblique banded leafroller in Quebec (Smirle et al. 1998). Strategies to maximize populations of natural enemies are being investigated including approaches to attract beneficial arthropods. To that effect, Bostanian et al. (2004) planted flowering plants in orchards to attract beneficial arthropods. Selection of the least disruptive chemical is another strategy to conserve natural enemies, for example Lefebvre et al. (2011) assayed six "reduced risk insecticides"on *Galendromus occidentalis* (Nesbitt) (Phytoseiidae), a major predator in the Okanagan Valley of British Columbia. Information collected in a voluntary survey of pest management practices in apple production during 2005 indicated that of the 528 tonnes of insecticide active ingredient applied, 88 % (465 tonnes) was mineral oil, a reduced risk product used to prevent pest population buildup (AAFC 2008).

IPM Delivery Programs in Apple As mentioned above, in Canada, provinces are responsible for extension services, and the modalities of program delivery vary from one province to another. The Quebec Apple network is an organization that coordinates information across all stakeholders in that province (Chouinard et al. 2006). Information is gathered mostly by agro-environmental clubs (i.e., nonprofit organizations) that are co-financed by apple growers and the Quebec Ministry of Agriculture. This ensures real-time access to information by the participants. Traditionally, the results of research programs have been made available through a number of technical bulletins (e.g., Vincent and Rancourt 1992; Chouinard et al. 2000). As in other provinces, information flow has been streamlined due to the availability of web-based documents in recent years. An unusual example of IPM delivery is the model used by British Columbia's OKSIR (OKSIR 2012), which is delivered by an organization funded through municipal taxes, the only example of its kind in Canada.

Apple orchards are mature systems in terms of research and markets. Overall, owing to the activities described above, pesticide usage in apple orchards has remained relatively stable and the expected gain in further reducing pesticide input is likely to be small.

9.3.1.3 IPM in Vineyards

Among horticultural crops in Canada, vineyards have experienced great economic growth in the past 40 years; this trend appears to be steady in the foreseeable future.

As mentioned previously, the scientific literature pertaining to Canadian vineyards is limited and the need for information urgent.

The principles on which IPM programs for vineyards rely have been discussed in Vincent et al. (2012). Grape diseases are major problems (Carisse et al. 2009) driving IPM programs, and in Canada, research efforts differ across provinces. The most serious insect pest management problems differ from one province to the next, and research activities in the producing regions also reflect this reality (AAFC 2009a). In Quebec for instance, the strategy has been to first systematically document the biodiversity of arthropods in unmanaged or lightly managed vineyards (summarized in Vincent et al. 2009). Thus, Bostanian et al. (2003) reported on the main arthropod pests, Goulet et al. (2004) found 124 carabid species, while Bolduc et al. (2005) found 97 spider species, Bouchard et al. (2005) reported 73 species of curculionids, Lucas et al. (2007a) reported 20 species of coccinellids, and Lesage et al. (2008) reported 59 species of chrysomelids. Such information should prove to be useful for the development of strategies to manage vineyards with relatively little use of broad-spectrum insecticides. The status of some important horticultural insect pests remains unclear. In laboratory experiments Fleury et al. (2006) found that adults and nymphs of the tarnished plant bug (*Lygus lineolaris* P. de B. (Hemiptera: Miridae)) may feed on vines early in the season and have a minimal impact at that time of year. In Ontario, the multicolored asian ladybeetle (*Harmonia axyridis* Pallas (Coleoptera: Coccinellidae)), originally imported as a biocontrol agent (Lucas et al. 2007b), became a problem in some years; when abundant and crushed with the grapes at harvest, it releases alkyl-methoxypyrazines that, in small concentrations, taint the wine (Vincent and Pickering 2013).

Alternatives to Insecticides In Ontario Trimble (2007) worked on the development and implementation of pheromone dispensing technologies to manage the grape berry moth (*Paralobesia viteana* (Clemens) (Lepidoptera: Tortricidae). Because of the sustained demand for planting new vineyards, Canada had to import vines from other countries, notably from Europe. However, to prevent the importation of phytoplasma diseases (vectored by cicadellids—see Olivier et al. 2012), the Canadian Food and Inspection Agency (CFIA) is enforcing strict regulations. Thus, thermal treatment of imported vines is required to prevent phytoplasma dissemination.

IPM Delivery Programs in Vineyards In Canada, IPM programs in viticulture do not benefit from the wealth of information and tradition enjoyed by their colleagues working in pomiculture. Owing to the paucity of local research information, a peek at the web sites of neighboring states in the USA is common. As described for apple orchards, viticultural information is available through provincial web sites. However the sustained growth of the viticultural industry and the advent of invasive arthropod species will exert pressure to increase resources devoted to research and extension.

Fig. 9.5 Adult wheat midge, *Sitodiplosis mosellana,* on wheat head; insert shows *Macroglenes penetrans*, a parasitoid of the wheat midge (photo credits AAFC- Saskatoon)

9.3.2 Management of the Wheat Midge, Sitodiplosis mosellana (Géhin)

9.3.2.1 Background and Context

Wheat is Canada's largest crop both in relation to area seeded (~14 million ha) and production (~30 million tonnes). Canada's annual wheat export revenues are approximately CDN$ 5.5 billion, making wheat the highest earner of all exported agricultural products. The major provincial producers are Saskatchewan (46 %), Alberta (30 %), Manitoba (14 %) as well as Ontario and Quebec (10 %). Wheat midge, *Sitodiplosis mosellana* (Géhin) (Diptera: Cecidomyiidae) (Fig. 9.5), is an invasive alien species accidentally introduced into North America in the early 1800s (Felt 1912). First reported in western Canada in 1902 (Fletcher 1902), *S. mosellana* did not emerge as a major pest until wheat growers in northeast Saskatchewan experienced losses in excess of CDN$ 30 million in 1983 (Olfert et al. 1985). Today, while the wheat midge is still a major pest of spring wheat, *Triticum aestivum* L., durum wheat (*Triticum durum* Desf.), and triticale (*X-Triticosecale*) in most wheat-growing areas of Canada and several neighboring U.S.A. states (Olfert et al. 2009), growers have access to a comprehensive integrated pest management program developed over the past 15–20 years.

9.3.2.2 Development of a Successful Integrated Management Program

As with all new pest problems, the development of an effective IPM program begins with knowledge of the biology of the pest and the nature of the pest/host crop interaction. The life cycle of *S. mosellana* was reviewed by Mukerji et al. (1988) for Canada. Adults emerge over a six-week period beginning in late June or early July. Populations tend to peak during the second or third week of July in western Canada. Females are most active in the evening, with egg-laying occurring primarily at dusk when conditions are calm and temperatures are above 10–11 °C. Eggs are laid singly or in clusters of up to four eggs on the florets of emerging wheat heads. Larvae crawl into the floret and feed on the kernel surface for 2–3 weeks. Mature larvae remain within their cast skin in the wheat head when conditions are dry. Once moist conditions occur, larvae drop to the ground, burrow into the soil, spin a cocoon and overwinter. The following spring, further larval development depends on temperature and soil moisture; if conditions are dry during May and June, larvae remain dormant until the following year; however, if moist, larvae leave their cocoons and move to the soil surface to pupate.

Although traditional Canadian wheat varieties differ in their susceptibility to damage, the severity of damage is largely dependent on the synchrony between egg-laying and heading. Wheat heads are most susceptible to damage when egg-laying occurs during heading (Zadoks growth stages 51–59; Elliott and Mann 1996). Damage declines dramatically when egg-laying occurs after the anthers are visible. Moist conditions in May and June favor larval development. Injury is caused by larvae feeding on the surface of developing kernels. A single larva developing on a kernel will result in scarring; however, three or more larvae within a floret will result in kernel abortions or not filling properly. Mature kernels from infested florets are cracked, shriveled or deformed. Damaged kernels that are harvested will lower grain quality (i.e., milling and baking properties).

9.3.2.3 Successful Management Tools

Biological Control

In 1984, *S. mosellana* populations in Saskatchewan were found to be parasitized by a native egg-larval parasitoid, *Macroglenes penetrans* (Kirby) (Hymenoptera: Pteromalidae) (Fig. 9.5) (Doane et al. 1989). Despite the presence of the parasitoid within the egg, the wheat midge larva completes its development and overwinters in the soil (Doane et al. 2013). The next spring, the parasitoid larva consumes its host, and emerges as an adult in July. In 1985, a study was initiated to evaluate parasitoids that could be introduced to augment the biological control provided by *M. penetrans*. From European studies (Affolter 1990), it was determined that *Platygaster tuberosula* Kieffer (Hymenoptera: Platygasteridae) was a good candidate for introduction into North America. Females of *P. tuberosula* lay their eggs in *S. mosellana* eggs or early-instar nymphs, and the parasitoid adults emerge from the host pre-pupae or pupae. Major releases of *P. tuberosula* were carried out in the mid-1980s. Although its overall impact on *S. mosellana* populations still needs to be quantified, the introduction of *P. tuberosula* to Saskatchewan was successful. Meanwhile, evidence shows that *M. penetrans* continues to play a lead role in regulating *S. mosellana* infestations in western Canada. In 2011, soil core samples from the major release site revealed that 33 % were found to be parasitized with *M. penetrans* and 22 % with *P. tuberosula*. The findings suggest that the two species are co-existing to enhance the control of *S. mosellana.*

Resistant Wheat Varieties

Wheat midge-tolerant wheat varieties were developed to mitigate the lower yields and market grades caused by wheat midge and to offer producers more flexibility in crop rotations (Barker and MacKenzie 1996). Expression of the *Sm1* gene activates a natural response within seeds that prevent larvae from establishing by releasing ferulic and p-coumaric acids (Ding et al. 2000). To conserve the effectiveness of the *Sm1* gene, new tolerant cultivars have been released as a blend, containing a ratio of 90 % resistant seed and 10 % seed of a registered susceptible cultivar. The blend helps to prevent the development of resistant mutations in midge populations by allowing sufficient numbers of susceptible midge to survive and mate with midge that become resistant to the *Sm1* gene. The susceptible cultivar also serves as a refuge and helps to conserve the parasitic wasp, *M. penetrans.*

Cultural Practices

Cultural practices were also found to be an important management strategy (Elliott and Mann 1996). Continuous wheat cropping can result in a buildup of *S. mosellana* populations. In areas where populations exceed 1200 larvae m^{-2}, growers are encouraged to plant resistant crops such as canola (Fig. 9.6), flax, *Linum usitatissimum* L., and legumes instead of wheat. In addition, other cereal crops such as barley, *Hordeum vulgare* L., oats, *Avena sativa* L., and annual canary grass, *Phalaris canariensis* L., can be grown with little or no risk of wheat midge damage. For low to moderate infestations, damage can be reduced by selecting less susceptible varieties of spring wheat, planting early, and at higher seeding rates. These practices promote uniform, advanced heading to avoid high adult *S. mosellana* populations.

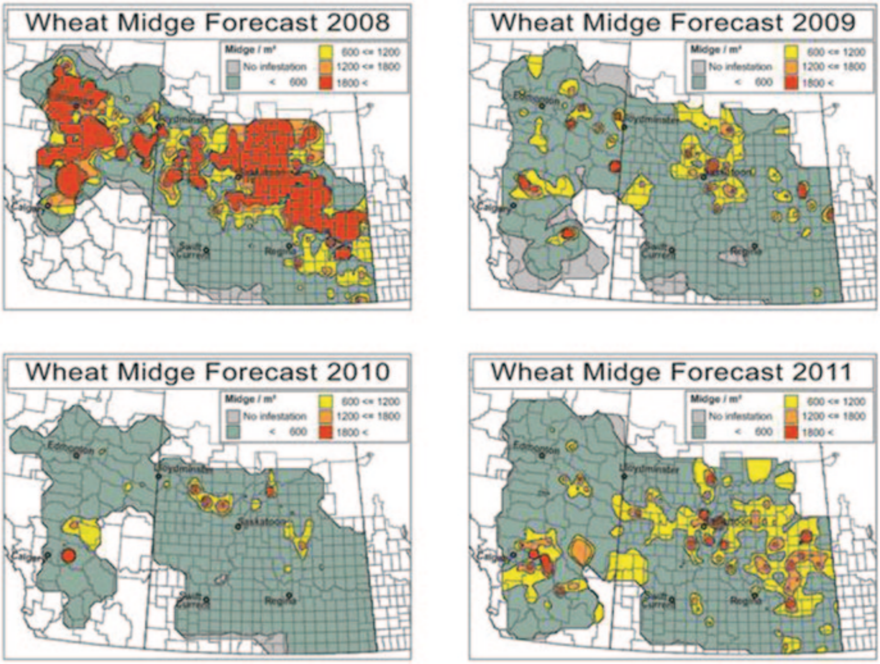
Fig. 9.6 AAFC field staff collecting wheat midge and parasitoids in wheat (*Triticum aestivum*) adjoined by canola (*Brassica napus*) in Saskatchewan, Canada (photo credit AAFC-Saskatoon)

Decision Support Tools

At the same time as these management tools were being developed, economic thresholds for insecticide applications were determined and widely adopted by growers. The recommendation was that insecticides should be used only when there was at least one adult midge for every four to five wheat heads at several locations in the field (Elliott 1988a, b), and that applications should be made at dusk. More recently, an early-warning system of crop risk associated with wheat midge populations has been established as a successful decision support tool. Surveys of the abundance and distribution of overwintering larval cocoons of both the pest (*S. mosellana*) and the native parasitoid, *M. penetrans*, are conducted annually in the fall (Olfert et al. 2011). The results identify potentially damaging populations for the following crop year (Fig. 9.7). In addition, accumulated degree-day models accurately predict the emergence of adult *S. mosellana* (Elliott et al. 2009) and the parasitoid, *M. penetrans* (Elliott et al. 2011) throughout the infested areas, and assist producers in scheduling the scouting of their fields for the presence of the pest and its natural enemy. Producers are encouraged to adjust the timing, rate and placement of sprays for control of wheat midge to protect and conserve natural enemies. The mean rates of parasitism in Saskatchewan ranged from 25 to 46 % and from 12 to 38 % in Alberta for the years 2001–2010 and resulted in an estimated saving of $248.3 million in pesticide costs alone. The environmental benefits of not having to apply this amount of chemical insecticide are additional (Olfert et al. 2009).

9.3.2.4 Summary

In conclusion, wheat producers in Canada have access to a comprehensive management program to minimize the economic and ecological impact of *S. mosellana*. This IPM tool kit was developed over a span of 15–20 years, and has been success-



Wheat Midge Forecast 2008

Wheat Midge Forecast 2009

Wheat Midge Forecast 2010

Wheat Midge Forecast 2011

Fig. 9.7 Population distribution and density of wheat midge, *Sitodiplosis mosellana,* in western Canada (2008–2011) (photo credit AAFC-Saskatoon)

fully adopted by producers, in large part due to the technology transfer efforts of researchers and provincial entomologists. Forecasts and risk warnings, monitoring tools, cultural control, agronomic practices, chemical control, biological control and host plant resistance are all available for the industry to manage *S. mosellana*. Prior to the growing season, forecast maps predict high risk areas. If the rotation allows, the producer may choose not to grow wheat, grow a resistant variety of wheat, or grow an alternate resistant crop instead. If a lower degree of infestation is predicted, producers may stick to their plans to grow wheat, but may choose a less susceptible wheat cultivar and plant early to avoid high midge populations during heading. Producers are encouraged to monitor crops closely in all areas where *S. mosellana* is present during the susceptible period (emergence of the wheat head from the boot until anthesis begins). Field scouting tools, including visual counts, sticky cards, and pheromone traps are readily available for producers to utilize. An insecticide application is recommended when the crop is heading but not yet flowering and wheat midge density is one adult per 4–5 wheat heads. To maintain optimum grade, insecticide should be used when the pest population reaches one adult per 8–10 heads. Late insecticide applications should be avoided as they are not cost effective and may adversely affect biological control agents.

9.3.3 Management of the Cabbage Maggot, Delia radicum (L.)

9.3.3.1 Background and Context

Vegetable brassicas are well suited to the climates of many regions across Canada and many are important as fresh and processing vegetables in British Columbia, Ontario, Quebec and the Atlantic Provinces in particular (AAFC 2005, 2010; Munro and Small 1997). *Delia radicum* (L.) (Diptera: Anthomyiidae), the cabbage maggot, is widespread through temperate regions of the Holarctic (35–60 N) and is one of the most chronic and challenging agricultural insect pests in Canada. It was accidentally introduced from Europe, probably during the nineteenth century (Griffiths 1991; Biron et al. 2000) and now occurs in every Canadian province. *Delia radicum* has undergone frequent name changes since first described (Finch 1989; Griffiths 1991). In Europe it is known as the cabbage root fly (Holliday et al. 2013), and the French Canadian common name is "mouche du chou". *Delia planipalpis* (Stein) and *Delia floralis* (Fallén) are sibling species of *D. radicum* and also crucifer pests, although they are thought to be native and their geographic distributions are more limited. Infestation of brassica roots by larvae of *Delia platura* Meigen and *Delia florilega* (Zetterstedt), is generally secondary (Griffiths 1991), but their presence further complicates an already taxonomically difficult situation. Brooks (1951) attempted to provide a key to the common species of root maggots infesting cruciferous crops in Canada. Correct identification is of course the basis of any IPM program but in the case of *Delia* spp, it is challenging because small and sometimes variable characters must be used to separate species (Brooks 1951; Griffiths 1991). The identification keys found in Brooks (1951) have been the standard reference in Canada for many years but according to Griffiths (1991), not all of Brooks' descriptions are now valid and should be used with caution and in conjunction with other literature.

Delia radicum larvae feed on the roots of many Brassicaceae, such as rutabaga (*Brassica napus napobrassica* (L.)) (Fig. 9.8a), turnip (*Brassica rapa rapa* L.), cole crops including broccoli, cabbage, cauliflower, (varieties of *Brassica oleracea* L.), and canola (Soroka et al. 2002). Canola is a genetic variation of rapeseed developed by Canadian plant breeders specifically for its low level of erucic acid in the oil and low glucosinolates in the meal. Although this section is focused on vegetable brassicas, the large acreage under canola production on the Canadian prairies is relevant as it acts as a huge reservoir for *Delia* pest species.

The insect overwinters as pupae in the soil and spring emergence of flies varies with temperature, soil type, moisture and whether the individual expresses the early- or late-emergence biotype (Finch and Collier 1983; Turnock and Boivin 1997; Andreassen et al. 2010). Eggs are deposited on or near the base of the host plant, usually just below the soil surface (Dixon et al. 2002). One to four generations occur annually in Canada, and they often overlap, in part due to different emergence biotypes (Andreassen et al. 2010; Dixon and Collier 2001). Further details of damage, host finding and life history can be found in Ritchot et al. (1994) and Parsons

Fig. 9.8 **a)** *Delia radicum* larvae on rutabaga (*Brassica napus napobrassica*) (photo credit Carolyn Parsons), **b)** Polyethylene insect netting demonstration on a field of rutabaga (*Brassica napus napobrassica*), St. John's, Newfoundland and Labrador, Canada (photo credit Anna DeMello)

et al. (2007). Natural enemies affect all stages of this insect. A summary of the biology of each species and past deliberate releases in Canada are given in Soroka et al. (2002) and Holliday et al. (2013). Several of the primary parasitoid species that attack *D. radicum* in Europe are present in Canada, presumably introduced along with their hosts. These include *Aleochara bilineata* Gyllenhall (Coleoptera: Staphylinidae) and *Trybliographa rapae* (Westwood) (Hymenoptera: Figitidae). Parasitism of *D. radicum* in Europe by *Aleochara bipustulata* (L.) can exceed 40 % (Brunel and Fournet 1996). *A. bipustulata* does not occur in Canada but its potential as a classical biological control agent has been investigated since 2004 (Andreassen et al. 2009), in part due to its synchronization with *D. radicum* in the spring.

In the past a number of insecticides were available for use against the cabbage maggot, but currently the organophosphate insecticide chlorpyrifos is the only one registered in Canada for management of this insect in vegetable brassicas (Malchev et al. 2010; Health Canada 2012b). With only one insecticide, it is perhaps not surprising that resistance to chlorpyrifos has been reported; in fact this led to an emergency registration of cypermethrin in 2011 in British Columbia (British Columbia 2011).

9.3.3.2 Current Management Practices

A summary of current methods used in cabbage maggot management in vegetable brassicas was obtained through interviews with extension personnel and crop scouts in each province, as well as IPM extension documents.

Cultural Control

Crop rotation is practiced by most growers, primarily to reduce the incidence of soil-borne diseases or other insects such as the swede midge, (*Contarinia nasturtii* (Keiffer) (Diptera: Cecidomyiidae)), but cabbage maggot infestations may be reduced if fields can be separated by a sufficient distance. Adult *D. radicum* are able to fly long distances (Finch 1989) and a limited land base on many farms limits the effectiveness of this practice. There is some indication that fall tillage is beneficial, with up to 75 % of *D. radicum* pupae killed when fields are tilled in the fall, compared with 40 % in the spring (Finch and Skinner 1980). The benefits of fall tillage for reducing *D. radicum* populations would have to be balanced against potential negative impacts like erosion. Many IPM guides recommend controlling weeds like shepherd's purse (*Capsella bursa-pastoris*). This is beneficial for disease management but it is less clear whether cruciferous weeds act as significant reservoirs for the cabbage maggot (Finch 1989).

Resistant Varieties

There are no resistant varieties available.

Insect Identification

The basis of an IPM program is accurate identification of the insect but as described, this is a major challenge with *Delia* spp. Eggs are rarely identified to species in the field. It is possible to separate eggs of some species, but not others, by examination of the pattern of grooves on the chorion (i.e., *D. radicum* and *D. platura* but not *D. radicum* and *D. floralis* (Brooks 1951; Biron et al. 2000)). This however requires the use of a microscope or hand lens. Identification of flies from traps is difficult, time-consuming and requires a microscope and specialized training. The traps available for this are non-selective, and there is a high likelihood that other species will be present. Flies often are not identified but are assumed to be either *D. radicum* or a related species requiring control. The level of precision required will vary with the region and the specific circumstances, for example, in an area where both *D. radicum* and *D. floralis* are present consistently and each pose a threat, does it really matter which species laid the eggs? To further complicate matters, there often is little correlation between egg counts or trap catches of adults, with damage or infestation levels, partly because weather and predation can affect the survival of immature stages. In situations where the majority of trapped flies are determined to be either *D. radicum* males, or *D. platura*, as sometimes happens, the implications for crop damage are not clear.

Crop Scouting

Monitoring of eggs or flies primarily is conducted to help improve timing of application of chlorpyrifos (see chemical control section), so that it coincides with pest activity. The proportion of brassica vegetable acreage scouted varies among provinces. In some, scouting consists of a small number of growers who search for eggs on their own farms, whereas in others, crop scouting is done more widely via grower associations, private companies and consultants who look for eggs, and occasionally, flies. Monitoring eggs in crops which are vulnerable until harvest, like rutabaga, continues through the season in areas where monitoring is carried out at all. Felt egg traps developed in Europe (Freuler and Fischer 1982) have been tested in Canada but did not adequately detect the start of cabbage maggot oviposition in the critical early season (Dixon et al. 2002). Crops are scouted for *D. radicum* eggs much more frequently than for adults, but flies can be monitored using yellow sticky traps, or sometimes, yellow pan traps containing water. Several provincial IPM guides recommend using traps for adults, but provide little guidance for correct identification. Occasionally, growers look for flies on leaves of the host plant during the day.

Prediction of Spring Emergence and Oviposition

The timing of emergence of flies from overwintering sites, and the start of oviposition, can be estimated indirectly using indicator plants or degree day accumulations. This sometimes is used to indicate when to start crop scouting. A proportion of growers and crop scouts use indicator plants; the blooming of yellow rocket (*Barbarea vulgaris*, Brassicaceae), pin cherry (*Prunus pensylvanica,* Rosaceae) and various species of *Amelanchier* (Rosaceae) (e.g., Saskatoon berry, service berry, wild pear, chuckley pear) is considered to coincide with *D. radicum* spring activity and oviposition. Using plant phenology lacks precision, but it is probably sufficient to indicate when monitoring should start. Degree day requirements and base thresholds for development for *D. radicum* have been assessed in some provinces, including Manitoba (Bracken 1988), Newfoundland and Labrador (Coady and Dixon 1997) and Ontario (Ontario Crop IPM 2009). However, accurate prediction of *D. radicum* emergence is complicated by the presence of emergence biotypes and overlapping generations as well as a complex of species, as discussed previously. The proportion of "early" and "late" biotypes in a population of *D. radicum*, varies by region and within a region, and over time (Turnock and Boivin 1997; Dixon and Collier 2001; Andreassen et al. 2010). With a large proportion of late emergers, and more than 1 generation, potentially flies could be present throughout the season, making forecasting difficult. However, forecasting may be useful as a simple indicator of timing to initiate crop scouting for eggs or flies, much like plant phenology.

Economic Thresholds

There are no published economic thresholds in use currently. The assumption usually is made that if eggs are present, regardless of species or quantity, action is required. This is not really an economic threshold, but simply an indication of presence/absence to improve timing of a control strategy like an insecticide drench. The presence of flies on traps can be used as an aid to optimize timing of a drench, or to indicate when to start looking for eggs. Difficulties with fly identification make this approach somewhat questionable.

Chemical Control

There are growers who do not use insecticides and rely on cultural control and physical exclusion methods like insect netting (Fig. 9.8b), but chlorpyrifos is used widely. Generally speaking, most growers apply liquid chlorpyrifos one or more times as a soil “drench”. A granular formulation sometimes is used at planting, particularly in rutabaga, and this is often followed by one or more drenches. Many growers apply drenches prophylactically according to a schedule recommended on the product label, especially in regions with extensive canola production where growers assume that they will have cabbage maggot problems.

9.3.3.3 Summary

There is a strong theoretical understanding of the biology and ecology of *D. radicum*, yet it remains a serious chronic pest. In terms of the key components of an IPM program, tools are available for monitoring flies and eggs but accurate identifications are difficult and time-consuming, there are no resistant varieties, few economic thresholds and limited control options. Most growers use preventative/prophylactic management strategies like insect netting or an insecticide drench, because the risks of crop loss are high if action isn’t taken. Recent Canadian research has focused on various aspects of integrated pest management for *D. radicum*, including physical exclusion by fences (Vernon and Mackenzie 1998) and insect netting (Dixon et al. 2011) (Fig. 9.8b), undersowing (Dixon et al. 2004) and relay cropping (Parsons et al. 2007), varietal resistance (Malchev et al. 2010) and biological control (Holliday et al. 2013; Andreassen et al. 2010). Meanwhile, to address the important issue of species identification, attempts to develop methods for rapid, accurate identification of flies, eggs and larvae are underway. Continuing and future work could be directed to improving trap technology, developing new reduced risk control products including biopesticides, assessing the potential of the sterile male technique, and revisiting the precision of indicator plants, the impact of *D. platura* and *D. florilega*, fall tillage, and brassicaceous weeds as a reservoir for *D. radicum*.

In 2009 the Pest Management Centre of AAFC established a working group consisting of stakeholders including growers, private IPM companies, provincial extension personnel and both University and government scientists. This group has focused on the prioritization of solutions and research needs for the cabbage maggot in Canada, and projects on exclusion fencing, physical barriers applied to the soil, development of resistant cultivars (rutabaga) and on-farm testing of insect netting from Europe, have been conducted. Some of these projects continue previous research with the hope that they will bring IPM approaches to the practical level for implementation by growers.

Vegetable brassicas are affected by many other insect pests and a number of serious diseases (Ritchot et al. 1994), some of which have more advanced IPM programs with accurate identification and economic thresholds. Root feeding maggots remain a problem apart, and are not yet able to be incorporated within a truly integrated program for multiple insect pests, diseases and weeds.

9.4 Conclusions

Agricultural production systems are complex and variable, as are IPM programs, and each requires an understanding at many levels, not only the ecology of the individual species but also their interactions and the ecology of the ecosystem. Unless IPM practices are easy, fast, and cost effective or there is a crisis such as insect resistance or loss of materials, their adoption by growers can be expected to be slow. The case studies presented illustrate examples of successful and not-so-successful IPM programs for agricultural insect pests in Canada. IPM in apple orchards is more developed than that in viticulture for a number of reasons, the most important being the increased research effort and consequent knowledge of the ecosystem in apples compared with grapes. The wheat midge is univoltine on the prairies, it can be identified with confidence, and most key components for successful IPM are in place: cultural practices, an early-warning system incorporating fall surveys, degree-day models, parasitism and economic thresholds. The development and wide adoption of the wheat midge IPM system has resulted in a decrease in the amount of insecticide used for its control. *Delia radicum* is a different story. Although its biology and ecology are well known, IPM programs for *D. radicum* in vegetable brassicas in Canada are rudimentary. Extension information and recommendations are available in most provinces, but implementation and uptake has been patchy. The main reason for this seems to be not a lack of interest on the part of growers, but that several key components needed for an IPM program to be successful, are underdeveloped or missing. Difficulties with accurate identification, few economic thresholds and limited control options coupled with a high risk of crop loss, mean that most growers use preventative management for this insect.

In comparison to many other regions of the world, agriculture in Canada is a relatively new activity. However, over the span of about 200 years, Canada has become one of the largest agricultural producers and exporters in the world. Also during that time, agricultural science has met the challenge to make significant gains in the integrated management of pest species.

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For additional information, the reader is directed to provincial agriculture websites

British Columbia. http://www.gov.bc.ca/agri/.
Alberta. http://www.agric.gov.ab.ca/app21/rtw/index.jsp.
Saskatchewan. http://www.agriculture.gov.sk.ca/.
Manitoba. http://www.gov.mb.ca/agriculture/.
Ontario. http://www.omafra.gov.on.ca/english/.
Québec. http://www.mapaq.gouv.qc.ca/fr/Pages/Accueil.aspx.
New Brunswick. http://www.gnb.ca/0027/Agr/index-e.asp.
Nova Scotia. http://www.gov.ns.ca/agri/.
Prince Edward Island. http://www.gov.pe.ca/agriculture/.
Newfoundland and Labrador. http://www.gov.nl.ca/services/agriculture.stm.

Part II
Asia

Chapter 10
The Political Economy of the Indonesian Integrated Pest Management Program during the 1989–1999 Period

Budy P. Resosudarmo

Contents

Abstract Indonesia is considered to have been successful in implementing the Integrated Pest Management (IPM) program during 1989–1999. The critical activity of this IPM program was to conduct the participatory training of farmers in IPM practices. Participants were asked to observe and find or discover, by themselves, pests and their natural enemies and then to discuss their findings with one another and freely express their own opinions. Then they were encouraged to derive practical conclusions and implement them. In this training there was no clear-cut distinction between trainers and trainees. Trainers only acted as facilitators. Most of these activities were conducted in the field, where half of the field was planted using techniques that farmers had normally practiced and the other half following the

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IPM practices being analyzed. Graduates were expected to change their beliefs and practices from exclusive use of pesticides more towards management of the ecosystem, growing healthy crops, and preserving beneficial natural enemies. This chapter aims to understand why this program worked from a political economy perspective. It concludes that among the requisite conditions for this program to work are strong national political support, thorough local research, appropriate mechanisms to implement the policy, and direct benefit to local people. The chapter also observes that when these requisite conditions were not there, the program collapsed.

Keywords Agricultural policy · Integrated pest management · Environmental policy

10.1 Introduction

Many agricultural scientists agree that the implementation of the Integrated Pest Management (IPM) program from 1989 to 1999 in Indonesia was a success (Kenmore 1992; Useem et al. 1992; Oka 1991, 1997, 2003; Winarto 1995, 2004). The critical activity of this IPM program was to conduct the participatory training of farmers in IPM practices. To achieve this goal nationwide, three steps were taken: training for trainers, training for farmers by these trainers, and training for farmers by farmers. The last two types of training were undertaken at the IPM farmer field school (IPM-FFS; Oka 1997, 2003). Farmers were expected to change their beliefs and practices from exclusive use of pesticides more towards management of the ecosystem, growing healthy crops, and preserving beneficial natural enemies, as well as being capable of making their own decisions as to the best way to grow their plants and to control pests in their fields, rather than following instructions to use pesticides regularly. Farmers were also expected to develop the habit of conducting regular field observations, and acquire the skills to identify pests and their natural predators (Kenmore 1992, 2002; Norton et al. 1999).

The main method of learning IPM skills in the IPM-FFS was a "learning by doing" process. Participants were asked to observe and find or discover, by themselves, pests and their natural enemies. Participants discussed their findings with one another. They were free to express their own opinions. Then they were encouraged to derive practical conclusions and implement them. In this training there was no clear-cut distinction between trainers and trainees. Trainers only acted as facilitators. Most of these activities were conducted in the field, where half of the field was planted using techniques that farmers had normally practiced and the other half following the IPM practices being analyzed (Dilts 1985; Useem et al. 1992; Winarto 2004).

This chapter does not aim to discuss in great detail the content of the Indonesian IPM program. The main goal here is to understand the political economy behind the reasons why Indonesia was successful in implementing it on a national scale during 1989–1999 and why it collapsed after that.

10.2 Indonesian Food Intensification and Its Problems

Indonesia is the largest archipelago and the fourth most populous nation in the world. Rice is the major staple food, supplying nearly 60 % of the total caloric intake of the average person, and even more for the poor. During the first two decades of its independence (1945–1965), the country experienced several periods of severe food shortages, which prompted the government to import significant amounts of food, particularly rice. At the end of the 1970s, the country imported on average approximately 2 million tons of rice annually, making the country the world largest rice importer (Oka 1997).

Not long after Soeharto resumed the leadership of the country in the mid-1960s, he established a comprehensive food intensification program. In the early 1970s, the program became one of the national priorities. This program included the large-scale adoption of high-yielding modern seed varieties, development of irrigation systems, expansion of food crop producing areas, increased use of chemical fertilizers and pesticides, expansion of agricultural extension services, establishment of farmer cooperatives and input subsidies, and stabilization of national food crop prices (Oka 1991; Pearson et al. 1991). Achieving and maintaining self-sufficiency in food, increasing farmers' income, providing job opportunities and alleviating poverty, increasing foreign earnings through exports of agricultural products, and providing strong support for the rapidly expanding industrial and service sectors were the main goals of this food intensification program (Oka 1997). Implementing this program on a large scale was possible during that period due to the country's huge revenues from the oil bonanza in the 1970s.

During this period, the prices of agricultural input, such as pesticides and fertilizers, were heavily subsidized. At one period, these subsidies would reach 80 % of their market prices (Tabor 1992). Farmers were instructed to use these inputs as much as possible. In the case of pesticides, farmers were required to spray pesticides on their rice fields regularly, even if there were no pests.

This food intensification program was considered successful as food crop production in the 1970s and 1980s grew at an annual rate of approximately 3.74 %,well above the annual population growth of approximately 2.3 % during this period. In the rice sector, production reached an average annual growth of 4.7 % during this period. In 1983 the rice intensification program graduated the country for the first time in history to a rice self-sufficient country (Oka 1991 and 1997; Pearson et al. 1991; Piggott et al. 1993; Resosudarmo and Yamazaki 2010). In the early 1990s, Indonesia, again, had to import rice to fulfill the national demand for rice.

Despite the remarkable success of the food intensification program, the excessive use of inputs caused serious environmental problems. In the case of pesticide resistance, brown planthoppers (*Nilaparvata lugens*) became resistant to pesticides and damaged more than 450,000 hectares of rice fields in 1976/1977. In 1980 green leafhoppers (*Nephotettix impicticeps*) became resistant to pesticides, causing damage to at least 12,000 hectares of rice fields in Bali alone (Oka 1997). Then in 1986, there was another brown planthopper outbreak, destroying approximately 200,000 hectares of rice (Useem et al. 1992).

Later on it was also detected that these chemical inputs created human health problems. In 1988, Achmadi (1991) found 1,267 cases of acute pesticide poisoning in 182 general hospitals throughout the islands of Java and Bali. He also observed that approximately 20–50% of the farmers who utilized pesticides contracted chronic pesticide-related illnesses. These illnesses included headaches, weakness, insomnia, and difficulties in concentrating.[1]

10.3 Driving Forces and Achievements

Various pest problems in the mid-1970s encouraged Indonesian scientists in various research institutes to investigate the reasons for pest resistance to pesticides and to find more successful methods to control the pest populations in rice fields. Most of these studies found that planting just a few modern varieties over wide areas made the plants more vulnerable to pest attacks; continuous planting of rice in a staggered manner throughout the year increased pest populations; and overuse of pesticides created pest resistance leading to pest outbreaks and severe human health problems (Oka 1978, 1979, 1981, 1997; Soekarna 1979; Soehardjan and Imam 1980). These findings were confirmed by worldwide reports from various international agricultural institutions on problems relating to the use of pesticides in agriculture (Pimentel et al. 1992; Antle and Pingali 1994). Indonesian scientists[2] concluded that Indonesia had to stop relying solely on pesticides and needed to employ several control tactics, including synchronized planting, crop rotation, and natural predators, as well as pesticides, that is, to adopt the strategy internationally known as integrated pest management (IPM).

In 1978, with strong support from the media and several nongovernment agencies, the IPM program was mentioned in the Third Five-Year National Plan (1979–1984). Its implementation, however, was limited. Extension workers were still not yet trained in the IPM approach so their pest control recommendations to farmers did not change, and pesticides were still highly subsidized. Many officials in the Ministry of Agriculture (MOA) tended to be against the IPM Program, because they, having had close relations with pesticide companies, still believed in the effectiveness of using chemical pesticides alone. They also thought that asking farmers to spray pesticides was easier to implement than teaching them to implement IPM techniques.

Another significant drive to establish the IPM program came from the concern of the Indonesian National Development Planning Agency (BAPPENAS)—at that time the most powerful government agency—that various brown planthopper outbreaks in the mid-1980s had threatened the country's rice production. At the same time, a significant drop in the world crude oil price caused government revenue to

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[1] See also studies by Kishi et al. (1995) and Kishi (2002).

[2] Among the most important scientists from these institutions are Ida Njoman Oka of the Research and Development Institute–Ministry of Agriculture, Kasumbogo Untung of Gadjah Mada University, and Soemartono Sosromarsono of the Bogor Institute of Agriculture.

drop significantly, and so the government, in this case BAPPENAS and the Ministry of Finance, had to reduce expenditures and started eliminating subsidies. BAPPENAS became very interested in the IPM program, knowing that it offered the possibility of abolishing pesticide subsidies, which at that time amounted to well over US $100 million, while at the same time affording better pest management and maintenance of national rice production (Oka 1997).

Together with scientists from the MOA and leading universities, BAPPENAS consulted intensively with the president concerning the need to implement the IPM program, and this resulted in the launching of the Presidential Instruction (*Inpres*) No. 3/1986, supporting the implementation of the IPM program. The decree had the following objectives: (1) to develop manpower, both farmers and field personnel, at a grassroots level to implement the IPM program; (2) to increase efficiency of input use of particular pesticides; and (3) to improve the quality of the environment and, by extension, human health (Oka 1997). This presidential instruction provided national political support to establish the IPM program as a national policy that required the support of all government agencies, including the military.

Along with this decree, the government decreased subsidies of pesticides from 75–80 % of the total price in 1986 to 40–45 % in 1987. Finally, in January 1989 these subsidies were completely eliminated. The government also banned 57 broad-spectrum insecticides, and only allowed the use of a few relatively narrow-spectrum insecticides (Useem et al. 1992; Kishi et al. 1995).

In 1989, BAPPENAS established the IPM Advisory Board, which consisted of high-ranking officers from BAPPENAS, the MOA, and the Ministry of Home Affairs. The Board was the supreme policy-making body, responsible for the success of the IPM program. Under the Board, a steering committee was formed to direct program activities, and to ascertain the need for policy improvement. The committee consisted of IPM experts from various government agencies, universities, and international institutions, such as the Asia and the Pacific regional office of the Food and Agriculture Organization (FAO). Certain members of the committee formed a working group, which conducted the day-to-day tasks of the committee. Collaboration between the Indonesian and international scientists, in particular those at the FAO, was important in developing the training program (Pincus 2002). The working group first trained extension workers and field pest observers to teach farmers. By the end of 1991, 2,000 extension workers and 1,000 field pest observers had trained approximately 100,000 farmers. By 1992, approximately 200,000 farmers, most of them rice farmers, were trained in IPM practice. Approximately 10 % of these 200,000 farmers were chosen to receive further instruction to become trainers themselves.

Funding for the first two years of this activity, 1989–1991, was mainly from the US Agency for International Development (USAID; approximately US $4.7 million) and they extended their funding until 1992. In 1992/1993, the program also received some support through a World Bank loan (approximately US $5 million) for other existing agricultural training projects, that is, not particularly designated for IPM training (SEARCA 1999). During this 1989–1993 implementation, Indonesia's IPM program was considered to be successful.

Studies revealed that the implementation of the IPM program had, among other things:

- Improved farmers' knowledge and attitude towards insects (Hate and Triyanto 1991; Kartaatmadja et al. 1991; Darmawan et al. 1993; Deybe et al. 1998; Winarto 1995). Farmers understood that there is an economic threshold of pest population, below which the pests won't have any significant impact on the amount of crop to be harvested, and also that there are harmless insects and, most important, there are natural predators for most pests in their fields.
- Changed farmers' attitude towards pesticides and pest control (Oka 1991; Pincus 1991; Useem et al. 1992; Darmawan et al. 1993; Winarto 1995). Farmers recognized that inappropriate and excessive use of pesticides is dangerous and harmful; that is, pesticides not only kill the pests but also their natural enemies and all other animals in the fields; overuse of pesticides leads to pest resistance to pesticides; and pesticides are poisons that are also very harmful to humans.
- Enriched farmers' general cropping skills (Darmawan et al. 1993). The IPM program also improved farmers' general knowledge as to how to grow healthy crops; that is, farmers learned about maintaining land quality, choosing the best crop variety, appropriate seeding techniques, proper synchronization and rotation, as well as applying proper types and amounts of fertilizer.
- Enhanced farmers' confidence in decision making (Oka and Dilts 1993). Farmers become more confident in making their own decisions as to how to control pests in their fields without instructions from agricultural extension workers or field pest observers.

There are, however, several targets that the IPM program should have achieved, but so far there has been no consensus among scientists that it actually did. First, did farmers who implemented the IPM technique improve their yields? Various case studies in Sumatra, Java, Bali, and Lombok reported that IPM farmers had been able to increase yields by approximately 10% and to reduce the use of pesticides by approximately 50%, resulting in a reduction of cost of approximately 11% (Oka 1997; Kuswara 1998a, b; Paiman 1998a, b; Susianto et al. 1998; Van der Berg 2004). However, a study by Feder et al. (2004a, b), using a panel data system, argued that there is no evidence that the IPM–FFS induced increases in yield and reduction in the use of pesticides. Second, there is the issue of diffusion. Although the program was designed for rapid diffusion of IPM techniques, evidence of this has been difficult to obtain (Feder et al. 2004b).

10.4 Implementation of the Program

Conducting the training of farmers in IPM practices was the critical activity of this program. To achieve this goal nationwide, three steps were conducted: training for trainers, training for farmers by these trainers, and training for farmers by farmers.

10.4.1 Training for Trainers

During the first year of the program, 22 senior field pest observers (*petugas pengamat hama* or PHP) were selected from major producing (food crop) provinces to be trained in IPM practices for a full year at the MOA field training facility (FTF) in Yogyakarta, which comprised a laboratory for studying insects and diseases and a two-hectare rice field for demonstrating rice IPM practices. After the first four months of training, these senior pest observers returned to their regional/district offices where they were capable of training a group of approximately 25 farmers in rice IPM practices for four months. After that these senior pest observers returned to Yogyakarta to receive the last four months training in non-rice IPM, particularly soybeans, and in the socialization and institutionalization of IPM training for farmers. Those who completed this training were called first-level field leaders (FL1 or *Pemandu Lapangan 1*).

At about the same time, two-week training for 90 other senior pest observers was conducted at the FTF in Yogyakarta. After completing this training, they were called second-level field leaders (FL2 or *Pemandu Lapangan 2*).

Each FL1 assisted by two FL2 was sent back to their province to form a provincial FTF. The local authorities were requested to provide facilities for the FTF, including a two-hectare rice field. Some provinces with extensive rice fields, such those in Java, were required to form more than one FTF.

Each year these provincial FTFs were able to train approximately 50–60 field pest observers in the same program received by the FL1 in Yogyakarta: four-month periods each in rice IPM, in farmer training, and in non-rice IPM. Those without this one-year diploma in plant protection had to take a four-month course in plant protection at the local university. This program was conducted continuously until all field pest observers had received IPM training. At the same time, the provincial FTF also conducted a two-week training course in IPM practices for agricultural extension workers (*penyuluh pertanian lapangan* or PPL).

After completing a year's IPM training at the provincial FTF, each field pest observer, assisted by two agriculture extension workers who had attended the two-week IPM training, would be ready to train farmers in IPM practices (Oka 2003).

10.4.2 Farmer Training: Establishing the Farmer Field School (FFS)

As mentioned before, one field observer and two agriculture extension workers who had received the appropriate training in IPM practices were asked to form a team to train farmers, which was called an IPM farmer field school (IPM–FFS, in Indonesian called *sekolah lapangan PHT* or *SLPHT*). The length of training at this FFS was 12 months during the rice season. Each team was asked to train four groups of farmers in a year. Each group consisted of approximately 25 participants drawn as much as possible from any existing group of farmers in the area. They were landowners, land-renters, agricultural workers, and others interested in IPM practice. No age, physical, educational, or gender requirements were set. However, relatively few women participated in this FFS, although the target was 30 %. The only province that achieved this target was West Sumatra.

There were incentives provided for farmers to participate in this IPM field school. First, the school offered a certificate of graduation to farmers who participated in the entire program and who passed the final "field ballot box posttest" in IPM skills. This turned out to be an important incentive, because most farmers did not have any formal school certificate. Second, during the initial programs, the school provided compensation of Rp. 1,000 (or approximately US $0.50 at that time) per session for farmers attending the training. This was roughly equal to half the income they could get if not attending the training. For regular training conducted afterwards, the school could only provide a snack box, costing the program approximately Rp 7,500 per group per session (Oka 1997).

10.4.3 Farmer-to-Farmer Training

The next stage of the program was crucial, establishing farmer-to-farmer training in IPM practice. Approximately the top 10 % of farmers who completed the IPM–FFS were offered enrollment in another course (training of trainee or TOT) in the administration of an IPM–FSS, in becoming a facilitator, and in other technical matters related to IPM practices. After completing this course, they were called "farmer leaders" (*Petani Pemandu*). Two of these farmer leaders, supervised by a field pest observer and an agriculture extension worker, then conducted a 12-week IPM farmer field school. Farmers who completed this training and passed a final test on IPM skills were given a certificate.

10.5 Scaling Up the Program

In 1994 the principal organization of the IPM program was transferred from BAPPENAS to the MOA. In the next five years, from mid-1994 to mid-1999, the program would receive much more funding (a total of approximately US $40.6 million) reflecting the intention to scale up the previous program. Approximately 62 % of the funding was in the form of a loan from the World Bank that was specifically targeted to support the IPM program. The Indonesian government and USAID provided the rest (US $8.7 million and $6.7 million, respectively), as the matching fund for the World Bank loan (World Bank 2000).

The foundation for the transfer of the IPM program was the Agricultural Ministerial Decree No. 390/1994, containing provisions for the administrative structure of the IPM program in the MOA. The decree provided strong political support within the MOA for the implementation of the IPM program, so that all officials in this ministry were expected to support the program. The MOA then formed an IPM Advisory Team, whose members and tasks were similar to those of the previous IPM Advisory Board. Under the Advisory Team, there was the IPM Technical Team whose members and tasks were also almost the same as those of the previous IPM Steering Committee. Instead of a working group, the team that conducted the daily activities of the IPM program under the MOA was called the Working Team, which consisted mostly of staff from the MOA. A project team called the IPM Project Team, headed by a project leader from the MOA, undertook the administrative and financial management of this program.

During the 1994–1999 IPM program, approximately 800,000 rice farmers, 50,000 palawija farmers, and 25,000 vegetable farmers attended the FFS (MOA 1999). Geographically the FSS conducted its program in 13 out of 27 provinces in Indonesia, that is, the major food-crop—particularly rice—producing provinces (MOA 1999).

Despite a growing number of farmers attending the program and a larger coverage of the program, a negative view of the 1994–1999 IPM program existed. The transfer of the program from BAPPENAS to the MOA was slow. The program also faced problems such as funding delays and other bureaucratic obstacles that negatively affected the implementation quality of the program. These problems reflect that MOA support for the IPM program was still limited. It is true that new officials in the MOA who were more in favor of the IPM program had replaced several of those who preferred intensive use of pesticides, but not all. These problems also indicate that the program had never received the strong national political support accorded to the previous IPM program. The new head of BAPPENAS, assuming his position in 1993, did not have much interest in the IPM program so it was left without BAPPENAS support.

It was suspected that training quality declined during the 1994–1999 program. There is evidence that farmers who graduated from the IPM–FSS returned after a while to the old method of routinely spraying pesticides and conducted field observations less often (Pincus 2002). Hence, there were doubts that scaling up and sustaining the efforts of the IPM program would ever be successful.

10.6 Collapse of the Program and Future Challenges

In 1997, the economic crisis hit Indonesia, resulting in a huge drop in its GDP in 1998. Of all sectors in the economy, the financial sector was hit the hardest. During this period, the number one priority of the government, including foreign donors, was to restructure the financial sector to prevent it bringing down the national economy even further and to soften the impact of this crisis on poor people.

Indonesian agricultural scientists whose research outcomes in the early 1980s initiated the establishment of the IPM program were either retired or close to retirement age by the end of the 1990s. Subsequent generations of scientists have not been able to produce significant enough work in this area to attract the attention of policy makers away from the issue of the financial crisis to that of proper pest management. Hence, no influential high-ranking officers supported the need to implement the IPM program. Suddenly, the IPM program was no longer a national priority and it lost all of its by-then only moderate political support.

Furthermore, programs to restructure the financial sector and provide a safety net for the poor, as well as local development programs, absorbed most of the funding from both domestic and foreign sources, including loans from the World Bank. Hence, neither the World Bank nor the Indonesian government was able to provide funding for the continuation of the IPM national program and it terminated at the end of 1999.

The question remains as to whether Indonesia will be able to re-establish its IPM program, and specifically what challenges the re-establishment of this program in the near future would entail. In general, challenges will come from the two important recent developments in the country's political and administrative systems. First, since the fall of Soeharto in 1998, the Indonesian political environment has rapidly transformed from an authoritarian to a much more democratic environment. Second, since 2001, Indonesia implemented a "big bang" administrative decentralization process. Most government functions were transferred from the central to regional (district/city) governments, including the transfer of a huge number of government employees. All agricultural extension workers and field pest observers became district government employees, no longer having a structural relationship with the MOA (World Bank 2003). In this new democratic and decentralized era, Presidential Instruction does not have its former strong political power, and the fact that the central government, including the MOA, has less authority/control over regional activities makes it much more difficult for the MOA to coordinate a program such as the IPM Program of 1989–1999 at a national level.

The re-establishment of the IPM Program will certainly require some new form of strong national political support and solid initiative from local governments. The development of the program will most likely have to be a bottom-up approach to fit the decentralization policy currently adopted, instead of the top-down approach of the 1989–1999 IPM Program. One option is for national political support to come from local people in majority regions of Indonesia, urging local environmental authorities to develop the IPM Program, as well as to coordinate with other regions and the Ministry of Agriculture in implementing this program.

Hence, even if some funding were to be available in the future to conduct another IPM Program nationally, a new model of coordinating the program among local governments and the MOA would be needed. However, no serious research has yet been conducted to design the new model.

10.7 Conclusion

The analytic narrative of the Indonesian experience in implementing the IPM Program during the 1989–1999 period provides us with insights into why the country could succeed in conducting this environmentally friendly policy. First of all, for such a scheme to succeed, there should be solid local research on the topic, possibly in collaboration with international scientists, providing a strong basis for a policy change. For example, local capacities in agricultural research were available when the planthopper outbreak crisis occurred in 1976. Local scientists, hence, had the answer as to why such a huge pest outbreak could have occurred.

Second, national political support of the policy was crucial, requiring the support of all agencies in the country. In the Indonesian 1989–1999 IPM case, Presidential Instruction No. 3/1986 explicitly endorsed the president's support for the IPM Program. At the time, Soeharto was politically very strong. No individual, group, or agency would have dared to challenge his policy openly.

Third, an institutional breakthrough might be needed to overcome problems created by excessively bureaucratic procedures. Although the Ministry of Agriculture should have been conducting the program, it was difficult to organize the first stage of the IPM program within this agency because most of its senior officials were closely associated with pesticide companies and hence opposed to it. Instead, BAPPENAS became the leading agency in organizing the national IPM Program.

Fourth, strong international support was important. Staff at the FAO regional office worked closely with Indonesian scientists in developing the learning-by-doing IPM by farmer training. Foreign donor agencies, in this case the USAID and the World Bank, made a strong commitment to finance the IPM Program.

Finally, an appropriate mechanism was needed so that the people affected by the policy can directly benefit. The choice of farmer field schools and the implementation of the learning-by-doing method in introducing the IPM techniques to farmers were very effective. Farmers quickly absorbed the knowledge as well as being able to feel and see the impact of the new knowledge in their fields and daily life activities.

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Chapter 11
Pesticide Use and Experiences with Integrated Pest Management Programs and Bt Cotton in India

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Abstract In India, agricultural productivity of food and other crops has grown tremendously since the advent of the Green Revolution. Pesticides have been one of the drivers behind this growth in combination with high-yielding varieties and increased irrigation and fertilization. Pesticide use increased from 10,993 metric tons in the mid-1960s to approximately 80,000 metric tons in the 1990s. Half was used on cotton, although cotton is grown on only 8 % (ca. 11.6 million ha) of the cultivated area. American-bollworm–susceptible, high-yielding cultivars introduced to cater to the needs of the mechanized spinning mills increased the pest problem and pesticide use on cotton. Pesticide use was also high on vegetable and rice crops. Crop losses from pests, however, increased by 16 %, and many pests developed resistance to the pesticides. This resistance, rather than environmental concerns, led to the birth of integrated pest management (IPM) in India for rice and cotton crops in 1974–1975, and vegetables and other crops since the 1990s, reducing pesticide use in the project areas. In the 1970s and 1980s, the first IPM program under the Operational Reseach Project (ORP) focused on pilot programs using a prescriptive approach to demonstrate IPM practices in cotton and rice crops in a cluster of villages in seven states. The government of India adopted IPM as the main strategy for plant protection in 1985. In the early 1990s, the farmer field school (FFS) model was adopted to implement IPM by educating farmers and extension workers. Between 1990 (before many ad hoc IPM programs began) and 2002 (when Bt cotton was introduced) pesticide use (a.i.) by weight decreased by 35 %, mainly because hexachlorocyclohexane, accounting for 30 % of the total pesticides, was banned in 1997 and low-dosage pesticides were introduced. Only about 2–4 % of the total cultivated area, including only 5 % of the farmers, however, is covered under IPM programs, so whether IPM has reduced overall pesticide use in Indian agriculture is debatable. Although the introduction of Bt cotton has reduced insecticide use in cotton by almost 50 %, mass pesticide use in Indian agriculture overall has increased by 9 % since 2002.

Keywords Green Revolution · External inputs · Pesticides · Crop losses · IPM · IPM programs · Cotton · Rice · Vegetables · Bt cotton

11.1 Introduction

Over the 65 years since gaining independence from the British, India has made great progress in agriculture. India is the world's second largest producer of vegetables, the second largest producer of wheat and rice (USDA 2013), and the third largest producer of cotton (USDA 2013). From 1950 to 2011, food grain production rose from 52 million metric tons to 259 million metric tons (MOF 2013), and cotton production increased from 3.04 to 35.2 million bales (170 kg/bale). Despite these statistics, the share of agriculture in the gross domestic product (GDP) declined to 14.1 % in 2011–2012 (at constant 2004–2005 prices) from 52.2 % in 1950–1951. Less than 10% (118.7 million) of the population (1.21 billion) are farmers (as per the 2011

Table 11.1 Pesticide Share per Area Cropped for Major Indian Crops in the 1990s. (Source: Modified after Abhilash and Singh (2009))

Crop	Pesticide Share (%)	Area (%)
Cotton	45–55	5
Rice	20–23	24
Chilies/vegetables/fruits	13–24	3
Plantation	7–8	2
Cereals/millets/oil seeds	6–7	58
Sugarcane	2–3	2
Others	1–2	6

census). Out of the total workforce of 481.7 million, only 24.6% are cultivators for whom farming is their occupation. Considering that three-fifths of India's land area is tillable (about 140 million ha) and 40% of that is irrigated, productivity is low compared with world averages. The small size of landholdings (mean farm size is 1.15 ha; MOA 2014) is not economically viable, lack of breakthroughs in farm technologies (GOI 2007) in the post-Green Revolution era, rainfed agriculture has not received precedence in research priorities (Gupta et al. 1989), and other abiotic and biotic factors limit productivity.

Pesticides are considered one of the driving forces for the five-fold increase in food production in addition to high-yielding varieties and increases in irrigation equipment and fertilization (Agoramoorthy 2008; Bhatnagar 2001; Rekha and Naik 2006). Pesticide use is considered necessary in tropical areas of India to manage insect pests and vector-borne diseases (Abhilash and Singh 2009) and began in India in 1948 with the introduction of dichlorodiphenyltrichloroethane (DDT) and hexachlorocyclohexane (HCH) for locust control (Shetty 2001; Gupta 2004; Bajpai 2005). Pesticide use in India, since the advent of the Green Revolution in the 1960s, has increased tremendously, reaching 0.600 kg/ha in 2009 (FICCI 2011). Pesticide use on cotton, rice, and vegetable crops accounts for 78% of the total used in India (Table 11.1). Before the introduction of Bt-cotton in 2002, between 45 and 55% of the pesticides (mainly insecticides) were applied to cotton, which was grown on only 5% of the total cultivable area (about 8 million ha), with 80% used in 28 districts in 10 cotton-growing states (Russell 2004). Thus, per hectare, pesticides on cotton totaled about 6 kg/ha in the 1990s. (For details, refer to Chapter 1, *Integrated Pest Management: Pesticide Problems,* Volume 3 of this series.) Herbicide use on rice and wheat crops is widespread in irrigated lands (Peshin et al. 1997; Peshin and Kalra 1998; R. Peshin unpublished data 2005 and 2014).

There was a threefold increase from 1984–1985 (7.3%) to 2011 (20%) in the total pesticide share in vegetable crops (Unni 1996; Agranova 2008, 2012). Pesticide share is also high for rice (20–23% of the total), cultivated on 38.4 million ha. To reduce the adverse consequences of pesticide use on cotton, rice, and vegetable crops, many integrated pest management (IPM) programs have been implemented, especially to reduce overreliance on insecticides. The earliest IPM effort was under the Operational Research Project (ORP) in cotton and rice crops by the Indian Council of Agricultural Research (ICAR) in 1974–1975 (Swaminathan 1975) to develop location-specific IPM practices. Since then, several new IPM programs have been implemented but without large-scale adoption of the practices by farmers (Peshin 2013). Because there is no comprehensive review of the IPM programs and outcomes in India, this chapter reviews the implementation and outcomes of these programs in cotton, rice, and vegetable crops and discusses empirical evaluations of several case studies.

11.2 The Advent of the Green Revolution in India

After independence was gained in 1947, Indian agriculture was relatively neglected in comparison with industrialization. Severe droughts in the 1960s badly hit the agricultural sector, which contributed 52 % of the GDP, greatly affecting the Indian economy. The consequent importation of metric tons of food grains to feed the growing population in the1960s led to a change in the government's agricultural policy. Before the 1960s, crop productivity was very low due to the use of low-yielding crop varieties and meager external inputs such as fertilizers, irrigation water, and pesticides. Fertilizer use was 69,000 metric tons in 1950–1951 (Sharma and Sharma 2000) and less than 1 million metric tons in the mid-1960s (0.78 million metric tons in 1965–1966; FAO 2005). By 1965–1966, the area cultivated with cereal crops increased by 18%, and 20.9 % of this area was under irrigation. Soon after the discovery of insecticidal properties in DDT and the development of the herbicide 2, 4-D and other pesticides in the 1940s, the synthetic pesticide era began, primarily in developed countries, while Indian farmers continued to practice traditional pest management practices, namely, cultural and manual or mechanical control. The pest pressure (mainly insect pests) was low on low-yielding, local varieties of rice and cotton. Pesticide use before the Green Revolution was 2 metric tons (merely 3.2 g/ha in 1954–1955 (Figure 11.1) (Atwal 1986).

The Green Revolution paradigm—high yielding varieties, chemical fertilizers, and pesticides—was imported from the developed world to developing countries including India in the mid-1960s (Murray 1994). Within two years, between 1964–1965 and 1967–1968, more than 60 % of the irrigated wheat area and 14 % of the rice area was planted to high-yielding varieties of these two crops (Herdt 1969). The area under high-yielding varieties increased to 16 % in the wet season (*kharif*) rice and 55 % in the dry season (*rabi*) rice. The adoption of high-yielding varieties was mainly confined to irrigated lands (Venugopal 2004) and initially on large farms (Ladejinsky 1969; Frankel 1971; Roa 1975; Dasgupta 1977). Fertilizer consumption increased from 0.78 million metric tons in 1965–1966 to 16.2 million metric tons in 1997–1998 at an annual growth rate of 12 % (Sharma and Sharma 2000; FAO 2005). The gross cropped area under irrigation increased from 31 million ha in 1965–1966 to 78 million ha in 2004–2005. In addition to high-yielding varieties and fertilization, pesticides were promoted to manage weeds, insect pests, and diseases. When pesticide use on Indian crops first started, rice, tobacco, and chilies accounted for 80 % of pesticide use, but with the introduction of American cotton in India the pes-

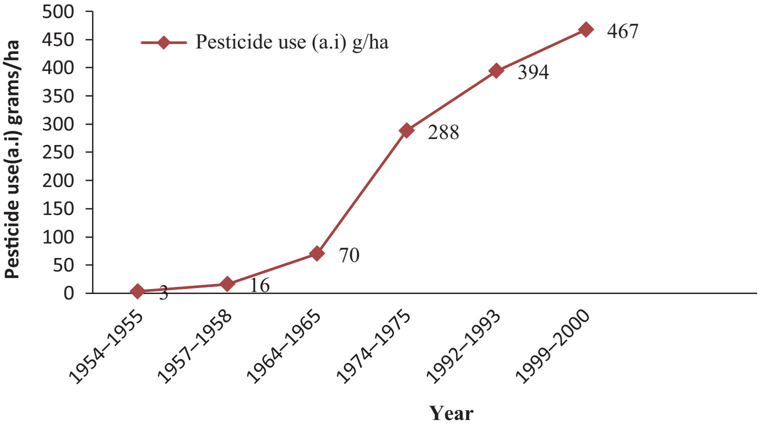

Fig. 11.1 *Pesticide use (a.i) by weight from 1954 to 2000***.** Pesticide use per hectare was about 70 g/ha (pre-Green Revolution) and increased to 288 g/ha (Green Revolution) and was about 467 g/ha in 1999–2000

ticide use pattern changed and between 67 and 78 % of pesticide was used on cotton and rice (Venugopal 2004). The use of pesticides increased from 10,993 metric tons (a.i.) in 1964–1965 to 75,033 metric tons in 1990–1991. Pesticide use per unit production grew exponentially until 1974–1975, then declined (Venugopal 2004); use increased from 70 to 394 g/ha between 1964–1965 and 1992–1993 (Figure 11.1). Pest management research focused heavily on pesticides, their mode of action, and toxicology. High-yielding varieties, fertilizer, and pesticide inputs plus the increase in cultivable area under irrigation ushered the Green Revolution into Indian agriculture. Of these, fertilizers alone contributed 50–60 % to the increased food-grain production between the mid-1960s and 1990s (Venugopal 2004).

The advent of the Green Revolution in the mid-1960s also gave impetus to research on input-responsive, high-yielding American cotton varieties and hybrids suited for machine spinning. Chlorinated hydrocarbon-based insecticides such as DDT, HCH, aldrin, endrin, and dieldrin were used mostly on American cotton varieties (Kranthi and Russell 2009). Between 1955 and 1960, an average of 4,500 metric tons of pesticides was used annually. Subsequently, endosulfan and organophosphate (OP) insecticides were introduced in the 1960s, and the annual average usage increased to 16,200 metric tons during the Green Revolution from 1960 to 1970. Simultaneously, research on hybrid cotton intensified. The world's first hybrid H-4 with superior fiber traits was released in 1970, and by then the area under American cotton species, *Gossypium hirsutum*, increased to 53 %. During this time, the American bollworm *Helicoverpa armigera* was noted to cause damage on *G. hirsutum* species (Nair 1981) which is also susceptible to a wide range of insect pests such as aphids (*Aphis gossypii*), jassids (*Amrasca devastans*), whiteflies (*Bemisia tabaci*), thrips (*Ceratothripoides brunneus*), and bollworms (*Helicoverpa zea*). By 1965, 40 % of the cotton area in India was cultivated with *Gossypium hirsutum*, and the rest with Desi cotton species, *Gossypium arboreum,* and *Gossypium herbaceum*.

11.2.1 Adverse Consequences of the Green Revolution

The Green Revolution enabled a great increase in the productivity of cereals, namely, wheat and rice. Food grain production rose from 51 million metric tons in 1951–1952 to 130 million metric tons in 1980–1981 (MOA 2003), thus making India self-sufficient in food grains. Cotton productivity also increased from 125 to 152 kg/ha between 1960 and 1980 (Singhal 2003). Only about 103 districts with assured irrigation and high rainfall in the states of Punjab, Haryana, Western Uttar Pradesh, some parts of Andra Pradesh, and a few other pockets of the country reaped the benefits of the Green Revolution, however, rainfed and resource-poor areas were ignored (Gupta et al. 1989). In the Green Revolution areas, adverse results were noticed such as the development of insect resistance to pesticides developed from the indiscriminate use of synthetic pesticides, especially on cotton. Initially, intensive pest-management using pesticides yielded great success, but as the area under American cotton increased, so did insecticide use. Plant protection scientists, especially entomologists, from the leading agricultural universities of India promoted calendar-based application of insecticides. The farmers got caught in a "pesticide treadmill" as the selection pressure from indiscriminate insecticide use failed to protect cotton, which received 50–60 % of the total pesticides used in India. Resistance developed in insect pests of rice, cotton, and vegetables (Jayaraj 1996), just one example of unanticipated undesirable consequences of pesticide use. In 1963, the Singara beetle (*Galercorcella birmanica*) was reported to have developed resistance to DDT and HCH, synthetic pyrethroids resistance in *Helicoverpa armigara* on cotton was recorded in Punjab in 1990–1991, and diamondback moth (*Plutella xylostella*) became resistant to all classes of insecticides (Dhaliwal and Arora 2001). Whitefly (*Bemisia tabaci*) again reduced cotton productivity in Andhra Pradesh, Gujarat, Tamil Nadu (Jayaraj 1987), Haryana, Punjab, and Rajasthan (Dhaliwal and Arora 1996) from excessive use of synthetic pyrethroids to control bollworm.

Thus, despite the increase in chemical use, crop losses from insect pests, diseases, and weeds ranged between 5 and 10 % in wheat, 25 % in sugarcane, and 50 % in cotton (before the introduction of Bt cotton; Dhaliwal and Arora 1996) and increased from the pre-Green Revolution era to the post-Green Revolution era. See Table 11.2 for estimates on losses caused by insect pests in India (Pradhan 1964; Krishnamurthy Rao and Murty 1983; Atwal 1986; Jayaraj 1993; Lal 1996; Dhaliwal and Arora 1996, 2002; Dhaliwal et al. 2004). On average, 33 % of crop loss occurs due to insect pests and diseases (Puri et al. 1999).

Such adverse consequences of pesticide misuse were foreseen by M. S. Swaminathan in his presidential address at the Indian Science Congress in 1968, well before the term Green Revolution was coined by William Gadd. His warning resulted in the first integrated pest management program in 1974–1975 under the Operational Research Project and the aegis of the Indian Council of Agricultural Research (ICAR). Thus, in India, IPM was not born from environmental concerns but from increased losses caused by insects, the changing insect pest spectrum in rice (e.g., new insects such as the white-backed planthopper [*Nilaparvata lugens*] and gall midge [*Orseolia oryzae*] became pests of economic importance) and cotton insect

Table 11.2 Crop Losses (%) from Insects Pre- and Post-Green Revolution in India. (Source: Modified from Puri and Ramamurthy (2009))

Crop	Pre-Green Revolution (Early 1960s)	Post-Green Revolution (Early 2000s)	Change in Total Loss
Cotton	18.0	50.0	+32.0
Groundnut	5.0	15.0	+10.0
Other oilseeds	5.0	25.0	+20.0
Pulses	5.0	15.0	+10.0
Rice	10.0	25.0	+15.0
Maize	5.0	25.0	+20.0
Sorghum and millets	3.5	30.0	+26.5
Wheat	3.0	5.0	+2.0
Sugarcane	10.0	20.0	+10.0
Average	*7.2*	*23.3*	*+16.1*

pest (*Helocoverpa armigera* became a major pest) resurgence, and the development of resistance to insecticides in insect pests.

11.3 The Era of Integrated Pest Management

The Government of India adopted IPM as the main strategy for plant protection in 1985. India is one of the seven countries that signed on to the Food and Agriculture Organization's (FAO's) commitment to implement IPM in the 1980s as a cardinal principle of pest management. In the 1990s, insecticide subsidies were phased out, and taxes were levied on insecticides (Kenmore 1997; Birthal 2004). The efforts to implement IPM gained momentum in the early 1990s with funding by the FAO, Asian Development Bank-Common Wealth Agricultural Bureau International (ADB-CABI), European Union (EU), and the United Nations Development Program (UNDP). Between 1986 and 1994, 227 demonstrations were organized and 4,951 subject matter specialists were trained (Pawar and Mishra 2004). The farmer field school model was adopted to implement IPM, and the government of India took a number of steps to promote IPM including:

a. Development of infrastructure;
b. Establishment of central integrated pest management centers (CIPMCs) in each state and union territory;
c. Development of human resources through a three-tier, season-long training program for subject matter specialists and establishment of FFS to train farmers;
d. Demonstrations on the adoption of field-tested IPM technologies;
e. Support of policies to promote need-based pesticide use and phase out hazardous pesticides (Ragunathan 1995).

Project reports of the IPM-FFS programs implementation by the Directorate of Plant Protection, Quarantine and Storage, Ministry of Agriculture, Government of India, highlighted the decrease in pesticide use and increase in yields (Peshin 2002).

In the 1990s, many pesticides were banned (for details, refer to Chapter 1, Volume 3 of this series), insecticide subsidies were withdrawn and excise duties were levied. Removal of insecticide subsidies and imposition of excise duties yielded an annual revenue of US $60 million (at 1997 rates) to the Indian government (Kenmore 1997).

11.3.1 Cotton

India had (and still has) the most area cultivated in cotton, but productivity was very low. For centuries, India was known for its excellence in spinning and handloom weaving. Interestingly, the country was famous for its finest fabric woven from fibers of the indigenous Desi cotton. The traditional indigenous Indian Desi (local) cotton species produced short fibers that were spun into fine yarn by communities of Indians who had mastered the art over generations. The Desi cotton species was generally sturdy and highly resistant to almost all biotic and abiotic stresses. However, Desi cotton varieties, in general, were only susceptible to pink bollworm, *Pectinophora gossypiella,* and the spotted bollworm, *Earias vittella*. The two indigenous cotton species constituted 97 % of the cotton area (about 5.3 million bales from 9 million ha) in India in 1950 with little need for insecticides (Lalitha and Ramaswami 2007) because they were resistant to pests. Before independence, several parts of the country had been evaluated for their suitability for the American cotton species (upland cotton), *Gossypium hirsutum*, especially suited for mechanized spinning mills. Erstwhile Punjab in Pakistan was found to be suitable for growing long-staple American cotton, *G. hirsutum*. However, after independence, the spinning mills suffered from the lack of raw fibers of American cotton. Thus, efforts intensified to identify regions suited for the long-staple American varieties.

Hybrid cotton was considered as a way to obtain high yields through intensive inputs. However, the full potential of many high-input–responsive hybrids could only be effectively harnessed under optimal conditions. Bollworm infestation on American cotton varieties and hybrids impeded the rapid adoption of American cotton species all over the country. In addition, the pest spectrum changed as the relative composition of the cotton species changed. Sap-sucking insects such as jassids, whiteflies, thrips, and aphids, which were minor pests on the indigenous Desi cotton species, became major pests on *Gossypium hirsutum*. The leaf-eating caterpillar *Spodoptera litura* and the three bollworm species (American bollworm: *Helicoverpa armigera*, pink bollworm: *Pectinophora gossypiella*, and spotted bollworm species complex: *Earias* spp.) also became major pests of *G. hirsutum.* Such changes in the pest composition were also influenced strongly by changes in the insecticides used on cotton; organophosphate and carbamate insecticides increased to an annual average of 47,100 metric tons from 1970 to 1980. Synthetic pyrethroids were introduced in 1980, primarily to control the pink bollworm and *Spodoptera litura* on cotton. Total pesticide usage in India increased from 67,200 metric tons/year in 1980 to 75,000 metric tons/year in 1990; of this total, cotton received 33,360–41,250 metric tons/year (or 50–61 % of the total) for a 10-year average on 7.5 million ha. The pesticide use by weight was between 4.448 and 5.500 kg/ha. This intensive usage led to high levels of resistance in insect pests of cotton such as whiteflies and bollworms to almost all the recommended insecticides. Bollworm resistance to synthetic pyrethroids was the highest (Kranthi et al. 2002). New pyrethroids were introduced intermittently, but were prone to cross-resistance. By 2000–2001, *G. hirsutum* was grown on over 75 % of the cotton area in the country, and many varieties of the exotic species such as *G. hirsutum* and Egyptian cotton *G. barbadense* were susceptible to jassids, whiteflies, *H. armigera*, parawilt, bacterial blight, *Verticillium* wilt, and leaf curl virus disease. The intensive continuous use of insecticides in cotton ecosystems over the past 50–60 years significantly disrupted the equilibrium between cotton insect pests and among predators, parasitoids, parasites, and entomopathogens.

IPM for cotton has been considered an essential prerequisite to restore the ecological balance and ensure long-term sustainable pest management. The ICAR sponsored ORP, a village-level project to evaluate and demonstrate the efficacy, practicality, and economics of IPM in cotton. The main components comprised:

- Adoption of short-duration, jassid-tolerant varieties of American cotton;
- Timely sowing;
- Judicious use of irrigation and fertilizers;
- Cultural and mechanical control measures for minimizing the carryover and build-up of pink bollworm;
- Removal of alternate host plants of spotted bollworms in and around the cotton fields;
- Economic-threshold–based sprays to control cotton jassid;
- Determination of the period for effective boll formation for different varieties and calendar-based spray recommendation during this period to manage bollworms (Simwat 1994).

The ORP in cotton was implemented on a pilot basis in 15 villages of Punjab and Coimbatore in Tamil Nadu. The adoption of IPM technology over a 15-year period in Punjab reduced the number of insecticide sprays to control sucking pests and bollworms by 73.7 and 12.4 %, respectively, in 15 villages covered under the ORP. Properly timed sprays along with a number of cultural and mechanical practices reduced bollworm incidence in the ORP area by 38.5 % relative to the adjoining non-ORP area. Despite reduced plant protection expenditure, the ORP farmers obtained a 23.2 % higher yield and 31.7 % higher net income than non-ORP farmers (Sidhu et al. 2010; Dhaliwal and Arora 2001). In Tamil Nadu, the mean quantity of insecticides used in ORP villages over a 4–5 year period was 3.8 kg a.i./ha in six applications compared with 9.2 kg a.i./ha in 11 applications in non-ORP villages (Simwat 1994).

After the ORP project from 1990 on, IPM strategies continued to be initiated, closely followed by fine-tuning the rational use of insecticides through insecticide resistance management (IRM).

The banning of HCH in 1997 reduced pesticide use by 30 % (Shetty and Sabitha 2009), and national implementation of IPM and insecticide resistance management

Table 11.3 Insecticide Expenditure as Percentage of Variable Costs of Cotton Production. (Sources: Dhaliwal and Arora (2001); Sen and Bhatia (2004); Shetty (2004); Peshin (2005))

Year	Percentage
1974	2.1
1979	4.6
1984	11.9
1989	15.5
1994	13.0
1998	21.2
2002	42.0–50.0
2004	Between 32 and 36

(IRM) strategies reduced average annual pesticide usage in India to 57,500 metric tons between 1990 and 2000. A regional cotton IPM program of the Commonwealth Agricultural Bureau International (CABI) in 1993, Food and Agriculture Organization-European Union IPM program in 2000, and National Agricultural Technology Project for cotton IPM in 2000, were also implemented through funding by international organizations. The Ministry of Agriculture, Government of India under the Technology Mission on Cotton (TMC) Mini-Mission (MM-II) initiated an IRM program in 2002. The Indian Council of Agricultural Research (ICAR) through the National Agricultural Reseach System comprising ICAR Instituions and state agricultural universities implemented the IRM-based IPM program in 10 cotton-growing states. The Central Institute for Cotton Research (CICR), an ICAR research institute, was the nodal agency for implementing the program. Between 2002 and 2006, the IRMIPM project was implemented on over 196,000 ha across 1,820 villages in India (Peshin et al. 2009), and based on annual project reports, the net financial gains to farmers was estimated to be US $23.0 million to $39.5 million from yield increases and US $16.5 million from savings on pesticides (Anonymous 2007; K.R. Kranthi, unpublished data, CICR).

Reduction in the use of pesticides by weight, treatment frequency, and environmental impact quotient are the important indicators for measuring the impact of the IPM programs (Lacewell and Taylor 1980; van de Fliert 1993; Dhaliwal et al. 1998; Peshin and Kalra 1998; Mullen et al. 1997; Birthal et al. 2000; Wilson et al. 2004; Gajanana et al. 2006; Mancini et al. 2008; Rao et al. 2008; Peshin et al. 2009; Sharma 2011). Despite the best of efforts, including the highly effective participatory farmer field school approach, IPM programs only partially succeeded. The FFS model placed emphasis on identification of pests and natural enemies and avoidance of use of insecticides (Peshin et al. 2009). There was less emphasis on pest management strategies in FFS, and the trainers in the agricultural department lacked competence in the content area as well as the process area (Peshin and Kalra 2000). Pesticide expenditure in Indian cotton continued to increase between 1975 and 1990 (ORP), and has increased since the implementation of IPM-FFS for cotton in the 1990s (Table 11.3).

Before the introduction of Bt cotton, all available pest management options were being integrated to keep bollworm populations below economic thresholds. IPM programs mainly amalgamated biopesticides and biological, cultural, and chemical control measures to develop the best possible eco-friendly options for effective control while efficiently conserving naturally occurring biocontrol systems. In general in India, cotton IPM strategies include the use of neem (*Azadirachta indica)*-based biopesticides, entomopathogenic fungicides, Bt (*Bacillus thuringiensis*)-based sprays, HaNPV (*Helicoverpa armigera* nuclear polyhedrosis virus), SlNPV (*Spodoptera litura* nuclear polyhedrosis virus), inoculative and inundative releases of parasitoids such as *Trichogramma* spp., *Chrysoperla* spp, *Bracon* spp., and the like, in addition to the use of light traps, pheromone traps, sticky traps, trap crops, and intercrops in consonance with selective insecticides, that would effectively control pests with the least disruption of the ecosystem (Kranthi and Russell 2009; Kranthi et al. 2009). Biological interventions have been useful, but the technical and economic performance of biological control has varied across different states as a result of agroclimatic conditions and choice of cotton varieties. For example, in Punjab the level of pest infestation and nonchemical pest management methods were negatively correlated; chemical control was better than biological control for pest management. In Tamil Nadu and Gujarat, however, biological intensive IPM was efficacious (Birthal 2004). IPM programs also emphasize the need for pest-resistant varieties so that extraneous insecticides can be reduced, and fertilizer applications must be optimized to prevent an abundance of insect pests (Kranthi et al. 2009).

Eventually, the inavailability of biological inputs and, many times, the poor quality of IPM options aside from campaigns promoting IPM as a zero-pesticide approach, led to ineffective pest management (Kranthi and Russell 2009). Although Bt cotton is currently very effective in controlling bollworms, sustainability of this control will eventually depend on bollworm adaptability to Bt cotton. Thus, in gearing up for sustainable approaches, IPM options need to be consolidated and scientific advances must be incorporated into protocols to mass-produce biocontrol agents reliably, such as *Trichogramma*, viruses (NPVs, GVs, and CPVs), bacteria (*Bacillus thuringiensis, B. cereus, Pseudomonas* spp.), and fungi (*Beauveria bassiana*, *Metarrhizium anisopliae, Verticillium lecanii, Nomuraea rileyii, Trichoderma rileyii, Gliocladium* sp.)(Kranthi and Russell 2009; Kranthi et al. 2009). Because NPV is not effective in the field against *Helicoverpa* (Jayraj et al. 1981), other agents must also be field-tested. Methods to scout for pests and to determine the best time to initiate interventions based on economic thresholds need to be redefined for bollworm-resistant, transgenic cotton. Intervention thresholds also need to be developed for biocontrol agents. Changing climate and pest populations need to be continually monitored relative to changing cropping patterns for predictive systems to be successful. In addition, optimum storage, efficiency, and shelf life for these biocontrol agents need to be developed to ensure that the efficacy of IPM programs along with Bt-transgenic technology in overall pest management will be sustained for the longest possible time. In the following section, we discuss the first 10 years of Bt cotton in India.

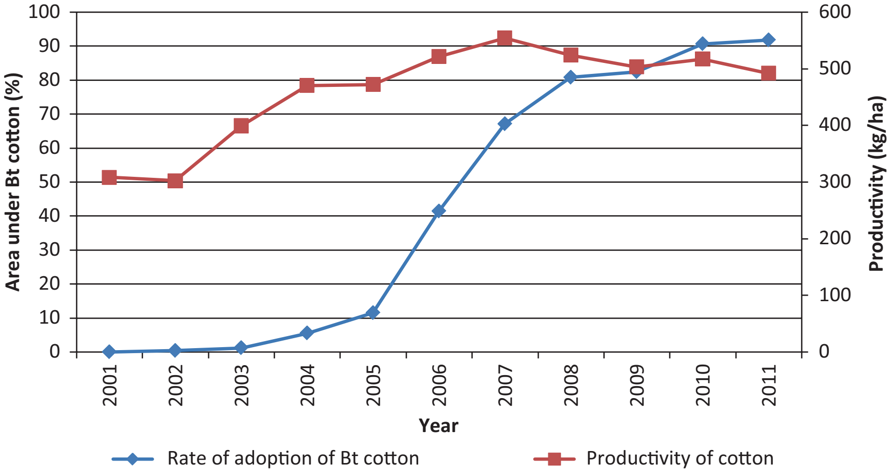

Fig. 11.2 *Rate of adoption of Bt cotton in India. The rate of adoption forms typical Rogers' "S"-shaped rate of adoption curve***.** The productivity of cotton has increased by 63 % since the introduction of Bt cotton in 2002.

11.3.1.1 First 10 Years of Bt Cotton in India

With the use of Bt cotton, the intensity of bollworm infestations was reduced significantly, thus reducing the fear of impending infestations and subsequent stress and exposure from the use of insecticide cocktails. In addition, Bt cotton hybrids matured 15–20 days earlier than normal because the near lack of bollworm damage resulted in greater retention of early formed bolls and more balanced plant growth. Because of the more synchronous boll bursting by Bt cotton, the effective number of pickings was also reduced. The early termination of the crop cycle also facilitated early sowing of a second crop such as wheat in northern India. Fiber quality from Bt cotton was also superior because bolls were undamaged by bollworms. The proportion of long staple cotton doubled to 76 %, so that Indian cotton, once considered inferior, is now accepted internationally as export quality. India has become a leading global exporter of raw cotton, averaging 5.3 million bales between 2003 and 2011, compared with an average of 0.118 million bales between 1997 and 2002 (before Bt cotton). Cotton imports into India declined from an average of 1.65 million bales between 1997 and 2002 to an average of 0.69 million bales between 2003 and 2011.

When Bt cotton was introduced in India in 2002 (officially approved for cultivation on March 26, 2002), the technology rapidly became immensely popular because of its high efficacy in controlling bollworms without insecticides. The area under Bt cotton reached about 5.5 % in 2004 and gained momentum after 2004. By 2011, more than 91 % of the area was under Bt cotton (Kranthi 2012). The rate of adoption formed an S-shaped adoption curve (Rogers 1983) within a short time (3–4 years, Figure 11.2). Because the technologies were similar to those of the Green Revolution, the diffusion theory fits here, but this is not the case with

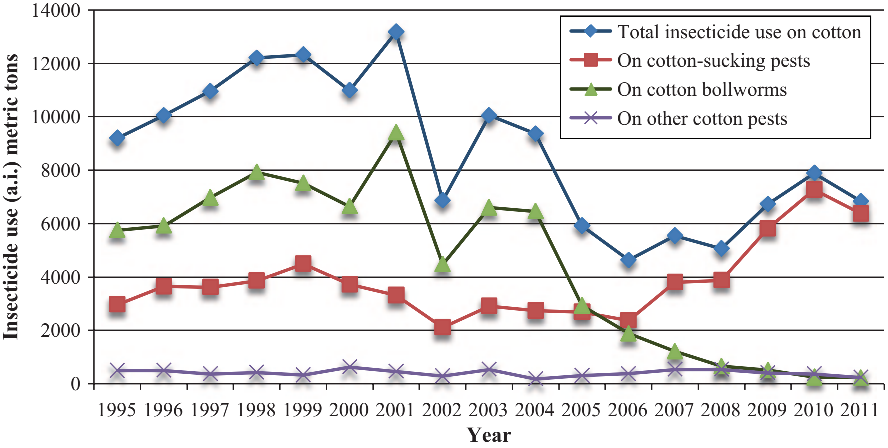

Fig. 11.3 *Insecticide use (a.i.) on cotton*. Insecticide use on cotton bollworms decreased 22-fold from 4,470 to 222 metric tons, whereas on sucking insect pests it increased threefold from 2,110 to 6,373 metric tons in the first 10 years of Bt cotton with no change in total insecticide use on cotton. (Source of data: Kranthi and Reddy 2012)

interdependent complex technologies such as IPM (Peshin et al. 2007). Before the technology was even approved by the Genetic Engineering Approval Committee (GEAC), illegal variants of Bt cotton hybrid seeds had been circulating in the market for about two years. In states such as Punjab, the technology was approved for release in 2005; however, 72 % of the cotton growers were growing Bt cotton in 2004, reaching an S-shaped rate of adoption curve between 2002 and 2004, and the grower percentage was predicted to reach 89 % by 2005 (Peshin et al. 2007). In 2011, 94 % of the cotton area in Punjab was under Bt cotton (Kranthi 2012).

Initially, Bt cotton hybrids were based only on one gene, *Cry1Ac,* in Bollgard as Monsanto's Mon 531 event. Subsequently, Bollgard-II with two genes (*Cry-1Ac + Cry2Ab2*) in their Mon 15985 event was approved in 2005, followed by approvals of event-1 (*Cry1Ac*) of JK seeds and GFM event (*Cry1Ac* fusion) of Nath seeds in 2006, *Cry1Ac* BNLA106 event of UAS Dharwad in 2008, and *Cry1C* event 9124 of Metahelix in 2009. Bt cotton hybrids are now marketed by about 44 seed companies in India. Only three Bt hybrids were approved between 2002 and 2004, but by 2012, 1,128 hybrids had been approved and planted on about 10.7 million hectares of the total 11.74 million hectares. The competitive clamor between companies probably accounts for the release of more than 800 Bt-hybrids within four years. However, although insecticide usage for bollworms has declined by more than 90 %, Bt hybrids are susceptible to sucking pests such as mirid bugs and mealybugs, which can also transmit plant pathogens such as the leaf curl virus and grey mildew, and pesticide use increased against sucking pests (See Figure 11.3).

Bt cotton has also significantly altered the cotton pest management scenario in India. Bt cotton was found to be highly effective in controlling all three bollworms throughout most of the season. Yield losses were reduced by 30–60 %, and insecticide usage was reduced from 13,176 metric tons (Figure 11.3) (38 % of the total) on 8.6 million ha in 2001 to only 6,828 metric tons (21 % of total) on 12.18 million ha in 2011. Insecticide usage on bollworms decreased from 4,470 to 222 metric tons between 2002 and 2011 whereas it increased on sucking pests from 2,110 metric tons in 2002 to 6,372 metric tons in 2011 (Kranthi and Reddy 2012). Productivity of cotton increased from 308 kg/ha (before Bt cotton) to 492 kg/ha between 2001 and 2011, an increase of 60 % in 11 years (See Figure 11.2). Before the introduction of Bt cotton, the 12-year growth in productivity between 1990 and 2001 was about 37 %. The area under cotton also increased from 9.13 million ha in 2001 to 12.19 million ha in 2011, a growth of 33.5 %. However, in 2002 (the year Bt cotton was introduced to India), only 0.38 % (0.03 million ha) of the total cotton area was under Bt cotton, and total insecticide use (a.i.) was 6,863 metric tons. By 2011, 92 % of the cotton area was under Bt (11.2 million ha), but the insecticide use on cotton stayed almost the same (6,828 metric tons in 2011) (Figure 11.3). Since the introduction of Bt cotton in India, low-volume insecticides such as spinosad and indoxacarb have ensured effective control of *H. armigera* infestations, which were significantly reduced with the use of Bt cotton (Kranthi and Russell 2009). The reasons, however, are not clear; perhaps infestations did not cross the economic threshold because of the introduction of Bt cotton or because a change in the insecticide use pattern, notably the decrease in use of synthetic pyrothroids complemented with the use of the new pesticides, caused the reduction. Reduction in insecticide use has been reported from the cotton-growing areas of India after the introduction of Bt cotton (Qaim and Zilberman 2003; Barwale et al. 2004; Pamsl et al. 2004; Orphal 2005; Qaim et al. 2006; Narayanmoorthy and Kalamar 2006; Peshin et al. 2007; Herring and Rao 2012). In their review of peer-reviewed studies on Bt cotton, Gruère and Sengupta (2011) showed a 31 and 41 % decrease in pesticide use in Andhra Pradesh and Maharashtra states, respectively, on Bt cotton relative to non-Bt cotton. This decrease was propelled by the fact that cotton farmers were divested of their livelihood by the losses caused by *H. armigera* making cotton cultivation economically inviable until Bt cotton offered extremely attractive, new options to manage bollworm. However, after the introduction of Bt cotton, some minor pests (*Spodoptera litura*, mealy bugs, mirid bugs, thrips, jassids, and weevils), which are not susceptible to the Bt toxin, began a resurgence (Kranthi and Russell 2009). Although the benefits of Bt cotton continue to be exploited, it is important not to underestimate the potential of bollworm to adapt to the Bt toxin. Effectively implementing appropriate IRM strategies is the key to ensuring the long-term sustainability of the Bt technology.

11.3.2 Rice

High-yielding varieties, chemical fertilizers, and increased areas under irrigation have increased the production of rice, the most important cereal crop in India, from 20.58 million metric tons in 1950–1951 to 89 million metric tons in 2009–2010, that is, from 688 kg/ha to 2130 kg/ha (Figure 11.4; MOA 2010). The major rice crop

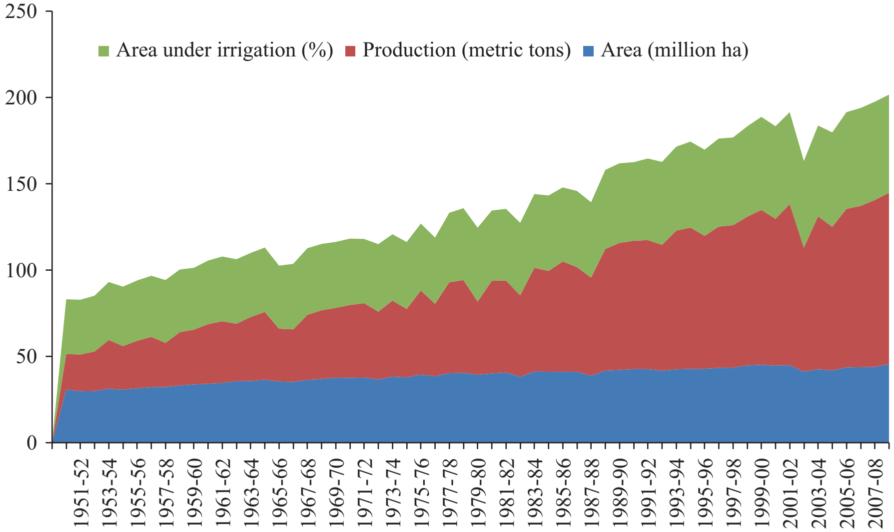

Fig. 11.4 *Cropped and irrigated area and productivity of rice*. (Data source: MOA (2010). Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India. http://agricoop.nic.in/statistics2003/chap4a.htm)

pests are stem borers, leafhoppers, plant hoppers, rice gall midge, rice leafhopper, whorl maggot, and thrips (Rajak 1986). Brown plant hopper was a minor pest until 1973, but is now a major pest. Pesticide use on rice is second only to cotton; the share of pesticide use in rice was about 22.8 % in 1984–1985, and in 1992–1993 it was estimated to be about 22.4 % (Unni 1996) of the total pesticide use in India, but per hectare by mass (a.i.) was only about 0.306 kg in 1992–1993 (Unni 1996). Pesticide use is significantly correlated with the availability of irrigation water (Gandhi and Patel 1997; Chand and Birthal 1997). Over the years, pesticide load on rice has fluctuated, with pest resurgence as the major contributor to increased use of pesticides as a result of widespread mortality of natural enemies, pesticide underdosing, and incorrect application (Chelliah and Bharathi 1993).

Subsequent to the Operational Research Project for rice IPM in the 1970s and 1980s, the Directorate of Plant Protection, Quarantine and Storage, Government of India implemented a large-scale Food and Agriculture Inter-country Program for Rice IPM through its 31 Central Integrated Pest Management Centres (CIPMCs) in the 1990s. Although the program is reported to have reduced insecticide use by mass as well as frequency of pesticide applications on rice (Qadeer and Tomar 1993; Thakur et al. 1993; Peshin and Kalra 1998; Peshin 2002), the technology has not been transferred adequately from IPM-trained farmers to other farmers, and over the years, the quality of training has suffered. Venugopal (2004), the author of Volume 8, *State of the Indian Farmers : A Millennium Study on Input Management* published by the Ministry of Agriculture, Government of India, reviewed different studies of IPM in India and found that the cost–benefit ratio was higher for rice IPM areas than for non-IPM areas (Table 11.4).

Table 11.4 Outcomes of Rice IPM Farmer Field School (FFS) Program

State	Pesticide use	Benefit in Terms of Crop Loss and Economics	Reference
Different states, 688 FFSs	Pesticide use reduced between 50 and 100% compared to non-IPM area	–	Ragunathan 1995
Haryana	Pesticide expenditure in IPM area was 58.2% lower than in the non-IPM from 1983 to 1990	Higher yields by 3.3%	Qadeer and Tomar 1993
Jammu and Kashmir	Not given	IPM farmers economically benefited with higher cost–benefit (CB) ratio: IPM = 1: 1.97 to 1: 1.98 Non-IPM = 1: 1.55 to 1: 1.58	Thakur et al. 1993
Kerala	–	Beneficial effect on agroecosystem	Thomas 1986
Karnataka 1983–1990	–	IPM = 1: 4.5 Non-IPM = 1: 3.4	Mishra et al. 1994
Tamil Nadu, 91 FFSs in two districts	Pesticide use reduced by 78% after IPM-FFS	–	Ragunathan 1995

11.3.3 Vegetables

The diversity in soil and climate of the several agroecological regions in India provides huge opportunities to grow a variety of tropical, subtropical, and temperate types of vegetable, making India the second largest vegetable-producing country behind China. In 2011–2012, the area under vegetable crops was 8.81 million ha, yielding 150.59 million tons and productivity of 17.1 tons/ha (Gupta et al. 2012). It is first in cauliflower production, second for onions, and third for cabbages (Kundu 2012). The per capita availability of vegetables over the same period increased from 236 to 312 g/day. In part, these achievements were brought about by progress in the use of hybrids, fertilization, and IPM.

Although India ranks second in vegetable production, insect pests cut crop yields by 40 % (Srinivasan 1993). The major pest of okra (*Abelmoschus esculantus*), the shoot and fruit borer *Earias vitella*, reduces yields between 22.79 and 54.04 % (Sharma et al. 1993; Satpathy and Rai 1998; Brar et al. 1994). The major pest of eggplant, *Solanum melongena*, is also a shoot and fruit borer (*Leucinodes orbonalis*), causing losses from 11.1 to 92.5 % (Dhankhar et al. 1977; Mote 1982; Gill and Chadha 1979; Krishnaiah 1980; Kumar and Shukla 2002; Mall et al. 1992; Kalloo 1988; Ali et al. 1980), and combating the borer has led to gross overuse of pesticides (Alam et al. 2006; Rashid et al. 2003). Low productivity of economically important cole crops such as cabbage (*Brassica oleracea capitata*), cauliflower (*B. oleracea botrytis)*, and knol-khol (*B. caulorapa)* is mainly attributed to the diamondback moth (DBM, *Plutella xylostella*), leaf webber (*Crocidolomia binotalis*), cabbage

Table 11.5 Estimated Pesticide Use on Vegetable Crops

Year	Vegetable Area (Million ha)[a]	Total Pesticide Use (Metric Tons)[b]	Percentage of Pesticide Use in Vegetables (%)[c]	Total Estimated Pesticide Use in Vegetables (Metric Tons)	Estimated Pesticide Use in Vegetables (kg/ha)
1984–1985	4.500	61,881	7.3	4,517	1.003
1992–1993	5.045	70,794	10	7,079	1.403
2006–2007	7.581	41,515	21	8,718	1.150
2010–2011	8.495	52,979	20	10,596	1.247

[a] NHRDF (2012); [b] DPPQ&S (2007); MOA (2012a); [c] Unni (1996); Agranova (2008, 2012)

web worm (*Hellela undalis*), head borer (*S. litura*), and aphid (*Brevicoryne brassicae*). The diamondback moth has developed resistance to all classes of insecticides in Punjab (Dhaliwal and Arora 2001).

Area under vegetable crops increased by 39% between 1984-1985 and 2010-2011. But pesticide use on vegetables increased by whopping 135%. Our estimates show that total pesticide use on vegetable crops was 4,517 metric tons in 1984–1985 (Table 11.5). Since then pesticide use on vegetable crops has increased to 10,596 metric tons in 2010–2011. The per hectare load of pesticides on vegetable crops was 1.247 kg in 2010–2011 (Table 11.5.), an increase of 24% over 1984–1985 value. Not surprisingly, in surveys by agencies throughout India, 50–70% of vegetables are contaminated with pesticide residues, placing a large population at risk (Karanth 2002). Many IPM programs have thus been developed to reduce such risks.

Approximately 950 IPM-FFS programs were implemented for vegetable crops throughout India by the Directorate of Plant Protection Quarantine and Storage, Government of India in the XI Plan Period (2008–2012). The World Vegetable Center (AVRDC) began an IPM program in Jharkhand and Punjab to promote safe vegetable production. Indiscriminate pesticide use on vegetable crops was widespread among the vegetable growers in Jharkhand state (Bond et al. 2009). As a result of research on the adoption of IPM practices for eggplant in West Bengal, studying farmers' socioeconomic status has been advocated to better understand their attitudes and practices (Baral et al. 2006).

11.4 IPM Case Studies

This section discusses selected studies that empirically evaluated IPM programs implemented under the FAO Inter-Country Program for IPM in Rice, the European Union-Food and Agriculture Organization IPM Program for Cotton, the Insecticide Resistance Management Program for cotton implemented by the Central Institute for Cotton Research, and the vegetable IPM programs implemented by India's Directorate of Plant Protection, Quarantine & Storage.

Table 11.6 Pesticide Use Before and After and With and Without IPM-FFS. (Source: Mancini 2006)

	Pesticide Toxicity Class Ib and II (kg a.i/ha)		Difference (%) Before/After	Pesticide Toxicity Class III and U (kg a.i/ha)		Difference (%) Before/After	Mean Frequency of Pesticide Sprays/ha		Difference (%) Before/After
	2002	2004		2002	2004		2002	2004	
IPM (*n* = 73)	1.086	0.252	−76.80	0.347	0.075	−78.39	7.9	1.7	−78.48
Control *(n = 63)*	2.128	1.533	−27.96	0.679	0.698	+2.80	8.2	7.2	−12.20

Class U: unlikely to present acute hazard in normal use, commonly called WHO Class U.

11.4.1 European Union-Food and Agriculture Organization IPM Program for Cotton

The five year ad hoc European Union-Food and Agriculture Organization (EU-FAO) IPM Program for Cotton was implemented in southern India from 1999 through 2004. Under this program between 2002 and 2004, 20 villages were covered. Mancini (2006) used five evaluation indicators: (i) health impacts of insecticides on spray operators and farm workers; (ii) changes in agronomic practices in cotton-based farming systems before and after IPM-FFS training in relation to changes in ecological knowledge of farmers; (iii) changes in labor allocation in cotton-based farming systems before and after IPM-FFS training; (iv) ecological footprint of conventional, organic, and IPM-FFS cotton; and (v) social impacts of IPM-FFS in terms of livelihoods and empowerment. The Double Difference (DD) design (Feder et al. 2004) was employed to conduct the evaluation study. The two districts, Warangal and Mahaboobnagar in Andhra Pradesh, were selected for the study. The sample size selected for the study was 73 IPM and 64 control farmers.

Pesticide use is an important parameter to evaluate the impact of IPM programs. The most common insecticides used on cotton in the study area were qinalphos (13.7 %), endosulphan (13 %), monocrotophos (12 %), chlorpyriphos (10 %), cypermethrin (8 %), indoxacarb (4.7 %), imidachloprid (4.7), acetamiprid (4.6 %), acephate (4.3 %), and phorate (3.7 %). Of the 26 types of pesticides used on cotton, organophosphates totaled 47 % of the sprays, and endosulphan (banned in India since 2011 by order of the Supreme Court of India) was used in 135 of the sprays. The use of highly toxic pesticides decreased in IPM-FFS villages and by the farmers participating in FFS program. The IPM farmers reduced their class I and II hazardous pesticide use (a.i.) by 76.8 % and mean pesticide applications by 78 % (Table 11.6). The differences between IPM and non-IPM farmers in mean pesticide applications and pesticide use by weight was significant.

The environmental impact quotient (EIQ) is another important indicator to assess the impact of IPM programs. The EIQ field rating is calculated by multiplying the table EIQ value for the specific chemical by the percentage of the active ingredient in the formulation and the dosage rate per hectare (Kovach et al. 1992).

The EIQ values for IPM and non-IPM fields were 62 and 257 metric ton of raw cotton, respectively. Monocrotophos (WHO toxicity class Ib) contributed 37 % to the total EIQ value, followed by chlorpyriphos (class II, 12 %) and endosulfan (class II, 12 %) in non-IPM farms. In IPM fields, insecticides in lower hazard classes, imidacloprid (class III, 23 %), acephate (class III, 18 %), chloropyriphos (class II, 10 %), and spinosad (class U, 8 %) were applied. Pesticide frequency and EIQ ratings are robust methods to measure the impact of IPM programs.

11.4.2 Insecticide Resistance Management Program in Cotton

Agriculture in Punjab state, the leader of the Green Revolution in India, has taken tremendous strides since the advent of the Green Revolution in the mid-1960s. With less than 1.5 % of the country's area, the state contributes 65 and 45 % of India's wheat and rice and 2.5 % of the rice, 3 % of wheat, and 2 % of cotton for the world (Anonymous 2006). Despite these advancements, the negative externalities associated with modern agriculture have affected the farmers and farming in Punjab, which always carries the dubious distinction of having the highest pesticide use of any state in India (Agnihotri 2000; Shetty 2004; Peshin 2005; Peshin et al. 2009). In addition to the Operational Research Project for cotton IPM in the 1970s and 1980s, many IPM programs in cotton and other crops have been implemented and funded by the public and private sectors. IPM Cotton Technology through Social Mobilization, a private sector initiative, by the Sir Ratan Tata Trust (SRTT) also operated in 10 cotton belt districts from 2005 to 2006. The Insecticide Resistance Management IPM program (IRMIPM) funded by the Ministry of Agriculture, Government of India under the Technology Mission on Cotton (TMC) Mini-Mission (MM-II), started in 2002, ran for five years, and an evaluation of this program between 2003 and 2005 illustrates the experience with cotton IPM.

In 2002, the IRMIPM program on promoting rational insecticide use (Table 11.7) and cultural practices for cotton was initiated by the Punjab Agricultural University (PAU), Ludhiana, India. The program was directly implemented by scientists at PAU, so that information flowed directly from scientists to farmers (i.e., from research subsystem to farming subsystem). More than 100 villages were covered under the program. This extension model differed from the FFS model in the flow of information (Table 11.8). The IRMIPM program was evaluated by Peshin (2005) using a nonequivalent control group design (with/without, before/after) to study three districts that were selected because they were in the IRMIPM program and accounted for 70 % of the total area (356,000 of 509,000 ha) cultivated in cotton in Punjab. Of 45 villages in the IRMIPM program in 2004–2005, 15 villages were selected randomly, five from each district. For the control, six non-IRMIPM villages were selected from the three districts. A sample of 10 farmers was selected from each village, making a total sample size of 210 (Peshin et al. 2009).

The IRMIPM program rationalized pesticide use, and the farmers reduced their number of applications by 18 % compared to the non-IRMIPM farmers (Table 11.9). The mean number of insecticide applications before the IPMIRM program on cotton

Table 11.7 IRM Strategy for Insecticide Use

Monitor the crop twice a week to identify insect pests, their economic thresholds levels, and natural enemies.

1. First window: Zero spray until day 90 after sowing to conserve natural enemies such as *Chrysoperla carnea, Coccinella septempunctata, Geocoris* spp., *Zelus* spp., and spiders. In case of emergency, use endosulfan 60–90 d.a.s. based on economic threshold level (ETL) because endosulfan is moderately toxic to natural enemies of insect pests. No organophosphates/carbamates/synthetic pyrethroids until 90 days after sowing. Use chloronicotinoids compounds if endosulfan fails to control *Amrasca bigutula*. Avoid use of endosulfan beyond 90 days after sowing.
2. Second window: 90–110 days after sowing, use synthetic pyrethroids/organophosphates/carbamates against *Earias vittella* based on ETL.
3. Third window: 110–140 days after sowing, use profenophos/quinalphos/triazophos for young larvae or chlorpyriphos/acephate for older larvae of *Helicoverpa armigera*. Use spinosad/indoxacarb if the first insecticides fail to control older larvae of *H. armigera*. During this period use triazophos/ethion for management of *Bemisia tabaci* and use chlorpyriphos/acephate/endosulfan/ quinalphos for control *Spodoptera litura.*
4. Fourth window: 140 days after sowing, use chlorpyriphos/indoxacarb/spinosad/quinalphos against H. armigera, ethion/triazophos against *Bemisia tabaci*. The pesticide application should be based on ETLs for major pests, 5% damage in shed fruiting bodies for *Helicoverpa armigera, Pectinophora gossypiella,* and *Earias vitella* (bollworm complex); appearance of yellowing and curling along leaf margins on 50% of plants in the case of *Amrasca bigutula* and six adults per leaf or appearance of honeydew on 50% plants in the case of *Bemisia tabaci.*

- The farmers were advised to stop tank-mixing of insecticides, avoid >2 sprays of synthetic pyrethroids and after late September not to use synthetic pyrethroids to avoid resurgence of *Bemisia tabaci.*
- Rotate the chemical groups/compounds to prevent the build-up of resistance against insecticides.
- After the last picking, clean the cotton fields of plant debris and unopened bolls.

in 2003 was 15.34 in the project area and 14.93 in the nonproject area. The IRMIPM farmers reduced the overall insecticide application to 10.05 (Bt and non-Bt cotton together), and to 4.63 in the case of Bt cotton alone (Table 11.10). IRMIPM farmers applied significantly fewer insecticide mixtures and, therefore, spent less on insecticides (Peshin et al. 2009).

The percentage of farmers who adopted the economic threshold for decision making on insecticide use for cotton insect pests before, during, and after the IRMIPM program was 0, 7, and 0% (Peshin et al. 2012). The main reason for the low adoption of the complex IPM practices is the requirement for new knowledge and analytical skills (Peshin 2013). The IRMIPM program could have been effective if the early evaluation results would have been used to improve the program. Few adopted the complex IPM practices such as sampling for insect pests, rotation of pesticides with different chemistries, and correct application methods. The impediments to implementation of the IRMIPM program highlighted by Peshin et al. (2009) included the lack of on-farm result demonstrations to address the farmers' perceived risks of the IPM technology, farmer training in sampling and identifying natural enemies, and attention to compatibility with farmers' cultural practices. Technological complexity and relative economic advantage contributed to a variation of 99% in the adoptability (i.e., the likely adoption of innovations in the future) (Peshin 2013). On the other hand, adoption of Bt cotton was rapid with high adopt-

Table 11.8 Extension Methodology Used by the IRM Program to Disseminate Information on IPM Practices. (Source: Peshin et al. 2009)

1. Training target	i. Farmer groups in IRM villages
2. Training methods	ii. Group meetings every week starting July up to end of September
	iii. Training by master trainer for each of the four windows of the IRM strategy, for judicious use of insecticides
	iv. Visit to IRM labs set up at PAU research stations
	v. Visit to selected good IRM farmer's field
	vi. Lectures and discussions
	vii. Trainers used as experts, not facilitators of the learning process
	viii. Scouts deployed in every village each week to provide feedback and estimate pest population and organize meetings
	ix. Training of scouts before the start of project and during 2003
	x. Visit of scientists and farmers to farmers' fields to identify insect pests and other problems
	xi. Information centers with exhibits and displays established in IRM villages
3. Training tools	i. Publication and distribution of IRM printed material to farmers.
	ii. Posters, banners, pamphlets, displays.
	iii. Information centers with all relevant information on cotton-growing.
	iv. Street plays to create awareness and interest.

Table 11.9 Outcomes of IRM Program in Punjab. (Source: Peshin et al. 2009)

Treatment	Mean No. of Insecticide Applications (Bt + non-Bt Cotton)		Difference Before/After (%)	Mean No. of Insecticide Applications on Bt Cotton	Mean No. of Insecticide Mixture Applications	Insecticide Use (kg a.i./ha)	Herbicide Use (kg a.i./ha)	Pesticide Expenditure as % of Total Production Cost	Output/Input Ratio of Production Cost
	Before IRMIPM	After IRMIPM							
I. IRMIPM ($n=150$)	15.34	10.05	−34.5	4.63	3.10	5.602	0.282	31.70	1.86
II. Non-IRMIPM ($n=60$)	14.93	10.31	−30.9	4.86	5.10	8.032	0.144	35.63	1.77
Difference with/without (%)	2.72	−0.26	Difference in differences = −14.5	−4.97	−64.60*	−43.40	+95.83	−11.03	+5.08

* Significant at $P < 0.01$

Table 11.10 Impact of Bt Cotton on Pesticide Use in Punjab (Source: Peshin et al. 2007)

Treatment	Mean No. of Insecticide Applications	Insecticide and Herbicide Use by Weight (kg a.i./ha)	Pesticide Expenditure as % of Total Production Cost	Output/Input Ratio of Production Cost
Bt cotton	4.76	2.820	16.87	1.96
Non-Bt cotton	10.46	6.680	Hybrid = 36.67 Nonhybrid = 40.97	Hybrid = 1.75 Nonhybrid = 1.55
Difference over Bt (With/without) (%)	119.74	136.88	Over Bt cotton: Hybrid = +19.80 Nonhybrid = +24.10	Over Bt cotton: Hybrid = −10.71 Nonhybrid = −20.92

ability, even before the official release of Bt technology in Punjab. Between 2002 and 2004, the rate of adoption of Bt cotton was 72 % with respect to farmers and 22 % with respect to area (Peshin et al. 2007).

The productivity of cotton in Punjab increased since 2002 from 410 kg/ha to an all-time high of 752 kg/ha in (GOP 2003; PAU 2008), an increase of 83%. The higher productivity has been propelled by a combination of factors: the cultivation of Bt cotton, which changed the composition of pest populations by reducing *Helicoverpa armigera* infestation, and implementation of many IPM programs. However, in 2009 cotton productivity was estimated at 667 kg/ha and the latest figures show that it declined to 523 kg/ha in 2011 (PAU 2011, 2013), the net increase of about 30 % between 2002 and 2011. Although the use of Bt cotton has reduced pesticide use on cotton (Table 11.10), our estimates show that pesticide (insecticides, herbicides, and fungicides) use in cotton is still very high (Table 11.11). Overall pesticide use by mass on all crops in Punjab is now at the 1988–1989 level (ca. 5,700 metric tons), despite the fact that HCH was banned for use in 1997; new low dosage insecticides (imidacloprid, spinosad, indoxocarb) and herbicides (e.g., butachlor 50EC used at 1.5 kg a.i./ha was replaced by anilofos 30EC and anilofos 50EC used at 0.450 and 0.375 a.i. kg/ha, respectively).

11.4.3 Rice IPM Program in Punjab and Pesticide Use

Rice is grown in Punjab on 2.8 million ha (PAU 2011). Its 2009 yield of 4,010 kg/ha is four times greater than the 1,000 kg/ha of 1965–1966 (pre-Green Revolution) when rice was grown on only 0.29 million ha, one-tenth of the 2009 area (PAU 2011). Productivity has increased by 300 % (Table 11.12). As the "rice bowl of India," Punjab is the major contributor of rice to the central pool of food grains in the country. This position was made possible by the introduction of semi-dwarf, high-yielding varieties and matching production and protection technologies. In India, Punjab ranks first with mean unhulled rice productivity (6 metric tons/ha) on par with the mean productivity of China (FAOSTAT 2009). With all the advancements in agriculture in Punjab, land and resources began to be overexploited. Cropping intensity increased from 126 % in 1960–1961 to 183 % in the 1990s, and

Table 11.11 Estimated Pesticide Use on Cotton in Punjab Last 20 Years

Year	Area with Cotton (million ha)	Area (or % of Farmers) with Bt Cotton (%)	Pesticide Use in Cotton to Total Use in Punjab (%)	Total Estimated Pesticide Use on Cotton (Metric Tons a.i.)	Estimated Pesticide Use on Cotton (kg/ha)
1990	0.70	0	50	3,250	4.643
1995	0.74	0	50	3,800	5.135
1998	0.56	0	50	3,650	6.518
1999	0.48	0	50	3,700	7.708
2002	0.45	4% of farmers[a]	50	3,600	8.000
2003	0.45	16% of farmers[a]	50	3,390	7.533
2004[a]	0.51	22[a] (72% of farmers)	48[a]	3,313[a]	6.497[a]
2005	0.56	07[b]	48	3,384	6.043
2006	0.59	21[b]	41	2,645	4.483
2007	0.60	50[b]	41	2,706	4.510
2008	0.53	76[b]	41	2,665	5.028
2009	0.51	82[b]	41	2,665	5.225
2010	0.53	80[b]	31	1,776	3.351
2011	0.56	94[b]	30	1,688	3.014

[a] Based on study by Peshin (2005). Percentage pesticide use on cotton from 2005 to 2011 was calculated using the reduction in pesticide use in Punjab for the respective period, with 2004 as the baseline; all reduction has been credited to cotton

[b] Kranthi (2012).

the pest spectrum has also changed over time. The white-backed planthopper, *Sogatella furcifera,* and the leaffolder *Cnaphalocrocis medinalis* became major insect pests of rice. Crop losses in rice increased from 10 to 25 % between the 1960s and 2000s (Dhaliwal et al. 2007), despite a rapid large increase in pesticide use (mainly insecticides and herbicides). In 1983, 40 % of the total cultivated area was under chemical weed control (Atwal 1986), and 100 % of the area received herbicides in 1995 (Peshin and Kalra 1998). Herbicide use by weight (a.i.) increased from 2.55 to 130 metric tons between 1977–1978 and 1983–1984 (State Department of Agriculture Punjab, cited by Atwal 1986).

The FAO Inter-country Rice IPM Program, started in Punjab in 1994, was envisaged by the CIPMC Punjab, Department of Agriculture Punjab and the Punjab Agricultural University (PAU) as a collaborative model. The program aimed to educate farmers and extension workers in IPM using farmer field schools, demonstrations, and mass media.

A study in 1995–1996 evaluated the outcomes of the IPM-FFS program in 10 villages of the Punjab district of Ludhiana. IPM technologies recommended under the FFS program included: (i) cultivation of resistant varieties recommended by the PAU; (ii) cultural practices to control pest build-up, namely, deep summer plowing, destroying crop residues, timely transplanting, and managing fertilizers and water; (iii) manual mechanical practices to dislodge and destroy insect pests; (iv) augment-

Table 11.12 Area, Production and Productivity of Rice in Punjab for Selected Years. (Source: Rice Knowledge Management Portal. http://www.rkmp.co.in, Directorate of Rice Research, Rajendranagar, Hyderabad)

Year	Area (Million ha)	Production (Thousand Metric Tons)	Yield (kg/ha)
1993	2.174	7,624	3,507
1995	2.161	6,768	3,132
1996	2.160	7,338	3,132
2000	2.611	9,200	3,523
2001	2.487	8,816	3,545
2002	2.530	8,880	3,510
2003	2.614	9,600	3,672
2004	2.647	10,437	3,943
2005	2.642	10,193	3,858
2006	2.621	10,138	3,868
2007	2.610	10,489	4,019
2008	2.735	11,000	4,022
2009	2.802	11,236	4,010

ing biocontrol agents and conserving beneficial insects; and (v) calculating the ETL of insect pests for need-based selective pesticide application.

IPM farmers reduced pesticide applications from 2.88 per season (before IPM) to 2.64 (during IPM) and 2.52 (after IPM), but the differences were not statistically significant (Peshin and Kalra 1998). However, the differences in insecticide sprays and expenditure between IPM and non-IPM farmers were significant. IPM farmers reduced their blanket applications of insecticide. IPM farmers cultivated bacterial leaf blight resistant/tolerant varieties (PR108 and PR111) on 26% of the total rice area (Table 11.13). Although they had reduced insecticide use, their use of the economic threshold level in deciding to use insecticides was negligible. During the FFS program, only 6% of the trainee farmers calculated the ETL of insect pests (rice stem borers) before applying insecticides. IPM farmers made 32% fewer insecticide applications than non-IPM farmers. Ten percent of the IPM-trained farmers did not apply any insecticide on rice (Table 11.13) without adversely affecting yields (Peshin and Kalra 1998). Adoption of manual mechanical practices recommended under IPM-FFS was negligible due to mechanization of agriculture in Punjab. Knowledge gain about insect pests and their natural enemies was the main impact of the IPM-FFS program, but farmers were not trained in the correct use of pesticides (selecting the right chemical, dose, and applying it safely).

Once the program had scaled up and the training shifted from the master trainers to the extension agents of the agriculture department, who were neither comfortable with the IPM philosophy nor the extension methodology for facilitating farmers, the IPM program failed to achieve its objectives for educating farmers about IPM principles (Peshin and Kalra 2000). Other than the IPM-FFS program, most information on pest control and pesticides came from pesticide dealers and companies (Peshin and Kalra 1998). In another study by Peshin et al. (1997) in the subtropical areas of the state of Jammu and Kashmir where irrigated rice is grown, the farmers trained in the IPM-FFS did not use any insecticides on rice during the implementation of the program in 1994 and after the program in 1996, without adversely affecting the

Table 11.13 Outcomes of IPM Program in Rice

Indicator	IPM Farmers	Non-IPM Farmers	Difference
Mean frequency of pesticide application	2.36	3.47	−1.11
Insect pests			
Blanket application of insecticides (% of farmers)	19	47	−28
Curative application of insecticides (% of farmers)	73	100	−27
Diseases			
Curative application of bactericides to control bacterial leaf blight[a] (% of farmers)	7	7	0
Adoption of bacterial leaf blight tolerant/resistant varieties (% of area)	26	4	+22
Weeds			
Application of herbicides (% of farmers)	100	100	0
Farmers not using any insecticides and fungicides (% of farmers)	10	0	−10

[a] Not recommended by the PAU but on the advice of pesticide retailers applied mixture of carbendazim and streptocycline. Does not include chemicals to treat seeds; modified from Peshin and Kalra (1998).

yield. Farmers trained in the IPM-FFS in Jammu only applied butachlor herbicide for weed management (Peshin et al. 1997).

Despite the initiation of the IPM-FFS program in 1994, pesticide use over time in the rice crop in the cotton belt of Punjab has increased since 1995. Many IPM programs were implemented by the CIPMC, the Punjab Agricultural University and other agencies in rice and cotton crops between 1995 and 2004. In 2004, insecticide use (a.i.) in the Bathinda, Mansa, and Ferozpur districts was 1.418, 1.261, and 1.711 kg/ha, respectively. Fungicides (other than for seed dressing) were used only in the Mansa district (at 0.073 kg/ha). The mean frequency of insecticide application was 3.11, 3.25, and 3.05 in the Bathinda, Ferozpur, and Mansa districts, respectively, with an average of one application of herbicide and negligible use of fungicides (R. Peshin, unpublished data 2005), all increases over 1995 values. The mean number of insecticide applications in the rice crop in the cotton belt of Punjab was 3.10, including the mean number of herbicide applications (1), and the mean number of pesticide applications was 4.10 in 2004 (R. Peshin, unpublished data 2005). Assuming that the pesticide use on rice in Punjab equals the national percentage of 23 % of the total pesticide use, then pesticide use per hectare has decreased over time (Table 11.14). However, pesticide usage in 2004 reflects an increase in the insecticides on rice. The pesticide use (excluding herbicides) ranged between 1.261 and 1.711 kg/ha. The plausible hypothesis is that pesticide use on rice in the cotton-growing areas of Punjab was higher than the national average (rice received 23% of the total pesticide used). When data are extrapolated per hectare, pesticide use on rice in the cotton belt of Punjab was between 2,614 and 2,647 metric tons in 2004. The discrepancy between the official pesticide statistics and the above estimates may be due to: (i) the sale of spurious pesticides (FICCI 2011); (ii) pesticide use on

Table 11.14 Estimated Pesticide Use on Rice in Punjab

Year	Total Pesticide Use (a.i.) Metric Tons[a]	Area Under Rice (Million ha)[b]	Estimated Pesticide Use in Rice (Metric Tons)	Estimated Pesticide Use in Rice (kg/ha)
1988	5,770	1.778	1,327	0.746
1990	6,500	2.015	1,495	0.742
1995	7,600	2.065	1,748	0.846
1999	7,400	2.604	1,702	0.537
2003	6,780	2.614	1,559	0.596
2004	6,900	2.647	1,587	0.600
2011	5,625	2.818	1,294	0.459

[a] Dudani and Sengupta (1991); Venugopal (2004); Puri (1995); DPPQ&S (2007); MOA (2012a)
[b] GOP (2003, 2012)

rice may be greater in the cotton belt; and (iii) collection of potentially inaccurate pesticide-use data by government agencies.

11.4.4 Vegetable IPM Program in Subtropical Areas of Jammu Region of Jammu and Kashmir

The vegetable IPM-FFS program in progress in the subtropical areas of Jammu region since 1997 was evaluted by Sharma (2011) in a comprehensive study using an experimental control group double difference design and an ex post facto (with/without IPM) critical multiplism model. The critical multiplism evaluation model is a synthesis of experimental and ex post facto studies used to generalize evaluation findings. The impact of the IPM-FFS was assessed in terms of the mean number of pesticide applications, pesticide quantity (a.i.), and environmental impact as an environmental impact quotient (EIQ, discussed earlier).

There was a difference in the use of pesticides in *rabi* (winter) and *kharif* (summer/rainy season) vegetable crops in both the IPM and non-IPM areas. In the case of winter crops (cabbage and cauliflower), pesticide use by mass and mean frequency was lower than for summer vegetables (okra and eggplant) because of the higher incidence of insect infestations and diseases in humid and hot weather. The average pesticide applications for winter vegetables in IPM-FFS ranged from 0.96 to 1.60, compared with about four applications for okra, and as high as nine applications for eggplant (Table 11.15). The environmental impact per hectare of vegetable cultivation was thus also higher for summer vegetables and the highest for eggplant. The mean number of applications, quantity by mass, and EIQ did not differ significantly between IPM and non-IPM farmers (Table 11.15) except for eggplant. Pesticide quantity differed significantly by weight on eggplant between the IPM and non-IPM farmers: 1.077 kg/ha in IPM villages and 1.744 kg/ha in non-IPM villages. IPM farmers also used 65% fewer applications. Surprisingly, the major findings with respect to implementation indicated that the trainers did not follow the 14-week schedule and activities as indicated in the guidelines for implementing IPM-FFS. Under the guise of participatory implementation of the FFS, the trainings were

Table 11.15 Pesticide Use on Vegetable Crops in IPM and Non-IPM Fields in Subtropical Region of Jammu and Kashmir State

Crop	Pesticide Use (a.i., kg/ha)		No. of Sprays		Pesticide Expenditure (US $/ha)		Field Use EIQ/ha	
	IPM	Non-IPM	IPM	Non-IPM	IPM	Non-IPM	IPM	Non-IPM
Cauliflower	0.208	0.201	0.96	1.23	19.86	22.17	46.2	34.0
Cabbage	0.370	0.321	1.60	1.34	33.81	25.57	38.6	39.9
Okra	0.828	0.624	4.18	4.25	85.14	93.90	178.2	134.9
Eggplant	1.077	1.744	5.50	9.10	123.21	209.34	302.8	205.6

** The environmental impact quotient (EIQ) is calculated by adding the field use rating of each pesticide. The field use EIQ was calculated by multiplying the reference EIQ with the number of applications, the rate of application and the percentage active ingredient as advocated by Kovach et al. 1992.

1 US $ = Rs. 45.09, at 2010 rates

more or less based on lectures rather than using farmers' fields as the laboratory for learning to identify insect pests, diseases, and natural enemies. The farmers did not receive experiential learning by setting up insect zoos, and many of the mechanical and biological practices such as setting sticky traps for sucking pests were omitted in the FFS. Thus, the IPM-FFS did not empower the farmers to make the shift from pesticide-intensive management to IPM (Sharma et al. 2012).

The IPM program for vegetable crops failed to rationalize or to reduce pesticide use in vegetables. Despite farmers participating in the IPM program, the main source of information on pests and pesticide decisions came from pesticide retailers/shopkeepers (72 %). A binary logistic model confirmed the hypothesis that the presence of a pesticide shop in the village increased pesticide use.

The high EIQ values in the IPM villages are due to the application of highly toxic pesticides by IPM farmers even after the IPM program, which indicates, as mentioned earlier, that the vegetable IPM program was not properly executed. The pesticides used were methyl parathion, phorate (WHO hazard class Ia), dichlorovas (WHO hazard class Ib) cypermethrin, chloropyriphos, carbaryl, cabosulphan, thiodicarb, endosulphan (WHO hazard class II), acephate, malathion, propineb, acetamiprid, imidacloprid, thiomethoxam, and flubendiamide (WHO hazard class III).

11.5 Pesticide Use in the Era of IPM and Bt Cotton

In India, pesticide use is not uniform, and it varies with the intensity of insect pests, diseases, crop weeds, cropping patterns, and agroecological regions. Pesticide use is high in regions with good irrigation facilities and in areas where commercial crops are grown (Shetty 2004). Pesticide use was determined primarily by the extent of irrigation (Gandhi and Patel 1997; Chand and Birthal 1997); size of the landholdings (Peshin et al. 2009); presence of cotton, wheat, and rice crops in the cotton belt (Gandhi and Patel 1997; Peshin et al. 2009; R. Peshin, unpublished data 2005); and the replacement of manual weed control by herbicides (Peshin et al. 1997; Peshin and Kalra 1998; Chand and Birthal 1997). Herbicides are used on rice and wheat crops in the Green Revolution regions such as Punjab, irrigated areas of Jammu (Peshin et al. 1997; Peshin and Kalra 1998; R. Peshin, unpublished data 2013), and on about 55 % of the cotton in Punjab (Peshin 2009). Pesticide use varies from crop to crop (Atwal 1986; Agranova 2008, 2012; Abhilash and Singh 2009) and from state to state (Table 11.16).

In 1997, HCH was banned, thereby eliminating 30 % of the total pesticide use in India (Shetty and Sabitha 2009). According to one estimate, since 1985 about 45,000 metric tons of HCH were used annually (Voldner and Li 1995). The new highly effective low-dosage chloronicotinyl insecticide group, comprising imidacloprid, acetamiprid, and thiomethoxam, was introduced in 1999–2000 as a seed treatment and a foliar spray to control sucking pests. Pesticide use was also reduced with the introduction of low-dosage herbicides such as pretilachlor, sulfosulfuron, clodinafor and metribuzin (e.g., in rice crop pretilachlor used at 750 ml a.i./ha compared with butachlor at 1500 ml a.i./ha) and insecticides such as spinosad, indoxacarb, emamectin benzoate, flubendiamide, chlorantraniliprole, novaluron, and lufenuron. As discussed already, these insecticides controlled lepidopteran pests effectively with less negative impact on beneficial insects (Kranthi 2012) and reduced the insecticide load by volume on cotton. All these were the predominant drivers in reducing agricultural pesticide use from about 73,000 metric tons in 1995–1996 (before the HCH ban) to about 43,584 metric tons in 2001–2002 (before Bt cotton). Therefore, crediting IPM programs alone for reducing pesticide use from 75,033 metric tons (a.i) in 1990–1991 to 41,822 metric tons in 2009–10 (http://ppqs.gov.in/Ipmpest_main.htm) is far removed from the facts based on science and scientific enquiry. Barely 0.8–3 % of the total cultivated area (NCIPM[1]) and about 5 % of farmers in India (Ragunathan 2005) have been covered under IPM programs, therefore, crediting the reduction of pesticide use exclusively to IPM programs is not correct.

Since 2002, the start of Bt cotton, pesticide use in Indian agriculture has been reduced by 4 % (from 43,584 to 41,822 metric tons between 2001 and 2009). India is the world's fourth largest cultivator of genetically modified crops (GM crops), with an area of 9.4 million ha in 2010 (only Bt cotton is cultivated in India). Cultivation of Bt cotton has reduced pesticide use in Indian cotton by about 39 % (Agranova 2012). Overall insecticide use in cotton has stabilized between 2002 and 2011. But, after a per annum negative market growth rate of 1.1 % from 1998 to 2007 and 0.9 % between 2003 and 2007, the pesticide market grew by 8 % between 2007 and 2011 (Agranova 2008, 2012). In 2010–2011, the pesticide market grew by an amazing 17.4 %. The total pesticide market in 2009 was US $1,022 million (Agranova 2012). In addition to these estimates, spurious and substandard pesticide sales in

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[1] Concept note on integrated pest management: Dr. C. Chattopadhyay, Director, NCIPM (ICAR), LBS Building, Pusa Campus, New Delhi 110012; Email: chirantan_cha@hotmail.com

Table 11.16 Pesticide Use (a.i.) by Weight (Metric Tons) in Different States of India

State	1988–1989	1989–1990	1990–1991	1991–1992	1992–1993	1993–1994	1994–1995	1995–1996	2002–2003	2003–2004	2004–2005	2005–2006	2006–2007	2007–2008	2008–2009	2009–2010	2010–2011	2011–2012
Andhra Pradesh	9910	11580	13520	13442	13650	14500	13000	12775	3706	2034	2133	1997	1394	1541	1381	1015	8869	9289
Bihar	1700	2000	2200	2300	1423	2600	2600	2550	1010	860	850	875	890	870	915	828	675	655
Gujarat	5500	5500	4100	5400	4792	5300	5100	5250	4500	4000	2900	2700	2670	2660	2650	2750	2600	2190
Haryana	4500	4690	5156	5265	5200	5200	5250	5300	5012	4730	4520	4560	4600	4390	4288	4070	4060	4050
Jammu and Kashmir	110	115	123	47	91	148	142	161	98	09	12	1433	829	1248	2679	1640	1818	1711
Karnataka	3900	4380	4150	4295	4125	4450	4400	4000	2700	1692	2200	1638	1362	1588	1675	1647	1858	1412
Kerala	1100	970	980	720	700	720	700	1167	902	326	360	571	545	780	273	631	657	807
Maharashtra	6020	4470	4920	5660	6450	6700	6900	4898	3724	3385	3030	3198	3193	3050	2400	4639	8317	6723
Punjab	5770	6000	6500	6500	6300	6300	6450	7600	7200	6780	6900	5610	5975	6080	5760	5810	5730	5625
Rajasthan	2758	3230	3198	2981	3200	3600	3900	4000	3200	2303	1628	1008	3567	3804	3333	3527	3623	2802
Tamil Nadu	12500	10000	7500	3500	5500	10500	9500	4000	3364	1434	2466	2211	3940	2048	2317	2335	2361	1968
Uttar Pradesh	8480	8910	8990	9000	9000	11000	11000	11500	6775	6710	6855	6671	7414	7332	8968	9563	8460	8839
West Bengal	5000	3600	4040	4607	4625	6084	5823	5338	3000	3900	4000	4250	3830	3945	4100	NA	3515	3670
Other states and Union territories	8170	6449	9656	8416	5738	6993	5919	5113	3156	2857	2818	3001	1306	4294	3121	—	2997	3238
Total	75418	71894	75033	72133	70794	84095	80684	73652	48350	41020	40672	39773	41515	43630	43860	41822	55540	52979

1988–1989: Dudani and Sengupta (1991); 1989–1990 to 1992–1993: Venugopal (2004); 1993–1994 to 1995–1996: Puri (1995); 2002–2003 to 2006–2007: DPPQ&S (2007); 2007–2008 to 2009–2010: DPPQ&S (2010); 2010–2011: MOA (2011); 2011–2012: MOA (2012a)

Bihar: 1988 to 1996 data for combined states of Bihar and Jharkhand and 2002 onwards data for Bihar state only.

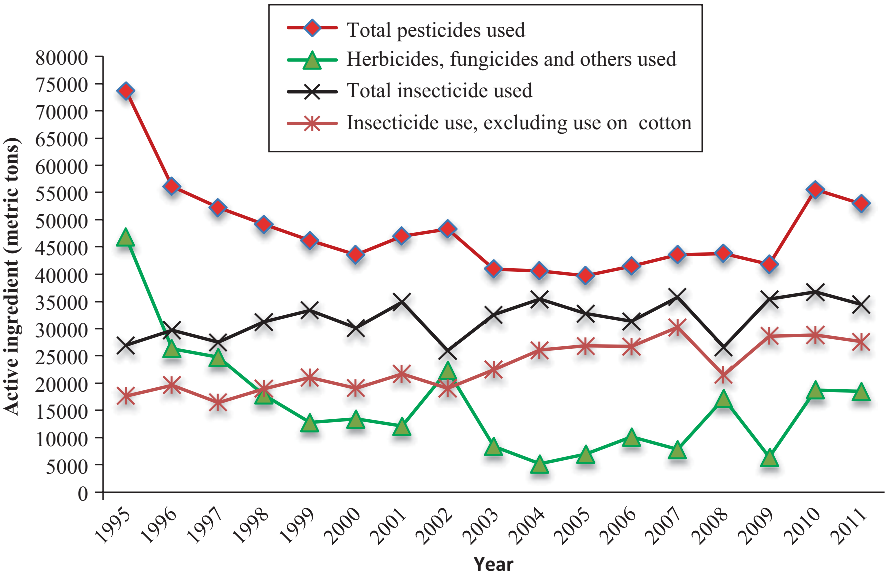

Fig. 11.5 *Pesticide use in Indian agriculture between 1995 and 2011*. Overall pesticide use in Indian agriculture has decreased by 28% since 1995 but increased by plus 9% in the first 10 years that Bt cotton has been grown. Total insecticide use increased by 28% and has increased by about 44% in all crops (excluding cotton) since the introduction of Bt cotton in 2002

2009 were estimated at US $267 million (FICCI 2011), which is about 25 % of the total pesticide sales. Therefore, pesticide use (52,979 metric tons) as reflected in the government statistics is a conservative estimate because the 25 % market share (about 13,000 metric tons) held by spurious/substandard pesticides was not included.

According to conservative estimates, pesticide use in cotton was 50 % of the total pesticide use in agriculture before Bt cotton or about 19,613 metric tons in 2001–2002 (2.254 kg/ha), and the number of pesticide applications averaged between 20 and 30 in Maharashtra, 15 and 20 in Punjab (Shetty 2004), and in certain cases, exceeding 30 applications (Peshin 2005). Considering that the average pesticide reduction driven by Bt cotton is between 30–40 % (according to a review of the Bt cotton impact on pesticide use), then overall pesticide use in Indian agriculture should have decreased, but the trend is just the opposite. Pesticide use has actually increased by 9 % since the introduction of Bt cotton (Fig. 11.5). Total insecticide use increased by about 44 % in all crops (excluding cotton) since the introduction of Bt cotton in 2002. Statewise data also reflects that pesticide use in Andhra Pradesh, Haryana, Maharashtra, Punjab, and Rajasthan (cotton-growing states) is at 1988–1989 levels (before large-scale IPM programs) and has decreased significantly in other cotton-growing states (Gujarat, Karnatka, and Tamil Nadu; Tables 11.16 and 11.17).

Table 11.17 Pesticide Use per Unit Area in 1988–1989 and 2011–2012.

State	Net Cultivated Area (Million ha) 2009–2010[a]	Pesticide Use, a.i. Metric Tons (% of Total)		Estimated PesticideLoad/ha(kg)	
		1988–1989[b]	2011–2012[c]	1988–1989	2011–2012
Andhra Pradesh	9.991	9,910	9,289 (17.5)	0.992	0.930
Bihar	5.332	—	655 (1.2)	—	0.123
Gujarat	10.302	5,500	2,190 (4.1)	0.534	0.213
Haryana	3.550	4,500	4,050 (7.6)	1.268	1.141
J & K	0.735	110	1,711 (3.2)	0.150	2.410
Karnataka	10.174	3,900	1,412 (2.7)	0.383	0.139
Kerala	2.089*	1,110	807 (1.5)	0.531	0.386
Maharashtra	17.401	6,020	6,723 (12.7)	0.346	0.386
Punjab	4.158	5,770	5,625 (10.6)	1.388	1.353
Rajasthan	16.974	2,758	2,802 (5.3)	0.162	0.165
Tamil Nadu	4.892	12,500	1,968 (3.7)	2.555	0.402
Uttar Pradesh	16.417*	8,480	8,839 (16.7)	0.517	0.538
West Bengal	5.256	5,000	3,670 (6.9)	0.951	0.698
Other states and Union territories	32.751	9,270	3,238 (6.2)	0.232	0.099
Total	140.022	75,418	52,979 (100.0)	0.534	0.378

[*] 2008–2009 data. Values in parentheses are percentage of total pesticide used in India.

[a] MOA (2012b); [b] Dudani and Sengupta (1991); [c] MOA (2012a)

11.6 Conclusion

Despite the adoption of IPM as the main strategy for plant protection in India, the success of IPM is limited to ad hoc projects implemented in different regions and crops. There has been no well-thought–out policy initiative to promote IPM effectively. The future of IPM will hinge on reduced-risk insecticides and increased use of herbicides and transgenic crops, which are simple, input-intensive technologies, whereas IPM, as envisioned originally, is based on knowledge-intensive, interactive, and complex technologies with low predicted adoptability (Peshin 2013). In areas with low external inputs and no access to irrigation, farmers by default practice nonpesticide pest management. According to Ehler (2006), for those who insist on practicing real IPM, a workable definition is needed to incorporate key components of IPM and set performance standards to assess IPM implementation. The farmer field school, viewed as the "classical model" in the developing world, did not reach millions of farmers in India. Providing the resources (trained manpower and finances) required to reach those millions of farmers across the country is a difficult task. Since 1993, only 5 % of the total farmers have been reached in 10 years (Ragunathan 2005). The ad hoc IPM projects/programs cannot reach the millions of small farmers in India, and project reports do not provide a reality check. This ad hoc approach to IPM programs is credited by IPM policymakers for all reductions in pesticide use from 1990 through 2009, and the Bt cotton lobby wants to take all the credit for reductions in pesticide use since 2002. So the contentious question remains, “Who is to claim credit for increased pesticide use in the first decade of the twenty-first century?” This controversy can be resolved if large-scale scientific evaluation studies are periodically conducted in a professional manner to measure the impact of IPM programs. Frequency of pesticide treatment and environmental impact quotient are the robust evaluation indicators for measuring the impact of IPM and transgenic crops. A combination of farmer education and mass media to compete aggressively against pesticide companies will go a long way in rationalizing pesticide use in Indian agriculture.

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Chapter 12
Experiences with Implementation and Adoption of Integrated Pest Management in China

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Abstract China has over 30 years of experiences with the implementation and adoption of integrated pest management. Ample evidence in China confirms that integrated pest management can decrease pesticide use without lowering crop yields, improve farmers' income, and protect the environment. This chapter provides a glimpse of the history, international and national programs, and the other efforts undertaken in the implementation of integrated pest management towards achieving agricultural sustainability in China. Different extension approaches used in the implementation of integrated pest management are compared and analyzed, integrated pest management impact assessment programs and their main outcomes are described, and comments on current issues and future challenges in the adoption of integrated pest management in China are put forward.

Keywords Integrated pest management · Extension approach · Training · Ecological management · Biological control · Farmer education · Training of trainer · Farmer field school · Impact assessment

12.1 Introduction

The agriculture production in China has been expanding continuously since 1978. However, the expansion and intensification of agricultural production has reduced the sustainability of the smallholder farming system due to outbreaks of crop pests, significant increases of inputs and rapid deterioration of agro-ecological systems. Integrated pest management (IPM) is believed to be the best solution to reverse those negative trends. IPM requires farmers to integrate different pest control methods including varietal resistances, cultivation, mechanical control, biological control and chemical control according to specific field conditions. Thus farmers need skills in pest monitoring and knowledge of pest biology and ecology. Most small Chinese farmers lack basic ecological knowledge of cropping systems. Despite the implementation of a number of national and international IPM programs in the past three decades, IPM has yet to be adopted by the enormous number of smallholder farmers to any significant extent in China. This Chapter describes the efforts undertaken to

Table 12.1 Production of major crops in China (in million tons). (Source: MOA (1990–2010), National Agricultural Statistics Year Books from 1990 to 2010. www.moa.gov.cn)

Year	Grains	Rice	Wheat	Corn	Soybean	Oilseed
1990	446.24	189.33	98.23	96.82		16.13
1995	466.62	185.23	102.21	111.99	17.88	22.50
2000	462.17	187.91	99.64	106.00	20.10	29.55
2005	484.02	180.59	97.45	139.37	21.58	30.77
2009	530.82	195.10	115.12	163.97	19.30	31.54
2010	546.48	195.76	115.18	177.25	18.97	32.30

apply the principles of integrated pest management (IPM) to achieve agricultural sustainability in China, with comments on the current issues and future challenges.

12.2 Part I: Historical Perspective

12.2.1 Crop Production

China, the country with the largest population in the world, had a rural population of about 670 million in 2011. Since "economic reform" started in 1978, China's agriculture has made dramatic progress. China has also become the largest producer of grain, cotton, oilseed crops, tea and fruits (Table 12.1) in the world. The per capita production for these crops and vegetables either matches or surpasses the world averages (Fan 2001; Yang et al. 2010). Consequently, farmers' lives also experienced obvious changes as their income increased considerably. In a span of 33 years, their per capita income went up from US$ 168 to US$ 955 from 1978 to 2011.

Most Chinese farmers are smallholders with an average farm size of less than 0.5 ha. Agricultural production is both labor and input intensive. In general, farmers use large amounts of chemical pesticides and fertilizers. In several crop systems, repeated failures in some local areas have been experienced, mainly due to poor pest management strategies and over-reliance on chemical pest control (Yang and Jiang 1995; Wang et al. 1999; Sonntag and Norse 2001; Xia 2008). Thus, finding improved agricultural practices, in particular sound pest management that will ensure sustainability, is of utmost concern to the agricultural sectors in China.

12.2.2 Pest Management

The early farming systems in China always used traditional techniques devised in accordance to the unique features of each particular area. Hence, the means were environmentally friendly. Cultivation practices, including pest management methods, tended to blend in well with the agro-ecosystem. In general, the pest management practices encouraged low material inputs, recycling, high labor inputs, and balancing the use of different techniques with traditional agronomic practices (Pan 1988; Guo 1998; Xia 2008; Xia 2010).

Under the traditional farming systems, pest outbreaks were usually related to changes in the natural environmental factors. For example, locust outbreaks were the result of dry weather in northern and eastern China (Wu 1951; Lei and Wen 2004; MOA 2010). Because traditional crop varieties planted possessed genetic diversity, epidemics of crop diseases rarely occurred.

However, the situation began to change three decades ago when the Green Revolution was launched in Asia. Due to this development, the small farm holders in China had better access to inputs and thus were able to improve their agricultural production dramatically, especially those with easy access to improved irrigation systems, high yielding crop varieties (rice, wheat, corn and oilseed crops), chemical fertilizers and pesticides. Hence, agricultural productivity increased substantially from 1970s to the middle of 1990s. However, helping the small farm holders establish a sustainable agricultural production system proved much more difficult than envisioned. This was because technologies developed in the Green Revolution were presented as “packages” to farmers in a direct and top-down manner (Röling and van de Fliert 1998; Pontius et al. 2002; Kamp and Yang 2000; Matteson et al. 1993). The initial success in technological transfer rendered the development of the top-down extension networks to progress rapidly.

Although the top-down extension approach succeeded in introducing small farmers to new inputs, many new problems soon emerged. Farmers adopting the technologies without the knowledge of how to use them appropriately soon led to the indiscriminate and excess use of both fertilizers and pesticides. This misuse resulted in widespread disruptions in agro-ecosystems. In the case of pesticides, it led to serious problems of pesticide residues, pest resurgence and pesticide resistance (Zhao 1983; Guo 1998; Xia 2010; Wang et al. 1999). Other problems included farmer poisonings, reduced farm income because of higher inputs and induced pest outbreaks, and contaminated agricultural produce.

Over the last three decades following the Green Revolution, there was seen an increasing consumption of pesticides. Many of the current problems associated with over-reliance on pesticides would not be averted unless this trend was reversed. The excessive and often unnecessary applications of pesticides clearly remained an important impediment to agricultural sustainability.

12.2.3 Consequences of Reliance on Chemical Control

12.2.3.1 Resurgence and Outbreaks of Crop Pests

In general, rice and cotton receives many more pesticide applications per season than most other crops in China. Cotton insect pests were the first to nationwide resistance to organophosphates and pyrethroids (Wang et al. 1999; Yang et al. 2010; Wang et al. 2001). The situation developed essentially into the “pesticide treadmill”, whereby more and more pesticides were used without effective control of the cotton pests and ultimately led to unprofitable cotton crops from 1991 to 1996 in some regions. Overuse of pesticides caused serious outbreaks of cotton bollworm from 1992 to 1994 in the Yellow River cotton zone and part of the Yangtze River cotton zone (Yang and Jiang 1995). Pest management costs increased 5–7 times, and yet the cotton yield decreased from 5 to 25 % in Hebei province in 1992 (Yang and Jiang 1995; Xia 2008).

Rice is the most important staple food crop in China with most production areas distributed in the sub-tropical and tropical regions. The main pests faced by rice farmers are rice stem borers (*Chilo suppressalis* (Walker)) and brown plant hoppers (BPH) (*Nilaparvata lugens* (stal)). For rice stem borers, farmers have been using the chemical dimehypo for the past ten years. Farmers fell into a dimehypo "pesticide treadmill" in the Yangtze rice zone. Spray applications increased from 1 to 4 times to 5–10 times per season, serious outbreaks of the stem borers occurred in the provinces of Zhejiang, Jiangsu, Hubei and Jiangxi in 2001 (Xia 2008; Fan 2001). BPH was a minor pest prior to the1970s before high yielding rice varieties were introduced; the introduction of these high-yielding varieties was accompanied by the heavy use of organophosphates for controlling rice pests. Thereafter, BPH infestations increased rapidly with major outbreaks occurring in central and southern China in 1992 to become a major pest of rice.

Rice pest outbreaks occurred during 2005 and 2010 in over 20 million hectare times[1] annually, with the highest recorded level of 32.7 million hectare times and 33.3 million hectare times in 2006 and 2007, respectively. Rice virus diseases rapidly spread along with the outbreaks of rice plant hoppers. Rice stripe virus (RSV) became the most severe disease in rice at early stages of seedling growth in the nurseries in the Yangtze, Jianghuai and Huanghuai river valleys. Rice dwarf virus (RDV) is spreading to the northern rice zones. The south rice black stripe dwarf virus (SRBSDV) outbreak in 2009 occurred in the main rice zones in China, the outbreak spread over 1.2 million hectares which caused a yield loss of 460,000 metric tons in 2010. The frequent outbreaks of rice pests made farmers more dependent on chemical pesticides for control of pests. The inappropriate management strategies and actions disrupted rice agro-ecosystems, that is, the ecological resilience of rice agro-ecosystems and their capacity for the natural control of rice pests has been weakened by the overuse of pesticides and the breakdown of rice host-plant resistance. Annually pesticide spraying for controlling rice pests has increased to 34 % of the total area planted, and even as high as 39–41 % during the outbreak years of rice pests from 2006 to 2008.

On wheat, repeated outbreaks of wheat stripe rust have occurred in western China in 2000, 2001 and 2002 which were of grave concern (Lei and Wen 2004; Wan et al. 2004; Wan et al. 2007).

Many of the above problems are associated with high consumption of pesticides. For example, pesticide use in the case of rice has tripled in terms of cost between 1980 and 2010 (at constant pricing) (Xia 2008; Fan et al. 2010). For vegetables, pesticide use has increased two times in terms of cost between 1998 and 2010.

12.2.3.2 Status of Pest Resistances

Pest resistance problems first emerged in the 1980s in China solely due to dependency on pesticides in some crops. To date, about 30 species of major insect pests

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[1] In Chinese system, all the occurring acreages of all the generations of insect pests in the whole season are expressed as hectare times because the occurrences of insect pests might have more than one generation in the season.

and mites, 20 species of plant pathogens and 7 kinds of weeds have developed resistance to pesticides (Xia 2008).

The first report of cotton bollworm (*Helicoverpa armigera* (hubner)) resistance to pyrethroids was in Xinxiang, Henan province, in 1986 (Guo 1998). Later, several insect pests such as cotton aphids (*Aphis gossypii* (Glover)), pink bollworm (*Pectinophora gossypiella* (Saunders)), red spider mite (*Tetranychus cinnabarinus* (Boisduval)), and Lygus bug (*Lygus lucorum* (Mey-Dur), were also reported to have developed resistance to over 10 kinds of pesticides used in cotton. In grain crops, rice stem borers, BPH, leaf rollers (*Cnaphalocrocis medinalis* (Guenee)), and other leaf feeders, wheat aphids (*Stiobion avenae* (Fabricius)) and corn borers (*Ostrinia furnacalis* (Guenee)) were found to be resistant to 8 kinds of pesticides. For fruit trees, citrus mites (*Panonychus citri* (Tetranychidae)), apple mites (*Panonychus ulmi* (Koch)) and hawthorn mites (*Tetranychus viennensis* (Zacher)) have developed resistance to 4 kinds of miticides. In the case of vegetables and melons, resistance was reported for diamond back moth (*Plutella xylostella* (Linnaeus)), aphids (*Brevicoryne brassicae* (Linnaeus)), and *Spodoptera* spp. (Xia 2008; Xia 2010).

In China, failures in pest control have been attributed to the development of pesticide resistance which subsequently resulted in crop losses. For example, it was estimated that bollworm resistance to pyrethroids and organophosphates has caused losses of over US$ 38 million in cotton, making cotton production in some regions unprofitable in the mid-1990s (Wang et al. 1999). In some areas of Jiangsu and Zhejiang provinces, resistance development of rice stem borers to dimehypo resulted in rice stem borer control failures and consequently to massive yield losses in 2001 and 2002 (Xia 2008). Frequently, pest resistance led farmers to unwittingly use more pesticides, therefore, leading to more agro-ecological disruptions and further pest outbreaks (Xia 2008).

12.2.3.3 Status of Pesticide Residues and their Impact on Trade

Pesticide residues have become a hot issue in food safety, especially in vegetables in China in recent years. Many concerns were actually raised by trade disputes after China's entry into the World Trade Organization (WTO). Importing countries of vegetables have instituted very strict regulations for pesticide residues. For example, new regulations in Japan require the tolerance of chorpyrifos in spinach to be less than 0.001 ppm, for cabbage and Chinese cabbage less than 1 ppm, and for tomato less than 0.1 ppm. Reducing pesticide residues in agricultural produce is currently a big challenge for Chinese farmers. The harsh competition in the international market requires the farmers to reduce the use of pesticides so as to ensure their agricultural produce will meet with acceptable export requirements.

12.2.4 Why Integrated Pest Management must be Adopted

To date, ample evidence exists from many cases for many crops, including rice, cotton, vegetables for both national and international programs in China that IPM can decrease pesticide use without lowering crop yields, improve farmers' income and health, and protect the environment. Clearly the need to adopt IPM is crucial for sound and sustainable agricultural production in China. The need is even more urgent now than ever before because of several current issues as follows:

1) Continuous decline in area under agricultural production caused production constraints. The resulting pressure to further intensify cultivation to make up for reduced area of production would lead to more intensive use of inputs, in particular fertilizers and pesticides, hence increasing the likelihood of more farmers becoming trapped in the "pesticide treadmill".

2) Decline in comparative prices of agricultural products makes it important to increase efficiency in agricultural production to maintain farm income by reducing the costs of production.

3) Pesticide residues in foods are posing an increasing threat to competitiveness in domestic markets and the expansion of exports.

4) Relevant agencies need to implement market policy to promote farmers as decision-makers in agricultural production and build their capacity to practice IPM for sustainable agricultural production.

5) Overcome the adverse influence from pesticide industrial sectors on government departments which deal with regulations, production and sales of pesticides.

6) Urgent need by government agencies to reorient current pesticide policies so as to comply with IPM strategies.

12.3 Part II: Experiences with Integrated Pest Management in China

12.3.1 Initiation Stage (Late 1970s to Mid-1980s)

The former Ministry of Agriculture and Forestry put forward the concept of Integrated Pest Control (IPC) in 1976, now referred to IPM, as a national long-term guiding principle of plant protection. The strategy for the implementation of IPM then was elucidated as "Executing IPC with Emphasis on Prevention". In the late 1970s, crop IPM programs were launched in China. Until the mid-1980s, IPM programs placed priorities on fundamental research to understand crop ecosystems, major pests and their natural enemies (Guo 1998). Laboratory and field studies were carried out on the basic biology and ecology of major pests and natural enemies. IPC methods in targeting single pests were developed and demonstrated in project zones with different ecological features. Economic threshold levels (ETLs) for major pests were used for decision-making in pest control. The conservation and utilization of natural enemies were promoted in an inter-cropping system of wheat with cotton. Implementation of IPM strictly followed a top-down extension approach at this stage.

12.3.2 Second Stage (Mid-1980s to Mid-1990s)

The control tactics of IPM were package based on the diverse ecosystems in different ecological zones of China (Guo 1998). As time went on, ETLs were revised, taking into account plant compensation capacities, availability of *Bacillius thuringiensis* (Bt) and nuclear polyhedrosis virus (NPV) formulations as they were developed and introduced for pest control. Gradually, the traditional top-down extension approach of implementation of IPM strategies brokedown because when the decision-making on agricultural practices was transferred to the millions of individual farmers as the land tenure system changed from the former cooperative farm system to the contemporary individual farmer household responsibility system, the top-down extension system could hardly meet the needs of the huge numbers of smallholder farms in the market economy[2].

From 1993 to 1995, the Ministry of Agriculture executed a nationally packaged IPM program, mainly to address the outbreaks of cotton bollworm (Yang and Jiang 1995; Xia 2008). This program applied a wide-area population management strategy. The IPM package consisted of conservation of natural enemies in the early season, plowing and irrigation immediately before winter to kill overwintering bollworm pupae to reduce the bollworm population in the subsequent season, planting trap crops, using light traps, and spraying highly toxic pesticides to keep the bollworm population in check (Yang and Jiang 1995). Implementation of this package was considered crucial to sustain cotton production in China.

12.3.3 Third Stage (Mid-1990s to Present)

During this stage, the agricultural policy changed again having great bearing on the national IPM programs. Highly toxic pesticides such as chlordimeform were banned on cotton, while restrictions were placed on monocrotophos, parathion, methamodophos. Increased investment in research and commercial production of biological control agents promoted widespread applications of Bt and NPV formulations for pest control. In 1994, transgenic Bt cotton was introduced and its use has expanded rapidly following its approval for cultivation in 1997 (Piao et al. 2001).

Besides the traditional top-down extension approach, other approaches were emerging and being tested. Support from international organizations helped to strengthen existing national IPM programs. In 1988, China joined the Food and Agriculture Organization (FAO) Inter-Country IPM Program for Rice that first introduced farmer-led IPM in rice through Training of Trainers program (TOTs) and Farmer Field Schools (FFSs). From 1994 to 1995, the World Bank Cotton IPM Program funded research on cotton IPM technologies and training methods. The Asian Development Bank/Commonwealth Agricultural Bureau (ADB/CABI) from 1993 to 1996 supported the benchmark survey of on-farm research and training of

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[2] This expression is commonly used in China, to contrast the economy before the economic reform in China.

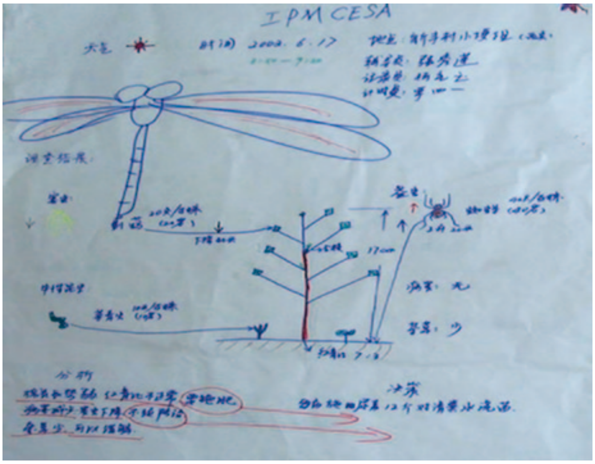

Fig. 12.1 Farmers' drawing summarizing the data they collected from fields and analyzing different elements including pests, neutral insects, and natural enemies, etc. in the cotton agro-ecosystem and using the picture as the decision making tool of pest management in the FFS in Dongzhi county, Anhui province, China in 2001. (Photo taken by Puyun Yang in 2001)

farmers in cotton IPM. Since 2000, the European Union (EU)/FAO initiated the farmer-led IPM program for cotton and supported Training of Trainers (TOTs) and the establishment of Farmer Field Schools (FFSs) for the training of cotton farmers. This is beyond the FAO Inter-Country IPM Program for Rice which China joined in 1988.

12.3.4 Different Extension Approaches in IPM

As the extension approach changes over time through the various IPM programs, much has been learnt in terms of IPM implementation. Moving from a top-down approach to a farmer-led approach has generated much interest, opportunities, and challenges (Ooi 1996, 1998; van den Berg 2001) (Figs. 12.1 and 12.2). Farmer-led IPM is yet to be implemented fully in most agricultural regions in China.

The Chinese extension network has its headquarters in the National Agro-Technical Extension and Service Center (NATESC) under the Ministry of Agriculture. The Chinese extension network provides the provincial, county and township plant protection stations with necessary technical guidance, demonstrations, and pest monitoring and forecasting technologies, which includes organizing urgent pest control activities (Xia 2010). The extension network was originally built with a top-down approach, with technology transfer dependent on a well-organized governmental support system. Farmers were expected to follow the guidance and recommendations from the extension stations.

Before the FAO-FFS programs, NATESC and several research institutes used to organize and implement national IPM programs in a top-down approach. IPM technologies were usually developed by research institutes, supported by the pest monitoring and forecasting network. Extension specialists would scout the fields

Fig. 12.2 Farmers surveying the rice field to collect data including pests, neutral insects, and natural enemies, etc. in the sampled plants in rice FFS in Yunnan Province in 2010. (Photo taken by Puyun Yang in 2010)

and predict the trends of pest infestation, then advise on control measures based on economic threshold levels (ETLs). Control recommendations were communicated directly through face-to-face meetings or news broadcasts or disseminated through newsletters. For the transfer of new IPM technologies, field demonstrations and classroom lecture training were conducted.

After the progress of the "economic reforms" in the early 1980s, the centralized top-down extension approach faced great difficulties because farmers got ownership of land as small landholders. The small landholders would divide their fields into smaller parts and sub-contract to other farmers. Under such a situation, individual farmers usually made their own decisions, such as types of crops to be grown and other related farming practices. The farming agro-ecosystems changed and become more diversified in terms of the range of crops cultivated, cultivation practices and cropping patterns. The decision making in pest management has thus become more complex since pest levels varied dramatically on a micro-geographic scale. Pest populations could easily build up in widely diverse fields and at varying times. To minimize risks, a natural reaction of the majority of farmers was to rely on calendar based and preventive pesticide applications.

The problems faced by the top-down extension approach to promote IPM to farmers after the "economic reforms" were unprecedented. These were:

1) The top-down approach was not adapted to the situations of an enormous numbers of smallholder farms in a free-market system.
2) Research achievements were unable to reach the huge numbers of farmers because there were no large-scale field training programs while research, extension and educational sectors were independent of one another.
3) Presence of an extensive and aggressive pesticide industry imposing their agenda strongly on policy-makers, researchers and extension workers. The pesticide industry adopted an aggressive pesticide marketing and sales strategy to lure farmers.
4) De-regulation of the market policy in fact allowed the extension services to sell agricultural inputs (including pesticides) directly, in order to enable the extension

service centers to become self-sufficient in income. So, the sales of pesticides generated a conflict of interest between the aim of reducing pesticide application in IPM and the intention to increase income of the extension agency.

To resolve the problems of the top-down approach, a shift has been made towards the farmer-led approach through FFS developed and promoted by the FAO. The farmer-led approach empowers farmers through a participatory and non-formal education process (Roling and Fliert 1998; Pontius et al. 2002; Matteson et al. 1993). Such an approach has been found to be highly effective in a large number of national programs in many Asian countries (Ooi 1996, 1998; Pontius et al. 2002).

In China, one of the biggest challenges is engaging current agriculture extension agents to the new extension approach which is at odds with their past experiences and practices of information dissemination and technology transfer developed over a long period by a top-down extension system. This top-down approach has a long history in both agriculture and culture in China where extension has been carried out by technicians or specialists, whose roles were clearly defined, understood and accepted, as providers of knowledge to the farmers who were lacking it (Xia 2010).

12.3.5 International IPM Programs

Like other Asia countries, the FFS-based national IPM programs in China were first developed in rice because of the implementation of FAO rice IPM program in 1988. So far, more than 20 training of trainers courses and 30,000 FFSs have trained over 3,000 facilitators and 100,000 farmers in rice in many provinces, for instance, Sichuan, Hubei, Hunan, Henan, Anhui (Fig. 12.1), Zhejiang, and Guangdong. Through joint efforts by the FAO and national counterparts, the IPM-FFS approach was gradually implemented nationwide for the major crops. From 2000 to 2005, China was involved in the EU/FAO regional cotton IPM program which supports FFS training in five major cotton growing provinces. The FAO-supported vegetable IPM-FFS program was launched in Yunnan Province in 2003 and Guangxi Province in 2007 and concentrated its efforts initially on capacity building for IPM FFS training for three vegetable crops (tomato, Chinese cabbage and sugar pea) in eight major vegetable growing prefectures in Yunnan Province. Other vegetable crops covered in the IPM-FFS included lettuce, broccoli, capsicum, pumpkin, squash, cauliflower, garlic, cucumber, potato, watermelon and cherry tomato, etc. In Guangxi province, the IPM-FFS training program is now operational in 33 counties in rice (Fig. 12.2), potato, corn, vegetables and fruit trees, etc.

The FAO IPM programs provided technical assistance for government-supported vegetable IPM training activities in other provinces/municipalities (Sichuan, Shandong, Beijing, Chongqing, Hebei and Shanghai, Guizhou, Jiangxi). Assistance was also provided to other donor-funded projects such as:

- the World Bank-funded Anning Valley Project in Panzhihua and Liangshan in Sichuan province;
- the GTZ-funded “Environmental Strategies of Intensive Agriculture in the North of China” Project;

- the CIDA-funded “Agriculture and Agri-food” Project in Western China, the FAO TCP “Enhancing food security and improving livelihoods in concert with environmental protection for farmers and herders in poverty-stricken ethnic minority areas of Western Sichuan Province”;
- the FAO Technical Cooperative Project (TCP) “Applied research on integrated pest management technology of *Actinidia* root-rot in Leye county, Guangxi”;
- EU/FAO/China “Model development and capacity building for agro-biodiversity innovation and system management in Sichuan, Yunnan and Xinjiang”; and
- International Fund for Agricultural Development (IFAD) program “Yunnan Agricultural and Rural Development”.

Along with the success of the international funded IPM-FFS programs, more and more stakeholders have adopted the FFS approach. In addition to international projects, the local governments are now actively supporting local FFS programs with their own funds. In China, local governments in Yunnan, Guangxi, Beijing and Chongqing provinces/municipalities have made active commitments to IPM-FFS. Other relevant projects, including the Chinese Ministry of Agriculture (MOA)-Global Environmental Facility (GEF) project, also provide funding for FFS in Shanxi, Shandong and Hubei provinces.

Recently, the Ministry of Agriculture launched a new initiative aimed at promoting the FFS model at the policy level to institutionalize and up-scale the FFS-based Agricultural Science and Technology System Reform Stations in 800 agro-extension demonstration counties in China. Funded by the central government, each county will reform and restructure its new agro-extension system, in which a local county FFS program will be included.

12.3.6 National IPM Programs

Current national IPM programs put priorities on developing and implementing IPM measures which include physical, biological and ecological control technologies. A few examples of national IPM programs are discussed here.

12.3.6.1 Locust IPM Management

The oriental migratory locust, *Locusta migratoria manilensis* (Meyen), has been listed as one of serious pests in ancient China since 707 BC (Wu 1951). Its outbreaks caused great crop losses in ancient Chinese history in terms of food security and societal stability (Wu 1951; Zhu 1999). Nowadays, in order to reduce potential damages due to locusts and avoid chemical residue problems, the national IPM programs prioritized the exploration and implementation of IPM technologies based on ecological control. For example, in 2010, cotton, alfalfa and winter dates were planted in the habitats of the oriental migratory locust in Hebei Province, vegetation manipulations were successfully implemented on about 8,000 hectares (ha) (Lei

Fig. 12.3 Flowering plant sesame was grown at rice bunds for providing a nursery and refuge for natural enemies in the rice eco-engineering system in the rice IPM project in Jinhua county, Zhejiang province in 2011. (Photo taken by Zhao Zhonghua in 2011)

and Wen 2004; Zhang et al. 2006; Peng and Pang 2004; Zhang et al. 2009; Li 2010; Yang et al. 2010). In the most recent decade, the area covered by the vegetation manipulations of locust habitats was about 12,000 ha each year, which significantly reduces the occurrence of locusts. In addition, about 129.8 tons of bio-pesticides were used, substituting for chemical pesticides (Chiu 1989; Zhu 1999; Zhang et al. 2006; Cheng et al. 2007). The national locust IPM program has increased the ecological and biocontrol portions of locust control from 20 to 38 % from 2001 to 2011.

12.3.6.2 Rice IPM Program

The Ministry of Agriculture launched the national rice IPM program in 2006 which mandates that plant protection agencies must provide public services and ensure rice production security. The National Agro-technical Extension and Service Center (NATESC), in cooperation with different levels of plant protection departments, coordinated and organized a series of activities on technical developments, field trials, demonstrations and farmer training in rice IPM techniques with significant achievements (Han et al. 2009; Xia 2010). Eco-engineering is one of the most active research and extension programs in recent years. Rice eco-engineering is achieved through the artificial design of ecosystems based on landscape ecology to protect habitats and food sources of natural enemies and to manipulate and enhance biodiversity (Figs. 12.3 and 12.4). Thus ecosystem services are improved to ecologically control rice pests and reduce irrational use of pesticides so rice plant hoppers could be kept under the level of economic thresholds to ensure sustainable rice production. The eco-engineering techniques employed in this national rice IPM program include the use of resistant varieties, adjusting cropping dates, extending the rice-duck system of raising ducks in rice fields, planting flowering plants on bunds, the application of light traps and insect sex pheromone traps, etc.

Fig. 12.4 Yellow boards were placed in the rice field to monitor the immigration of parasites of rice pests from flowering plant sesame at bunds in the rice eco-engineering system in the rice IPM project in Jinhua county, Zhejiang province in 2011. (Photo taken by Zhao Zhonghua in 2011)

(Schnepf et al. 1998; Qi et al. 2005; Wei et al. 2008; Xia 2010). The rice ecosystem services were improved by the adoption of eco-engineering techniques. For example, the populations of egg parasites and predatory spiders of the rice pests were doubled in the eco-engineering demonstration fields compared to those of farmer's practice fields and the populations of dragonflies (*Aeshnoidea* spp.*, Cordulegastroidae* spp.*, Libelluloidea* spp.) and frogs were increased 5–10 times. Normally, in the eco-engineering demonstration fields there is no need to spray pesticides to control rice plant hoppers, with no impacts on rice yields.

12.3.6.3 Tea IPM Program

Tea, *Camellia sinensis* (L.) O. Kuntze, is an important cash crop in China. The crop is planted on 32 million hectares and production reached 1.6 million tons in China in 2010. Annual pest damage resulted in about a 25 % yield loss. Another important issue is the consumers' concerns with pesticide residues in tea which is the greatest threat to tea production and international trade. Emphasis was put on substituting chemical pesticides in the Chinese national tea IPM program. Mechanical, physical, biological and ecological control tactics are considered as safe strategies. In tea fields, black-light traps, the Pest-O-Flash traps that emit near-UV light of 350-nm wave length or the insect killer lamp are used for capturing adult lepidopterans (Han and Chen 2002; Qi et al. 2005; Wei et al. 2008; Jiang et al. 2010). Colored sticky boards are used as an effective method to control tea pests such as *Empoasca flavescens*, and Spiny Black Whitefly (*Aleurocanthus spiniferus* Quaintance) (Liu et al. 2010).

In the tea IPM program, the biodiversity of the tea plantation was enhanced by intercropping. The tea varieties were intercropped with another appropriate crop that can inhibit whitefly populations. Trimming and plucking can also change this pest's habitation and reduce the tea pest damage.

12.3.6.4 Vegetables IPM Program

The photo-taxis techniques have been widely implemented in national vegetable IPM programs. Different vegetable crop pests are attracted to different colors. *Phyllotreta striolata* preferred yellow and white, and *Myzus persicae* and *Liriomyza sativae* are attracted to yellow, while *P. xylostella* is attracted to green (Chen et al. 1995; Fu et al. 2005; Zhou et al. 2003; Zeng et al. 2008). Insect sex pheromones were also used in controlling diamond back moth (DBM) (Zhong et al. 2005; Zhong 2008). The alcohol extracts from *Amaranthus retroflexus* L. *Rubia tinctorum*, *Calystegia hederacea* Wall, *Scirpus wallichii* Nees, and *Stepkania longa* Lour have been used as repellents to *P. xylostella*. The non-alkaloid extracts from *Tripterygium wilfordii* have a strong anti-feedant and growth inhibition effect on DBM (Xu et al. 2006). Ecological measures based on cultivation control and biological control played an effective role in suppressing DBM.

12.4 Part III: Impact Assessment of Integrated Pest Management in China

12.4.1 Impact Assessment Programs

The cotton IPM impact assessment (evaluation) was launched in May 2001 for evaluating the China/EU/FAO cotton IPM program. This is the first systematic effort to measure changes, intended or unintended, brought about by IPM programs in China. Coverage of IPM programs in Chinese agriculture is less than 10%. The identified cotton IPM impact indicators are: cotton outputs (yields), pesticide application, pest management knowledge and skills, and other overall impacts of the project activities at the farmers' level. The cotton IPM impact assessment was done in the three pilot locations: namely, Yingcheng City of Hubei province; Dongzhi county of Anhui province; and Lingxian county of Shandong province. Farm-household surveys, TOF/FFS log analysis for investigating and analyzing training activities in detail, and case studies were conducted. Secondary data collection and analysis from the published and unpublished statistics were conducted for this IPM impact assessment.

Under the framework of FAO vegetable IPM program in Yunnan province, a comprehensive impact assessment of the vegetable FFS was carried out from 2003 to 2007 to measure whatever changes were brought about by vegetable IPM-FFS trainings and profile those changes to identify needs and opportunities for upgrading IPM farmer training, and develop new directions for future IPM programs. As one of the crucial components of the impact assessment, this study aimed at investigating the impacts of the vegetable IPM-FFS on reducing pesticide risks in vegetable production, and to find feasible approaches for effectively reducing pesticide risks in vegetable production in smallholder farming systems.

12.4.2 Economic Impacts

Under the FAO community IPM program in rice, an impact study was undertaken in six participating provinces where 1,181 trained farmers were compared with 395 untrained farmers in 1999, IPM farmers achieved an average yield of 6,600 kg/ha before training and 7,335 kg/ha after training, while non-IPM farmers obtained an average of 6,855 kg/ha. Net profit was also higher for FFS-trained farmers, at US$ 502.5 per ha while the net profit of untrained farmers was only US$ 393.6 per ha. Another study undertaken in 1998 also showed a similar trend. Under the cotton program, the same trend was also obtained. Data collected by both TOT participants and facilitators showed that the IPM treatment is consistently more efficient in terms of economic returns than the Farmer's Practice (FP) treatment. Findings by 30 TOT participants in Lingxian County, Shandong Province in 2000 indicated that pesticide sprayings in IPM plots were 7 times less than that in FP plots, resulting in cost savings of US$ 58.31/ha and increase in net income of US$ 115.62/ha. For 2001, the savings and increase in net income were respectively, US$ 23.04/ha and US$ 379.97/ha. Likewise, data obtained by 33 TOT participants in 2000 in Yingcheng County (Hubei Province) and by 30 TOT participants in 2001 in Dongzhi County (Anhui Province) showed a similar trend.

In addition to the above, many other data sets obtained by facilitators in numerous FFS have also confirmed the benefits of IPM. In 2000, for instance, FFS farmers in Sanba village (Yingcheng County) had reduced the number of pesticide applications by an average of 34.9% when compared with untrained and non-FFS farmers. The cotton yields and net income increased by 8.2% and US$ 36.5/ha, respectively. Likewise, farmers of 6 FFSs in Wenshang County, Shandong Province, decreased spraying by an average of 4.2 sprays/season and reduced the amount of pesticide used by 38%. Net income increased by 5.1% when compared with non-FFS farmers. For Lingxian county, farmers of 6 FFSs reduced the amount of pesticides by 57.9% with an increased net income of US$ 90.3/ha (or 3.1%) as compared to non-FFS farmers.

12.4.3 Environmental Impacts

In terms of ecological stability, there was a clear increase in biodiversity, in particular a greater diversity and larger populations of beneficial natural enemy species that prey on crop pests. Natural enemy species increased in number and diversity because of significant reduction in the use of pesticides in IPM plots that resulted in less negative impacts on them. For instance, in 12 FFS in Yuekou Township (Tianmen County, Hubei province) in 2001, the total predator population in IPM plots had increased by 98% when compared to that of the FP plots. Among these, lady-bird beetles (*Coccinella septempunctata*) accounted for most of this increase, followed by lacewing (Chrysopidae), then others. Likewise, data of 6 FFS in Yangzhuang village (Lingxian County) in 2000 showed that the overall predator population in IPM

Fig. 12.5 The chain stores for marketing IPM apples in Luochuan county, Shaanxi province. IPM apples were produced by the FFS farmers and were free of pesticide residues. (Photo taken by Shan Xunan in 2012)

plots increased by 53.37 %. Comparatively, lady-bird beetles, spiders and lacewing increased by 52.27, 63.75 and 42.84 %, respectively.

12.4.4 Social Impacts

The educational investment through IPM-FFS can be expected to produce outcomes that go beyond IPM, which include farmers' contributions to the social development of their communities. Ample evidence demonstrates the impact of IPM-FFS on social developments in the farmers' communities, which would normally not be expected from the traditional training approach. A complete picture of the impact the IPM-FFS based only on a small sample of farmers represented in the previous IPM impact studies is difficult. The important community impacts of IPM-FFS graduates from available evidence include:

1. FFS graduates conducted field studies after their FFS training, farmer experimentations were organized or conducted by the FFS graduates and recorded from most counties involved in IPM-FFS implementation.
2. Development of IPM communities: The FFSs resulted in the establishment of a critical mass of IPM alumni in farmer communities. In most cases, FFS alumni organized IPM associations and have been conducting several types of activities, for example, FFS alumni might organize farmer clubs to conduct field researches.
3. Certification of IPM products: Up to the end of 2011, IPM farmers' associations have been established in about 200 villages in the project areas in China. IPM associations in these villages are certifying and labeling agro-products produced by FFS alumni (Fig. 12.5). FFS alumni were responsible for the season-long field inspections. If farmers cultivated the agro-products in compliance with the producing standards of safe products, they can submit requests to their IPM

association for approval to label their products as having been produced employing IPM practices.

4. Connecting to markets: The development of IPM farmer associations in these villages has attracted attention from agricultural marketing companies. Some of the certificated IPM products have entered into supermarkets, and several vegetable companies have signed purchasing contracts with IPM associations in recent years. Farmers reduced marketing risks by joining contract farming schemes with the vegetable marketing companies.

To establish vegetable IPM communities, local governmental support is necessary which is especially crucial at the initial stages. In particular, local policy makers need to appreciate how IPM and FFS can contribute to local community development and social cohesion. Understanding this would enable them to consider generating local funding for farmer education, to build technical infrastructure and to develop policy support for IPM. Local government support could promote better acceptance of IPM at the community level to make farmer-centered IPM programs more sustainable and more widespread.

12.4.5 Policy Impacts

Both directly and indirectly, the IPM programs have significant impacts on national plant protection policies, in particular towards reduction in pesticide use or giving priority to less toxic products (Waibel 1998). Of particular significance is the influence of IPM programs on the government to provide increased support to IPM development through national funding. The impacts of the program have also encouraged other commodity programs to re-orient their IPM development towards the FFS approach. Given below are some specific examples:

In 2000: Chinese government stopped registration of highly toxic pesticides—methamidophos, monocrotophos, parathion-methyl and phosphamidon. (Decree of the Ministry of Agriculture 2000).

In 2000: A decree directed China to stop production and marketing of methamidophos, monocrotophos, parathion-methyl and phosphamidon by 2007. (Decree of the Ministry of Domestic Commercial and Trade 2000).

In 2002: The registrations of phorate, omethoate, isocarbophos, terbufos, phosfolan-methyl, sufotep, isofenphos, demeton, aldicarb, carbofuran and methomyl were withdrawn.

In 2002: Banned the use of omethoate on vegetables, aldicarb and isofenphos on fruit trees, carbofuran and phorate on citrus, and tubefus on sugarcane. (Decree No. 194 of the Ministry of Agriculture 2002)

In 2002: Banned the use of the following pesticides on all crops—HCH, DDT, camechloe, chlordimeform, EDB, nitrofen, aldrin, dieldrin, mercury compounds, arsena and acetate. (Decree No. 199 of the Ministry of Agriculture 2002).

In 2002: Banned the use of the following pesticides on vegetables, fruit trees, tea and herbs: methamidophos, parathion-methyl, parathion, monocrotophos, phosphamidon, etc. (total of 19 kinds of pesticides) (Decree No. 199 of the Ministry of Agriculture 2002).

In 2002: Banned the use of dicofol and fenvalerate on tea trees (Decree No. 199 of the Ministry of Agriculture 2002).

12.4.6 Impacts on Pesticide Use

The FAO rice IPM program showed that farmers have learned from the IPM-FFS training. On average, FFS farmers applied 5.17 and 3.18 pesticide applications per rice season, respectively, before and after training. Untrained farmers, continued to apply more pesticide, averaging 5.1 applications per rice season. In terms of the amount of active ingredient applied, FFS farmers used an average of 4.290 kg and 2.430 kg per ha before and after training per rice season. The untrained farmers averaged 4.550 kg per ha.

The results from the FAO vegetable IPM impact assessment program showed that the FFS farmers significantly reduced their applications of pesticides after participating in the IPM-FFS. However, the reductions evident from the pesticide use patterns were crop specific. Overall, all the FFS farmers eliminated the use of highly toxic pesticides (WHO Ia + Ib: WHO recommended classification of pesticides by hazard. http://www.who.int/ipcs/publications/pesticides_hazard/en/) in all the three surveyed vegetable crops: sugar pea, Chinese cabbage and broccoli. Both for sugar pea and broccoli, control farmers eliminated the use of highly toxic pesticides. Declining trends in terms of reduced use of highly toxic pesticides among the control farmers might be due to policy reform changes, banning of pesticides and the elimination from the market of highly toxic products.

12.4.7 IPM with Transgenic Crops

Bt cotton (cotton varieties with *Bacillius thuringiensis* endotoxin gene) is the only genetically modified crop in China cultivated nationwide. Bt cotton was initially introduced into China in 1994, and its acreage has been increasing dramatically since 1997. Bt cotton was highly resistant to cotton boll worm (*Helicoverpa armigera*) at several growth stages (James 1999; Shoemaker et al. 2001). The existing high pressures of cotton bollworm infestation drove Chinese farmers to accept and extend the cultivation of Bt cotton voluntarily at an unimaginable speed in their cotton production systems. Many research programs and field experiments were carried out in recent years to elucidate the role of Bt cotton in the cotton integrated pest management system. However, the information promoting Bt cotton to farmers concentrated on short-term economic returns and not on long-term impacts. The long-term impacts, desirable or undesirable, on cotton production are unknown. Farmers adopted Bt cotton without a deep understanding how this adoption would impact other pests or other cultivation issues. This lack of understanding extended to researchers as well as extension agents. To date, a number of secondary pests have emerged in Bt cotton such as Lygus bugs (*Trialeurodes vaporariorum* (Westwood)).

There is still an urgent necessity to launch a thorough research program on the assessment of appropriateness of Bt cotton in the cotton production system in China. At least four priorities are needed to be studied, namely: helping farmers to thoroughly understand both short and long term effects of Bt cotton on their cotton ecosystem and properly handle the cultivation of Bt cotton; monitoring the evolution of resistance to Bt cotton by target pests; assessing the impacts of Bt cotton on biodiversity and non-target organisms; and addressing the need for policy makers for the information on both biological and social impacts of Bt cotton.

12.5 Part IV: Challenges to Achieving IPM's Potentials

12.5.1 Maintaining Support and Enthusiasm Among Stakeholders

Among others, currently the main stakeholders of IPM are largely the farmers and the extension staff at all administrative levels, such as provincial, municipal and prefectural. Maintaining their support and enthusiasm for IPM is crucial for IPM program sustainability. This may be achieved through a number of activities that include at least the following:

- visits among national and provincial staff to update and share IPM information and experiences involved in the implementation of IPM;
- field days for major activities to highlight the achievements of IPM farmers
- Regular follow-up by extension staffs to encourage farmer activities that will further strengthen the IPM knowledge of farmers;
- formation of farmer IPM clubs/associations where beneficial community activities can be undertaken, especially the generation of new IPM technologies; and
- widen the current IPM-FFS curriculum and activities beyond the current confines of pest management to include other information that could improve the livelihood and well-being of farmers, e.g., health improvement.

12.5.2 Reaching Huge Numbers of Farmers

China has a large number of small farm households. Reaching 14 million cotton growers, 120 million rice farmers and over 150 million vegetable growers is a challenging task. Community IPM in rice, already implemented for 25 years in China, has only reached 0.07 % of the total rice farmers who have the opportunity for FFS training. Therefore, more farmers in China have to be reached.

For a start, the extension agents would play a key role. But the total numbers of plant protection specialists who could be trained to undertake this task is estimated in 2011 to be only about 20,000. Such limited numbers are clearly insufficient to address the FFS needs of all farm households, not considering the fact that a portion of these plant protection specialists will either soon retire or possibly be transferred to other activities. Moreover, those who potentially could be trained as facilitators are usually also overloaded with many other extension functions. It is obvious that relying on facilitators alone will not suffice. Initiating community IPM activities seems a plausible alternative presently. Once a community IPM program is established, IPM alumni could take over the roles of facilitators, including becoming leaders of the local IPM program. Farmer-to-farmer training is perhaps the realistic way to scale up the IPM FFSs. This could shorten the time frame necessary to reach the huge numbers of farmers in China.

12.5.3 Policy Re-orientation to Support IPM

An important objective of IPM activities is to institutionalize IPM in farmers' communities. To achieve this, strong local governmental support is necessary. Thus, local governments must themselves be fully aware of the benefits of IPM, especially at the initial stages of adoption. In particular, they need to appreciate how IPM can contribute to local community development and social cohesion. Understanding this would enable them to consider generating local funding for FFSs and to develop policy support for IPM. This has begun to take place in China where local government funded FFSs have been initiated since 2001. More importantly, over the long term, local government support could promote better acceptance of IPM at the community level to make farmer-centered IPM programs more sustainable; strengthening extension staff capability and knowledge in IPM is crucial as well. At the higher levels of government, instituting a policy conducive to IPM would be necessary.

12.5.4 Building Sustainable National IPM Programs

The potentials of IPM are now well recognized. That IPM is currently the best option for overcoming many of the problems of pesticide overuse cannot be denied. However, expanding IPM programs to the large number of farmers in China without losing effectiveness yet ensuring the sustainability of post-IPM activities poses many challenges. Building sustainable national IPM programs is necessary.

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Part III
Africa

Chapter 13
Push–Pull: A Novel IPM Strategy for the Green Revolution in Africa

Zeyaur R. Khan, Charles A. O. Midega, Jimmy O. Pittchar and John A. Pickett

Contents

Abstract Africa faces serious challenges in feeding its population, mainly due to poor yields of cereals that serve as both staple and cash crops occasioned by insect pests, weeds, and poor soil fertility, and more recently effects of climate change. A novel IPM approach dubbed "push–pull" has been developed and implemented in eastern Africa, based on locally available companion plants, that effectively addresses these constraints resulting in substantial grain yield increases. The technology involves intercropping cereal crops with stemborer moth repellent crops

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(push), the forage legume desmodium or molasses grass, and planting the attractive Napier grass (pull) as a border crop. Desmodium is very effective in suppressing striga weed while improving soil fertility through nitrogen fixation and improved organic matter content. The companion plants provide high-value animal fodder, facilitating milk production and diversifying farmers' income sources. The technology, currently practiced by over 55,000 farmers in East Africa, has been adapted to dry conditions associated with climate change by identifying and incorporating drought-tolerant companion plants. The development of this technology, its benefits and subsequent efforts to expand its geographical suitability and effectiveness are described.

Keywords Food insecurity · Cereals · Push–pull · Semiochemicals · Stemborer · Striga

13.1 Introduction

Food insecurity and poverty are serious challenges in Africa resulting from poor crop yields, and complicated by high human population growth rates, environmental degradation, and climate change. Agriculture forms the backbone of the economy of most African countries. Indeed approximately 80 % of the human population in sub-Saharan Africa (SSA) alone depends on agriculture for food, income, and employment. Increasing agricultural productivity therefore represents a significant opportunity for addressing food insecurity and poverty while allowing economic growth in the continent where human population tragically grows faster than the rate of agricultural production. Efficient production of staple cereal crops (including maize *Zea mays* L., and Sorghum *Sorghum bicolor* (L.) Moench) for millions of resource-constrained farmers on the continent, is central to this challenge. Unfortunately, grain yields of these cereals in Africa are the lowest in the world at around 1 ton(t)/ha (Jagtap and Abamu 2003) compared with 2.4 t/ha in South Asia, 3.2 t/ha in Latin America, and 4.5 t/ha in East Asia and Pacific (World Bank 2008). Agricultural growth in Africa is achievable by reducing major constraints to productivity that are mainly related to water stress, degraded soils, pests, diseases, and weeds. These constraints, already cause high levels of food insecurity, malnutrition, and poverty and are expected to increase as a result of climate change.

Insect pests are a major constraint to efficient production of cereals in Africa, with lepidopteran stemborers, such as the indigenous *Busseola fusca* (Fuller), and the invasive *Chilo partellus* (Swinhoe), being the most important in most parts of the continent. Attack by the stemborer pests results in yield losses ranging from 10 to 80 % of the potential yield, depending on the pest population density and the phenological stage of the crop at infestation, among other factors. There is therefore a continued quest and significant interest among farmers to find better approaches for solving these pest problems.

Stemborers are difficult to control, largely because of the cryptic and nocturnal habits of the adult moths and the protection provided to immature stages by the stem of the host crop (Ampofo et al. 1986; Kfir et al. 2002). Chemical pesticides are the main method of stemborer control recommended to farmers by the governments' ministries of agriculture. However, these are not only environmentally unfriendly and unsustainable, but also uneconomical and impractical for most resource-poor farmers (Kfir et al. 2002), and a direct threat to beneficial arthropods. They are therefore not widely used by the majority of small-scale farmers in Africa (van den Berg and Nur 1998). Additionally, there is also near-absence of extension service providers to inform the farmers of the right pesticides and dosages to use, and absence of application equipment (Midega et al. 2012). Use of synthetic sex pheromones has also been attempted to monitor stemborer moth population levels. The number of male moths captured by pheromone-baited traps provides useful information on timing of insecticide application and is often employed by large-scale and commercial cereal farmers. These traps also provide information on the seasonal and annual flight patterns of the moths and can guide planning of application of pesticides. They can also be used to disrupt communication between male and female moths thereby disrupting mating. Indeed, some reduction in damage levels caused by *B. fusca* was observed in Kenya resulting from mating disruption between moths (Critchley et al. 1997). In addition to these, cultural and biological control methods have also been attempted, with variable results. Cultural control methods are often considered the first line of defense against pests, and include techniques such as intercropping, crop rotation, manipulation of sowing dates, and destroying of crop residues. Although most of these techniques are affordable, they are labor intensive. Indeed, effectiveness of some of these cultural methods is questionable (van den Berg et al. 1998), with the majority of smallholder farmers not attempting stemborer control, with devastating consequences (Chitere and Omolo 1993).

Although efficient integrated pest management (IPM) has long been proposed as a sustainable crop protection approach, the concept requires new interventions devised through a thorough knowledge of biological interactions and information on the crop and on the surrounding environment. Some of the key components of IPM should include integrating cropping practices and genetic resistance to pests, and preservation and/or enhancement of the effectiveness of natural enemies. Here we describe a new multifaceted IPM approach, which is based on smallholder farmers' own practice of companion cropping that has been developed for efficient management of stemborer pests in Africa and beyond.

13.2 The Push–Pull Technology

13.2.1 Discovery and Development

Scientists at the International Centre of Insect Physiology and Ecology (*icipe*) based in Kenya, in collaboration with various national and international partners, including Rothamsted Research of the United Kingdom, have developed and implemented a technology for integrated pest, weed, and soil management through efficient use of natural resources to increase farm productivity. Dubbed “push–pull,” the technology exploits chemical ecology and diversity of local fauna and flora to deliver effective management of these pests. Cereal stemborers are polyphagous and their host plant range includes other members of the family Poaceae as well as the Cyperaceae and Typhaceae (Ingram 1958; Khan et al. 1997a; Polaszek and Khan 1998). The wild host plants are important not only in maintaining stemborer populations when the cultivated crops are out of season, but also for conservation of the pests’ natural enemies. The wild hosts often harbor food sources for many insect pest species and may encourage insect invasion and outbreaks in neighboring agroecosystems (van Emden 1990). *icipe* and partners from a series of surveys and bioassay studies identified the most attractive plant species as trap plants and repellent plants as intercrops. Among these, Napier grass, *Pennisetum purpureum* Schumach, was selected as the putative trap crop (pull) as it attracted considerably more oviposition by stemborer moths than maize (Khan et al. 2006a, 2007; Midega et al. 2011). However, it did not allow much survival of stemborer larvae, with over 80 % of the young larvae dying within the first 15 days of larval feeding (Khan et al. 2006a, 2007). Mortality was caused by the gummy substance produced by Napier grass that immobilized the larvae as they tried to bore into the stem in addition to the poor nutritive value of the grass (Khan et al. 2007).

Similarly, through a series of field trials and bioassay experiments, Molasses grass, *Melinis minutiflora* P. Beauv, was selected as a putative repellent (push) plant as it neither attracted oviposition by stemborer moths nor supported survival of the young larvae (Khan et al. 2000). In subsequent studies, leguminous plants in the genus *Desmodium* were selected as the intercrop as they efficiently repelled ovipositing stemborer moths and at the same time suppressed emergence of the noxious and devastating parasitic weeds in the genus *Striga* (Khan et al. 2000, 2008a; Midega et al. 2013). The push–pull technology thus involves intercropping the main cereal crop with molasses grass or desmodium which are repellent to gravid stemborer moths (push) while Napier grass planted as a border crop around the main crop simultaneously attracts the stemborers and thus acts as a trap plant (pull; Cook et al. 2007; Hassanali et al. 2008; Khan et al. 2010; Fig. 13.1). The intercrop also attracts parasitic wasps, which are natural enemies of the stemborer (Khan et al. 1997b).

13.2.2 Semiochemistry of the Push–Pull Technology

Insects use specific semiochemicals (Dicke and Sabelis 1988) or specific ratios of semiochemicals (Bruce et al. 2005) from plants to detect exploitable hosts and to avoid unsuitable plants. Stemborer host plants produce attractive semiochemicals, notably octanal, nonanal, naphthalene, 4-allylanisole, eugenol, and linalool. It was discovered that Napier grass was preferred by stemborer moths because it produced significantly higher amounts of these attractive compounds relative to maize and

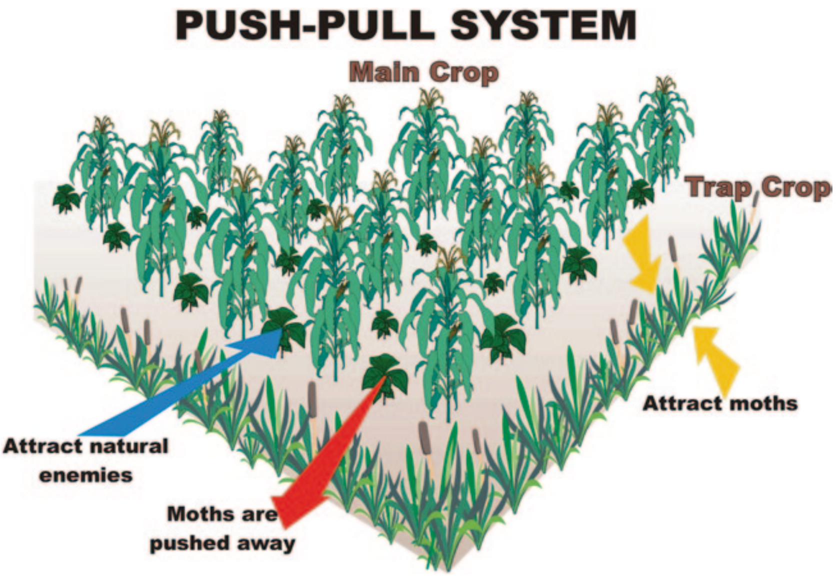

Fig. 13.1 Diagrammatic presentation of push–pull strategy for insect pest management. (Courtesy of Dr. Johnnie van den Berg, North West University, South Africa)

sorghum. Furthermore, there was over 100-fold increased emission of these attractive semiochemicals during the first two hours of darkness (Birkett et al. 2006; Chamberlain et al. 2006). This coincided with the period during which stemborer moths were most actively seeking host plants (Päts 1991). The repellent intercrops, molasses grass and desmodium, on the other hand, were found to emit semiochemicals often associated with plants under herbivore attack, known as herbivore-induced plant volatiles (HIPVs), such as (*E*)-ocimene and (*E*)-4,8-dimethyl-1,3,7-nonatriene (DMNT; see review by Khan et al. 2008b). These HIPVs were subsequently shown to have dual functions: they repelled ovipositing moths and at the same time increased foraging behavior of the pests' natural enemies, principally the parasitic wasp, *Cotesia sesamiae* Cameron (Hymenoptera: Braconidae). The DMNT in particular was demonstrated to be responsible for the increased parasitoid foraging in the plots intercropped with molasses grass (Khan et al. 1997b). There were higher parasitism rates of the larvae in push–pull than maize monocrop fields in western Kenya (Khan et al. 1997a; Midega et al. 2009).

It was also discovered that fodder legumes in the genus *Desmodium* are effective repellents for stem borers (Khan et al. 2000), with the added benefit of fixing nitrogen in the soils as well as serving as a cover crop to prevent soil erosion (Khan et al. 2006b). From the studies on the mechanisms of striga suppression by *Desmodium* spp., Khan demonstrated that, in addition to the benefits derived from increased availability of nitrogen and soil shading, there was a strong allelopathic effect of the root exudates of the legume (Khan et al. 2002). These *Desmodium* spp. root

Fig. 13.2 A young farmer in eastern Uganda shows his push–pull field planted with maize intercropped with *Desmodium uncinatum* and Napier grass planted as a trap plant around the field

exudates contain novel flavonoid and isoflavonoid compounds that interfere with striga parasitization of maize (a striga plant produces tens of thousands of seeds that can remain dormant in the soil for decades). Some of these compounds stimulate striga seed germination whereas others prevent attachment of the parasite's roots to the maize roots (Khan et al. 2008a). This combination thus provides a novel means of in situ reduction of the striga seedbank in the soil through efficient suicidal germination even in the presence of graminaceous host plants.

13.2.3 Uptake and Impact of the Push–Pull Technology

During the last 15 years, on-farm implementation of the push–pull technology has been achieved through a number of technology dissemination pathways involving farmer-to-farmer approaches such as field days, farmer teachers, and farmer field schools (Khan et al. 2008c; Amudavi et al. 2009a, b; Murage et al. 2011). Other approaches have included use of mass media, print media, brochures and pamphlets, and more recently use of information and communications technology (ICT) approaches, principally mobile phones and participatory video. To date over 55,000 smallholder farmers in East Africa are practicing push–pull technology (Fig. 13.2). These farmers have realized effective control of stemborers and parasitic striga weed resulting in significant increases in grain yields from < 1 t/ha to at least 3.5 t/ha for maize, (Khan et al. 2008c) (Fig. 13.3), from < 1 t/ha to at least 2.5 t/ha for sorghum (Khan et al. 2008d) and from < 0.5 t/ha to at least 1 t/ha for finger millet (Midega et al. 2010). These farmers have also achieved significant improvements in soil fertility (Khan et al. 2008d) because desmodium is an efficient nitrogen-fixing legume (Whitney 1966) and also improves soil organic matter content, in addition to preventing soil erosion (Midega et al. 2005). It also improves abundance and diversity of beneficial arthropods (Midega et al. 2008). The

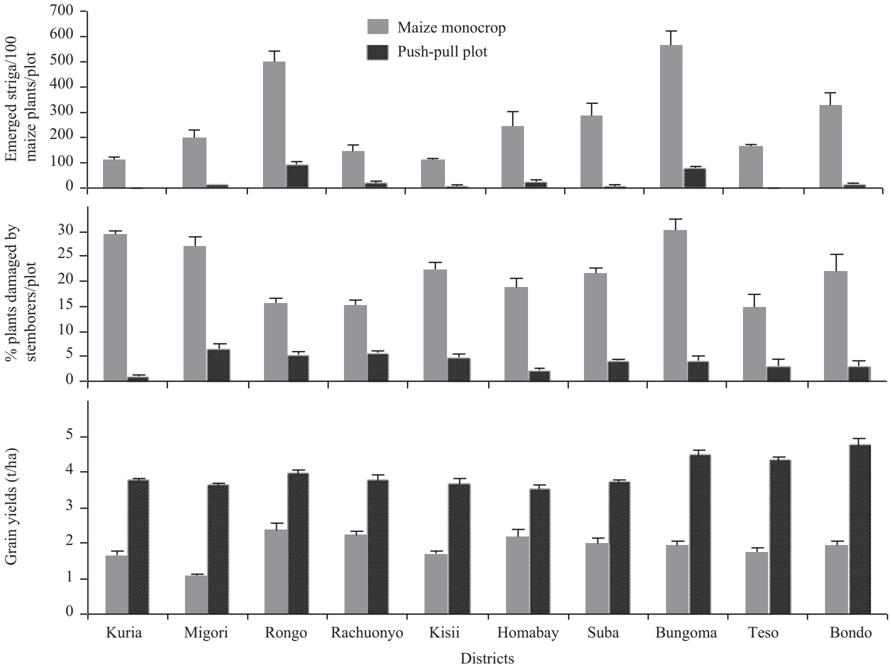

Fig. 13.3 Mean number of emerged striga from 100 maize plants per plot, average proportion of plants damaged by stemborers per plot, and mean grain yields (t/ha) from push–pull and maize monocrop plots during the long rainy season of 2011. In all districts emerged striga and proportion of maize plants damaged by stemborers were significantly higher in the maize monocrop and grain yields were significantly higher in the push–pull plots

companion plants are valuable and nutritious fodder and therefore the technology allows cereal–livestock integration. Farmers have mentioned increases in fodder and milk production (Khan et al. 2008d), with an overall improvement in incomes and livelihoods (Khan et al. 2008e). Thus the push–pull technology opens up significant opportunities for smallholder growth and represents a platform technology around which new income generation and human nutritional components, such as keeping livestock, can be added.

13.2.4 *Additional Benefits of Push–Pull Technology*

Soil Improvement Push–pull technology improves soil health through nitrogen fixation with desmodium as an efficient N-fixing legume (Whitney 1966), increased soil organic matter content, conservation of soil moisture, and reduced soil temperatures. Moreover, the companion plants prevent soil erosion, thereby protecting fragile soils (Khan et al. 2006b).

Increased Biodiversity The technology enhances arthropod abundance and diversity, part of which is important in soil regeneration processes, pest regulation (Midega et al. 2008), and stabilization of food webs, and thus the system ensures ecosystem stability. There is also a clear demonstration of the value of biodiversity because of the important roles played by companion crops and beneficial insects in the system.

Mitigation of Climate Change Desmodium provides live mulch and together with Napier grass lowers temperatures within the cropping system (Khan et al. 2002). By increasing organic matter content, the technology improves the soil's ability to sequester atmospheric carbon and thus mitigate the effects of climate change. Indeed preliminary data show that soil carbon is higher in push–pull plots than in monocropped plots. Farms under push–pull are therefore sustainable and resilient, with improved potential to mitigate the effects of climate change.

Improved Environmental Health In addition to improved biodiversity that is partly exploited for pest management, the technology eliminates the need for pesticides to be deployed in these cropping systems. This ensures that the environment and associated biodiversity are not harmed and no chemical residues drift into water bodies.

13.2.5 Economics of the Push–Pull Technology

A number of studies have demonstrated that push–pull technology is more profitable than the farmers' own practices, and some of the practices designed to improve soil fertility. Indeed Khan et al. (2001) reported significantly higher benefit–cost ratio with push–pull technology compared with maize monocrop and/or use of pesticides, posting a positive return on investment of over 2.2 compared with 0.8 obtained with the maize monocrop, and slightly less than 1.8 for pesticide use. Additionally, push–pull technology with no fertilizer had the best gross returns and less profit was registered with the use of fertilizer, implying it was economically propitious to invest in the push–pull technology. In a more detailed economic analysis utilizing data of over seven cropping seasons, returns to investment for the basic factors of production under push–pull technology were significantly higher compared to those from maize–bean intercropping and maize monocrop systems (Khan et al. 2008e). Positive total revenues ranged from $ 351/ha in low potential areas to $ 957/ha in the high potential areas, with general increases in subsequent years. The returns to labor that were recovered within the first year of establishment of the technology ranged from $ 0.5/person day in the low potential areas to $ 5.2/person day in the higher potential areas under the push–pull technology, whereas in the maize monocrop, this was negligible or even negative. Furthermore, the net present value (NPV) from push–pull technology was positive and consistent over the years. More recently, a study by De Groote et al. (2010) that used discounted

Fig. 13.4 A farmer group in western Kenya showing an adapted push–pull field with sorghum intercropped with drought-tolerant *Desmodium intortum* and *Brachiaria* cv mulato planted as a trap plant around the field

partial budget and marginal analysis corroborated these findings and concluded that push–pull earned the highest revenue compared to other soil fertility management technologies, including green manure rotation.

13.2.6 Adaptation of the Push–Pull Technology to Climate Change

As there is evidence of increasingly hot and dry conditions associated with climate change, and to ensure that push–pull technology continues to affect food security positively in Africa over the longer term, new drought-tolerant trap (*Brachiaria* cv mulato) and intercrop (drought-tolerant species of desmodium, e.g., *D. intortum*) plants have been selected from research undertaken with funding from the European Union. The new companion plants also have the appropriate chemistry in terms of stemborer attractancy for the trap component and stemborer repellence and striga suppression, and ability to improve soil fertility and soil moisture retention for the intercrop component. In addition, they provide other ecosystem services such as biodiversity improvement and conservation and organic matter improvement. Currently over 4,000 smallholder farmers in drier parts of Kenya, Tanzania, and Ethiopia have taken up the adapted technology and have reported effective control of stemborers and striga weed resulting in significant increases in grain yields of both maize and sorghum (Khan et al. 2014). The work to isolate and purify all the active compounds in the desmodium root exudates and fully elucidate their effects on striga suppression is ongoing. Similarly, the full mechanism of stemborer control by the new companion plants is currently being elucidated, with the aim of providing both sustainability and quality assurance as more companion plants are selected for new agroecologies (Fig. 13.4).

13.3 Exploiting Early Herbivory Alert for a "Smarter" Push–Pull Technology

New opportunities for exploiting early herbivory in plant defense and elucidating the underlying mechanisms of plant–plant communication between companion plants and cereal crops are being explored with aim of selecting "smart" cereal and companion crops. Under natural conditions, plants have evolved direct and indirect defense strategies against attacking organisms. Directly, they produce toxins, digestion inhibitors, and HIPVs repellent to phytophagous insects (De Moraes et al. 2001; Kessler and Baldwin 2001); indirectly, they use HIPVs to attract natural enemies antagonistic to the herbivores (Turlings et al. 1990; De Moraes et al. 1998; Heil 2008). Stemborer larvae inflict substantial physical damage to cereal plants by their feeding, which induces qualitative and quantitative changes in the plant's profile of volatiles (Tumlinson et al. 1993; Turlings et al. 1998; Ngi-Song et al. 2000). Some of the key compounds in the HIPVs include (E)-ß-ocimene and (E)-4,8-dimethyl-1,3,7-nonatriene (Turlings et al. 1990). HIPVs are generally induced by elicitors in the herbivore saliva or oral secretions. These HIPVs provide parasitoids with early alert cues for plants colonized by their host and thus enhance their foraging efficacy. They are thus important in recruitment of these beneficial natural enemies thereby facilitating biological control. However, this pest control occurs following plant damage. Recruitment of natural enemies prior to plant damage would thus be more beneficial in preventing crop losses.

Many wild relatives and landraces of grass species from which crop plants and fodder crops have been selected continue to survive today. Some African poaceous plants have sophisticated responses to herbivory that involve multitrophic interactions with natural enemies. We discovered a trait in the African signal grass *Brachiaria brizantha* (Hochst. EX A. Rich.) where egg deposition by *C. partellus* moths induced qualitative changes in the volatile profile, making the plant attractive to the larval parasitoid *C. sesamiae* (Bruce et al. 2010). This trait would also be useful in cultivated cereal crops. Additionally, some reports had shown that egg laying on plants by herbivores could induce defense in host plants (Hilker et al. 2002). Our subsequent studies identified a similar trait in maize landraces and smallholder farmers' own varieties where oviposition by *C. partellus* led to increased emission of HIPVs making these plants attractive to both egg and larval parasitic wasps, *Trichogramma bournieri* and *C. sesamiae*, respectively (Tamiru et al. 2011, 2012). Notably, this trait was absent in the elite maize hybrids, implying it must have been lost during the breeding processes as desirable qualities such as high yields are selected for.

Plants that are able to produce HIPVs in response to egg deposition have the advantage of defending themselves early on, before hatching larvae can damage the plant. The HIPV emission following oviposition enables egg parasitoids to distinguish odors of plants colonized by hosts. Moreover, the attraction of larval parasitoids in response to oviposition indicates that their recruitment occurs in anticipation of larval hatching and before they damage the plant. Although it is of adaptive value to the plant to emit HIPVs, there is also selection pressure on the parasitoids to respond to such signals, as it enhances their foraging efficiency and thus improves their ecological fitness. In the short term we have selected maize varieties with the early herbivory trait that have now been incorporated in the push–pull technology with the added benefit of initiating biological control of stemborers at oviposition, the earliest stage of attack. In the medium to long term we are studying the molecular basis of this egg-induced semiochemical production with a view to developing molecular markers that will allow advanced selection of crop varieties and introgression of these traits into mainstream commercial hybrid maize varieties that will provide novel and ecologically sound approaches to the control of these destructive stemborer pests.

13.4 Exploiting Plant–Plant Signaling for Stemborer Management

Evidence is accumulating indicating that some plants respond to HIPVs produced by damaged neighbors even when they themselves have not been attacked (Baldwin and Schultz 1983; Bruin et al. 1992; Karban et al. 2000). For example, wild tobacco, *Nicotiana attenuata*, plants grown with clipped sagebrush, *Artemisia tridentate*, neighbors had increased levels of the putative defensive oxidative enzyme, polyphenol oxidase, relative to control tobacco plants with unclipped sagebrush neighbors. Tobacco plants near clipped sagebrush experienced greatly reduced levels of leaf damage by grasshoppers and cutworms (Karban et al. 2000). Also, cotton plants growing next to those that are attacked by herbivorous mites experience reduced oviposition of these herbivores, and are attractive to predatory mites (Bruin et al. 1992). Our previous studies had shown that intact molasses and desmodium plants produced similar semiochemicals as those produced by maize under attack by stemborer pests (Khan et al. 1997b, 2000). Subsequently, we have recently observed that maize growing next to *B. brizantha* with oviposition becomes less attractive to *C. partellus* for oviposition but becomes attractive for the parasitic wasp, *C. sesamiae* (C.A.O. Midega et al., unpublished data). In addition, maize plants growing next to molasses grass produce similar semiochemicals as those under attack by stemborer larvae (Z. R. Khan et al., unpublished data). This suggests that semiochemicals emitted by molasses grass act as airborne signals that induce resistance in the neighboring, undamaged maize plants. Our preliminary results also show that these neighboring maize plants are "primed" to respond more quickly or aggressively to future attack by stemborers. Efforts are underway to identify the key compounds within the HIPVs that induce and/or prime these responses in a variety of plants. In cotton as well as other plants, *cis*-jasmone has been identified as one of the key compounds mediating these responses, causing dramatic induction of direct and indirect defense compounds, such as (E, E)-4,8,12-trimethyltridecaca-1,3,7,11-tetraene (TMTT). These then lead to a reduction in colonization by sucking insects (Birkett et al. 2000). Understanding these processes will enable their full exploitation in crop protection and in the development of future push–pull strategies with these traits. We are currently identifying companion plants with the ability to induce defense against insect attack in cereal crop varieties for possible incorporation in the push–pull technology, or for development of other companion cropping-based approaches, a common feature in smallholder cropping systems in Africa, to enhance natural plant defense.

13.5 Conclusions

The push–pull system effectively addresses the constraints to production faced by the farmers and is an appropriate system because it uses locally available companion plants rather than expensive imported inputs. Although the technology was originally devised to control insect pests it has multiple benefits in controlling striga weeds, improving soil fertility, and providing livestock fodder in a truly integrated system. It is thus a novel IPM approach that was developed with full participation of the target farmers and is modeled alongside their practice of multiple cropping thereby enhancing its acceptance. It is currently used by over 55,000 smallholder farmers in eastern Africa and has been adapted for drier areas vulnerable to climate change by identifying and incorporating drought-tolerant trap and repellent plants. This has made the technology more resilient in the face of climate change as rainfall becomes increasingly unpredictable. Moreover, the technology is being made "smarter" through identification and incorporation of cereal crops with defense systems against stemborer pests that are inducible by egg deposition by the pests. Companion plants that are able to signal defense systems of the neighboring smart cereals are also being identified. Accompanying these are efforts to elucidate full mechanisms of these responses. Science-based IPM solutions, which are environmentally sustainable and low cost, like push–pull, are urgently needed to address the real and increasing dangers of food insecurity, and for a real Green Revolution in Africa without causing any ecological and social harm.

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Chapter 14
Promoting Integrated Pest Management for Cotton Smallholders—The Uganda Experience

Rory Hillocks and Derek Russell

Contents

Abstract Cotton production in Uganda which depends on smallholders, has fallen well below the levels of national production seen in the 1960s. Poor standards of crop management contribute to low profitability and control of insect pests is an important management component, with insecticides accounting for up to 50 % of input costs. An integrated pest management (IPM) system appropriate for smallholder adoption was developed and promoted as part of a larger program based on large numbers of on-farm demonstrations. The main insect pests in Eastern Uganda are the bollworms (*Helicoverpa armigera*, *Pectinophora gossypiella* and *Earias insulana* and *E. biplaga*) and Lygus bug (*Lygus* spp.) can cause leaf tattering and destruction of flowers. Later in the season, stainer bugs (*Dysdercus* spp.), can cause

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lint staining and secondary boll rots. The two key IPM components were the use of soapy water to control early season aphids, so as to delay the first use of a toxic insecticide and a ‘user friendly’ pest scouting method, to inform the farmer of the optimum time to spray and help in deciding what to spray. The use of a ‘peg-board’ as a scouting aid was adopted among cotton farmers in Uganda and spray schedules informed by scouting delivered better pest control and higher profits than fixed schedule spraying. Implementation of the IPM system did not necessarily result in decreased number of sprays compared to the nationally recommended fixed schedule of 4 sprays. In a season of low bollworm pressure, one less spray was required but in a season of higher pest pressure, one additional spray was required under the scouting-based IPM system. However, the timing and appropriateness of the intervention was greatly improved, with positive implications for crop protection and yields. The main lesson from the experience in Uganda was that pest scouting and IPM can be readily adopted by African smallholders, provided they have access to good quality inputs and sufficient technical support. The large number of on-farm demonstrations was also an important method of knowledge transfer.

Keywords Cotton · IPM · Uganda · Bollworms · Spray thresholds

14.1 Introduction

Cotton was introduced to Uganda in 1903. Production increased from around 13,000 bales in 1910 to a peak of 430,000 bales in the early 1970s when the country was one of Africa’s largest cotton producers. However, during the political instability and civil war from 1973, production declined sharply, reaching its lowest level in 1987/1988 when production stood at 11,000 bales. Production started to recover following the liberalization of the sector in 1994 and higher prices throughout the 1990s—though the El Nino year (1997/1998) represented a setback (Figure. 14.1).

However Russell and Gordon (1999) found average productivity less than 150 kg lint/ha. Despite a floor price set by the Ugandan Cotton Development Corporation of 300 Ugandan shillings/kg seed cotton, net income per ha after seed and pesticide costs was at an astonishingly low US$ 105/ha. By 2004–2005 production had reached 253,000 bales [400 lb -185 kg lint/bale] (ICAC 2005), but by 2010, total production had fallen back to 70,000 bales (CDO 2012). Together with differing patterns of rainfall distribution, farm-gate price is the main factor influencing large annual variations in national output. There are a number of constraints and inefficiencies in the cotton industry in Uganda, including lack of access to high quality inputs, including inorganic fertilizer, seeds and insecticides. Inorganic fertilizer has to be trucked from Mombassa on the Kenyan coast making its use very expensive. Cotton remains an unattractive option economically for any smallholders who have market access for alternative agricultural commodities, because of the high cost of insecticides and fertilizer, and the labor requirements for weeding and harvesting (You and Chamberlain 2002). With the structural adjustment and liberalization of internal markets in Africa

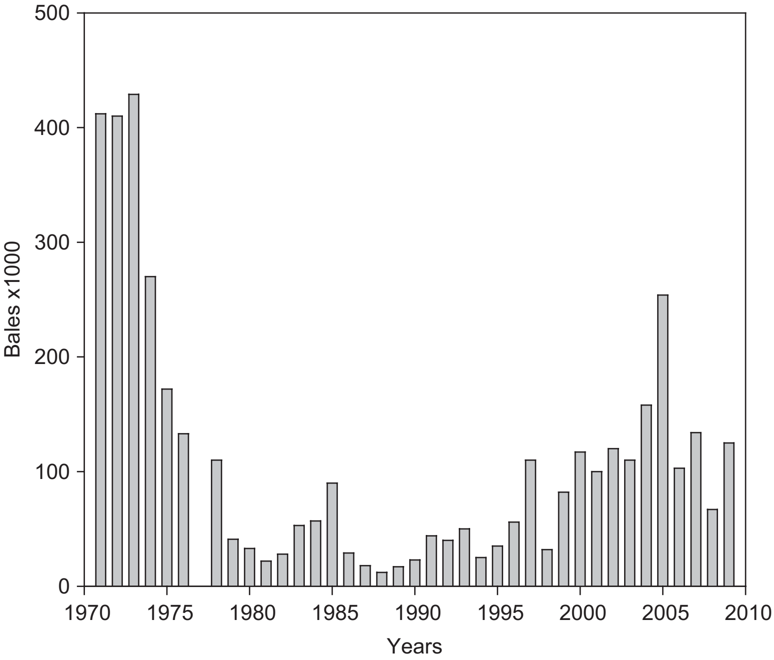

Figure. 14.1 Cotton production in Uganda 1970–2009 (400 lb bales of lint). Years of low production between 1975 and 1995 coincide with periods of conflict

in the 1980s and 1990s, there was a marked decline in public sector investment and the expected private sector replacement in the provision of extension advice and inputs did not materialize (Farrington 1977; Nyambo 1989; Farm Africa 2004). French W. Africa retained its extension system far longer and the recommended 4–6 calendar insecticide applications had some positive effect on yields (Cauquil 1990).

In 2001, when the activities described here were commenced, Uganda had around 250,000 farmers growing 150,000 ha of cotton and producing 18,450 tonnes of lint. In Sub-Saharan Africa (SSA) generally, smallholder cotton yields are well below the yield potential of the current varieties but Uganda's average yield of ca.123 kg lint/ha in 2001 (ICAC 2002) was only 20 % of the world average and well below the average for other countries in Eastern Africa and considerably below the potential for the cotton varieties grown (BPA = Bukalasa Pedigree Albar and SATU = Serere Albar-Type Uganda). In addition to the uncontrollable environmental factors that contribute to this yield gap, standards of crop management often leave much room for improvement. Factors such as poor soil fertility, late planting, disease spread through the largely deregulated seed multiplication system and inadequate weed control are often exacerbated by socio-economic factors related to constraints on family labor and over-riding concerns for household food security.

Insecticides are the main purchased input used on cotton by smallholders in SSA. Where farmers and their households have the capacity to make improvements to crop management, integrated pest management (IPM) can make a significant contribution to the profitability of cotton growing by making the most effective use of costly insecticides.

The history of IPM adoption in cotton does not provide us with many success stories. It may be argued that an IPM system can be designed in which pest control interventions do not depend on being informed by pest scouting and damage thresholds. However, control efficiency and cost benefit cannot be optimized through reliance on fixed-schedule spraying where the make-up and level of the pest complex are unknown. The main reason for slow adoption of IPM in SSA has been that smallholders find it difficult to understand the benefits derived from the additional time they have to devote to regular scouting and few have the financial resources to pay for extension services, which in any event are rarely available. The government extension services in Africa are poorly motivated, often inadequately trained and too few in number to promote and provide technical support for IPM to large numbers of farmers. The standard recommendation has therefore been to apply insecticide on a fixed schedule. For Uganda in the early 2000s this was an application every two weeks from first flower bud (square) (ca. 35 days after planting) up to a maximum of 6 sprays. Before the commencement of the IDEA study, the Ugandan Cotton Development Organisation was supplying a ‘starter pack’ to farmers containing enough insecticide for two applications and making knapsack sprayers available for use by groups of farmers, with the costs recovered from by a cess (tax) on lint delivered at the ginnery. It was rather rare for farmers to purchase insecticides for later applications. If the first insecticide was used early in the season for aphids, that left only one application available for the later pests—particularly Lygus bug and the bollworms. In practice, most cotton smallholders try to apply as few sprays as possible and decide to apply a spray only when they notice the pests or the damage the pests have caused. Usually, the spray comes too late to prevent boll loss and, may even stimulate worse pest attack than if no spray had been applied, as a consequence of the pesticide application disrupting the natural enemy populations. In the cotton district of Kasese, for example, the average (non—trained) farmer sprayed 1.6 times in the 2002–2003 season.

14.2 The Cotton Pest Complex in Uganda

There are few published data on cotton pest problems in Uganda. Coaker (1959) surveyed cotton pest problems and explored the natural enemy fauna. Sekamatte (1994) undertook studies on *Aphis gossypii,* but it was not until the IFAD/World Bank Cotton Smallholder Cotton Rehabilitation Project—1993–1996 and the subsequent Cotton Subsector Development Project (CSDP) that comprehensive studies were attempted (El-Heneidy et al. 1995) and numerous published and unpublished reports by El-Heneidy and Sakamatte (held by the authors).

Data on beneficial insects in the cotton system are largely limited to surveys of predators and parasitoids. El-Heneidy and Sekamatte (1998a, b and unpublished reports) collected 4 species of parasitoids from the cotton aphid, *Aphis gossypii*, and 21 parasitoid species from the cotton bollworm complex from 7 families (9 new records for E. Africa) and placed them in their temporal context in terms of bollworm life cycles. A further report (El-Heneidy and Sekamatte 1996a) covers the changes in bollworm predator numbers over the season. Lady beetles (ladybirds) hover flies, spiders and ants were the most important groups of beneficials at Namulonge, near Kampala, while spiders and ants dominated at the NARO research site further North, though lady beetles (ladybirds) were significant. Epieru (1997) examined predator incidence in cotton/bean inter-cropping in Eastern Uganda (esp. spiders). There were no practical recommendations for manipulation of these predator populations. Translating this information on the numbers of beneficial insects into an estimation of their impact on pest insect numbers awaits more detailed life history studies of the bollworm species involved.

Work on the development of control action thresholds for insect pests was undertaken by Sekamatte and El-Heneidy (1998) for Lygus bug and by Sekamatte and El-Heneidy (1997) for the bollworm *Helicoverpa armigera.* The intervention thresholds for the IPM system described below drew on that work but with less conservative thresholds and using sampling techniques which were practicable for the farmers.

An investigation of the role of trap crops (maize, sorghum and beans) in unsprayed small plot trials on research stations (El-Heneidy and Sekamatte 1996b) showed the attractiveness of sorghum to lygus bugs and cotton stainers; of maize to stainers and of beans to whiteflies and jassids. No differential attractiveness could be shown for American bollworm and the spiny bollworm species. The population of predatory arthropods was higher in the cotton/trap crop combinations and the resulting seed cotton yields were 20–25 % higher than in the cotton only fields, suggesting the potential for a significant contribution of the manipulation of cropping patterns to cotton pest management. However, further studies would be required in a real farm context before management recommendations could be made.

Most of what insecticide is applied, is applied by hand pumped back pack equipment. This involves the carrying of significant quantities of water and is relatively ineffective in terms of spray penetration. Sekamatte and Okoth (unpublished) explored the efficiency of micron ULVA+electrodyne sprayers (at 5–15 l/ha) which are widely used in West Africa in comparison with the conventional knapsacks and found great advantages in work rate, ease of use, improved precision and comparative costs. However there was little or no uptake in the very restricted Ugandan market.

During the early part of the growing season young plants may be affected by sucking pests—in dry conditions, aphids can reach damaging numbers. Cotton farmers often apply their first spray against aphids and indeed insecticide resistance in aphids was demonstrated by El Gurban et al. (1992). The leaf feeding pest, *Taylorilygus vosseleri* (a Lygus bug) can cause leaf tattering throughout the season beginning around first flower. The original chewed holes are very small but expand as the leaf grows. Leaf damage is conspicuous but flower damage less so, although it probably contributes more to yield loss. Lygus bugs are effectively controlled by sprays targeted at bollworms but sprays based on visible leaf damage are generally too late to be useful. The key bollworm caterpillar pests in Uganda are the Africa bollworm, (*Helicoverpa armigera*), the pink bollworm (*Pectinophora gossypiella*) and the spiny bollworms (*Earias insulana* and *E. biplaga*) which are both shoot and boll feeders. In tropical areas such as Uganda, the bollworms do not enter diapauses and can therefore multiply year-round, unless steps are taken to restrict host availability. A 70 day close season and mandatory cotton stalk and trash destruction is imposed in bye-laws in many areas of Uganda but is widely ignored, especially by those renting land for a season only. Towards the end of the growing season, the seed-feeding true bug (Hemiptera) cotton stainers (*Dysdercus* spp.) can become a problem requiring an additional spray. The main effect of the stainer is to cause a yellow discoloration of the lint, due to the introduction into the boll of bacteria or fungi. This represents a potential loss to the grower, especially where seed cotton is purchased on the basis of quality grading and can significantly downgrade the export crop. Jassids (*Empoasca* spp.) can be a problem due to the injection of a toxin during feeding which causes 'hopper burn'. However, most East African cottons are deliberately bred to be jassid resistant (though hairy leaves) to a greater or lesser extent. The cotton mosquito bug (*Helopeltis* sp.) sucks from the exterior of bolls, where it can result in bacterial or fungal infections. It is, however, relatively susceptible to most insecticides and is rarely a significant problem.

Set against these pest species are a number of beneficial insect groups, most particularly the generalist predators (spiders; lady beetles (ladybirds) (*Cheilomenes* sp. and *Scymnus* sp.); predatory bugs (*Orius* spp.); rove beetles (*Phaedrus* sp.); earwigs (*Diaperasticus* sp.); black ants (*Pheidole* spp., *Myrmicaria* spp. and esp. *Lepisiota* spp.). *Lepisiota* spp. ants are generalist predators in the region and are encouraged by farmers in cotton intercrops, including through feeding of animal protein waste and the movement of nests. However, these ants appear to be extremely sensitive to insecticide applications. Judicious reduction in insecticide use has the capacity to increase the impact of these useful, but insecticide-sensitive, groups.

14.3 Development and Implementation of a Cotton IPM System

14.3.1 Development of an IPM System

Appreciating the poor yields being obtained nationally and as part of a national Cotton Productivity Enhancement Programme (2001–2007) aiming to raise yields in key crops, the United States Agency for International Development (USAID) Investment in Developing Export Agriculture (IDEA) project, promoted an improved crop management system for cotton smallholders consisting of adherence to recommended planting and weeding dates, combined with the use of fertilizer and insecticide applied four times on a fixed schedule. In 2001–2002 the program ran 874 cotton production demonstration plots across the nine major cotton districts, employing 115 site coordinators to train farmers and help disseminate the practices. Some 46,000 cotton farmers attended the demonstration field days. In order to decrease pesticide wastage and improve profitability, from 2002 the Natural Resources Institute of the University of Greenwich, United Kingdom (UK) in partnership with the National Cotton Research Program and the Ugandan Cotton Development Organization, was invited to design and validate an integrated pest management (IPM) system.

Implementation of the IDEA cotton project was based on a large number of on-farm demonstrations. The developed IPM system was trialled in the 2002–2003 cotton season in Kasese district, on 30 of the 600 selected framers who hosted IDEA demonstrations. Each farmer was expected to pass on the knowledge gained to at least another 12 cotton farmers, who were invited to training sessions throughout the growing season at the demonstration site. Technical support was provided by a team of specially trained site supervisors, financed by the participating ginning companies. Each supervisor was responsible for 10 demonstration sites and so, for influencing around 120 farmers. The IPM practices were extended to all 600 demonstration farmers in each of the Kasese and Palissa districts in 2003–2004. With experience, and following some refinements and simplifications, the IPM module became part of the national initiative from the 2004–2005 season (under what was by then the Agricultural Productivity Enhancement Programme (APEP)). By then, there were 8 lead ginners running demonstrations in the 9 cotton districts, running 6,560 demonstrations which were observed by a total of 90,900 farmers, with the expectation that the program would reach almost all of Uganda's 250,000 cotton farmers by 2007.

14.3.2 IPM Practices

Scouting: Under the developed IPM practices, spraying with insecticide was informed by weekly scouting. Supervisors and farmers were trained to examine up to 25 plants per field, chosen on the following system.

1. Enter the field at any position.
2. Take 5 steps up the row.
3. Take 5 steps to your right.
4. Sample the 5th plant along the row.
5. Repeat steps a 2 to 5 until 25 plants have been sampled or an intervention threshold has been succeeded.

To aid scouting, wooden pegboards (Figure. 14.2) were used, as pioneered by Graham Matthews in Zimbabwe in the 1960s, on which was marked the action thresholds for the key pests. The pegboard is a ca. 20 cm × 8 cm × 0.5 cm piece of wood drilled with narrow and shallow holes in 5 columns of 25 + 1. At the top of the board, the head of columns 2 to 4 have a simple but recognisable outline picture of one key pest (aphid, Lygus bug, bollworm and stainer). The first column is reserved for plant counts. A string attached to the middle of the bottom of the board was used to carry the board around the farmer's neck, leaving his hands free for examining

Figure. 14.2 Ugandan cotton farmer with pegboard scouting aid - a simple form of sequential sampling plan. Each column of peg holes is for one pest group (aphids, Lygus, bollworms and stainers). As the farmer examines each of the 25 plants in the sample, the peg is moved down the column by one hole each time the insect/damage is present on a plant. When the peg in any column moves out of the blue area, a pest treatment is required. *(See text for details)*

the plants. On the back of the board was stuck the instructions for scouting and the recommended insect management practices when an intervention threshold was exceeded. Matchsticks sit in each of the +1 holes before scouting begins. As the farmer scouts each plant the matchstick in the first (plant) column is moved down one hole. If damage or insect numbers of a particular pest is sufficient to score the plant as damaged, the matchstick in the column for that pest group is moved down one hole. The intervention thresholds (Table 14.1) were marked in red across the appropriate row of holes (3 or 5) for each species. The farmer scouts (weekly) until either the 25 plant sample is complete or, until a threshold is crossed, triggering a spray intervention.

The IPM team of the IDEA and APEP projects produced colored brochures for the demonstration supervisors and simpler versions for the individual farmers to help with insect identification and IPM practices. In addition, one of the chemical companies produced laminated cards with color photographs of each main pests on one side and the major beneficial organism on the other, as an identification aid for the farmer. Farmers were given half a day's training in the theory of IPM and pest identification and half a day of field practice in identification and scouting and were encouraged to spray only when the thresholds were reached. The principle was to spray as little as it was safe to do (i.e., only when thresholds were exceeded) and to rotate the chemical groups used in such a way that they were effective against the pest group at the time but minimized the opportunity for resistance build-up against any particular chemical group.

Table 14.1 Decision system for the key pests in Uganda (per 25 plants examined). (Source: refs. In Sekamatte et al. 2004)

	Early season	Mid season		Late season
Key pests	Aphids	Lygus bug	Bollworms (3 species)	Cotton Stainers
Threshold no. of plants/25	5	5	3	3
Symptom	'Crinkled' leaves in top 5	'Shot-hole' damage within top 5 leaves	Any 'fresh' damage or larvae	Any nymphs or adults present
Action	Soapy water	Organophosphate	Pyrethroid	Pyrethroid or Organophosphate[a]

[a] Not the same chemical group as the previous application

14.3.3 Intervention Thresholds

Action thresholds were based on existing recommendations for Uganda (Table 14.1) derived particularly from the work of El Heneidy and Sekamatte (see Sekamatte et al. 2004 for details).

The first component of the IPM system was to prevent disruption of the population of beneficial insects that was occurring due to the first spray early in the season, against aphids. This was achieved by spraying with soapy water, directed at the underside of the leaves.

During the small scale validation of the IPM system in Kasese in 2002–2003, the IDEA improved crop management system, using fixed-schedule insecticide applications, was compared with the same system using the IPM practices. Both systems were tested with and without the application of fertiliser and an early season herbicide (which might increase yields but could also affect pest populations) and compared with normal farmer practice (very variable, but averaging around two insecticide applications).

The IDEA practice plots management systems ('high input'—with fertilizer and herbicide, and 'low input'—without fertilizer and herbicide) included early land preparation, good sowing timing, using delinted seed, proper plant spacing, appropriate thinning and weeding. For the 'high input' plots the recommended fertilizer was 125 kg/ha at planting (N:P:K 11:52:0) and a top dressing designed to deliver 50 kg N/ha split into two doses at 6 and 12 weeks after planting. The herbicide glyphosate was used as a weeds clean up (at 400 ml/15 l) at least two weeks before planting.

Table 14.2 IDEA project principles for the application of insecticides for pests seen by the farmer

Stage of pest incidence	Product group
Aphid	Soapy water sprayed upwards on the underside of leaves
Aphid plus Lygus bug	Single systemic insecticide (usually an organophosphate)
Early bollworm	Single pyrethroid
Late bollworm	Single organophosphate (or a pyrethroid if there have been no early bollworm sprays)
Stainers	Either a single pyrethroid or a single organphosphate—not the same group as the last material sprayed

14.4 Strengths and Weaknesses of the National Pest Management Recommendations in 2000

This new IPM system was compared to the existing national recommendations to farmers and against what most farmers actually did. The national recommendations, as incorporated into the original IDEA demonstrations, were based on a calendar spraying system and comprised a first application at 35 days after germination i.e., shortly after thinning and just before first squaring, followed by three further applications at 14 day intervals.

Insecticides were bought on the tender market by the Cotton Development Organisation and provided to the ginneries for distribution to farmers. At the time of the studies, these emulsifiable concentrate (EC) formulations were:

- *Contra-Z*— a mixture of 500 g chlorpyrifos (an organophosphate) and 50 g of cypermethrin (a pyrethroid)/l used at 40–50 ml/15 l tank;
- *Fenkill*– 200 g/l of fenvalerate (a pyrethroid) used at 50 ml/15 l tank;
- *Ambush*—200 g/l cypermethrin (a pyrethroid) used at 50 ml/15 l tank;
- *Ambush-Super*—lambda-cyhalothrin (a pyrethroid) used at 50 ml/15 l tank;
- *Rogor*—dimethoate (an organophosphate) used at 30 ml/15 l tank.

(Application volumes per hectare depend on the height of the crop e.g., 50–150 l).

More sophisticated (and safer) materials were available on the market but cost considerations strongly influenced the choice of these older materials. Farmers usually received the *Contra-Z* mixture and one other chemical.

The advantages of the national recommendations were: that they were easy to use and to train famers to use; and were reasonably effective in protecting yield. The limited number of applications limited the financial risks which might come from poor weather and the system allowed the Cotton Development Organisation (CDO) and the ginneries to calculate the requirements in advance and provide the necessary materials on time (though this was, in practice, always a problem). The disadvantages were that they did not take account of the pest species or populations at particular times, resulting in some unnecessary applications, some applications were of inappropriate materials and, at times, interventions were required but not made. The widespread early season spraying of the upper side of leaves for aphid control, was particularly unfortunate as it was not effective in killing the main populations of aphids, which were on the under side of leaves, but was effective in disrupting the populations of beneficial organisms (Sekamatte and Ogena-Latego 1999). The almost inevitable successive spraying of insecticides in the same chemical class was a recipe for rapid resistance development, especially among the bollworms. The recommendations provided plant cover for up to 77 days out of the ca.120 day growing season. Late season pests (especially pink bollworm and the strainers) were therefore not well controlled. The principles are given in Table 14.2.

The recommendations for the chemicals to use had to conform to the CDO guidelines for each cotton zone. These were drawn from the following:
Pyrethroids

- *Fenkill*—200 g/l fenvalerate at 49.4 ml/hectare (20 ml/acre)
- *Ambush*—200 g/l cypermethrin at 494 ml/hectare (200 ml/acre)
- *Ambush-Super*—lambda cyhalothrin at 494 ml/hectare (200 ml/acre)
- *Bulldock* -beta-cyfluthrin at 395.2 ml/hectare (160 ml/acre)

Organophosphates
- *Rogor*—480 g/l dimethoate at 296.4 ml/hectare (120 ml/acre)

Mixtures *(not really IPM-friendly and not actively promoted in the IPM programme)*

- *Cydon Super*—100 g dimethoate (OP)/l and 400 g cypermethrin (pyrethroid)
- *Contra-Z*—500 g chlorpyrifos (OP) and 15 g cypermethrin (pyrethroid)/l
- *Curacron K*—300 g chlorpyrifos (OP) and 14 g lambda-cyhalothrin (pyrethroid)/l

In the 2002–2003 trial, weekly farmer scouting ran from mid-October to mid-January, assisted by the site coordinators. 30 farmers' demonstration plots were selected for detailed data collection and comparison. These plots received additional fortnightly scouting by the NARO technical team to provide reliable data for comparisons. Sampling took around 20 min per average half-acre plot after the initial training sessions.

14.5 IPM Gives Higher Returns

All improved crop management systems decreased insect pest numbers compared to farmer practice (Figure. 14.3) but the effect was greater in the plots where IPM was implemented. Insecticide use was highest in the IDEA system (average 3.4 times) as they were following the recommendation of four calendar-based sprays as best they could. As expected the unsupervised farmers left to themselves used less than the full spray regime (average 1.6 applications) which explains their poor bollworm control. Under the IPM system only an average of a further 1.6 insecticide sprays were required after the first spray with soapy water to control aphids, which was needed on half the plots (Figure. 14.4). The 'high' and 'low' input plots had si-

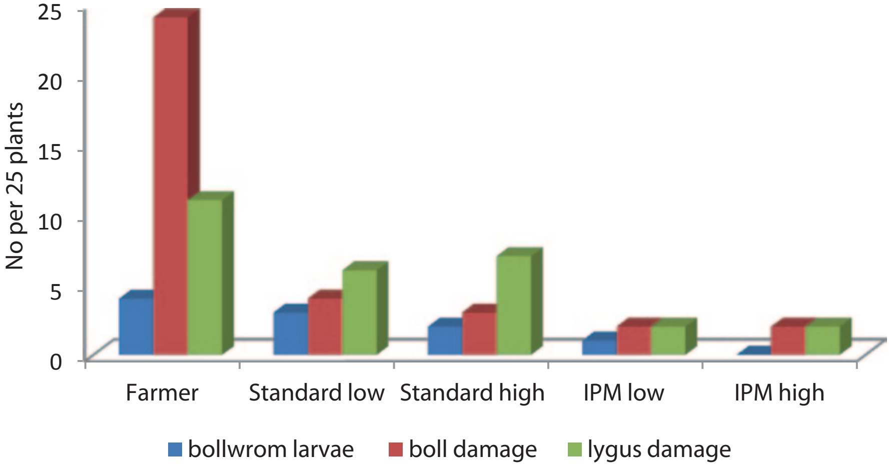

Figure. 14.3 Insect impact on cotton (Kasese 2002–2003) *Bollworm larvae* number per 25 plants, *Boll damage* bollworm damaged bolls per 25 plants, *Lygus damage* number of damaged plants, *Lint stained* % of 4 kg sample. 'Standard' refers to the normal IDEA/SPEED practices as detailed in the text. IPM practices replace the pest management component of standard practices while retaining the other components. Bollworm damage is greatest with farmer practice, decreased with the standard treatment and least in the IPM treatments

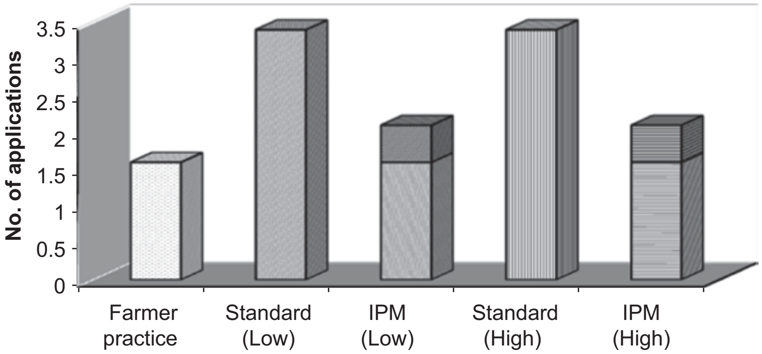

Figure. 14.4 Effect of crop management systems on number of insecticide applications (Kasese 2002–2003). Dark boxes on top of IPM columns are a single soapy water application for aphids. 'Standard' refers to the normal IDEA/SPEED practices as detailed in the text. IPM practices replace the pest management component of standard practices while retaining the other components. Farmers use fewer than the recommended 4 sprays which were used in the standard treatments but effective pest control was achieved with the least number of sprays when spray timing was informed by scouting in the IPM treatments

milar insect profiles throughout the season and the great majority of spray decisions were the same for both plots for any individual farmer in the same week.

All improved crop management systems delivered yields which were more than double that obtained using farmer practice. The IDEA 'low input' plots obtained 2.7

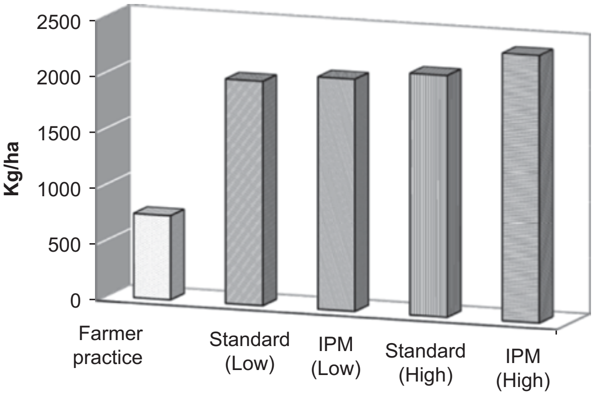

Figure 14.5 Seed cotton yield (kg/ha ± s.d.) (Kasese 2002–2003). 'Standard' refers to the normal IDEA/SPEED practices as detailed in the text. IPM practices replace the pest management component of standard practices while retaining the other components. Farmer practice returned the lowest yields and the IPM treatments gave the highest yields although fewer sprays were used, due to superior spray timing

Table 14.3 Seed cotton yields (kg/ha) in two Ugandan cotton districts in 2003–2004

	Farmer Practice[a]	Agronomy/IPM Demonstrations	
		Low Input	*High Input*
Kasese (n=249)	574	1,462	2,335
Palissa (n=309)	275	776	1,788

[a] Farmer Practice Figures are the average from the area prior to the demonstrations

Note: seed cotton contains 35 % lint. Source: Russell 2004

times the farmer practice yields and the IDEA 'high input' plots 3 times the yield. IPM plot average yields were not significantly higher than yields in the corresponding IDEA plots (Figure. 14.5). However, the gross margin was higher where IPM was implemented compared to the fixed-interval IDEA standard spray regime due to lower expenditure on insecticide.

The above results were obtained in a season when bollworm pressure was average to low. In the following season (2003–2004) pest pressure was higher. Data from 249 expanded IPM plots at Kasese, showed that on average in 'high input' plots, one spray was required for aphids, two for Lygus bug and one for bollworms. In the 'low input' plots an average of one aphid application, one Lygus application and one bollworm application was required. Average yields from the 'low input' plots were 487 kg lint/ha compared to 778 kg lint/ha from the 'high input' plots.

Scouting on the much larger sample of 833 IPM demonstration plots in Palissa in 2003–2004 (where the pest infestation was again higher than in 2002–2003 and yields were historically lower than on the volcanic soils in Kasese), suggested that an average of 2.6 insect control applications were required. All individual farmers in all the demonstrations got more yield from the 'high' input system and the IPM plots were on average more profitable than the non-IPM plots. Looking back at farmer practice yields in 2001 before the IDEA project began and comparing them with the results in the IPM plots in 2003, we see the following improvement in yield (Table 14.3).

Much of the benefit no doubt came from the adoption of the full package of crop production practices being promoted by IDEA of which the IPM component was a part. The time saved from not undertaking the four recommended calendar sprays was more than sufficient to undertake the 10 scouting sessions required over the season and of course there were reduced insecticide exposure benefits from the IPM system.

The parent crop enhancement project went on to expand the demonstration system, including the IPM component as standard. In the 2004–2005 seasons the program was active with eight lead ginners in the cotton provinces, running 6,560 cotton demonstrations, with 90,900 farmers attending the series of field days at each demonstration plot. The intention to work with all of Uganda's ca. 250,000 cotton farmers by 2007 was therefore within reach.

14.6 Sustainability of the IPM System

A full *ex ante* impact assessment of the impact of the IPM component was not conducted but it was clear that using the peg-board scouting aid became popular during the 4 year duration of the project. The pegboards became iconic items and were for a time, in high demand as a badge of a good cotton farmer, to the extent that local entrepreneurs in Eastern Uganda were making and selling them. There is no data for the number of additional farmers, beyond those hosting the demonstrations, who fully adopted the IPM system. The IPM components were presented as a series of actions, each of which, even on its own, would provide a benefit. For instance, the use of soapy water as a first spray against aphids, could be adopted, even if scouting was not. The adoption of aphid control with soapy water was negatively impacted by three factors. Firstly, farmers had great faith in chemical insecticides and doubted the efficacy of soap. Secondly, too much time was involved in preparing the soapy water spray from hard soap, as liquid soap is too expensive for most rural households. Thirdly, the concept of spraying so as to thoroughly wet the underside of leaves was unfamiliar (even though this would also have benefitted farmers using conventional insecticides).

In 2004 the APEP project surveyed uptake of all the recommended crop production practices in a sample of seven ginners 'zones' (Nyakatonzi, Dunavant, CN Cotton, Cott Co, Novo Tororo, North Bukedi and Bo Holdings) (APEP unpublished). Unfortunately, pesticide use was not surveyed in detail but only 21 % of farmers had yields less than 200 kg lint/ha (which had been the norm earlier), 44 % had yields of 200–400 kg and 36 % had yields over 400 kg (over 3 times the 2000 average). Surveyed farmers had some remaining difficulty with pest identification (18 %) and with the plant sampling system (20 %), but only 7 % had difficulty in deciding when to take pest management action. Full adoption of all IPM practices was limited to around 20 % of farmers but full plus partial adoption of pest identification was being undertaken by 72 % of farmers, the scouting practices by 66 % and IPM decision making by 67 %. Individual farmers had at most two seasons of experience with the IPM program at that stage. Further support in IPM practices was clearly desirable. Nonetheless, the capacity building activity associated with the IDEA Agronomy/

IPM system will have had a lasting impact as such large numbers of farmers were exposed to the concepts but this is difficult to quantify.

14.7 Conclusions and Lessons Learned

In seasons with low to average pest pressure, improved targeting of insecticide sprays through the use of pest scouting can decrease the number of insecticide sprays applied, compared to a fixed-schedule system.

In seasons with higher than average pest pressure, the use of scouting to inform the spray scheduling may result in more sprays than the recommended calendar-based schedule. However, the economic returns are still better from the scouting-based system, as less insecticide is wasted by spraying at the wrong time or from inappropriate insecticides being sprayed against the particular pest present.

Smallholder cotton farmers in SSA are able to adopt scouting-based IPM but only where its introduction is linked to extensive training inputs and there is access to technical assistance.

The public extension service does not have the human resources to provide the intensity of training and technical support required to sustain scouting-based IPM. This has to be done through farmers' organizations or the private sector. In the case of cotton, the ginning companies are best placed to provide such services, as they have a major presence in the districts and benefit directly from the extra cotton output generated. The Ugandan Cotton Development Organisation was very successful in providing incentives for lead ginners in each of the main cotton growing districts to provide training and inputs for farmers in the area, mainly through giving the lead ginners priority access to the cotton produced in their 'zone'.

National production reached 253,000 bales in 2004–2005 with a national average yield of 365 kg lint/ha (ICAC 2005), three times higher than in 2000. However, low world cotton prices from 2006 and great ginning over-capacity in the country, enhanced the practice of farmers 'side-selling' production to merchants other than the lead ginner, weakening the incentive for the lead ginner to provide inputs and training, and the system floundered in the late 2000s and with it, average yields. This experience re-emphasises the need for effective cotton extension systems which can survive through periods of low prices.

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Part IV
South America

Chapter 15
Agent-Based Models and Integrated Pest Management Diffusion in Small Scale Farmer Communities

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Contents

Abstract The purpose of this chapter is to present how agent-based models can be used for the diffusion of Integrated Pest Management (IPM) information in small scale farmer communities, using the potato tuber moth in the North Andean region as a study case. This issue was addressed through an international project called INNOMIP (*INNOvación en el Manejo Integrado de Plagas*, 2009–2012, funded by the McKnight Foundation), which operated in three Andean countries (Ecuador,

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Peru, and Bolivia). This project involved scientists from a broad range of disciplines, from agronomists to modelers to extensionists. With the specific objective of proposing innovative IPM extension tools, we first developed a role-playing game relying on an agent-based model to simulate the consequences of individual behaviors on pest control in a theoretical landscape. We then tried this role-playing game with 90 farmers belonging to 6 communities in three countries. Briefly, the training sessions consisted of a board game where farmers could exchange and discuss information about IPM practices and visualize the benefits of IPM adoption and cooperation within a theoretical landscape. Based on farmer interviews and comparison of IPM level of knowledge before and after the sessions, our study suggests that the role-playing game sessions significantly increased the IPM knowledge score in the community and also reduced farmers' knowledge heterogeneity. Moreover, our analyses suggest that farmers' age and extension experience significantly affected role-playing game success, with younger participants (and among them, those with higher initial knowledge) more inclined to increase their IPM knowledge after the session. While we have no evidence of the long (mid)-term benefits of our sessions in the adoption/changes of IPM practices, farmers revealed themselves more predisposed to understand and realize the importance of the cooperative basis of IPM and therefore disseminate to their peers IPM information they had acquired. At a broader scale, this study exemplifies how a computer simulation model can be used for teaching purposes and may represent a promising complement to existing IPM diffusion programs. More broadly, our experience with ABM (Agent-Based Models) for IPM issues suggests that new approaches in pest management extension practices should include topics such as group decision making, intergroup relations, commitment, and persuasion which deal directly with how other farmers influence each other's thoughts and actions and consequently with the level of insect infestation in the community.

Keywords Role-playing game · Potato tuber moth · Andes · Social-ecological systems · INNOMIP program

15.1 Introduction

Food security of millions of people in the third world has faced a growing number of challenges in recent years including risks associated with climatic change and extreme events, unprecedented price hikes for basic food and the continuing growth of the human population (Gregory et al. 2009). If future world demand is to be met, food production must virtually double by the year 2050 (Thomas 1999). One potential approach of meeting part of this demand is the control of insect pests and diseases, which are estimated to cause losses approaching 60–70 % in available crop production and storage in developing countries (Nwilene et al. 2008); farmers cannot afford to feed pests in addition to themselves. In the Andes, climate and habitat changes are considered to be one of the most serious threats to sustainable development, with adverse impacts expected on the environment, human health, economic activity and food security (Young and Lipton 2006). Over the last decade, the tropical Andes have also experienced socio-economic and institutional changes that have increased the pressure on natural resources, weakened the internal social organization and caused cultural erosion in the Andean society, reducing the capacities of populations to overcome these challenges (Perez et al. 2010). At the interface between environmental and social changes, the risks related to agricultural pests are of major concern for the food security of thousands of Andean farmers. For example, the emergence and spread of new invasive insect pests (*e.g.,* potato tuber moths in Ecuador, *Tecia solanivora*) are a consequence of both climatic and socio-economical factors (Dangles et al. 2008, 2009). The risks related to agricultural pests in a changing climate will be of major concern for the food security of thousands of Andean farmer communities for at least two reasons. First, effects of temperature increase on insect pests is expected to be greater in the mountainous regions than in lowlands, reflecting the prediction of much larger proportional temperature rises in the mountainous regions (Hodkinson 2005). Second, the wide range of thermal environments found along altitudinal gradients in the Andes may increase the risks presented by invasive pest species in the near future (Hagen et al. 2007; Dangles et al. 2008). More species can "be packed" into a long thermal axis than into a shorter one. Small differences in elevation can also create strong microclimatic differentials over short distances and allow persistent microclimatic refuges for pests to develop (Bale et al. 2002).

However, given the paucity of studies on Andean pest response to climate and the complexity of agro-ecosystems and farmer mitigation response, mid- to long-term predictions regarding the effect of climate change on pests in the Andes remain uncertain. In view of recent developments in empirical data analysis and modeling (Gelman and Hill 2007), new approaches are now available to better understand and predict pest dynamics. A transfer of this knowledge to local technicians is a great way to strengthen the resilience of the Andean region to pest problems; technicians have a key role in transferring advances in scientific knowledge to farmers (Feder et al. 2004).

Because of important limitations such as access to technology and funding, low levels of education, or village inaccessibility, the transfer of integrated pest management (IPM) knowledge through pest management programs is a difficult task in developing countries and policy makers have long been in search of new and better strategies to promote IPM (Oerke 2005). During the last decade, several participatory research, management and teaching programs have been implemented in the Andes to help small farmers facing risks presented by agricultural pests (Thiele et al. 2001). Among them, farmer field schools (FFS) are an intensive training approach extensively applied in the last decade to promote knowledge of agroecological concepts, apply IPM practices, reduce the use of pesticides and improve crop yields (Pumisacho and Sherwood 2005). Because of the high training cost, the success of FFS depends on the effectiveness of knowledge diffusion from a limited number of trained farmers (graduate farmers) to other farmers (exposed farmers). Graduate farmers are therefore encouraged to share their knowledge with other farmers within their communities. Although this aspect is fundamental for the progress of knowledge enhancement programs, theoretical studies on diffusion from FFS have received little attention and empirical evidences provide conflicting conclusions (Feder et al. 2004). The way acquired information is spread by exposed farmers is a complex process that can be affected by a number of factors such as the structure of the interaction social network, the size of the community, the level of homophily (common interests among farmers) or the spatial organization of the community (Feder and Savastano 2006). A better understanding of the processes by which new knowledge spreads through farmer communities is of crucial importance for the success of farmer training programs (Dangles et al. 2010; Rebaudo and Dangles 2011). We believe that new approaches, such as agent-based models (Bonabeau 2002; Rebaudo et al. 2010, see definition thereafter), would strengthen the role of education in reducing community vulnerability to pest risks, and spur adaptation to ongoing climate-driven changes in pest distribution and abundance.

15.2 Diffusion Theory and Integrated Pest Management

For almost half a century, the theory and practice of agricultural extension has been dominated by Rogers' "diffusion of innovation theory" (Peshin et al. 2009). As mentioned above, the success of IPM programs depends on the effectiveness of information diffusion from farmers to farmers, a precept that has demonstrated varying results (Rebaudo and Dangles 2013; Matteson 2000). These may be due to the very nature of the information being disseminated: is it the philosophy of IPM (i.e., an integration of all elements of the agro-ecosystem and their interaction leading to a given set of practices in a given context) or rather advised practices in an IPM context for a given problem? As exemplified by Peshin et al. (2009), there are several levels of integration that constitute the IPM approach. Along with these considerations, there are several technical and socio-economical factors that must be taken into account, from the trialability and risk perceived by farmers, to the farmers' social network. Trialability (one of the criteria for acceptance of innovation according to Rogers (2003) is the perceived degree to which an innovation may be tried on a limited basis or small-scale, and thus reduce risk, which would enhance the chance of acceptance. Such complexity can however be represented in a simplified way using different modeling approaches. The common approach is mathematical and relies on the Bass model (Mahajan et al. 1990; Bass 1969), describing the "S-curve" of cumulative adopters as follows:

$$\frac{dN(t)}{dt} = \frac{q}{m} \cdot N(t)(m - N(t)) + p \cdot (m - N(t)) \tag{15.1}$$

Where *N(t)* represents the cumulative number of adopters and *dN(t)/dt* the variation of the cumulative number of adopters as a function of time *t*, *p* and *q* the coeffi-

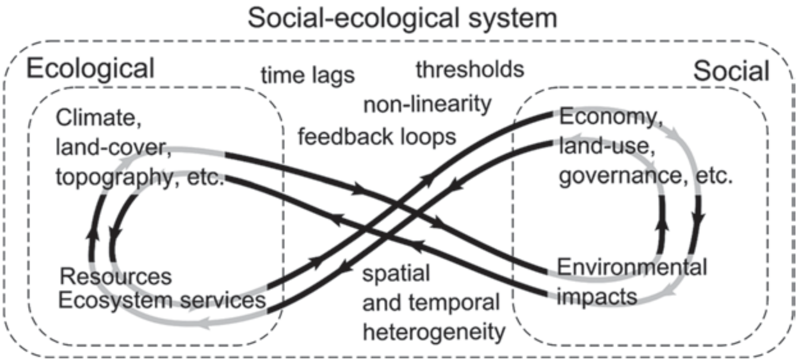

Fig. 15.1 Representation of a social–ecological system that is affected by ecological (*left-hand side*) and social properties (*right-hand side*), and exhibits time lags, thresholds, non-linearity, feedback reciprocity loops and heterogeneity. (based on Chapin et al. 2009; Liu et al. 2007)

cient of external (*e.g.* marketing, television, radio) and internal (world-of-mouth, mimicry) influence, respectively, and *m* is the number of potential ultimate adopters.

In the Bass model, however, social networks through which the innovation is disseminated, are not taken into account, while the importance of social networks has been recognized to influence information diffusion (Fowler and Christakis 2010), with different networks favoring the spread of new ideas or technologies (Montanari and Saberi 2010). In this context, another modeling approach, using agent-based simulations, seems particularly promising (Kuandykov and Sokolov 2010).

15.3 Agent-Based Models in Social-Ecological Systems

In most countries around the globe, land is dedicated to crops, so that agriculture plays a major role in shaping landscapes (Firbank et al. 2008; Ziegler et al. 2011). These landscapes constitute social-ecological systems (SES), i.e., systems where environment and human activities are tightly linked (Hufnagl-Eichiner et al. 2011; see Fig. 15.1). SES are characterized notably by non-linear dynamics, thresholds, feedback loops or delays in time (Liu et al. 2007), and are consequently susceptible to unexpected changes (Chapin et al. 2009).

However, questions related to the interactions between ecological dynamics and social dynamics have been examined for many years either as "an ecological system subject to anthropogenic disturbance" or, as "a social system subject to natural constraints" (Bousquet et al. 1999). In this context, agent-based models appeared to be a good alternative to integrate knowledge from both social and ecological sciences (Smajgl et al. 2011). This type of computer model is composed of autonomous entities able of acting upon themselves and their environment (Daudé 2003). When considering human agents, it allows the integration of behavioral heterogeneity, which in the case of IPM programs, is a key issue to understand and predict the success of pest control information diffusion on a large scale (Paredes 2010; Rebaudo and Dangles 2013).

Agent-based models (ABM) in a social-ecological context have been widely used to represent the management of commons, for example natural resources like water (Becu et al. 2003), bush meat (Bousquet et al. 2001), or forests (Bonaudo et al. 2005). ABM have also been employed to represent land-use and land-cover changes (Parker et al. 2003), but less often to simulate farmers' behaviors facing a pest (Carrasco et al. 2012), or as an educational tool for sustaining functional agrobiodiversity in farming systems (Speelman and Garcia-Barrios 2010). Moreover, ABM have proven to be excellent support for teaching and role-playing games, as exemplified by the Cormas group (*e.g.* Guyot and Honiden 2006; Dray et al. 2006; Mathevet et al. 2007; Barnaud et al. 2008), and seemed promising in the case of IPM diffusion among small scale farmers of the Northern Andes.

15.4 Application Within Farmer Communities in the Northern Andes

We designed a computer model of the Andean agricultural system as a support to realize a role playing game with potato growers of the Andean region facing pest problems. The main objective was to use the model to enhance the farmers' awareness that pest problems should be considered at the regional scale and that individual actions should be coordinated to reduce pest populations to an acceptable threshold. A key factor of coordination was underlined as being the wide sharing of information regarding integrated pest management among community members. The pest model consists of a cellular automaton which represents pest densities on a spatially explicit landscape, implemented on the basis of previous work of our team on the potato tuber moth *Tecia solanivora* (see Crespo-Pérez et al. 2011). The farmers (mainly subsistence and market-oriented farmers, see Dangles et al. 2010 for a description of Ecuadorian potato growers of the Andean region) were represented through an agent-based model where actions of each participant were updated at each time step, depending on their selection of practices. Briefly, IPM technologies for the potato tuber moth *T. solanivora* consist of prophylactic measures targeting fields and storage facilities (see Pollet et al. 2003 for a complete description). These technologies were developed taking into account farmers' local constraints whenever possible. Their implementation requires a low economic investment and is reasonably time-consuming compared to existing practices, to ensure sustainability of the production system. A board game was used to represent the landscape, the farmers and pest densities in grid cells represented farms. The formation was divided into five parts: (i) preliminary session with farmers (Fig. 15.2, part c and d); (ii) presentation of the role-playing session and appropriation of the board game by participants (Fig. 15.2, part e and f); (iii) initialization according to inquests among participants (Fig. 15.3, part a and b); (iv) role-playing session (Fig. 15.3, part c, d and e); and (v) discussion and diffusion of information (Fig. 15.3, part f).

Fig. 15.2 Pictures of the role-playing game sessions. *Part (a)*: board game with participants of the Marcopamba community in Ecuador. **(A)** theoretical landscape composed of 16 grid cells where farmers managed the pest. **(B)** playing cards representing management decisions. **(C)** set of colored cards used to update pest abundance in each grid cell (based on the simulation model outputs). *Part (b)*: Screenshot of the agent-based model computer simulation. The gradient of colors indicates the severity of pest infestation, from blue (no infestation) to red (high infestation). *Part (c)* and *Part (d)*: preliminary sessions in Bolivia and Ecuador, respectively, with participants filling out the questionnaire. *Part (e)* and *Part (f)*: Presentation of the game board in Bolivia and Peru, respectively. Participants localize their farm in the board game and appropriate the space thanks to drawings representing their main activities

Fig. 15.3 Pictures of the role-playing game sessions. Initialization of the game board is realized thanks to questionnaires and dispersal of the pest from one farm to another (part (a) and (b) in Peru and Ecuador, respectively). Then a specific pest management practice is discussed according to playing cards (Part (c) in Peru and (d) in Ecuador). Each participant's practices can then be updated according to their choices which consequently are updated in the board game thanks to the computer simulation (Part (e) in Peru). When all pest management practices have been discussed, a general discussion is opened between farmers (Part (f) in Bolivia)

15.4.1 Preliminary Session with Farmers

The preliminary session with farmers was organized about two weeks prior to the role-playing game session in order to get a first contact with farmers involved. At the beginning of the session, there was a consensus among farmers about the need of implementing a pest management program in their area. In order to evaluate farmers' IPM knowledge, participants were asked to fill in a questionnaire including 11 items on pest management practices during different stages of the potato crop (seed selection, field practices, harvest, storage, see Fig. 15.2, part c and d). We also registered on the questionnaire the participant's age and sex for further analyses (see Sect. 15.4.5). Based on the completed questionnaires, we built a "knowledge index" for each farmer, which corresponded to the percent of questions answered correctly. These data were later used to initialize the model. Note that some partners of our group (in Peru) had been promoting IPM among farmer communities, and documenting this process over several years and, in this case, the preliminary session was not necessary and the whole session was realized in a single day (instead of two days).

15.4.2 Presentation

The computer model consisted of a coupled cellular automaton (CA) representing pest dynamics and agricultural landscape (see Crespo-Pérez et al. 2011), with an agent-based model representing potato farmers facing the pest. Briefly, the CA was a spatially explicit simulation model accounting for the pest dynamics (reproduction, survival, and dispersion), in a theoretical landscape divided into grid cells. The farmers of the agent-based model behaved accordingly to participants' decisions which were updated at each time step in the model (information diffusion and control practices). These decisions influenced pest dynamics which were used to update the role-playing game in return (see Rebaudo and Dangles 2011 for a detailed description of the model).

The role-playing game consisted of a game board divided into grid cells (similar to the computer simulation model), used in parallel with the computer model (see Fig. 15.2 part a and b). The game board itself was composed of 16 square cells representing participants' farms (see Figs. 15.2 and 15.3). Note that if more than 16 farmers came to the session they were observers, but conceivably they could team up to play in pairs. The cells were disposed to form a grid of four by four cells. Each participant was responsible for one cell representing a potato production unit (i.e., a farm). Participants' pest management decisions were made within pre-defined options through playing cards and pest abundances were represented through a set of colors (from no pest to severe abundance, see Fig. 15.2, part a). Once participants were familiar with the representation of the landscape and the management options, we initialized the simulation model.

15.4.3 Initialization

In the preliminary session (see above), each participant was asked to answer questions about theoretical and practical aspects of integrated pest management (Fig. 15.2, part c and d). Answers were used to initialize the level of pest infestation in each farm. One of the 16 participants in the role-playing game was systematically an extension agent whose role was to adopt unsuitable control strategies to foster the heterogeneity among agents regarding control practices, and consequently underlined the negative effect of individual behavior at the community scale.

15.4.4 Role-Playing Session and Discussion

Once levels of pest infestation were initialized for each farmer, a computer simulation was run to determine a scenario of pest dynamics, given the spatial configuration of all participants in the role-playing game (dispersion of the pest to neighborhood farms, see Fig. 15.2 part b). Levels of pest infestation were updated accordingly in the board game and a discussion was opened among farmers, which focused on hypotheses to explain the new situation. In any case, the presence of the extension agent participating as a farmer without good control practices led to the necessity of : (1) integrating more components in control practices to ensure a better control of the pest (e.g., IPM practices, vision of the landscape as a whole); and (2) diffusing the IPM information to neighbors so that fewer pests would disperse from neighborhood farms (see Fig. 15.3 part c and d).

Using a set of playing cards (see Fig. 15.3 part d), farmers were then offered the possibility of changing their practices. Each card, read collectively among all participants, represented a key point of potato production regarding the pest in question. Then different control strategies were offered to reduce pest incidence and a discussion was opened to let farmers exchange information and decide which strategy they wanted to apply (see Fig. 15.3, part c and d). Then, decisions were updated in the computer model and levels of pest infestations were updated in the board game. The role-playing game continued as long as there were remaining playing cards. Finally, a general discussion ensued.

At the end of the role-playing session, a majority of the theoretical landscape contained low levels of pest infestation, except for the extension agent's farm and farms neighboring it. A general discussion among all participants stressed the need of diffusing information to all farmers of the community to reduce pest incidence at the landscape level (see Fig. 15.3, part f). To conclude, we reevaluated participant knowledge on pest management issues with the 11-item questionnaire used for the first session.

15.4.5 Impact of Role Game Sessions on Farmers' Knowledge

Our sessions gathered both male (64 %) and female (36 %) participants, young and old (39 % less than 40 years, 41 % between 40 and 60 years, and 20 % more than 60 years). Their mother language was Spanish (30 %), Quechua (35 %) or Aymara (35 %); the sessions were carried out in Spanish with translation to Quechua and Aymara. Most participants had received limited IPM training sessions in all countries. We assessed participants' learning by comparing their IPM knowledge before and after the training session using a pair t-test (knowledge scores before vs. after training). Results for the six studied communities (total of 90 potato growers directly participating in the role game) and for each of the four stages of pest control practices (during seed selection, crop production, harvest, and storage) are given in Table 15.1. Overall, we found that all participants increased their pest management knowledge after the training session (significantly in 66% of the surveys, t-test, $P<0.05$, Table 15.1). Importantly, our data also show that training sessions decreased farmers' knowledge heterogeneity in the community, as evidenced by lower standard deviation and min-max range values after the training session than before (see Table 15.1).

We further used generalized linear models (GLMs) to test the effects on farmers' learning (expressed as the difference between their knowledge after the session and before the session) of five variables: participant age, sex, initial knowledge, community, and country (Ecuador, Peru, and Bolivia). We used standard model simplification procedures to identify significant terms of the initial models, by starting with the most complex model (including all variables and interactions) and subsequently eliminating higher-order terms. Of the five variables included in our GLM analysis, age and country best explained differences in farmers' learning among the six training sessions (see statistics in Table 15.2). Overall, older participants (>60 years) had lower learning scores than younger ones. Also, learning scores differed among the three countries (they were higher in Peru, followed by Ecuador and Bolivia), suggesting that factors associated with the experience of the local training team (e.g., long-term interaction with the communities, experience of the extensionist to lead the session, etc…) is likely to influence the success of the sessions. IPM knowledge, sex, and community were not significant predictors of farmers' learning after the role-playing game session ($P=0.167$, 0.198, and 0.251, respectively). Interestingly the GLM revealed a significant interactions term between age and initial knowledge (see Table 15.2) suggesting that young (<40 years) participants with high initial IPM knowledge had the highest probability to increase their IPM knowledge during the session ($P=0.023$).

All this suggests that while role game-based sessions had an overall positive impact on the IPM knowledge of the whole community (both increasing mean IPM knowledge score and decreasing heterogeneity among farmers), their effectiveness increased with young participants and when the extensionist group has a long experience in pest management training.

15.5 Conclusion and Discussion

A key achievement of the role-playing game based on an ABM was that, by providing farmers with evidence that pests propagated through their community not as the result of isolated decisions by individuals but rather as the result of repeated interactions between multiple individuals over time, our ABM pointed at key psychological and social issues that were highly relevant for efficient management

Table 15.1 Farmers' pest management knowledge (% correct answers) before and after their participation in the role-game-based training session in six communities of three Andean countries (Ecuador, Peru, and Bolivia). Focus pests were the Gelechid potato moths for all communities except Ccasapata and Quiripujo; in these cases the insect pest was Andean weevil as tuber moth which although present so far has not shown damage. Data are means ± standard deviation (SD) of 15 farmers' marks for four different stages of the potato crop: seed, field, harvest, and storage. Minimum and maximum IPM knowledge values are given between brackets.

	Ecuador				Peru				Bolivia			
	Marcopamba		Santa Ana		Quilcas		Ccasapata		Callisaya		Quiripujo	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
Seed	34±16	68±10*	37±18	77±9*	64±37	98±7*	68±39	72±32	22±12	58±10*	43±25	62±12*
	(0–70)	(10–100)	(0–70)	(40–100)	(0–100)	(80–100)	(0–100)	(0–100)	(0–50)	(5–85)	(0–90)	(30–100)
Field	50±19	79±13*	31±22	69±11*	59±18	91±7*	66±16	89±9*	38±11	42±10	50±23	55±17
	(0–80)	(45–90)	(0–70)	(30–100)	(25–85)	(80–100)	(45–95)	(65–100)	(0–60)	(5–70)	(10–80)	(15–90)
Harvest	52±23	78±12*	56±22	64±11	47±19	80±18*	39±19	59±11*	29±12	51±8*	30±15	39±15
	(0–100)	(55–100)	(0–90)	(10–85)	(0–70)	(50–100)	(0–70)	(30–70)	(0–60)	(20–90)	(10–80)	(10–80)
Storage	49±21	79±14*	42±23	78±12*	76±28	89±17	95±5	100±0	44±11	50±12	39±17	59±9*
	(0–80)	(43–90)	(0–80)	(25–100)	(20–100)	(50–100)	(70–100)	(100–100)	(0–65)	(10–80)	(20–70)	(30–90)

* denotes significant increase in pest management knowledge after the training sessions (Pair t-test, $P < 0.05$)

Table 15.2 Results of the generalized linear model (GLM) analysis on farmers' learning (expressed as the difference in pest management knowledge after vs. before the training session). Data include 15 farmers in six communities in three countries (total 90 farmers). For each analysis, all terms and their interactions are included in the model. AIC is the Akaike's Information Criterion for the initial model after removal of the "effect" term. ΔAIC corresponds to the difference between the AIC of the initial model and that of the reduced model. Likelihood ratio test (LRT) and associated P-values test the hypothesis that the suppression of the 'effect' term provides no better fit than the initial model. Only significant interaction terms of the GLM analysis are shown. Analyses were performed using the MASS library for R (R Core Research Team 2009)

Effect	AIC	Δ AIC	LRT	*P*-value
Initial knowledge	161.3	1.8	1.439	0.167
Age	157.9	5.2	4.551	0.032*
Sex	161.3	1.8	1.654	0.198
Community	161.6	1.5	1.320	0.251
Country	158.7	4.4	3.897	0.043*
Age × initial knowledge	155.7	7.4	6.091	0.023*

* denotes significant likelihood ratio tests (p-value < 0.05)

of invasive pests, and a central point of integrated pest management (Peshin et al. 2009). ABM may therefore be a powerful tool to advance the application of social psychology theory by stakeholders in rural communities (Smith and Conrey 2007) and to change individual attitudes (Jacobson et al. 2006), all of which is needed for the adoption of IPM in remote areas of developing countries. This suggests that new approaches in pest management extension practices should include topics such as group decision-making, intergroup relations, commitment, and persuasion which deal directly with how other farmers influence each other's thoughts and attitudes toward cooperation and actions (Mason et al. 2007; Urbig et al. 2008). By examining group- and population-level consequences on the invasion process, agent-based modeling may therefore reveal its potential as a powerful pedagogical approach to change behaviors across large populations, a long lasting issue in pest management outreach programs worldwide (Feder et al. 2004). While we have no evidence of the benefits of our sessions in the adoption/changes of IPM practices, farmers revealed themselves more predisposed to understand and realize the importance of the cooperative basis of IPM and therefore disseminate to their peers IPM information they acquired. This suggests that more than being a support for teaching IPM, role-playing games served as a support for discussion between farmers facing the same problems but with different perceptions (Meulen et al. 1996). Moreover, the theoretical landscape can be perceived as a unique tool for virtual experiments (Macy and Willer 2002; Grimm et al. 2005), especially relevant in the case of agriculture and IPM, where adoption is conditioned by trialability (Peshin et al. 2009). In this context, any farmer can evaluate the consequences of his/her collaboration, enhancing collaboration of others (Fowler and Christakis 2010). Because ABM telescopes the time of training sessions and expands the discussion at a landscape level, with a minimal time cost for participants they may represent a useful complement to farmer field school extension events. At a broader scale, this study exemplifies how a computer simulation model can be used for teaching purposes and may represent a promising complement to existing IPM diffusion programs. More broadly, our experience with ABM for IPM issues suggests that new approaches in pest management extension practices should include topics such as group decision making, intergroup relations, commitment, and persuasion which deal directly with how other farmers influence each other's thoughts and actions. In this context, understanding to what extent ABM-based farmer thinking and discussion could be used more directly to support increasing adoption remains a promising area of research to assess how ABM may help strengthen food security in small-scale farmer communities.

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Part V
Australia

Chapter 16
Pesticides and Integrated Pest Management Practice, Practicality and Policy in Australia

David Adamson, Myron P Zalucki and Michael J Furlong

Contents

Abstract Policy settings influence how farmers manage pests. To successfully grow and market a crop an individual farmer has to engage in pest management. Their management strategy is subject to the relevant domestic policies. These policies are in turn shaped by international agreements concerning maximum residue levels for pesticides and the sanitary and phytosanitary (SPS) agreements on trade. Policies are designed to solicit a response by using incentives and penalties to achieve a set of social objectives. These policies create signals to which the wider domestic settings and international economies respond. Consequently the ultimate

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outcome from these signals may be counter to the initial design (or intention) of the policy. This chapter outlines some of the economic underpinnings required for good pest management policy and it explores why farmers respond to the same pest problem differently. The discussion will examine the national drivers behind pest management in Australia and discuss the implications for both on-farm pest management and the wider community. To enable this discussion the economics of integrated pest management is presented to articulate individual responses to a policy setting. Finally we examine the policies required to create successful area-wide management systems in rural Australia.

Keywords Economics · Policy · Resource · Allocation · Decision making

16.1 Introduction

The central narrative of this chapter is built around a simple question, but one which is deceptively difficult to answer:

> Why do we manage pests?

This question can be broken down to a number of subsidiary issues. What drives the decision to undertake pest management? Is the individual's decision based on a passive action (for example, only undertaking routine pest management actions or purchasing pre-treated seed), an active response to a situation (for example, monitoring and responding to density thresholds), or was the individual compelled to act by the direction of another individual (for example, legal enforcement to comply with an eradication campaign)? How does an individual justify the decision to allocate financial, capital and labor resources to their chosen response, which may include no action? At a given point in time are the constraints on the available management choices due to policy, subjective preferences, the individual's ability to manage pests or the resource endowments available? What role does policy play in framing the pest management context for an individual and society at large?

Ultimately the complexity of the initial question is daunting and well beyond the scope of a single chapter. This chapter summarizes the economic arguments that drive the national approach to pest management in Australia and the resulting policy implications for the farming community and Australian society as a whole. To maintain focus, practical case studies help frame the economic debate.

The definitions and practice of Integrated Pest Management (IPM) are context specific. The 'I' in IPM has been challenged and it has been suggested that in practice 'I' could be defined as 'integrated', 'improved' or even 'incidental' (Zalucki et al. 2009). If 'I' truly represents integrated then the problem becomes how an individual would best manage a pest with all available resources. 'Best' to an economist would be an optimal combination of management tools derived from all possible management options with the objective function to maximize economic rents through time, subject to resource limitations. 'Best' could equally apply in a scientific framework as the eradication (or sustainable abatement) of a pest population, or 'best' as in least pesticide use, or 'best' as the adoption of 'natural enemies' (predators, parasitoids, etc.). If 'I' implies 'improved' then what is improved, the financial bottom line, efficiency of pesticide use or biodiversity within a paddock or landscape? If 'I' really means incidental, does this mean that we have arrived at a research treadmill where we jump from one problem to the next to achieve short-term gains but create no long-term solution? For IPM to be a plausible alternative to a pure pesticide management strategy, the benefits from its adoption must be justified either from an individual or national perspective. If it is the individual farmer who benefits, then no compensation is required. If the transformation to adopt IPM is for the national good, but the shift comes at direct private costs for individual farmers or managers, then what policy signals are required to stimulate wide-scale adoption of IPM? Policy engages in trade-offs between groups aiming to maximize social objectives. It must determine which instruments (regulations, prices and/or compensation) are required to facilitate this adoption of new policy.

We deliberately take a wide view of pesticides, integrated pest management and policy to illustrate the complexity and diversity of issues that policy must consider within an integrated world. First, we contextualize how Australia's domestic policy has been shaped by international regulatory frameworks, the biophysical characteristics of Australia's agricultural development, past policy decisions and national social objectives.

16.2 Policy and Pest Management in Australia: A Top Down View

Domestic pest management policy is a multifaceted legislative framework that has scale, scope, spatial and temporal dimensions. Policy scale ranges from compliance with international agreements through to local government and industry requirements. Policy scope includes issues as diverse as chemical regulation procedures, minimizing environmental harm and protecting human health and providing the legal and financial settings for compliance in pest management procedures. The spatial dimension defines at which scale and scope settings apply. The temporal dimension adds both obsolescence to existing policy settings and evolving requirements in response to emerging issues at a scale, scope and spatial level. Policy has created an intertwined quagmire of compulsory regulations and suggested management practices that have evolved through time, creating opportunities and constraints for producers. This policy labyrinth can create conflicting signals for farm managers.

Australian agriculture is export-focused. Consequently Australia has developed a rigorous policy stance on quarantine and food safety to preserve its comparative export advantage, maintain its biodiversity and protect human health. This stance has three key aspects. First, the policy stance defines the level of risk from the unintended consequences of international trade (to humans, economic activity and impacts on the environment) that Australia is willing to accept. Second, Australian policy focuses on maximizing trade opportunities by ensuing that agricultural products meet international standards for market access. Third, it subsidises the costs of managing existing and new pest issues.

Policy impacts do not stop at the intended target. Their signals influence Australian society and international markets. These signals can unintentionally create perverse outcomes for both those directly targeted but also in the wider community. Within this policy framework individuals operate within a range of personal, industry and institutional goals. The adherence to these goals occurs at a cost, both financially and operationally. An individual's compliance to all policies can be circumspect since, despite a range of incentives and penalties designed to solicit a given response, the outcome can be counterintuitive. This section focuses on the past policy settings and the resource endowments that have shaped production systems in Australia. We discuss two policy areas: the national approach to chemical registration, which increases costs and limits management choice; and public expenditure, which subsidizes management expenditure.

16.2.1 International Policies and National Objectives

Donald (1982) argues that a combination of just plain "dumb luck", strict quarantine regulation and geographical isolation are responsible for Australia being free of many of the trade restrictive sanitary and phytosanitary (SPS) issues facing producers in the rest of the world (Nairn et al. 1996). This quarantine policy has contributed to Australia becoming the fourth largest net food exporter in the world (Keogh 2011). Australia specializes in producing bulk commodities including wheat (McNeill and Penfold 2009), barley (Murray and Brennan 2010), canola (Gu et al. 2007), sugar (Allsopp 2010), cotton (Agbenyegah 2012), pasture-based beef (Petherick 2005) and sheep-based products (Kahn and Woodgate 2012). A combination of a highly variable climate (Khan 2008), biophysical resource constraints (Davidson 1965) and limited assistance to agricultural producers (Anderson et al. 2007) have driven this specialization towards low input, low output production systems.

A reliable market is essential to retain the economic viability of low-input bulk commodity production. Due to the limited Australian domestic market, the agricultural industry is heavily reliant on international market access. Between 2003–2004 and 2010–2011, over 70% of the gross value of Australia's agricultural production was derived from international market sales (ABARES 2011).This dependence on exporting ensures that the wider agriculture sector delivers outputs that meet international market requirements. Here we simplify market requirements as 'nil' for both pests and chemical residues. 'Nil' pest compliance occurs when no live pest is found at the import terminal. The compliance to 'nil' chemical residues is achieved when detectable residue is less than or equal to the predetermined maximum residue levels (MRL) described by the market. Failure to comply can result in direct financial penalty, the partial loss of market access where only areas that are declared to be designated free of the problem can export, the temporary closure of the market until the issues are resolved and ultimately total closure of the market. At each stage in the process, the net costs for exporters and Australia as a whole increase.

The CODEX Alimentarius Commission (Codex), which is recognized under the World Trade Organization's SPS Agreement, develops internationally recognized food safety standards, including MRL levels. However, an individual country can apply alternative standards to the Codex based upon scientific evidence relevant to their specific risk profile. As both science and the 'willingness to accept risk' evolve through time, MRLs remain fluid, as they are defined by both real and perceived risk. This fluidity creates both opportunities and threats for producers in individual countries (Adamson 2010) and can be met with an appropriate response in changes to inputs for producers determining management options.

This combination of export market preservation and a low input agricultural production system drives Australia's national policy in pest management. This includes constraining the inputs pest managers use, shaping research and development priorities and providing wider social benefits.

16.2.2 Competing National Goals

Australian policies related to agriculture, trade, veterinary products, chemical registration and the environment are designed to maximize social welfare, but they constrain how farmers use pesticides. While strict quarantine policies aim to provide an environment free from exotic pests, they create higher prices for domestic consumers. Sound policy must determine the trade-offs from alternative actions and decide if compensation is required for those adversely affected by a policy. Policy needs to determine what is best for the nation now and into the future. However, policy is based on subjective social preferences and incomplete information. As social preferences change and future uncertainty abounds, policy must adapt.

Being 'pest free' and having the ability to determine individual MRL levels allows the Australian Pesticides and Veterinary Medicines Authority (APVMA) to specify what pesticides (insecticides, herbicides and disease management compounds) and production additives (hormone growth regulators) are registered and the conditions for their use within specified production systems are specified (Adamson 2010). These specifications are altered through time as new information emerges and results in change, not only in which types of pesticides remain registered for use, but also how they are used by different industries.

For a new pesticide to be registered in Australia, it must pass three tests. First, the compound and its handling must be deemed safe for the commodity it is applied to, the individual applying it, consumers of the final product and the environment in which it is applied. Second, the stated benefits of the compound must be substantiated. Third, it must be ensured that its use "would not unduly prejudice trade or commerce between Australia and places outside Australia" (Commonwealth of Australia 2011, p. 20). The registration testing operates on a cost recovery basis and is applicable to each application, variation of compound or use, and for each major food group that the pesticide is applicable to. For a pesticide to remain registered, both an annual fee and a levy on the value of sales must be paid. This pricing structure forces costs to be passed onto consumers in one of two ways. First, due to the high cost of registration and a small market, not all pest management products are registered in Australia. Second, the cost of purchasing some pesticides deters their widespread use.

This combination of high cost and limited options drove Walker and Stirling's (2008) work to explore nonchemical approaches for nematode management in viticulture. In this situation only a limited number of pesticides were registered. The first, a nematicide (fenamiphos) was facing deregistration in response to new scientific information in the United States concerning human health. A second group, fumigants based on 1,3-dichloropropene, were in practice only used as an option of a last resort due to high costs. In this case, Australia's registration policy forced producers to adopt industry specific research that had developed low pesticide integrated pest management strategies.

Is low pesticide use for nematodes then, an example of traditional IPM practice, which is driven by intelligent policy design, or an accidental outcome that is an artifact of inflexible policy? There are wider social benefits and costs applicable to the registration process that need investigation.

Climatic conditions complement the low input farming systems and the stance on chemical registration by the Australian Government. As cattle production in Australia is primarily low-input pasture-based and, due to a moderate climate, animals are not over-wintered. In production systems that have to over-winter stock at high densities, preventative disease management treatments (antimicrobials) are used to maintain health and livestock receive production supplements to ensure live weight gain. This has allowed APVMA to separate antimicrobial agents between humans and livestock in Australia and not register a number of production supplements used overseas. Although in practice not always perfectly applied, only those antimicrobial agents considered as low importance for humans are registered for livestock (Jordan 2007). This separation of antimicrobial registration has two impacts. First, it slows the rate of antimicrobial resistance caused by cross species use (JETACAR 1999) reducing human medical costs. Second, based on cross-country studies, there is clear evidence of lower antimicrobial resistance in piggeries in Australia, implying costs savings from the reapplication of treatments (Adamson 2010).

However, the lack of registered antimicrobial compounds in Australia encourages loophole exploitation through'off-label' use in intensive industries, especially in in aquaculture. (Akinbowale et al. 2006). 'Off-label' usage ranges from deliberate breaches of regulations where legal penalties can be applied, especially if detection threatens trade, to legally prescribed use on the basis of animal health and welfare issues (Bond 2005). Akinbowale et al. (2006) reported that the resistance to antimicrobials detected in Australian aquaculture posed a human health risk. This policy outcome occurs when ethical and welfare issues coincide with a lack of management alternatives, creating a disincentive for policy enforcement. Such intractable situations then require increased research to develop alternative practices. The

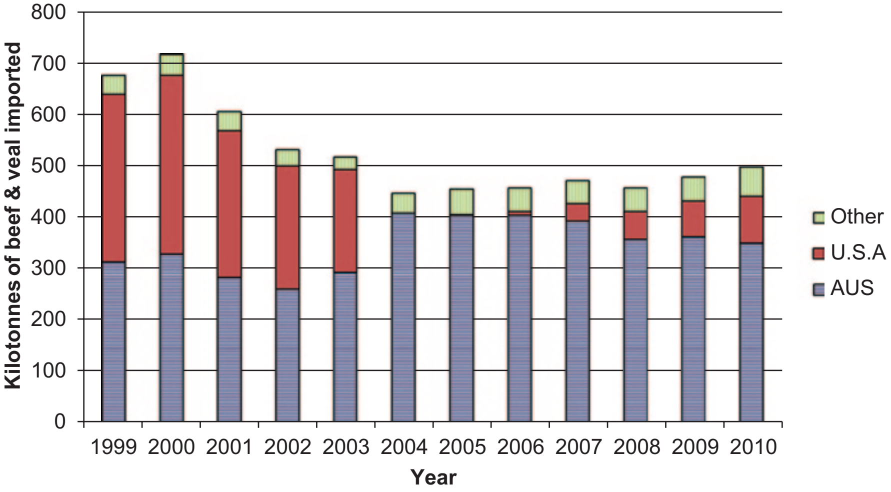

Fig. 16.1 Japanese beef and veal imports (kilotonnes) from all sources from 1999 to 2010. Bovine Spongiform Encephalopathy (BSE) was detected in the U.S.A. in late 2003 and it allowed Australia to dominate the market. Data from ABARE (2007) and ABARES (2011)

questions then become who should pay for this policy remedy, and whether there is an economically viable solution.

Australia's deliberate registration approach to additives (chemicals and feed stuffs) and strict quarantine barriers help exporters gain and retain market access by exploiting differences in international food standards and taking opportunities when they present themselves (Buzby and Mitchell 2006). For example, the outbreak of Bovine Spongiform Encephalopathy (BSE) in the United States of America (U.S.A) in December of 2003 effectively gifted the entire Japanese beef market to Australia (Adamson 2010). Since the outbreak, Australia has dominated the high value Japanese import market for beef and veal (ABARE 2007; ABARES 2011), see Fig. 16.1. These preventative measures in effect provide a positive feedback loop for a policy continuing without the need for rigorous analysis.

Although strict quarantine barriers provide market access for producers, it comes at a direct cost to Australian consumers. The embargo of banana imports is a prime example (James and Anderson 1998). This quarantine policy was exposed by the recent cyclones, which decimated the Australian banana industry and crippled local supply. The inability to import bananas to meet demand then created a price spike causing inflation to rise (Australian Bureau of Statistics 2011).

Policy is about trade-offs. For example, social pressures may lead to a desire to reduce the negative externalities associated with pesticides in order to improve human and environmental health. Policy then must trade these improvements off against any reduction in economic returns from constraining pesticide use. Policy analysis needs to consider who benefits, who is made worse off and determine if compensation is required or justified. To achieve the stated goals of the policy, the best mechanisms to facilitate the transition to the policy need to be determined. This will include choosing which incentives, regulations, or combination thereof to send the appropriate signals to create the transition to the policy objective. If policy priorities are poorly stated, economic growth will be slowed because the restrictive nature of policy can create situations where the outcomes were not intended in the original design. Policy is derived from social preferences that can be subject to changes in social ideals leading to a reallocation of policy priorities (Rostow 1959). Policy is also about stimulation and compensation and in the current case it involves definition of the role of government in managing pests.

16.2.3 National Expenditure on Pest Management

Determining the total public expenditure on managing pests in Australia is difficult for a number of reasons. First, there is inconsistent reporting and the ability to identify direct public expenditure on pests varies greatly between all levels of government and public research providers. Inconsistencies include whether or not funding by external research organizations is included in costs, whether expenditure on different objectives within research programs can be differentiated and different methods for estimating costs of policy development, staffing, overheads and infrastructure. Second, the federal government provides a combination of tax incentives for private companies to sponsor research; subsidizes funds raised by rural development corporations (RDCs) to undertake research; and provides a proverbial raft in the form of alternative funding mechanisms available for community-based programs and university research opportunities. The following data (Table 16.1) has a number of limitations and double counting problems[1].

Public expenditure on pest management was at least AUD$ 1 billion in 2007–2008 (Table 16.1). The Australian Federal government directly allocated AUD$ 735 million to fund federal government departments to work or commission activities associated with pest management. The data for Commonwealth Scientific and Industrial Research Organization (CSIRO) is incomplete and may be misleading. A further AUD$ 208 million was spent by state governments and RDCs spent at least AUD$ 25 million. The total figure is an underestimate since not all departments could be contacted or considered. Also, local government expenditure and university funding are not included.

These funds help manage pests that occur on both private and public lands. They help to varying degrees of success by reducing the costs, both direct and indirect, borne by farmers. They also prevent pest spread to and from public and private land. For example, investment includes research into classical biological control agents with the aim of reducing the density and spread of established exotic pests. McFadyen's (2007) review of economic analyses of Australia's weed biological control program suggests that the annual benefit to Australia was greater than

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[1] These data were derived by contacting finance officers in state departments and from publically available budgetary expenditure reports.

Table 16.1 Estimated national expenditure on pest management in Australia (2007–2008) by federal government agencies, state based agencies, research corporations (RDCs) and universities (– indicates unknown)

	Expenditure By Organization	Amount (million AUD$)	Data source and notes
Federal Departments	Department of Agriculture, Forestry and Fisheries	$ 699.6	Commonwealth of Australia (2008)
	CSIRO	$ 19.1	CSIRO (2008) includes all in-kind expenditure to rural CRCs only.
	Department of the Environment and Water Resources	$ 16.5	DEWH (2008)
	Others	–	
	Total federal	*$ 735.2*	
State Governments	New south wales	$ 14.9	Personal communication, Brad McCartney 2009
	Northern territory	$ 5.6	Personal communication, John Thomson 2009
	Queensland	$ 90.3	Queensland Government (2009)
	South Australia	$ 5.2	PIRSA (2008)
	Tasmania	$ 13.9	DPIW (2009)
	Victoria	$ 101.8	Department of Primary Industries (2008)
	Total states	*$ 208.6*	
RDCs	Cotton	$ 3.3	CRDC (2008)
	Grain	$ 18.8	GRDC (2008)
	Sugar	$ 0.5	SRDC (2008)
	Beef	$ 2.8	MLA (2008)
	Others	–	
	Total RDCs	*$ 25.4*	
Universities	–		
Total Expenditure		$ 1,041.2	

AUD$ 95 million per year for an AUD$ 4.3 million annual investment. Biological control programs often provide the classical ‘free rider’ outcome for producers where an individual directly benefits from a program despite not directly contributing to the costs of the program. These types of expenditures help Australian farmers to maintain low input production systems.

Despite the policy focus on strict quarantine and managing pests, the true economic benefits or costs from this expenditure are unknown, making it difficult to justify policy decisions. A major limitation is the complexity involved in estimating the true costs of all pests and identifying the major current and future problems.

Broad analyses of rapidly obsolescing estimates of annual costs (generally described as management costs plus residual production losses) of either pest groupings or specific species examples do exist (see below). Pest groups or key species analyses are designed to provide policy makers with an estimate of the magnitude of the problem to highlight where to allocate funding. For example, weeds top the national expenditure bill at AUD$ 4 billion per annum (Sinden et al. 2004), vertebrate pests cost AUD$ 720 million per annum (McLeod 2004), *Helicoverpa* species were estimated to cost between AUD$ 159 to $ 328 million per annum (Adamson et al. 1997) and diseases in barley are estimated at AUD$ 252 million per annum (Murray and Brennan 2010).

Specific analyses of individual species or management programs are designed to justify expenditure or obtain funding. For example, the 2010 control of locusts by the Australian Plague Locust Commission (APLC) is estimated to have prevented over AUD$ 913 million in losses. The benefits from controlling Siam weed are estimated to be approximately AUD$ 14 million by 2044 (Adamson et al. 2000). Programs designed to meet the ‘nil’ pest requirement in Australian grain exports are estimated to be worth at least AUD$ 70 million per annum (Adamson 2002). However, these values are generally only useful as discussion points for two reasons. First, the critical understanding of what the monetary value means, the underlying assumptions upon which the estimate is built, why the study was undertaken and who commissioned it is often either lacking or not clear. Second, the numbers used take little account of what other research into rival species or groupings have found or claimed as their benefit and double counting of management costs and yield losses is rampant. Many of the examples listed above use the default setting of a residual 10 % yield loss, with no justification.

Once this data gets into the public arena, it is readily accepted in an information poor environment and rarely challenged, thereby reducing the quality of the policy debate. Zalucki et al. (2012) provide a rare example of what is needed by directly challenging the often quoted US$ 1 billion worldwide cost of diamondback moth, *Plutella xylostella* (L.) and providing a detailed analysis of the process and assumptions used to calculate a revised estimate of the costs of this pest. Javier (1992) raised the initial value as a suggestion, not an analysis, in a short forward for a conference. Despite it being only a suggestion the value remained constant over time and reached axiomatic status. This acceptance creates problems, as the value is over 20 years old. Either those quoting have not adjusted the value for inflation or they are assuming that 20 years of research and implementation has achieved nothing. By shedding light on the original number and offering an evaluation of the global impacts the Zalucki et al. (2012) study suggests that the current cost is four to five times greater than Javier (1992) suggested. This lack of economic justification about the relative importance of existing, emerging, exotic and yet to be discovered pests compounds the misallocation of research funding towards pet projects.

The allocation of funding to individual pest management programs can create transitory patterns of adoption of the different aspects of IPM in two ways. First, suppose that funding is allocated in the short term as a piecemeal process with no solid foundations of what to fund and why. The result is then a range of temporary reductions in pesticide use for individual farmers, but not necessarily an overall reduction in pesticide use nationwide in the longer term. Zalucki et al. (2009) found that over a 30-year period in Australia the national cost of insecticides per hectare increased dramatically in real terms, in part due to the transition away from low-input wheat to higher input oilseed and cotton production systems.

Second, it fails to ask the simple question: is the objective of IPM to reduce pesticides or to provide managers/producers with the tools to create greater return on their assets? These can be mutually exclusive goals. To understand this, we need to understand the economics behind allocating resources from a farmer's perspective.

There is a wider problem associated with many pest programs and policies. By treating each pest or industry group as separate, they ignore the fundamental problem a decision maker faces, how they allocate scarce resources to maximize economic return through time (Villano et al. 2010). A farmer does not deal with only one pest but a range of pest management issues over their entire farm. Therefore we need to understand not only the farmers' expenditure on pest management but the rationale for managing pests as a whole.

16.3 Pest Management: A Bottom Up Approach

Integrated pest management is a subset of the overall allocation problem that farmers face in their day-to-day activities. In a steady state, under active management, the combination of individual pest species 'success' (their composition within the base load) then defines a baseline pest level (or pest load) in temporal and spatial terms. This premise then allows for the estimation of the economic return of alternative management options for all enterprise choices. This information then helps determine how farmers allocate their resources between alternative production choices.

16.3.1 Allocating Resources On-farm

Farmers have to allocate limited resources between all activities on a farm. Pest management like all management options requires the use of capital equipment, labor and financial resources. A producer has to decide the quantity of all resources they can allocate to all competing activities. The relative importance of a single activity can be determined by its share of the total resources available for use on a farm.

The breakdown of total average financial expenditure on Australian farms over a 15 year time period is presented in Fig. 16.2. The use of the averages smooths annual discrepancies and impacts of drought. In droughts the declining income is matched by a contraction in expenditure allocation. By assuming that everything termed 'chemicals' is the cost of purchasing chemicals for active pest management, it is estimated that on average about 5.7 % of total farm financial costs in Australia

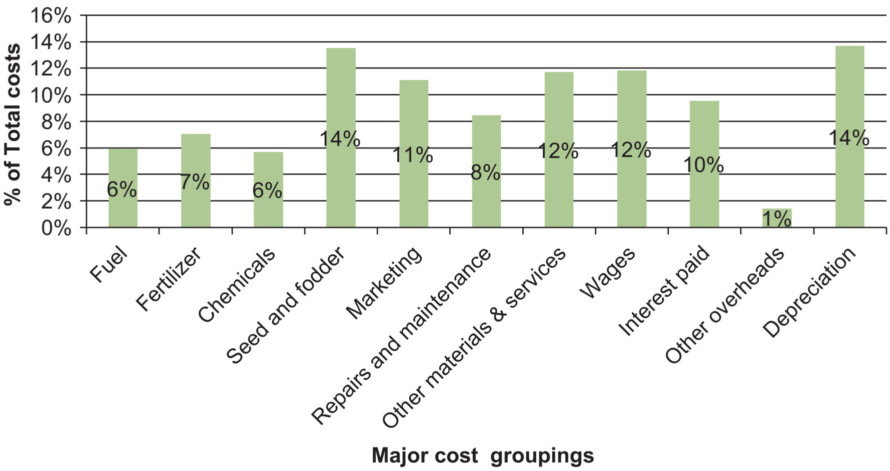

Fig. 16.2 Average percentage breakdown of the major on-farm costs Australia wide from 1995–1996 to 2010–2011 based on ABARES (2011). It has been assumed that all costs associated to the cost group chemicals applies to pest management costs. Therefore approximately 6 % of total farm costs are allocated to purchasing chemicals to control pests

are allocated to chemical cost for pest management. This is about the same as that allocated to fuel costs.

Total resources allocated to managing pests are greater than direct chemical expenditure. Australian Bureau of Statistics (2008) data suggests that chemical costs contribute to about 60 % of total active pest management expenditure with the remainder spent on labor and application costs, see Table 16.2. Assuming that this estimate holds constant, it implies that active pest management costs are not 5.7 % of total farm costs, but at least 9.5 % of total financial costs. Total resources to pest management need to include passive pest management costs, which includes genetic material bred to be resistant to a pest (for example, tick resistant cattle or root stock resistant to nematodes), chemical seed treatments and licence fees paid to access genetically modified organisms (e.g., cotton, see below), but such costs are often unknown.

The data presented is based on an average for all Australian producers. What this data does not illustrate are the changes in expenditure by commodity groups across Australia through time. Some of this analysis is provided in Zalucki et al. (2009) where it was illustrated that the real total unit cost of insecticide treatments, ignoring application and labor costs, had increased over time. Part of the increasing cost could be explained by the transformation of grain producers away from wheat, where insecticides are rarely used, to other commodities where the economic returns justify increased management expenditure. The increased insecticide costs could also indicate a substitution away from labor requirements found under IPM systems. Once again the lack of data impedes the analysis. Logically the time period, the climatic conditions and how the agricultural sector changes to seek higher returns all contribute to how inputs are allocated on-farm.

Table 16.2 Itemized expenditure on pest control in Australia in 2006–2007. (Australian Bureau of Statistics 2008)

	Pesticides (Million AUD$)	Contractors (Million AUD$)	Labor costs (Million AUD$)	Other (Million AUD$)	Total expenditure (Million AUD$)	Pesticides % of total costs
Weeds	982	159	211	222	1,574	62 %
All other Pests	430	77	153	109	768	56 %
Total	1,412	236	364	331	2,342	60 %

There is no national time series data set for pest management approaches, including IPM adoption, to help augment this discussion. Consequently we are reliant on case studies and economic theory to explain why individuals adopt different approaches to pest management in Australia.

16.3.2 *Justifying Pest Management Resource Allocation*

Starting with a steady state, where we hold the pest base load and all prices and costs of producing goods constant, we can assume that the objective of a farmer is to make money (or profit). Profit can simply be defined as:

$$\text{Profit} = (\text{Price} \times \text{Quantity}) - \text{Costs}$$

Where the profit made on the farm at a given time is subject to the income made (price) from all that is produced (quantity) less the total farm costs. From this premise we then relax the steady state assumption about pests and density through time and we can examine the economic foundations of IPM, economic thresholds and the pay-off matrix.

The transition of pest management from the concept of economic injury (Stern et al. 1959) to economic thresholds (Headley 1972) allows for the theoretical understanding of why rational farmers would not spend money on managing pests based upon their density in crops. Economic injury or the damage threshold (DT) is the density where a pest starts causing economic harm, the economic threshold (ET) occurs when the costs of controlling the pest are equal to the harm caused by that pest (that is the benefit of the control), see Fig. 16.3. Consequently a background pest level at which it is not economic to implement management activities will always exist. These foundations help in understanding of the nature (both economic and ecological) of the pest problem and the options available for its management in space and time.

Carlson's (1970) examination of pest management using a pay-off matrix to specify alternative sets of rational decision-making responses to given pest densities is central to explaining why producers' behavior changes. For example, the pay-off matrix helps explain why producers switch management practices at different pest densities (at X in Fig. 16.3, the returns from calendar spraying and IPM are equal)

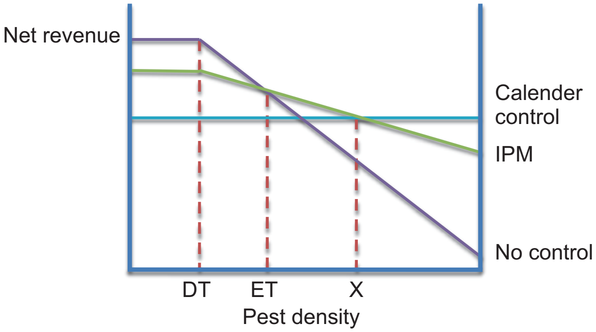

Fig. 16.3 The economics of integrated pest management (Norton 1985). Here net revenue of production is a function of the density of a given pest and the management decision. DT (damage threshold) is the pest density level where it causes 'injury' to production. ET (economic threshold) is the density at which the costs of control equal the benefits of control. Here the costs of adopting IPM is economically justified when compared to calendar spraying until density X is reached. After X, IPM provides less revenue than calendar spraying

and justify why producers switch between commodities based upon changing background pest load. In economic terms, IPM can be described as decision makers making informed decisions about how to allocate resources to management of all pests throughout a farm, based on the impact on profit from their response. It is this understanding about the nature of the resources allocated to manage pests and the benefits from that action that, in given situations, can justify either greater expenditure on pest management through increased pesticide use (Maupin and Norton 2010) or the movement of producers between bio-control programs and calendar spraying programs when resources are constrained or returns are better in alternative systems (Wilson and Tisdell 2001).

Economic return (profit) is not constant as there are continuous endogenous (on farm events, such as changing crops or pest management responses) and exogenous (off-farm factors such as prices, interest rates, climatic variability) variables that change through time. Climatic variability can be a major determinant of pest management strategy as during times of drought, farmers stop spending money. This inconsistent profit in time and space not only directly impacts an individual's allocation of resources to pest management now but also their future responses. Fluctuating farm debt levels can then constrain an individual's ability to actively respond to a pest incursion. Australia's emergence from the millennium drought has coincided with high commodity prices. For the first time in 30 years the broadacre industries throughout Australia are expected, on average, to make an annual operating profit (ABARES 2012). Blank et al. (2004) study of farm wealth in the United States helps explain why farms continue to operate despite negative or low returns. By having the ability to diversify into off-farm capital acquisitions and income streams, farm operating costs can be augmented in bad years. Continuation of activity then allows the farm returns to be invested into capital assets both on- and off-farm to minimize tax liabilities. However, this asset-rich and cash-flow-poor status can result in an individual opting in and out of IPM programs depending on liquidity issues. This situation can be exacerbated if the individual has mounting debt allowing both the distribution and densities of pests to increase. This is a common theme underlying the spread of woody weeds in Australia's dry land pasture systems (Zull et al. 2009).

The decision of whether or not to use certain pesticides can also be determined by an individual's beliefs and preferences. For example, an individual may believe that they have a social obligation to head towards biodynamic or organic farming. They may also see it as a choice to obtain a marketing advantage (Chang et al. 2003) and possibly a higher return (McBride et al. 2012). These subjective decisions are, in essence, a subset of IPM as they limit the available management choices. The diversity in individual preferences and attitudes to pest management can be reflected in alternative economic objectives. This may include profit maximization, bounded rationality to satisfy a given set of goals (Simon 1955), and maximizing utility through time.

In addition, an individual's decision to manage a given pest is dependent on the rigorous stance of a policy that may be based on transitory social beliefs (that is mandatory involvement in an eradication campaign, to a self-defeating loophole system), their ability to act within legal frameworks applicable to application of controls and the species being controlled, environmental legislation, social expectations (NSW Department of Primary Industries 2012), and their ability to allocate resources. Their final management choice ultimately determines which market they then interact with. These choices are underpinned within an uncertainty framework and the consequences of their actions have implications for area-wide management programs (see Sect. 16.4).

16.3.3 Risk, Uncertainty and Pests: Is it Adoption, Adaptation or Luck?

Pannell's (1991) review of risk, uncertainty and pesticide use highlights the complex nature of IPM through time. Policy makers and pest managers operate with incomplete current information and have to deal with unknown future issues. This complexity has to deal with the existing stochastic nature of biological functions and the non-linear response from management choices. The paradox that over time IPM programs can both reduce and increase the long term risks (social, environmental and economics) associated with managing different pests within a landscape. While the future is unknown, it will contain unwelcome surprises. The frequency of unwelcome surprises increases if management and policy decisions are predicated on using the mean or average to explain the future. The focus on averages to justify decisions results in the failure to anticipate the next pest problem. Consequently policy and pest managers end up jumping from one pest crisis to another, causing a backsliding in the level of IPM adoption (Zalucki et al. 2009).

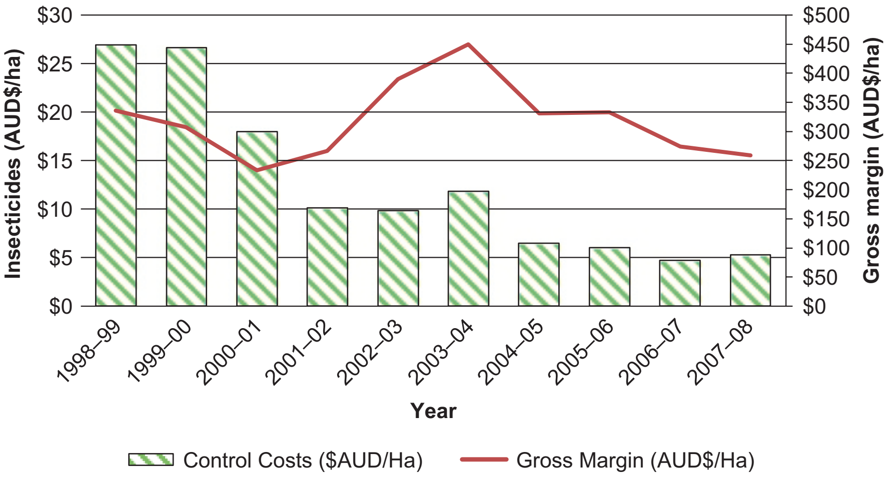

Fig. 16.4 Real costs of managing insects (AUD$/ha) in canola and the real gross margin return (AUD$/ha) in the Southern Zone of New South Wales from 1998–1999 to 2007–2008, all values in 2007–2008 AUD dollar terms. The data suggests that farmers have reduced the real insecticide costs of controlling insects in canola from over AUD$ 25/ha in 1998–1999 to about AUD$ 5/ha in 2007–2008

A bio-security breach leading to a pest or disease outbreak is a situation where the pest base load is altered in such a way that either management costs increase or there is a negative influence on yields or price, thereby changing the comparative advantage of production systems beyond the known distribution. The ability to adapt to pests is determined by the individual's ability to recognize the pest state; the constraints on the management options and the success of the response are all underpinned by uncertainty. The pests' state of nature is the fundamental understanding of economic thresholds in IPM. Further complexity and error in successful management occurs when producers invest in a 'new' activity, because they have to re-learn about managing the dynamic pest base load in regards to the new activity (Shea et al. 2002).

We can illustrate this by examining the case of pest management costs for canola in New South Wales. Brennan et al. (2005) outline the introduction of canola as a viable economic alternative to wheat within the winter cropping rotation system over the period of 1984 to 2004. By examining a set of gross margin budgets from 1989–1999 to 2007–2008, we see that the cost (insecticides and application costs) of managing pests per hectare decreases through time, see Fig. 16.4. We cannot definitively prove that a direct relationship between time and efficiency of control exists, as the data was not collected for this purpose. We know that costs have reduced, but we have no documented reasons why. Have farmers learnt from past mistakes and adapted their managing strategies? Has there been a fundamental change in the pest base load? Are producers benefiting from a collective wider regional control strategy? Is this a prime example of a successful IPM program (Gu et al. 2007)? Is it a direct response to falling commodity prices? Or is some other factor at play?

A producer's attitude to pest management may not be constant through time due to risk preferences, understanding of the problem, learning how to manage, financial constraints on resources, the policy settings constraining or influencing choices, and off-farm shocks like the Global Financial Crisis. However, IPM does change the nature of the management approach, as once an individual becomes aware of the issues and the options available, it can lead to non-linear changes to management strategies. Nevertheless, even a diligent farmer may find that the successes of their management activities are in fact largely due to activities of their neighbors creating an opportunity for a spatial free rider.

16.4 Pests, Policy and How's My Neighbor?

Within a landscape the actions of farmers in response to policy signals, their choice in management participation and their management action impacts directly on the composition and the density of the pest load. Rebaudo et al. (2011) point out that the diversity of managers within a landscape influences the success of regional control, as each group responds to different pest signals with varying degrees of success. Ceddia et al. (2008) illustrate this by examining how alternative levels of hobby farmers and professional farmers within a landscape influence the rate of pest spread. Collective management opportunities exist not only when production systems are similar but when the pests are the same. For example, citrus producers in the Central Burnett region of Queensland developed an area-wide management strategy for fruit fly in response to possible MRL levels for dimethoate and the ability to diversify into previously closed domestic markets (Lloyd et al. 2007).

Public area wide management strategies subsidize individuals' management costs. They may use alternative management options to allow producers to operate as normally as possible. For example, plague locusts are considered a public problem in Australia (Millist and Abdalla 2011) and their management falls under the purview of the Australian Plague Locust Commission (APLC). The ability to migrate throughout Australia over areas of environmental significance and well-defined organic beef enterprises in the Channel country (Wynen 2006) drove the adoption of *Metarhizium,* a bio-insecticide (Story et al. 2005). The cost of preserving market integrity is then paid for out of the public purse.

The success of an action is not predetermined solely by the wider public and private management strategies employed, but also by the path by which the pest arrived. For example, a lettuce IPM program in New South Wales (NSW) resulted in a net financial gain and a reduction in 'active ingredients' (g/ha) used to manage *Helicoverpa* spp.from 1998 to 2006 (Orr et al. 2008). Although the authors claim the net benefits would be greater if the spill over effects to other industries and human health were considered, they fail to consider the spill over benefits from other research. This was around the same time as when genetically modified cotton was being adopted in Australia. This acted as a population sink for *Helicoverpa* spp. (Knox et al. 2006) while the climate was not conducive for *Helicoverpa* spp. population development (Zalucki et al. 2009). A question then needs to be asked in the context of the review: did the lettuce IPM program really deliver benefit? Or was its success a product of timing or the limited scope of the review?

Schellhorn et al. (2008) suggest that the spatial scale of the ecological and economic problem need to be intertwined in order to develop successful management programs. The heterogeneity of the spatial landscape, how it has been modified, the temporal cropping patterns, localized and regionalized climatic events, available refuges and the management actions taken by individuals and groups not only provides pre-selection bias for the pests but the beneficials as well. A polyphagous migratory species can experience rapid population expansion under a changing landscape where the change in farming systems creates a favorable redistribution of its traditional overwintering locations. This is the case for *Helicoverpa* spp. and cotton in northern Australia. By providing policy incentives (price bounty systems and subsidized irrigation) to develop the cotton industry in the Ord, the landscape transformation provided a favorable habitat for *Helicoverpa* spp. (Davidson 1965). The rapid increase in *Helicoverpa* spp. density combined with tactically naïve management strategies resulted in unprecedented levels of insecticide resistance to develop. Ultimately, the combination of increasing costs and falling yields saw the cotton experiment in the Ord finish after ten years (Longworth and Rudd 1975).

The *Helicoverpa* spp. and cotton story does not end there. The cotton industry in Queensland and New South Wales was able to continue despite the removal of the price bounty. This continued industry development provided a positive correlation for *Helicoverpa* spp. development and a continual cycle of insecticide resistance creating a corresponding 'new' crisis for IPM research on a regular basis (Zalucki et al. 2009). These crises continued to occur despite the cotton industry's wide adoption of resistance management programs at a regional scale and other IPM strategies for over 30 years with temporary success permeated with the next spray and pray failure. The continual search for a 'magical bullet' culminated in the development of genetically modified (GM) cotton.

The search for the magic bullet in cotton is still debated. Although GM cotton undoubtedly acted as a population sink, the recent drought reduced the area of cotton planted and had a negative impact on *Helicoverpa* spp. populations, thereby clouding the true success of GM cotton to manage the pest complex (Zalucki et al. 2009). The long run success of GM cotton is still being debated as the recent resistance tests suggests that *Helicoverpa* spp. express natural resistance to the novel Vip3A Bt toxin which forms part of the next commercial release of GM cotton in 2016 (Mahon et al. 2012). Even if GM cotton eventually proves to be a technical success in suppressing *Helicoverpa* spp. in both the short and long term with a revolving rerelease of GM cotton varieties, it has perverse impact on IPM. In effect it turns the economic notion of IPM back into a calendar spray, see Fig. 16.5.

By setting the licensing fee to plant GM cotton identical to the cost of the 11 insecticides used to control *Helicoverpa* spp. in conventional cotton, GM cotton resembles the calendar spray (Fig. 16.5). In this case it only remains profitable to grow GM cotton if the density of *Helicoverpa* spp. remains high. As GM cotton operated as a population sink, there were reported cases where conventional cotton

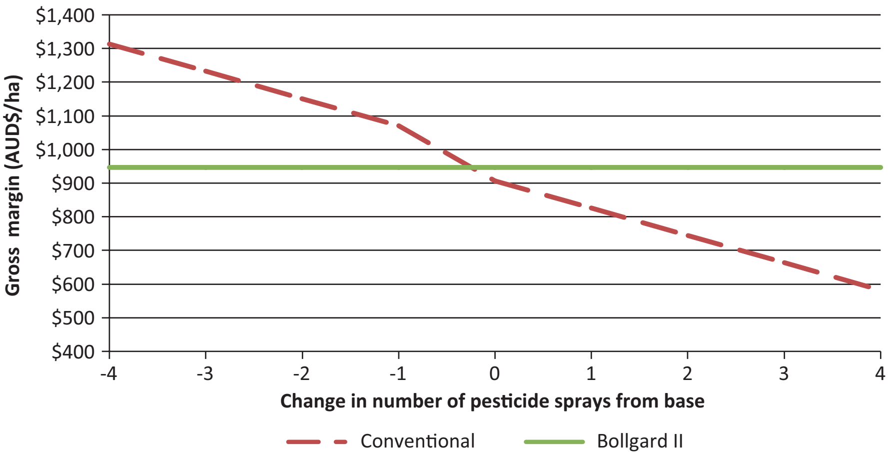

Fig. 16.5 The Genetically modified (GM) technology trap. Based on expected gross margin data from Bollgard II has a higher return than conventional cotton. However, if the expected density of pests is less than forecasted, then conventional cotton producers can reduce the number of sprays applied and increase their return per hectare above Bollgard II returns. This occurs as Bollgard II costs are primarily due to the licence fee which is fixed. Please see the discussion in Fig. 16.3 where 0 sprays equates to X and Bollgard II is calendar spraying and conventional cotton equates to IPM. (Cotton production costs based on the NSW Department of Primary Industries Enterprise Budget Series for Bollgard II cotton and conventional cotton, Northern Zone for 2005/2006)

was not being sprayed in 2006 (Personal communication, David Murray 2007). In effect encouraging the use of conventional cotton for individuals and not the industry as a sensible IPM farmer would free ride on the wide scale industry adoption.

Back and Beasley (2007) found that farmers have adopted GM despite the reduction in revenue because it is considered easier to grow, not because of the environmental and social benefits from using fewer pesticides. Thus GM technology is a passive pest management response and not really an active IPM tool. As the cotton industry is now firmly committed to GM crops the question from an IPM perspective remains are we doing our ‘best’ or have we accepted ‘incidental’ yet again?

16.5 Concluding Comments

This chapter aims to provide an understanding of how policy decisions can influence the adoption and use of IPM. The choice of how to manage pests is dependent upon: the regulatory environment in which they operate, the market the producer is aiming for, the inputs and management options available, the cost of the choice and the benefits of the decision. A combination of these factors then influences a producer’s final decision regarding the adoption of a pest management strategy. Producers also take other factors into account, including subjective preferences and beliefs, to determine if they want to maximize profit, satisfy their desires or attempt to maximize their utility. This helps explain why some producers adopt a subset of IPM practices at the expense of profit.

Producers' attitudes to resource allocation can be dependent upon time and the net returns of actions. Australia specializes in producing bulk commodities with low inputs. The development of variable output and marginal prices leads to a system of low management inputs. For example, wheat crops are generally only sprayed once for insects. Beef is primarily produced on open rangelands systems without the need to overwinter stock thus limiting the need for preventative disease management. The combination of low inputs, marginal returns and time poor individuals often leads to the use of chemicals where possible. If the use of IPM requires increased time and inputs, then there has to be a net positive return to the producer. This then raises several questions: are we using IPM as it is the only option left? Or does it provide a clear market advantage? Or is it just "dumb luck" in the production system choice?

Every policy has positive and negative implications for alternative sections of the community. There are always winners and losers but the objective of 'good' policy is to attempt to improve. Policies at an international, domestic and industry levels are not constant but are continuously evolving, changing the incentives and disincentives for a given outcome. Sometimes the end point of a policy is not what was expected. This can provide positive and negative outcomes for farmers, the environment, the community and the economy as a whole. The current lack of information on what are the current economic problems, the emerging problems and a framework for forecasting the next adverse pest requires a mythical 'silver bullet'. This prevents the requisite detailed discussion to drive policy decisions to the next level.

The inability to analyze the policy at the next level may be a blessing in disguise. This chapter has barely scratched the surface of the policy winners and losers, as well as the difficulties in attempting to quantify the economic benefits and costs throughout society, the environment and the economy. Since the domestic pest management policies work with international SPS policies, perhaps this lack of clarity in the debate is a deliberate strategy for Australia. If only one country brings clarity to the discussion in the international arena, it may create a self-defeating outcome (Adamson and Cook 2007).

Perhaps the only certainty we have in evaluating Australia's policies on pest management is that despite the quarantine barriers sooner or later the plain 'dumb luck' described by Donald (1982) will run out as geographical barriers are overcome with both the increased speed and volume of trade. A single 'BSE' style event in Australia will have ramifications that are not yet in the public consciousness.

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Part VI
Europe

Chapter 17
Integrated Pest Management Policy, Research and Implementation: European Initiatives

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Contents

Abstract Times are changing for pest management in Europe. Stronger societal demands and pesticide resistance pressure farmers to reduce their reliance on pesticides more than ever before. Reconciling human health and environmental goals with production is a challenge for farmers as well as for all crop-protection stakeholders. Expectations that research and extension will quickly provide solutions

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are high everywhere. Although a few European countries have acquired experience with pesticide action plans or implementation of integrated pest management (IPM) guidelines on a national scale, many others are starting from a more modest base. Stakeholders in Europe are looking beyond their national borders to create synergies and share experiences and know-how. Representatives of the European Commission and Parliament, governments, research, extension, farmers, industry, and civil society are engaged in dynamic interactions. A Europe-wide structure (an ERA-Net) able to coordinate national calls for research and extension proposals on IPM is planned for 2014. Since 2007, the 10-country network ENDURE has pooled expertise among its 15 research, education, and extension member institutions. It has conducted joint reviews and original studies on IPM, organized summer

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schools, set up an internet-based platform on wheat cultivars and pathogens, and continues to support workshops, newsletters, and an information center with 1,600 entries for advisers. After earlier successes on insect pest management in North America or with resource-poor farmers in developing countries, Europe is set to become a source of renewed inspiration for IPM applied to conventional agriculture in industrialized countries and broadened to encompass all pest categories.

Keywords Crop protection · IPM · ENDURE · Europe · Coordination · Transnational · Research · Extension

17.1 Introduction

Faced with a shrinking diversity of available pesticides and their increasingly restricted use, many in the crop-protection community now wonder about the future of pest management in Europe. To help explore options and provide crop-protection stakeholders with the tools they need to respond proactively to this new situation, ENDURE, a European network of universities, research centers, and extension groups, conducted a foresight study (Labussière et al. 2010). From this collective exercise, five contrasting scenarios emerged. Taken separately, each scenario points to research efforts in specific areas where innovation is required, and different roles assumed by farmers, depending on contextual priorities. If priority is placed on:

- European agriculture competing on the global market with basic commodity crops, then research is needed on developing radically new low-impact "green chemicals" and on reducing their undesired effects. Here, farmers are legally accountable for any measurable impact caused by pesticides.
- European agriculture competing in the global market with specialized high value-added agricultural products, then research is needed on controlling the agrosystem and developing high-tech solutions. Farmers in this scenario are technological innovators who are part of a successful web of economic activities.
- Ensuring food self-sufficiency in Europe, then research is needed on making the most of ecological processes and creating robust agroecosystems to stabilize and diversify production. Farmers are recognized and appreciated as food providers.
- Providing food at a low energy cost, then research is needed on zero-pesticide crop protection in urban farming and minimizing energy inputs in the management of pests in large rural farms less reliant on synthetic nitrogen. Farmers produce food for local consumption and must find compromises between minimizing energy inputs and reducing yield losses due to pests.
- Ensuring that agriculture satisfies multiple local demands, then research is needed on using ecological and landscape processes, coordinating multiple local stakeholders, and developing economic compensation mechanisms. Farmers are locally recognized for the multiple services they provide and their contribution to the economic attractiveness of their community.

It is easy to envision that, in fact, just as contrasting agricultural production systems currently exist in Europe, the five scenarios will indeed coexist in some form in the future, and that such diversity may be an asset for Europe. Taken as one whole set of scenarios that will evolve in parallel, a general message emerges. The set of scenarios shows that in all cases, the challenge to research, extension, and policy is to balance agricultural activity with increasing health and environmental demands. It shows that "business as usual" is not a viable option, even in the scenario where crop protection remains based on pesticides where radically new types of chemicals and ways of controlling impact need to be developed. To ensure the sustainability of such a diverse food system, a higher level of research, policy, and stakeholder coordination effort is needed. This chapter offers an insight into the present European process aiming at reconciling health and environmental concerns with export-oriented agriculture, food production imperatives, energy-saving, and multifunctional farming.

17.2 A Conducive Policy Landscape

Societal demands and expectations led to national and European legislation creating a policy landscape conducive to the design and implementation of new IPM (integrated pest management) schemes that contribute to sustainable development while preserving the competitiveness of European agriculture. In 2006, the European Union initiated a legislative package that was passed into law in 2009 which increased restrictions on the range of available pesticides and for the first time also placed constraints on their use. This set of regulations and directives includes:

- Regulation 2009/1107/EC concerning the placing of plant protection products on the market;
- Directive 2009/128/EC establishing a framework for community action for the sustainable use of pesticides;
- Directive 2009/127/EC amending Directive 2006/42/EC with regard to machinery for pesticide application;
- Regulation 2009/1185/EC concerning statistics on pesticides.

The key points of the regulation concerning the placing of plant protection products on the market are:

- A positive list of approved active substances is drawn up at the EU level. New pesticides are then authorized in the respective zones and via mutual recognition licensed at the national level.
- Certain chemicals are banned according to their inherent properties referred to as "cut-off criteria" which are now based on "hazard" rather than "risk" as was previously the case. These include chemicals that are carcinogenic, mutagenic, or toxic to reproduction, those that are endocrine disrupting, and those that are "persistent, bio-accumulative and toxic" or "very persistent and very bio-accumulative."

- For developmental neurotoxic and immunotoxic substances, higher safety standards may be imposed.
- If a substance is needed to combat a serious danger to plant health, it may be approved for up to five years even if it does not meet the above safety criteria.
- Products containing certain hazardous substances are to be replaced if safer alternatives are shown to exist via a comparative assessment.
- Substances likely to be harmful to honeybees are to be banned.

The key points of the directive on the sustainable use of pesticides are:

- Member states must adopt national action plans for reducing risks and impacts of pesticide use on human health and the environment, including timetables and targets for use reduction.
- Aerial crop spraying is in general banned, albeit with exceptions subject to approval by the authorities. No aerial spraying is allowed in close proximity to residential areas.
- Member states must take appropriate measures to protect the aquatic environment and drinking water supplies from the impact of pesticides. These include buffer zones around bodies of water and safeguard zones for any surface and groundwater used for drinking water. There must also be protected areas along roads and railways.
- The use of pesticides must be minimized or prohibited in specific areas used by the general public or by vulnerable groups, such as parks, schools, sports grounds, and close to hospitals.
- New rules on mandatory training for pesticide users and salespeople on handling and storage, on information and awareness raising, and on the inspection of pesticide application equipment.

The legislation marks a significant boost for IPM. The directive on the sustainable use of pesticides specifically requires all member states to "take all necessary measures to promote low pesticide-input pest management {…}. Low pesticide-input pest management includes IPM as well as organic farming {…}" and to "describe in their National Action Plans how they ensure that the general principles of IPM {…} are implemented by all professional users by 1 January 2014." Also, the directive and the regulation on placing plant protection products on the market jointly require that "plant protection products are used properly" and that "proper use" means compliance with the general principles of IPM. To this end, all professional pesticide users are required to receive training that includes "notions on IPM strategies and techniques, integrated crop management strategies and techniques, organic farming principles, biological pest control methods, information on the general principles and crop or sector-specific guidelines for IPM." In short, the spirit of the European legislation calls for the rapid and widespread mainstreaming of IPM. The process extends beyond the European Union. Other European countries, such as Switzerland, which are not European Union member states, but geographically, economically, and culturally closely associated with the European Union, develop their legislation with regard to crop protection and pesticide regulation on the basis of IPM principles in similar ways and in parallel with the European Union.

In parallel to the legislative process, dynamic information exchange and discussions are taking place at the European level among a diversity of stakeholder groups. Representatives of the European Commission and Parliament, of governments, research, extension, farmers, industry, and civil society regularly meet either formally via the Pesticides Thematic Strategy expert group on the sustainable use of pesticides convened by the EC's Health and Consumers Directorate General (DG Sanco) or at other less formal events organized by one or another of these stakeholders. Discussions and exchanges also take place in more regional forums. CEUREG, the Central and Eastern European Regional technical forum, for example, is a group of central and eastern European countries originally set up in 1994 to harmonize pesticide registration, which more recently expanded its scope to cover all aspects of reducing pesticide risks. The Nordic Association of Agricultural Scientists, a grouping of researchers from the Nordic zone of Europe, also holds seminars on IPM. Such meetings are valuable opportunities to share experiences and points of view and promote consensus building.

In October 2013, at the time of this writing, there are signs that the European-level legislation is indeed making a difference in terms of national legislation and funded programs. Several European countries are investing and building on significant progress already achieved via their past national action plans or regional schemes for IPM implementation. For example, Denmark in 2012 initiated its fourth action plan, known as the Green Growth plan which strongly emphasizes IPM implementation, and fully addresses the requirements of the Framework Directive. Denmark has been supporting major IPM activity at the advisory level, creating demonstration farms, taxing pesticides according to their health and environmental risks, subsidizing advice on IPM, and setting up a scheme to measure the degree of IPM uptake at the farm level (see Chapter 19 of this volume for more details).

Switzerland has a strong history in regulating crop protection at the legislative level and with regard to involving stakeholders and research and extension in national action plans. IPM-based crop protection strategies developed by federal research institutions in the early 1970s and promoted by non-governmental organization (NGOs) such as GALTI, SAIO, and Viti Suisse have been widely adopted by growers early on. In 1996, Swiss citizens voted for an amendment to the federal constitution to include the principle of multifunctionality and sustainability for the Swiss agricultural sector. Henceforth, growers were not only expected to supply the population with high-quality and healthy foodstuffs, but also to conserve natural resources, foster biodiversity, minimize polluting emissions, and tend an attractive landscape. These additional ecological services are compensated by direct payments to farmers. The impact of this policy on sustainability has been evaluated via an agroenvironmental monitoring program since 2002. Presently, 90% of the agricultural surface in Switzerland is cultivated according to either integrated production (80%) or organic (10%) guidelines. Public R&D makes a continued and re-intensified effort to develop tools and methods building on the high standards of formalized integrated and organic production programs to cope with the challenges of climate change, the need for reducing pesticides, and to compete with economic pressures. Ecological intensification is the strategy sought to provide solutions (Lötscher and Tschumi 2012). New knowledge and methods such as decision-support tools (Graf et al. 2002; Samietz et al. 2007; Viret et al. 2011) are continuously developed and transferred into practice via internet platforms and stakeholder organizations.

Other countries with no outstanding history of major national pesticide action plans have also embarked on new and ambitious initiatives. France, for example, has set up a major program named Ecophyto to cut pesticide use by 50 % between 2008 and 2018. Germany adopted for the first time a quantitative goal as part of its pesticide risk and use reduction plans. The German plan aims to achieve a 25 % risk reduction as compared to a baseline from 1996 to 2005 and to reduce the rate of maximum residue levels exceedance for pesticides in domestic and imported food to less than 1 % in each product group by 2021 (Anonymous 2008).

In any case, all 27 member states are to transpose the Directive on the sustainable use of pesticides into national legislation, and in June 2012, the European Commission[1] reported that thirteen had completed this, nine had partially done so, and five were yet to do it. This is a major process requiring that a diversity of stakeholders come to an agreement on goals and means to reach those goals, which at times takes place in countries with no particular history of pesticide use and risk reduction policies.

The types of goals, and presumably the focus of the national policies, vary greatly. They sometimes refer to reduction of overall use (France), risk reduction (Bulgaria, Czech Republic, Estonia, Finland, Germany, Italy, Latvia, and Switzerland), reducing dependency (France, Norway, United Kingdom) or environmental impact (Belgium, Denmark, Italy, and Switzerland), the impact on water quality (Sweden and Switzerland), minimizing the impact on human health (Belgium, Italy), or may also cover all the above (Turkey). In some cases the goals focus on learning (Norway and Sweden) and adoption of alternative techniques (United Kingdom). IPM is clearly presenting most national policies with an explicit reference to it, for example, Belgium, Germany, Italy, Norway, Poland, Sweden, Switzerland, and Turkey. In some cases, it is part of a broader policy. In Norway, IPM is embedded within a program on sustainable innovation at the food chain level. In Denmark, it is within the economic development policy Green Growth. A D.G. Sanco survey in 2012 reports that 16 out of 20 member states consider that measures to promote IPM are already in place and 8 out of 20 member states are planning to strengthen existing ones (Sanco 2012). Explicit IPM-specific research or extension programs are found in several countries, including Denmark, Norway, Sweden, and Turkey.

17.3 Research and Extension for IPM

Any Europe-wide initiative faces the challenge of overcoming national and sometimes even regional languages. The mainstreaming of IPM throughout Europe faces the additional challenges of differing legislation, agricultural practices, growing conditions, and research and extension organizations. The diversity—which the Agricultural Knowledge and Innovation Systems group has begun to map out (EU SCAR 2012)—

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[1] D. G. Sanco, June 20, 2012 meeting, Brussels.

is particularly acute regarding the link between applied researchers and farmers. These are the complexities that policy makers, researchers, farm advisers, and other stakeholders are confronting to bring together resources and reach farmers across Europe.

17.3.1 Pooling Europe's Research Capacity on IPM

A number of factors pressure researchers concerned with crop protection to pool scientific resources and create synergies across Europe. There are pressing demands to find workable solutions reconciling health, environmental, and agricultural production objectives and, on the other hand, shrinking human and financial resources. The emergence of resistance of pests to pesticides and the banning of a number of active substances means that the farming community is faced with an ever-shrinking range of pesticides and IPM appears more than ever to be a desirable alternative to chemical-based crop protection. Also, European policy makers perceived the need to complement the Framework Directive on the sustainable use of pesticide with a research and extension component that would support its implementation. The European Commission therefore proposed four years of funding for a Network of Excellence that would have to commit to the creation of a permanent and self-funded network. This enabled the launching of the European network ENDURE in 2007. In 2010, the 14 institutional members of ENDURE, who cover 10 European countries, made good on their promise and committed their own resources to ensure its continued operation beyond the EC-funded period.

Pooling the expertise available across the network, ENDURE conducted joint reviews and original studies on:

- Existing knowledge on reducing and optimizing pesticide use on a per-crop basis (ENDURE 2010);
- Weed management (Melander et al. 2013);
- New and emerging technologies (Zijlstra et al. 2011);
- Biological control (Nicot 2011) and landscape ecology (Ferguson and Alomar 2010; Moonen et al. 2010; Petit et al. 2010; Veres et al. 2010, 2011);
- Decision-support systems (ENDURE 2009);
- Redesigning cropping systems and future innovations to reduce reliance on pesticides (system case studies) (Vasileiadis et al. 2011; Meissle et al. 2010);
- Multicriteria evaluation of cropping systems: DEXiPM (Pelzer et al. 2012) and Sustain OS (Mouron et al. 2012);
- The role of the food chain and sociological aspects of the transition toward IPM
- National pesticide action plans (Barzman and Dachbrodt-Saaydeh 2011);
- The future of plant protection and what it means regarding research priorities (Labussière et al. 2010);
- The implementation of the eight principles of IPM (ENDURE 2011a).

As a contribution to higher education, ENDURE organizes summer schools in Tuscany, Italy. The summer schools allow Ph.D. students and postdoctoral researchers to become acquainted with systemic approaches to IPM in an international and interdisciplinary environment. Past summer schools covered:

- Biodiversity for crop protection in 2007;
- Modeling approaches to support IPM in 2009;
- New and emerging agricultural pests, diseases, and weeds in 2010;
- Agroecological engineering for crop protection in 2012.

ENDURE created Eurowheat, an Internet-based platform collating and displaying host and pathogen characteristics, and pesticide efficacy on a European scale. Bringing together existing information from national programs and ensuring that these data are in a format that can be readily understood across national borders provides added value on a European scale. New disease and resistance data are quickly published on the platform to support effective disease control, deployment of host resistances, and breeding programs. For example, recent monitoring has revealed the occurrence of new aggressive rust strains. Eurowheat continuously updates information on rust virulence by sharing information from national monitoring activities thereby improving the overall level of knowledge in the area of yellow rust control.

The network quickly identified the importance of experimental work at the cropping system level to devise both short-term solutions "tweaking" existing systems and longer-term solutions bringing about more fundamental changes. ENDURE successfully convinced the European Commission to release a call for research proposals based on this concept. This led in 2011 to the launching of PURE, "pesticide use-and-risk reduction in European farming systems with IPM," a project that takes research work initiated in ENDURE one step further (ENDURE 2011b). It focuses on the systems approach started by ENDURE, examining the role of larger spatial (cropping system) and temporal (multiyear) scales in crop protection. For each of six selected cropping systems (wheat-based and maize-based rotations, field vegetables, pome fruit, wine grape, and protected crops), PURE combines existing methods with new tools and technologies into novel IPM solutions.

Another significant research player at the European level is the International Organization for Biological Control which has been active in Western and Eastern Europe since its founding in 1956. Its Working Groups, which organize seminars and produce scientific output, stimulate research in many aspects of biological control including landscape ecology. Its Integrated Production Commission also produces crop-specific integrated production guidelines that have formed the basis for IPM programs in Switzerland, the Czech Republic, and the Emilia-Romagna region (Italy), to name a few.

Efforts to further coordinate IPM research at the European level continue. Faced with the challenge of responding to the requirements of the Framework Directive on the Sustainable Use of Pesticides, a number of European countries perceived the need to coordinate national research and share or even combine results and lessons learned. To this end, a Europe-wide structure able to coordinate national calls for research proposals on IPM (an ERA-Net) is in the planning stages. Already, representatives from 17 European countries have joined a collaborative working group precursor to the ERA-Net set to be launched in 2014 with initial coordination support from the European Commission. This structure is expected to ensure information sharing across Europe and will also be instrumental in promoting joint research and development initiatives.

For example, the collaborative working group already identified ongoing cropping system experiments where a number of factors are studied in parallel in the field for more than one year regarding crop protection research questions in Germany, France, Denmark, Italy, Poland, Sweden, and the United Kingdom. These experimental setups typically test combinations of factors involving crop sequence, varietal mixture, and weeding and soil management regimes. The group is considering setting up an EU-level network of such experiments to share information and results and in the long-term, coordinating objectives and protocols. The obvious added value will be to consider variability among the major factors and save national efforts.

Europe's influence extends beyond the mainland European continent, in direct ways via its outermost regions across the world. Most of these include islands particularly vulnerable to pest and pathogen invasions as well as environmental pollution (soil and water) due to intricate cultivated and residential areas. In addition many of them are biodiversity hotspots. In France, agriculture in the overseas territories must comply with the French National Action Plan.

Research, training, and dissemination in Reunion focuses on the agroecological management of fruit flies, which can cause devastating losses in field-grown cucurbit crops. Techniques that have been applied at the field scale are based on the principles of prophylaxis, habitat management, and conservation biological control. They incorporate assisted push–pull (namely maize field margins sprayed with a food bait mixed with a tiny quantity of bioinsecticide), sanitation (namely collection and composting of infested fruits), and mass trapping of male flies. It resulted in a dramatic reduction of infestation without any use of synthetic insecticide (Deguine et al. 2012). Such techniques are considered for extension to neighboring islands via the Agroecology-Climate Change Regional Initiative. In Guadeloupe and Martinique, the "Sustainable Banana Plan," implemented in 2008, aimed at 50% pesticide use reduction in 2013 as compared to the 2006 levels. It is based on disease-resistant cultivars to reduce fungicide spraying, live mulches to reduce herbicide and nematicide use, and habitat management/conservation biological control to reduce insecticide applications (Risede et al. 2010). Martinique reached this goal by 2010 with 6 kg of total active substances per ha, against 12 kg per ha in 2006, and Guadeloupe reached it by 2011 with 5.5 kg per ha, against 11 kg/ha in 2006 (Anonymous 2013). This plan (particularly regarding foliar diseases) was extended to neighboring Dominica, St. Lucia, St. Vincent, and Grenada via the EU-funded "Sustainable Banana Caribbean Project" in 2009.

17.3.2 Support for IPM Implementation

In addition to research-related activities, ENDURE invested significant resources to provide scientific support to farmers via their advisers. The most notable achievements in this respect include the creation and maintenance of the ENDURE Information Centre, the facilitation of a Europe-wide network of farm advisers, and the production of an IPM training guide.

The ENDURE Information Centre disseminates practical information on crop protection. It is a central point of reference for extending expert knowledge, recommendations, and advice for extension services, advisers, and researchers concerning all aspects of integrated pest management. For users it provides a search through a crop/pest or disease/country combination. The search results offer a European quality selection (European Best Practices) with validated IPM tactics and strategies including prevention, chemical pest and disease control, as well as nonchemical alternatives such as biological control. The ENDURE Information Centre took on the challenge to make the content of grey literature from a broad variety of national sources available in English summaries and thereby initiate cross-fertilization between countries and regions.

Researchers have long benefited from well-established international networks. For farm advisers, on the other hand, information exchange and networking across borders is a novelty and a challenge. The ENDURE Network of Advisers aims to facilitate such interactions by creating a forum for sharing knowledge on plant protection. It currently has 200 members across Europe and is open to all farm advisers involved in the use of IPM. Members receive news and information from ENDURE and from current work in EU countries and participate in an online forum where farm advisers share knowledge, results, and experiences to tackle pest control challenges and improve their IPM practices. Some current topics under discussion in the online forum include alternative control of powdery mildew on pepper, apple, and strawberry, the Danish experience with reduced herbicide dosages, and IPM-related apps for iPhone and Android-based mobile phones. Through VfL, the Danish Agricultural Knowledge Centre, ENDURE organizes yearly workshops attended by advisers from across Europe who discuss progress regarding the IPM toolbox itself as well as advisory and learning methods to facilitate IPM uptake.

ENDURE has developed a training guide on IPM for educational and advisory purposes. The guide is a compendium of 52 training sheets covering methods, tools, and training modules on a diversity of topics pertinent to IPM. ENDURE collaborates with "New Advisers," a vocational education and training project developing new ways of delivering farm advice on crop protection. In this project, discussion groups, problem-based learning, clear vision, and forum theater are among the learning methods that will be tested by farm advisors in eight European countries. The innovative educational resources emerging from this experience will be made available on the ENDURE website alongside the IPM Training Guide.

In the near future, the European Innovation Partnership—a new guiding strategy initiated by the EC's Directorate-General for Agriculture and Rural Development—will be introduced to serve as a catalyst for innovation by promoting the creation of consortiums in multiactor research projects through both Horizon 2020, the new Research and Innovation Framework Program, and the Rural Development Programming. Although the strategy covers all agricultural production aspects, some of the projects emerging from it will doubtless include farmers, advisers, and researchers driving IPM-related innovation.

Looking at the bigger picture, the current European experience with IPM emerges as a good example of how initial problems and constraints also offer opportunities for innovation. The spreading emergence of resistance to pesticides and the strict stand taken by the European Union on pesticide legislation initiated a sustained and determined action to promote the design and implementation of new IPM solutions. Concerted efforts in research and extension are putting IPM firmly back on the map. After earlier successes of IPM on insect pest management in North America or with resource-poor farmers in developing countries, Europe is set to become a source of renewed inspiration for IPM applied to conventional agriculture in industrialized countries and broadened to encompass all pest categories: animal pests, weeds, and diseases.

The task is nevertheless considerable. Implementing IPM in industrialized countries is not merely a question of managing pests but also of questioning the paradigm of simple, relatively cheap and reliable solutions obtained with pesticides. Here research, the generation of new knowledge to understand long-term processes and the impact of modifying farming practices needs to go hand in hand with an increased and revived knowledge sharing involving all actors of the food chain. The process, based on the generic principles of IPM, must be locally adapted, tackling complexity at crop, cropping, and farming system and landscape level and must make economic sense within a competitive world. ENDURE, as well as other European-level actors are facing up to this task by coordinating research, promoting exchange of experiences, building knowledge hubs, and building on the output of past research and extension projects.

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Chapter 18
Experiences with Implementation and Adoption of Integrated Plant Protection (IPP) in Germany

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Abstract In Germany, the European legal requirements concerning plant protection are supplemented by exhaustive national regulations on the use of plant protection products and a national action plan for sustainable use of plant protection products since 2008. Those provisions ensure the achievement of the key target of risk reduction arising from use of plant protection products, provide a high level of security and protection of human health and environment, and support the implementation of integrated plant protection in all sectors. Important elements to achieve the risk reduction goal are applied research in integrated plant protection and plant breeding mainly based on federal programs, growing resistant cultivars, the use of biological and biotechnical measures, the use of decision support systems supported by a dense network of weather stations, applying damage thresholds, use of certified application equipment, training of farmers, use of inspection systems, support by incentives and maintaining efficient advisory services. The national network of reference farms and the set up of demonstration farms across several sectors are recognised as valuable sources to obtain robust data about plant protection in Germany. Furthermore, integrated plant protection is strongly driven by crop- or sector-specific guidelines which are mainly developed, implemented and controlled by producer associations.

Keywords Germany · IPM · Regulation · Biological control · Resistant cultivars · Sprayers · Control · Incentives · Research · Advice

18.1 Introduction and History in Plant Protection

Germany has an intensive and profitable agriculture system with a high share of fixed and variable production costs to grow crops for food, feed, energy, and raw materials. Fertile soils, favorable climate conditions, innovative researchers and engineers, and highly qualified and motivated farmers and advisors enable an intensive agriculture. However, integrated plant protection is only one element in sustainable agriculture; all components in farm management are optimized in order to achieve sustainability. The total agricultural land area is about 16.72 million hectares (m ha), of which 11.87 m ha land are used for arable farming, 0.066 m ha for orchards, 0.098 m ha for vineyards, 4.64 m ha for pasture land, and 0.02 m ha land for tree nurseries. The four major crops in arable farming with more than one million hectares each are: winter wheat, maize, winter oilseed rape, and winter barley, and together account for 8.2 m ha or about 70 % of the total arable land. Winter rye, summer barley, sugar beets, triticale, and potatoes are grown on 0.614, 0.420, 0.398, 0.383, and 0.259 m ha, respectively. Growing of legumes, with less than 100,000 ha, does not play an important role in Germany as the majority of protein feed crops for livestock husbandry are imported soybean. About 293,900 conventional and 16,500 organic farms with about one million employees are the backbone of Germany's agriculture. About 3.7 % of all farms are larger than 200 ha; the larger ones of more than 750 ha are located in northeastern Germany. Farms over 200 ha cultivate 37 % of the total agricultural land. The average yields and yield development are shown in Table 18.1 (Anonymous 2012a).

Table 18.1 Yields of the main arable crops in Germany, in tons per ha (Anonymous 2012a)

Crop	Mean 2005/2010	2010	2011
Winter wheat	7.50	7.25	7.06
Winter barley	6.49	6.66	5.67
Winter rye	4.92	4.63	4.11
Triticale	5.69	5.43	5.23
Summer barley	4.71	4.92	4.90
Grain maize	9.32	9.09	10.72
Silage maize	43.36	39.38	47.61
Winter oilseed rape	3.82	3.90	2.93
Sugar beets	61.99	61.63	62.87
Potatoes	41.45	39.88	45.76

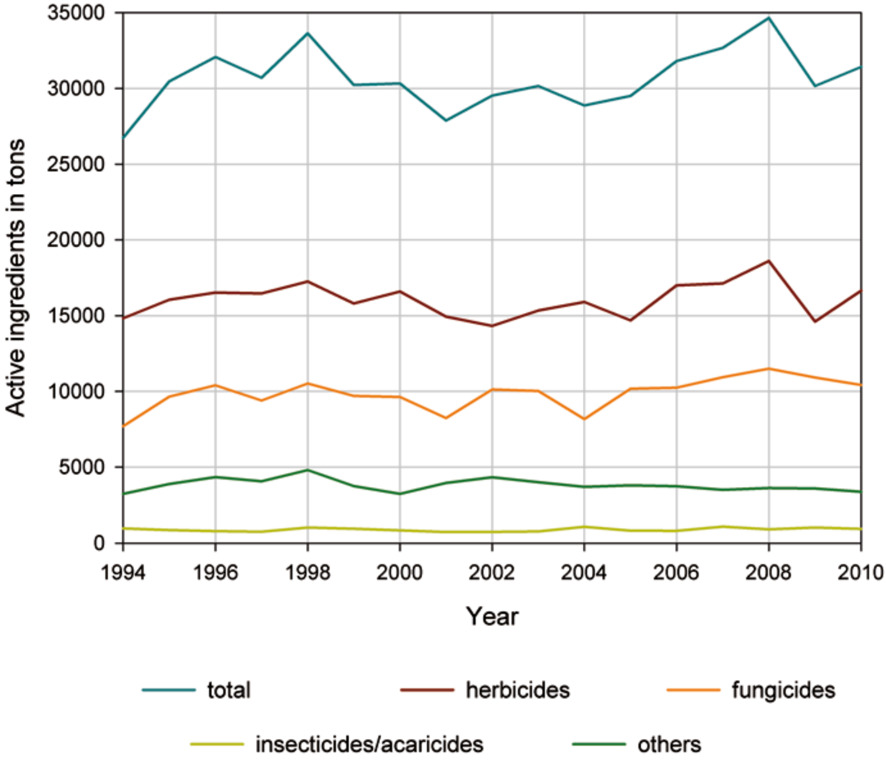

Fig. 18.1 Annual sales of plant protection products in Germany. (Anonymous 2011)

Plant protection products (PPPs) are an important tool for farmers to protect crop health and productivity, to help keep farms profitable, and to ensure the high intensity in crop production. Since 1994, between 27,000 and 35,000 tons of active ingredients (a.i.) of PPPs have been sold annually in Germany, with a slight increase over the years (Fig. 18.1). This upward trend has particularly been caused by a strong decline of fallow land, a continuous increase in the employment of low tillage systems, new harmful organisms and the application of resistance strategies of PPPs. Overall, PPP resistances have appeared more frequently in recent years which has contributed to the reluctance of farmers and advisors to use reduced dose rates of PPPs, and their adherence to the schemes of efficient resistance strategies, that is, the use of full dose rates and a variation of modes of action. German farmers faced a slight decline of available a.i. from 275 in 1998 to 249 in 2010 (including safeners and synergists). Between 2005 and 2007, 24 new a.i. were authorized, and from 2008 to 2010 only 11 new a.i. were placed on the market. The number of PPPs (without suspended registrations) reached 644 in 2010 with 1,206 trade names (very close to 1,115 trade names in 1998). It is remarkable that the number of market authorization holders has almost decreased by half from 139 to 79 since 2003, whereas, in the same period the number of distributers of PPPs has increased strongly from 18 to over 90 in 2010. The number of authorized PPP use areas (indications) is little changed since 2004, and fluctuates between 4,069 and 4,316 which is, however, a distinct reduction compared to the 5,084 indications in 2003. In the same period, the number of authorizations for individual cases or minor uses (Sections 18 and 18a of the German Plant Protection Act) had more than doubled, from 981 in 2003 to 1,831 in 2010 (Anonymous 2011), which is an indicator of the very limited availability of PPPs in specialized crops/plants or sectors.

The proportion of farm expenses for plant protection measures depends on several key factors, including yields, soil properties, farm area and field size, cost of farm land lease, and market prices. For example, the average expenses in a four-year period (2007–2010) in winter wheat and winter oilseed rape amounted to about 214 EUR (280 USD) and 247 EUR (324 USD) per ha annually, respectively (Kamrath et al. 2011). It is noteworthy that the costs of PPPs in Germany do not include extra tax payments, compared to other countries in Europe such as Denmark.

A growing Internet trade and (illegal) parallel imports of PPPs are serious concerns for regulatory bodies in Germany. In these cases, users might not be aware of the risks arising from counterfeit products and the obligatory product-specific information between customer and retailer is not ensured.

The use of chemical and biological PPPs is regulated exhaustively, providing a high level of security and protection for human health and the environment. The regulations are specified in the German Plant Protection Act (Anonymous 2012b) and other legal provisions related to plant protection, and are controlled and monitored by authorities of the federal government and federal states.

In 2009, new requirements for regulation and use of PPPs in the European Union fundamentally changed plant protection in European member states. The so-called “pesticides package” comprises three main parts:

- Regulation (EC) No 1107/2009 of the European Parliament and of the Council of 21 October 2009 concerning the placing of plant protection products on the market and repealing Council Directives 79/117/EEC and 91/414/EEC;
- Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for Community action to achieve the sustainable use of pesticides (in the following referred to as Sustainable Use Directive, SUD);

- Regulation (EC) No 1185/2009 of the European Parliament and of the Council of 25 November 2009 concerning statistics on pesticides.

Today in the European Union, placing PPPs on the market is only allowed if a PPP and its use is consistent with good plant protection practice and by having regard for realistic conditions of use. PPPs shall meet the following requirements: (1) it shall have no immediate or delayed harmful effects on human health, and (2) no unacceptable effects on the environment and biodiversity (Anonymous 2009a). That means a core element of IPP, namely risk reduction for human health and the environment, is already addressed with the strict approval requirements and proper use of PPPs. Nevertheless, to switch to more sustainable agricultural systems with a focus on prevention and cultural measures, and less misuse, remains one of the main challenges for farmers.

With the enforcement of the new German Plant Protection Act of February 6, 2012, and the amendment of the National Action Plan on sustainable use of plant protection products (NAP), Germany transposed the European "pesticides package" into national legislation. Recommendations are also considered for these changes, from the OECD Strategic approach in pesticide risk reduction which focuses on IPP and national action plans as appropriate tools to speed up the implementation of sustainable plant protection strategies worldwide (OECD 2009).

Germany adopted its first reduction program in 2004. The second action plan was adopted by Germany's federal and state agriculture ministers in 2008 (Anonymous 2008) and aims, in particular, at further reducing the risks associated with the use of PPPs, at reducing misuse, unnecessary usage and point and diffuse sources of pollution, and at reducing the dependence of farmers on chemical PPPs. The two main quantitative goals are: (i) to reduce the risks that may arise from the use of PPPs by 25 % as compared to the baseline 1996 to 2005, and (ii) to reduce the rate of exceeding maximum residue levels (MRLs) for PPPs in domestic and imported food to less than 1 % in each product group by 2021. The results are (Hommel 2012):

1. Twelve out of the fifteen aquatic and terrestrial risk indexes already reached the target of being below the 75 % baseline.
2. In 2009 and 2010 PPPs exceeding MRLs were observed in samples of all product groups rejected as follows: produced in Germany 0.7 % and 0.7 %, respectively, imports from the European Union 1.4 % and 1.9 %, respectively, and imports from third countries 3.2 and 2.7 %, respectively.
3. The regulatory limit of PPPs and relevant metabolites in drinking water of 0.1 µg/l, was met at 95.4 % of all measuring points in the German groundwater network during the last assessment period (2006–2008). Compared with the three previous 5-year periods, the situation has been steadily improving.

A core element of Germany's Plant Protection Act and the NAP is integrated plant protection (IPP). The term integrated pest management (IPM), as mentioned in the SUD and usually used worldwide, is not commonly used in Germany. The term integrated plant protection (IPP) is used, as it is more accurately translated and reflects the German perspective where plant protection is prioritized rather than the management of pests. The term "pest" is used in this chapter synonymously for all harmful organisms (insects, mites, nematodes, mice, diseases, weeds, etc.), if not specified otherwise. The term plant protection product (PPP) is used instead of "pesticide", because "pesticide" summarizes, according to European legislation, PPPs and biocidal products.

The SUD differentiates between general principles of IPP described in Annex III "General principles of integrated pest management" and crop or sector-specific guidelines (Anonymous 2009b). Although professional users of PPPs in all EU member states have to comply with the general IPP principles, at the latest by January 1, 2014, the implementation of crop- or sector-specific guidelines will remain voluntary.

In Germany, the definition and use of IPP were first implemented in national law in 1986. There, it is statutorily required that farmers and advisors have to utilize good plant protection practice and have to consider the principles of IPP and the protection of groundwater. Freier and Burth (2006) summarized four key tasks for widespread IPP implementation beyond the good plant protection practice:

1. Minimum requirements for IPP must be defined, in particular for preventive and nonchemical alternatives, and the necessary minimum in PPP use. It must be clearly defined which measures are economically feasible and which need financial support.
2. Research and development of innovation is essential. As a bridge between research and practice, demonstration farms play an important role. These farms are also of great importance for communication and knowledge dissemination.
3. There is a need to increase economic evaluation of IPP strategies. This is needed to assess benefits and risks of PPP uses.
4. Information and advice are important for IPP. Decision-support systems (DSS), field visits, training, and experiments are core elements for IPP uptake.

In Germany, the IPP principles of Annex III "General principles of integrated pest management" of the SUD became mandatory for farmers and advisors with the entry into force of the new Plant Protection Act in February 2012. Thereby the general principles of IPP became part of the mandatory good plant protection practice. Furthermore, individual voluntary contracts between farmers and retailers, and many risk mitigation measures are implemented in the framework of the NAP. With the implementation of crop- or sector-specific IPP guidelines, a high quality of IPP with a premium level seems to be in reach within the next few years. However, due to the mandatory good plant protection practice, high standards of plant protection have already been implemented in Germany. General principles of IPP, good plant protection practice, and easy-to-use IPP measures can be considered as standard IPP. IPP is a dynamic system and single measures are subject to permanent evolvement (Fig. 18.2). System changes beyond standard IPP, using reduction measures, innovations, or optimization, are required for not risking farm profitability. Ambitious farmers, good extension, and incentives are important to implement voluntarily premium IPP. Investments in more research and development, in particular the transfer from fundamental to applied knowledge, are continuously needed. Incentives or compensation payments may be necessary to change farmer behavior and reach a sustainable IPP beyond mandatory rules. To make progress applied research, education of the next generation of farmers, and extension services have to be strengthened as well. The availability of reliable nonchemical measures and easy to use decision-support systems has to be

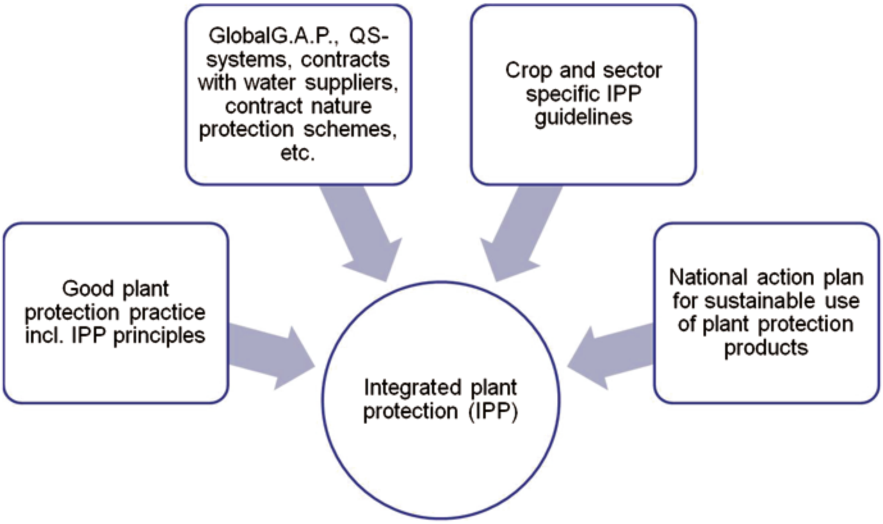

Fig. 18.2 Main spheres of activity to strengthen IPP in Germany

increased and their use has to be promoted. Agriculture faces the challenge to ensure food security in a sustainable manner, for example, securing soil functionality and biodiversity and ecosystem services (Anonymous 2012e). Germany will benefit from the new European Research Strategy Horizon 2020, in which the European Commission underlines the crucial role of research and innovation in preparing the European Union for future challenges in agriculture, that is, economic viability of farms and linking chains and sectors such as bio-energy, bio-mass, climate change, biodiversity, water protection, resource management, and food and feed supply chain integration.

18.2 Definition and Explanation of Terms

18.2.1 Good Plant Protection Practice (GPP)

In accordance with the German Plant Protection Act (Section 18.3), plant protection must be accomplished in line with good plant protection practice (GPP) (Anonymous 2012b). This includes: (1) compliance with the general principles of IPP as stated in Annex III “General principles of integrated pest management“ of the SUD; (2) maintaining plant health and quality based on preventive measures, preventing the spread of invasive species, control of pests, and enhancement of natural mechanisms to control pests; and (3) measures for the safe use of PPPs and other plant protection methods. Principles for applying the GPP were developed and agreement reached between the federal and state governments, authorities, and relevant stakeholders (Anonymous 2010). The specified principles comprise the four general principles: (i) all plant protection measures should be carried out site-, crop-, and situation-specific and the use of PPPs should be restricted to the necessary minimum; (ii) reliable culture techniques and other nonchemical alternatives should be used preferentially; (iii) infestation of crops with pests should only be reduced with reliable measures, to the extent that economic loss is prevented; (iv) the diverse offers of public and other advisory services and decision-support systems should be used, and with advanced training all plant protection measures should comply with the current state of the art. Furthermore, the GPP includes 28 specific principles with regard to preventive measures (7), control and monitoring (2), decision making for the most appropriate nonchemical or chemical measure or treatment (2), appropriate adoption and management of all measures (3), proper use of PPPs (6), record keeping (1), proper use of application equipment (1), protection of adjacent areas (1), storage and disposal of PPPs (4), and efficacy of control (1). Good plant protection practice is continuously updated according to the state of the art.

In conclusion, the obligatory rules of the GPP are a strong and efficient legislative tool to direct plant protection and use of PPPs to more sustainable approaches.

18.2.2 Integrated Plant Protection (IPP)

Integrated plant protection was first announced in legal documents as an overall concept in Germany's Plant Protection Act of 1986. The definition has not changed to date: "IPP is a combination of measures – with priority consideration of biological and biotechnical measures, resistant cultivars, and cropping and cultural control measures – where the use of chemical plant protection products is restricted to the necessary minimum" (Anonymous 2012b). The preferential aim of IPP is to keep crops highly productive and stored products healthy, in order to prevent economic damage to farms, poor resource efficiency, and risks to human health and the environment. IPP is divided into general principles and crop- or sector-specific guidelines. Whereas general principles describe rules for decision making in plant protection as scope of action, crop- or sector-specific guidelines contain a detailed set of different measures, additional recommendations for plant protection, and their voluntary implementation needs manifold support. IPP guidelines can also contain further measures beyond plant protection, such as elements of conservation of biodiversity specifically adapted to the particular crops or cropping systems or sector.

18.2.2.1 General Principles of IPP

The eight mandatory general principles of IPP are described in Annex III "General principles of integrated pest management" of the SUD (Anonymous 2009b): (1) measures for prevention and suppression of pests (e.g., crop rotation, resistant cultivars, enhancement of beneficial organisms); (2) tools for monitoring; (3) threshold values as a basis for decision making; (4) preference for nonchemical methods; (5) preferential use of target-specific and low-risk PPPs; (6) reduction of use to necessary minimum; (7) application of resistance strategies; and (8) documentation and check for success. These general principles of IPP are deliberately kept flexible and un-specified in order to take into account the regional variability of production systems and to suit the situation on the farm and field level across European member states. These eight principles are to be applied in plant protection as a decision tree for successful plant protection. The principles range from the initial prevention and/or suppression of harmful organisms, using monitoring and intervention threshold values for decision making to choose the appropriate control strategy, giving preference to nonchemical measures and leaving the targeted use of PPP as the last possible option. Thus, the general principles are not controllable in a systematic manner. An elaborate description of individual principles, especially in reference to the crop and regional adaptation, is necessary. Crop- or sector-specific guidelines are built on the general principles but are more specific and contain detailed controllable measures.

In Germany, general principles of IPP have already been considered in the framework of the GPP, as stated in the Plant Protection Act of the year 1986 (Anonymous 2010). This was an important step, because the future approach explicitly requires IPP mandatorily. Many activities and changes, both in research and development and in plant protection policies over the last 25 years, relate to the prescription of IPP by law in 1986 (Meinert 2006). The principles of GPP and IPP were announced in detail in the *Official Gazette of the Federal Republic of Germany* and in a brochure, last published in 2010 (Anonymous 2010). The general principles of IPP, within the GPP as of 2010, are (Anonymous 2010):

1. IPP constitutes a holistic approach and requires complex actions.
2. The concept of IPP includes the ecological needs at the same value as economic and social aspects, in order to act ecologically acceptably and therewith to secure sustainability.
3. In the concept of IPP, preventive measures have priority over direct measures.
4. IPP requires careful consideration over all decisions in plant protection.
5. IPP as a knowledge-driven concept favors the utilization of new knowledge and justifiable technological progress (e.g., transgenic crops are currently not considered as “justifiable technology” by the German public) and sets high standards for the preparation and transposition of site-specific information.

These five principles of IPP formed the basis for previous guidelines of IPP that are part of the guidelines of controlled and integrated crop production. The new general principles of IPP in the EU legislation are more concrete and action-oriented.

18.2.2.2 IPP Crop- or Sector-Specific Guidelines

First, IPP guidelines are an elaborate description of the eight principles of IPP relating to a specific crop or sector. They contain reliable and effective preventive and direct control measures against pests. Second, all measures should be characterized regarding their potential effects on the environment and sustainability, including economics. The voluntary preference of individual, especially durable or environmentally compatible preventive and direct control measures, can be motivated with the help of effective incentives and support tools. The SUD states: “Member States shall establish appropriate incentives to encourage professional users to implement crop or sector-specific guidelines for integrated pest management on a voluntary basis. Public authorities and/or organisations representing particular professional users may draw up such guidelines. Member States shall refer to those guidelines that they consider relevant and appropriate in their National Action Plans" (Anonymous 2009b, p. 79).

The German NAP will describe minimum standards for such guidelines. Several agricultural and horticultural associations, such as the German Railway Company and other stakeholders, supported by the Julius Kühn-Institut (JKI), have started developing, or as in the case of sugar beet (Gummert et al. 2011), have finalized crop-specific or sector-specific guidelines on IPP.

Still, the challenge remains to integrate IPP into farming practice. The uptake of voluntary crop- or sector-specific IPP by farmers can be fostered in many cases by incentives and different support schemes. However, it still seems necessary to incentivize additional measures, since in the short term the use of chemical PPPs represents the easiest and most effective measure compared to preventive long-term or alternative measures. Incentives and support tools are crucial to compensate economic disadvantages and to change the attitude of farmers towards sustainability, provided that the alternatives are effective.

As an example, the IPP guideline for sugar beets comprehensively describes the eight general principles for important pests such as emerging diseases, soil-borne diseases, leaf diseases, arthropods and other animal pests, and weeds (Gummert et al. 2011, 2012). The main purpose of the guideline is to inform growers, advisors, and sugar companies about the importance and implication of IPP and its advanced measures and opportunities. The guideline has two main chapters, the general part and the pest-specific part. The elements of the general part are mandatory, whereas the pest-specific part with reliable preventive and direct plant protection measures and with supplementary information remains voluntary and represents the earlier-mentioned premium level of IPP. The uptake of those voluntary measures will strongly depend on farmers' attitudes, support schemes and incentives, and will facilitate the development and introduction of further measures within the guideline. There is no doubt that the IPP guideline for sugar beets has to be continuously adjusted to the state of the art (Gummert et al. 2012).

18.2.3 Necessary Minimum

The necessary minimum amount of PPPs is a key element in IPP in Germany. It is part of the IPP definition, and defined as: "In the use of chemical plant protection products, the necessary minimum is the term used to describe the amount needed to ensure crops are successful, not least as regards their economic viability. It is assumed, that all other practicable options to prevent and deter harmful organisms have been fully exploited and that consumer, the environment and user protection provisions have been adequately taken into account." (Anonymous 2008, p. 11).

Farmers' and advisors' decision making, to fulfill the requirements of the necessary minimum, is influenced by a number of factors: (a) potential sales of the agricultural products; (b) production costs; (c) yield and quality assurance; (d) production according to specific agreements with the retailers/merchants (e.g., sales agreements/contracts, certification); and (e) participation in particular programs to protect the environment (such as agroenvironmental and/or contract nature protection schemes), or in specific production areas (such as organic farming). The necessary minimum amount of PPP uses is annually calculated on the basis of data from the Network of Reference Farms (see Section 18.6.2).

Bürger et al. (2008) examined the necessary minimum on the basis of three assumptions: (1) applying a PPP at the recommended dose; (2) applying a PPP that considers the real situation (i.e., adjusted dose, thresholds, etc.); and (3) minimizing PPP need by changing the cropping system to lower the risk of pests. The smallest PPP intensity can be expected by combining the two latter approaches. Bürger et al. (2008) stated that in practice, calculations of the necessary minimum should have a stronger focus on all feasible nonchemical measures and should also include economic considerations.

18.2.4 Treatment Frequency Index (TFI)

In practice, the PPP use intensity in Germany is described by the Treatment Frequency Index (TFI). It considers dose reduction in proportion to the authorized dose and partial field application of each PPP. For example, application of the full authorized dose in an entire field means a TFI of 1.0, half-dose in an entire field means TFI of 0.5, and half-dose in half a field means a TFI of 0.25. The TFI calculation in Germany is based on on-farm use surveys called NEPTUN (Rossberg 2006).

In general, the TFI data, comparing farms over time, is different. There are farms with a high and low intensity of PPP use. Such data provide an overview on the PPP use situation in particular crops and, at the same time, an indication of deficiencies in appropriate and targeted PPP use. The observation and the understanding of why some farms apply more PPPs than others is considered as the main risk mitigation potential and anchor for knowledge dissemination. Therefore, targeted advice and training can reduce the number of farms with high TFI scores, but on the other hand there is also a decrease of farms with low TFI below the range of the necessary minimum possible. Insufficient knowledge or advice is not always a reason for unnecessary treatments, but also for omitted treatments. The example, Fig. 18.3, shows the variation of TFI scores in representative surveys in sugar beet in 2005, 2007, and 2009 on 584, 524 and 477 farms, respectively. The reasons are that in the years 2007 and 2009 there were more farms with higher TFI (>4.0) than in 2005. In 2007, very dry weather conditions in May required additional herbicide use, and the increase of fungal diseases led to higher fungicide treatments in 2007 and 2009 (Rossberg et al. 2008).

The TFI calculation is also an important prerequisite for applying Germany's risk indicator SYNOPS (Strassemeyer and Gutsche 2010).

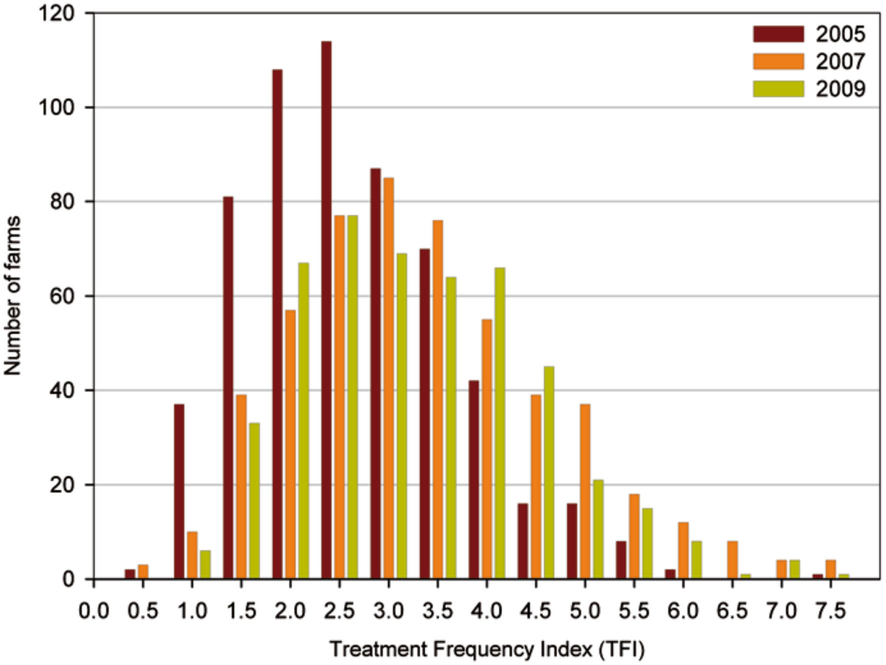

Fig. 18.3 Variation of the treatment frequency index (TFI) overall treatments in sugar beets in Germany in 2005, 2007 and 2009. (data from Rossberg 2006, Rossberg et al. 2008, 2010)

18.3 Key Tools in IPP

18.3.1 Decision-Support Systems (DSS)

Development, implementation, use, and update of decision-support systems are core elements for the targeted use of PPPs limited to the necessary minimum. Jörg and Bartels (2008) formulated simple but crucial questions for IPP, the use of DSS, and forecasting systems: When does a pest occur? When do very favorable conditions for infestation exist? Is the threshold exceeded? Is the threshold exceeded on a certain field? Do I have to apply PPPs on my field, and if so, when?

Germany has a long tradition in development and use of DSS (Jörg and Bartels 2008, Racca et al. 2011). With the support of DSS, users can estimate the occurrence and the development of pests. Advanced DSS work as a combination of expert systems, where decision rules are based on expert knowledge combined with pest biology and forecast models which, in mathematical algorithms, combine weather data and pest biology. In Germany, the Central Institution for Decision Support Systems in Crop Protection (ZEPP, www.zepp.de) is the main public institution for the development and maintenance of DSS. The development of new forecasting systems and maintenance of existing forecasting and simulation models is supported by a very dense network of more than 560 weather stations of Germany's National Meteorological Service (DWD, www.dwd.de). Through the utilization of geographic information systems (GIS), the weather data are interpolated spatially and the results of the prognosis models are displayed as nationwide risk maps on the internet platform ISIP (www.isip.de). The precipitation data are supplemented on the basis of the RADOLAN (Radar-Online-Adjustment) network of the DWD. Daily risk maps, based on the aforementioned elements, show the infection pressure of different pests in cereals, potatoes, sugar beets, and horticultural crops. The most important applications of DSS for agricultural and horticultural pests are: (i) estimation of the infestation risk; (ii) estimation of the necessity of PPP treatments; (iii) forecast of the optimal timing for field assessments; (iv) forecast of the optimal timing for PPP treatments; and (v) recommendations of appropriate PPPs (Racca et al. 2011). A further system is available for estimating the growth stages of the main crops.

DSS are distributed by different institutions in Germany. The public plant protection services of the federal states are the main source in agriculture for cereals, oilseed rape, potato, sugar beets, maize, and in horticulture for onion, cabbage, and apple. In addition to the paper warning letters, fax, teletext, or SMS, the internet is used more and more to disseminate knowledge and advice. The most important online tool is the Information System for Integrated Plant Production (ISIP, www.isip.de), with partial free access. Based on site-specific information (i.e., sowing or planting dates, cultivars, preceding crops) combined with a regional calculation, site-specific prognosis results are provided. Additionally, the public plant protection services in the federal states run permanent cultivar trials as well as pest monitoring systems, and engage in field monitoring to estimate the regional infestation of pests and permanently validate the results of the DSS.

Further prognosis models are available to advisors of the plant protection services via the software package PASOWIN.

From the ZEPP, over 45 forecasting models are currently in use, in validation or in development, 24 models of which have reached ready-to-implement status, and 20 DSS are already accessible online via the platform ISIP (Table 18.2).

In long-time experiments and demonstration trials, the ZEPP and the federal state plant protection services showed explicitly that a reduction of PPPs with improved yield protection is feasible by the application of DSS. For example, the model SkleroPro has been run very successfully in winter oilseed rape since 1994. Until now, the infestation with stem rot, *Sclerotinia sclerotiorum,* was predicted as precisely (70 %) with only a small number of overestimated and underestimated infestations of 24 % and 6 %, respectively (Hommel 2012).

Further DSS in Germany (and Europe) are distributed by the company ProPlant as PC software packages and an online tool, which can be purchased via www.proplant.de.

In the fruit-growing sector, private extension services also offer prognosis models. Many agrochemical companies offer online DSS, (e.g., for major diseases of wheat or potato).

Table 18.2 Overview of IT-Based decision support system (DSS) used in arable farming and horticulture in Germany. (Jörg and Bartels 2008, Racca et al. 2011, www.zepp.info, www.isip.de)

Name	Pest	Crop	Performance
SIMONTO	–	wheat, rye, barley, triticale, oilseed rape	calculation of the ontogenetic development
SIMCERC3	eyespot, *Pseudocercosporella herpotrichoides*	wheat, rye, triticale	epidemic development, field-specific control decision making
PUCREC/PUCTRI	brown rust, *Puccinia triticina, P. recondita*	wheat, rye	initial occurrence, epidemic development, field-specific control decision making
SEPTRI1	*Septoria tritici*, *S. nodorum*	wheat	initial infection, first foliar lesions, life span of leaf levels
SIMLAUS	aphids, *Sitobion avenae, Rhopalosiphum padi, R. maidis*	wheat, barley	population dynamic depending on an initial population, optimal date of control
SIMPHYT1	Late blight, *Phytophthora infestans*	potato	initial occurrence, optimal date of first spray
SIMPHYT3	Late blight, *P. infestans*	potato	infection pressure, optimal spray intervals, selection of fungicides
Öko-SIMPHYT (based on SIMPHYT1 and 3)	Late blight, *P. infestans*	potato	optimal spray interval, spray volumes and spray break of copper fungicides in organic farming
SIMLEP3	Colorado potato beetle, *Leptinotarsa decemlineata*	potato	population dynamic and relative abundance, field-specific control decision making (date to control infestation, first spray)
CERCBET1	*Cercospora* leaf spot*, Cercospora beticola*	sugar beets	initial occurrence, optimal rating start
CERCBET3	*Cercospora* leaf spot*, C.beticola*	sugar beets	daily rate of infection, field-specific control decision making (estimating threshold exceeding)
SKLERO-PRO	stem rot, *Sclerotinia sclerotiorum*	oilseed rape	field-specific control decision making (need for treatment during flowering)
SIMPEROTA1	Tobacco *blue* mold, *Peronospora tabacina*	tobacco	initial occurrence, optimal rating and spray start
SIMPEROTA3	Tobacco *blue* mold, *P. tabacina*	tobacco	calculation of infection pressure, control decision making (need for a next treatment)

Table 18.2 (continued)

Name	Pest	Crop	Performance
ZWIPERO	downy mildew, *Peronospora destructor*	onion	determines the sporulation and infection risk, control decision making (estimating the need for treatments)
POMSUM	different arthropods, in particular codling moth, *Cydia pomonella*, summer fruit tortricid moth, *Adoxophyes reticulana*, winter moth, *Operophthera brumata*, apple aphid, *Aphis pomi*, red spider mite, *Panonychus ulmi,* apple blossom weevil, *Anthonomus pomorum, apple* sawfly, *Hoplocampa testudinea*	apple	calculates the effective temperature sum, determines phenological data (e.g., initial flight, egg-laying, larval hatch)
LTZ-Feuerbrand	fire blight, *Erwinia amylovora*	apple, pear	calculation of the infection risk
FEUERBRA	fire blight, *E. amylovora*	apple	calculation of the epidemic outbreak and infection risk for four susceptibility classes
ANLAFBRA	fire blight, *E. amylovora*	apple	Site-specific calculation of the infection risk
TAPDEF	peach leaf curl*, Taphrina deformans*	peach	calculation of the optimal spray date
MONILIASIM	brown rot blossom blight, *Monilia laxa*	cherry	calculation of the infection risk and of new infections,
SIMSCAB	apple scab, *Venturia inaequalis*	apple	determines primary infections and days with high infection risk, control decision making (estimating the need for treatments)
DELRAD	cabbage root fly, *Delia radicum*	cabbage	population dynamic and relative abundance, field-specific control decision making, foil/net management
DELANT	onion root fly, *Delia antiqua*	onion	population dynamic and relative abundance, field-specific control decision making, foil/net management
PSIROS	carrot fly*, Psila rosae*	carrot	population dynamic and relative abundance, field-specific control decision making, foil/net management

In individual federal states, particular DSS are developed and implemented for important regional high-value crops. A good example is the DSS VitiMeteo (www.vitimedeo.de) which was developed and is maintained by the Viticulture Institute of the State Baden-Württemberg (WBI) in cooperation with the Swiss research station Agroscope Changins-Wädenswil (ACW). It provides a forecasting tool, based on weather data, for the important fungal diseases downy mildew (*Peronospora sp.)*, powdery mildew (*Oidium*), and black rot. VitiMeteo is free of charge for wine growers and advisors in Baden-Württemberg. Other systems exist for the flight prognosis of grapevine moths, *Lobesia botrana* and *Eupoecila ambiguella,* and the planthopper *Hyalesthes obsoletus*.

A further example is a dispersal model for the invasive Western corn rootworm, *Diabrotica virgifera virgifera,* which integrates all relevant regional conditions for optimized pest control dates. The model consists of the following components: occurrence of *D. virgifera virgifera*, regional distribution, long distance flights, and global spatial distribution (Balschmiter 2011, Krügener and Balschmiter 2011). The first online version allowing GIS-supported single-field simulation is available for the plant protection services. But, further validation is needed.

18.3.2 Damage Thresholds

Intervention or damage thresholds are recognized as one of the major elements supporting the decision making in the classical concept of IPP. Thresholds for economic or yield damage are calculated based on the epidemiology of pests and their injury profiles. However, it has to be recognized that thresholds are not available in all regions and crops or, if available, they vary between regions and depend on agronomic practices. Moreover, they can be seen only as one element in combination with the exploitation of all other agronomic measures and are only useful in combination with field monitoring. In addition, existing thresholds might not always be adapted to the current situation and disease resistance profile of the cultivars. The application of economically justified threshold values requires the scouting of fields, profound knowledge, and advice. Many thresholds for pests in Germany were developed years ago. A future task will be to update these values. Nevertheless, they are a tool supporting the decision making, although decision making based on thresholds is not simple, as in practice there are multiple pest infestations, pest–weather interactions, different developmental stages of pests, or the necessity for a decision before pests can be monitored. Use of thresholds in weed control is less common. Methods used for checking whether the thresholds are reached are: field monitoring or tools such as color, lime, pheromone, or light traps. The frequency of pest counts, number of individual plants or species per unit depend on the pest. Information about thresholds provided by the plant protection services and via the ISIP online portal has become an important part of independent advice. It is also communicated to farmers that use of damage thresholds can cause less-efficient treatments and, therefore, reduced profitability per field (Brinkjans and Scholz 2003).

Table 18.3 Examples of damage thresholds for aphids in different crops recommended in IPP guidelines in Germany

Crop	Pest	Threshold	Source
Winter wheat	*Rhopalosiphum padi, Sitobion avenae* as vector	20 % infested plants in autumn, 10 % infested plants in spring	Freier et al. 1997
Winter wheat	*R. padi, S. avenae* as direct pest	20 % infested stems in GS 59 (end of heading), 3–5 aphids per ear in GS 65–69 (end of flowering) or 60 –80 % infested stems	www.isip.de (accessed 2012)
Faba bean	*Aphis fabae*	5–10 % infested plants in colonies	www.isip.de (accessed 2012)
Sugar beet	*Myzus persicae* as vector	1 winged aphid per 10 plants	Gummert et al. 2011
Sugar beet	*A. fabae*	before raw closing 10 % infested plants, after raw closing 50 % infested plants or > 20 % of plants with colonies	Gummert et al. 2011
Apple, pear	*Rhopalosiphum insertum*	preflowering stage 80 colonies per 100 flower clusters	Köppler et al. 2011
Apple, pear	*Dysaphis plantaginea*	preflowering stage 1–3 infestations per 100 flower clusters (control of at least 300 clusters); postflowering stage 1–2 colonies per 100 shoots; summer 1–3 colonies per 100 shoots	Köppler et al. 2011
Cauliflower, cabbage	*Brevicoryne brassicae*	20 % infested plants with < 100 aphids or 10 % infested plants with > 100 aphids	Brinkjans and Scholz 2003
Carrot	*Semiaphis dauci*	8 % of plants (over 10 cm length) with > 5 aphids	www.isip.de (accessed 2012)

Threshold examples for aphids in different crops can be found in Table 18.3. With regard to aphids, it is recommended to consider the natural occurrence in fields of predators such as ladybirds, syrphid larvae, or green lacewing larvae in treatment decisions (Freier et al. 1998). Predator units were determined per species and stage, for example, a *Coccinella septempunctata* adult has a unit of 0.94 (female 1.0 and male 0.88) and a larva 0.33, *Episyrphus balteatus* larva and other syrphids 0.46, and so on to assess their predatory efficacy. For example, it was found that more than 15 predator units of ladybirds per m^2 are needed to keep aphids in winter wheat below the damage threshold.

18.3.3 Resistant Cultivars

The choice of resistant cultivars, according to regional conditions, is a further key element of IPP. The rationale for the choice of resistant cultivars is to support resistance management strategies, to control pests where PPPs are not available (e.g., viral diseases), to solve minor use problems, and to reduce the use of PPPs.

The availability of resistant cultivars has continuously improved in Germany since 1965. Yield and stability are demanded by growers as quality and resistance against pests. For example, modern winter wheat cultivars are less susceptible to powdery mildew, *Erysiphe graminis* (regression coefficient B=–0.073), brown rust (–0.038), and Septoria leaf blotch (*Mycosphaerella graminicola*) (–0.024) than old cultivars (Ahlemeyer and Friedt 2012). Only for tanspot of cereals (*Pyrenophora tritici-repentis*) (–0.003) is it difficult to produce a large number of less-susceptible cultivars.

Despite the availability of resistant cultivars, the results from the Network of Reference Farms since 2007 have not shown a correlation between TFI and scores of disease resistance or the use of resistant cultivars. It seems that resistant cultivars are treated in the same intensity as susceptible cultivars (Freier et al. 2011). This observation might have several reasons: most grown cultivars have high resistance scores for only a few diseases, average dose rates are not adjusted to the particular disease resistance levels, or the use of broad-spectrum pesticides for a range of diseases does not take into account the resistance levels in terms of the TFI reduction. According to the results from the Network of Reference Farms, highly susceptible cultivars are rarely cultivated in Germany.

The quality of new cultivars is tested for several years in different regions by the Federal Plant Variety Office (BSA), in order to protect the consumer and to ensure the provision of high-quality seed and planting stock material of resistant and high-performance cultivars for farmers and horticulturists. The successfully tested cultivars are included in the National List of Cultivars. The agricultural and horticultural cultivars are tested for characteristics of value, including yield, quality, resistance, and cultivation qualities (www.bundessortenamt.de). In addition to the testing of new cultivars, the existing cultivars are continuously monitored and tested in variety trials of the federal states.

In order to counteract the genetically based adaptability of target organisms and to guarantee a durable protection of crops, there is a need for continuous and long-term research to manage resistant cultivars and explore new sources of resistance. Furthermore, if no alternatives of PPPs and seed treatments exist, research of host resistance mechanisms, particularly against the most damaging pests, has to be initiated and maintained. In Germany, more than 50 very successful small and medium-sized plant breeding enterprises (SMEs) exist that are supported by public research institutes and field stations (cf. www.bdp-online.de/en/Homepage/).

The commitment to grow resistant cultivars is often complex for the growers as they are dependent on other actors in the retail chain and the retail actors' acceptance of the new cultivars (Meinert 2006). Validated experimental and field results and their communication by advisors play a crucial role in proving that resistant cultivars can contribute significantly to the necessary minimum in plant protection if resistant cultivars and chemical PPP compete against the same pest.

Resistant cultivars are not sustainable per se. Rather, they represent one element in the suite of IPP components; in some cases resistant cultivars should not be considered primarily as a preventive measure, but rather as a direct measure with low risk. For example, transgenic insect-resistant maize (Bt maize) against the European

Table 18.4 Commercial growing of conventional and Bt maize against the European corn borer, *Ostrinia nubilalis,* in Germany from 2005 to 2008. (Anonymous 2012f)

Year	Parameter	Bt maize	Conventional maize
2008	number of locations	201	–
	acreage in ha	3,173	2,087,520
	acreage in %	0.15	–
2007	number of locations	174	–
	acreage in ha	2,685	1,871,397
	acreage in %	0.14	–
2006	number of locations	106	–
	acreage in ha	947	1,746,900
	acreage in %	0.05	–
2005	number of locations	58	–
	acreage in ha	342	1,705,658
	acreage in %	0.02	–

corn borer (ECB, *Ostrinia nubilalis*) can contribute substantially to stabilizing low tillage systems, whereas (transgenic) Bt maize with resistance against the Western corn rootworm (*Diabrotica virgifera virgifera*) allows farmers to continue with monoculture of maize instead of introducing an appropriate crop rotation. Therefore, each system should be scrutinized as to whether resistance indeed contributes to a resilient and sustainable cropping system.

In Germany, resistant cultivars of transgenic maize (Bt maize against ECB) were introduced in the year 1998 but were prohibited by the federal government in 2009 for commercial growth due to public concerns. In addition to commercial growth of transgenic crops, field experiments for research purposes also have been stopped since 2012 (Anonymous 2012f). Nevertheless, transgenic crops (e.g., soybean, maize) are imported in large quantities as feed for livestock husbandry.

From 2005 to 2008 the acreage of Bt maize with resistant cultivars against the ECB increased annually, mainly on large farms with low tillage systems located in northeast Germany (Table 18.4). The very high resistance of Bt maize against the ECB was impressive and stabilized yields (Fig. 18.4). The risk of adaptation of the ECB to Bt maize cultivars has to be managed (e.g., with the refuge strategy). In field experiments, Degenhardt et al. (2003) showed that resistant cultivars are more cost efficient than the use of the parasitoid *Trichogramma* or chemical insecticides (Table 18.5). Many German farmers and advisors are convinced that Bt maize can stabilize low tillage systems and that it reduces the mycotoxin content in feed, particularly in corn-cob-maize (CCM) for pork production. Without ECB-resistant cultivars, large farmers have to apply PPPs or need additional resources to mulch the stubble or even return to the plow.

18.3.4 Biological, Biotechnical and other Nonchemical Measures

Biological control includes measures: (1) to protect and support natural enemies of pests in fields or in field margins; (2) to introduce commercially available natural enemies; (3) for the use of plant extracts; and (4) for the use of microorganisms. The

Fig. 18.4 A field with Bt maize in northeast Germany. The rows in between with nonprotected maize were visible due to severe infestation with ECB larvae, and impressively demonstrated the high resistance of Bt maize. (Photo: JKI/Hommel/2002)

Table 18.5 Cost comparison of control strategies against the European corn borer. (Degenhardt et al. 2003)

Method	*Trichogramma*		Insecticide		Bt Maize	
Location	Rheintal	Oderbruch	Rheintal	Oderbruch	Rheintal	Oderbruch
Additional costs (EUR/ha)	90	90	40	40	35	35
Return (EUR/ha)	−52	−57	18	55	84	93

commercial production and, especially, the marketing of biocontrol agents entail a much more difficult process, as it mostly involves small enterprises with a limited product portfolio, trying to enter the plant protection market which is dominated by the agrochemical companies. An additional difficulty that can indeed impair entire biological control agents is the low or very low efficiency of plant strengtheners (Lüth 2010). As most biological control agents have to follow the same authorization process as chemical PPPs, legislation might further limit the future registration and availability of biological control agents (Jehle 2011).

Biological control measures are characterized as highly selective and low risk in regard to human health and the environment. Therefore, biological, biotechnical, mechanical, and other nonchemical measures are key direct measures in IPP. Compared to chemical PPP and resistant cultivars, the availability of practical and efficient nonchemical measures is limited and varies enormously between agricultural sectors. Biological and—in the case of using pheromones or the sterile-male technique—biotechnical plant protection measures are used in almost all sectors and crops but to differing extents, particularly in field vegetables, field ornamentals, orchards, viticulture, arable farming (i.e., maize, oilseed rape, potato), forests, greenhouses (i.e., vegetables, ornamentals), the storage sector, private gardening, and the amenity sector (Anonymous 2003).

More than 90 different biological control agents (BCA) are produced and distributed by about 15 companies, mostly SMEs, in Germany (Herz 2011). The main BCAs are: lacewings (1 species), parasitic wasps (42), predatory beetles (9), predatory flies (3), predatory thrips (1), predatory mites (9), predatory bugs (7), insect parasitic nematodes (5), snail parasitic nematodes (1), pollinators (2), and predators and parasites against stall flies (8). There are also microorganisms available, such as *Bacillus thuringiensis*, *Coniothyrium minitans*, Baculoviruses, and plant extracts (Azadirachtin, Quassin).

In recent years, biological control, including biotechnical methods, has made enormous progress in perennial crops (grape and fruits) and high-value greenhouse crops, mainly due to a highly specialized control of harmful arthropods. The revenue in these sectors compensates for the high expense of biological and biotechnical control products. In addition, these sectors are efficiently supported by public and private extension services.

Knowledge transfer has a crucial role in biological control. The use of biological control measures often requires the adjustment of the whole production process, very skilled growers, and advisory support. The initial financial support, for example, agroenvironmental programs, can foster and incentivize the system change to biological control.

In arable farming, biological and biotechnical control measures are rarely used in plant protection (Meinert 2006), except for a few successful applications on a small acreage Affordable and effective measures are missing, and on the other hand, financial incentives for the farmers to replace chemical with biological measures are lacking. Furthermore, biological and biotechnical control measures in many cases require a special knowledge of users and superior extension services (Heimbach 2010). Important measures applied in open fields are: *Trichogramma spp.*, *Bacillus thuringiensis*, Baculoviruses, *Coniothyrium minitans*, and pheromones. There are some successful examples available:

1. Control of the European corn borer (ECB), *Ostrinia nubilalis* in maize: in the southwest German maize-growing regions, the use of *Trichogramma brassicae* is a success story of biological control in arable farming. In total, *T. brassicae* is released on about 25,000 ha in Germany today (2003: about 11,000 ha); thereof about 21,000 ha in Baden-Württemberg, mainly in seed, sweet and grain corn. In Baden-Württemberg almost the total area (19,000 ha) is supported by the agroenvironmental program called MEKA III with 30 EUR per ha. The efficiency reaches approximately 75 %, with two releases of 100,000 parasitoids per ha. Field experiments with *T. brassicae* to control a new bivoltine race of ECB, which was first observed in 2006, were successfully carried out in Baden-Württemberg. But the number of parasitoids had to be drastically increased to 500,000 parasitoids per ha. There were also field experiments combining use of *T. brassicae* and PPPs that are known as compatible for beneficial organisms. *Trichogramma* wasps are produced and distributed in Germany by only a few companies (e.g., http://www.amw-nuetzlinge.de). Wasps are supplied on cards (2,000 parasitoids per card) and in beads (1,000 parasitoids per bead). Beads are robust and can even be applied with machines and helicopters. Monitoring of the ECB, warnings, and

advice for using *Trichogramma* wasps are made available by the plant protection service in the federal states. To identify the optimal time to look for eggs in the fields and release the parasitoids, the plant protection services prefer light-traps instead of pheromone traps due to incorrect results of the latter. The results are available online via ISIP or directly from the advisors. To find the right release date, farmers are asked to control their maize fields to identify egg masses of the ECB. Experimental use of *Trichogramma* wasps in infestation areas of the ECB in northeast Germany was not successful due to large field sizes and often unfavorable weather conditions (Hommel 2012). Experiences show that use of *Trichogramma* is probably unreliable on field sizes larger than 25 ha.

2. Control of codling moth, *Cydia pomonella*, in apple orchards: several formulations, on the basis of *Cydia pomonella granulosis virus* to control the codling moth, are available. These highly selective biological control agents can be combined efficiently with chemical insecticides. In Baden-Württemberg about 6,000 ha of apple orchards are treated with this virus, mainly in organic farms. Problems with granulosis virus resistant codling moths could be solved in a short time by the identification and production of new virus strains (Hommel 2012; Jehle 2010).
3. Control of tortricid moths in vineyards: application of the pheromone-based mating disruption technique (or confusion technique) to control the grape berry moths *Lobesia botrana* and *Eupoecilia ambiguella* is used today on about 60,000 ha or on 60% of the total vineyard area in Germany, representing the highest proportion in Europe. It is important to mention, however, that growers are supported with 125 EUR per ha per year (average of 2008 to 2012). The successful implementation of this biotechnical control measure requires a vineyard area of at least 20 ha; therefore it faces difficulties in areas with many small vineyards because farmer/user communities are difficult to set up. In main regions such as Rhineland-Palatinate, the effect of the mating disruption technique is monitored continuously (Hommel 2012).
4. Control of harmful mites in vineyards: the group of predatory mites as a natural biological control agent plays an important role in plant protection in vineyards. In many cases, only one mite per leaf is sufficient to control harmful mites and thrips species. For example, due to mite-friendly treatments using selective PPPs in Rhineland-Palatinate during the last 25 years, the use of acaricides was reduced substantially from 100% of the vineyard area in 1985 to about 0.5% today.

An important nonchemical measure in arable farming combines mechanical weed control with cultivation methods, such as a choice of cultivar, sowing date, and row distance, especially in wheat and maize. The effectiveness of using hoe and currycomb weed control equipment can be increased by exploitation of the competitive ability of cultivars. But in row crops such as maize with low weed suppression, the use of herbicides is essential. However, by band spraying, the necessary minimum of herbicides could be reduced and simultaneously could increase efficacy, but entails higher inputs in terms of time and human resources. The diverse innovations in mechanical weeding in the last years are promising (e.g., based on precision farming tools). But in practice, these potentials are often not used by farmers, because costs are high, knowledge of farmers and advisors about optimal uses is insufficient, or the need to accompany integrated measures to reduce weed pressure or to control selectively problematic weed species is not adequately used (Hommel 2012).

Successful implementation of biological control depends a great deal on the availability of PPP control strategies that conserve beneficial arthropods or combine both tactics against multiple pest infestations.

18.3.5 Application Equipment

Well-functioning and innovative application equipment and its proper use and regular inspection are considered as key issues in IPP to meet the necessary minimum in PPP use and to reduce risks to human health and the environment. Implementing IPP can only be successful in farms where this high standard or a willingness to invest in new and innovative sprayers exists.

The obligatory biannual inspection of PPP application equipment in use achieves, for field sprayers, on average 70,000 inspections per year and for airblast sprayers in space crops 20,600, that is, about 100 % inspection intensity. The most frequent deficits are often observed in spray patterns (uniform distribution is needed), line system, and fittings. In general, defects have already been repaired before inspection. Over the 20-year period from 1990–2010, the frequency of deficits declined continuously or has stabilized on a low level. Farmers exchange broken parts before inspections and maintain their application equipment in better condition than 20 years ago (Hommel 2012).

The nozzle types are essential to obtain both a precise lateral and longitudinal distribution and a low-drift application at the usual driving speed. If the use of a certain PPP requires a distance from water courses, this distance differs depending on the nozzle type, that is, a conventional or low-drift nozzle (Hommel 2012). In Germany, the high demand of low-drift technologies has led nozzle producers to check the quality of their products more thoroughly. Low-drift technology is also needed to apply certain PPPs in resistance management systems. For example, using herbicides containing clomazone in oilseed rape or insecticides containing neonicotinoids for seed dressing is only permitted with certified and listed low-drift technology and under strict requirements (Ganzelmeier and Nordmeyer 2008).

The cropping systems are increasingly adapted to the variability of regional and field parameters. This concept, called precision farming, requires a spatial variation and situation-related use of PPPs, with well-adjusted and technically advanced application technology. Therefore, sprayers are increasingly equipped with innovative and partly automated computer technologies. These modern technologies such as section control, sequence control, distance control, and track guide contribute to an increase in quality and to the considerable ease of work for the driver and, in particular, the handling and adjusting of broad boom sprayers at high driving speed.

Risk problems in 2008, with insecticide-coated maize seeds, led to important changes in sowing equipment in order to reduce the risks arising from dust drift and the seed quality requirements were changed. In Germany, according to the new requirements, sowing machines for corn had to be retooled to prevent dust drift, to deflate PPP dust-contaminated air at low speed near the soil. The drift reduction has to reach at least 90 % compared to conventional machines. Since 2009, all machinery has to be verified in a mandatory inspection and is listed by Julius Kühn-Institut (JKI). Furthermore, the seed dressing companies that use neonicotinoids have to set up a quality system to reduce dust in seed bulk bags in accordance with the European regulation 2010/21/EU. JKI accompanies this process; it collaborated to develop the check-list for the inspections and run preaudits in companies. Seed dressing companies that have successfully introduced the quality system are listed by JKI. A German network called Seed Guard Society for Seed Quality was initiated in 2011 to support these important risk mitigation activities. SeedGuard is responsible for the certification of seed coating equipment or companies (www.seedguard.de).

18.4 Training and Advice

A continuous knowledge transfer goes both ways, from research to end-users, that is, farmers, advisors, and retailers, and feedback from practice to science. It is an important task to implement and develop IPP on a regional scale. Independent training and advice for farmers are regulated by the German Plant Protection Act and accompanied regulations, such as the Regulation on Professional Knowledge. Each of the 16 federal states is responsible for advice, awareness-raising, and training, in particular on good plant protection practice including IPP and the implementation of NAP measures. The federal states are also required to diagnose and monitor pests, carry out field experiments, cultivar and PPPs trials, and maintain databases such as ISIP. The organization of public extension differs from state to state. The conditions for the acquisition of the legally required knowledge of users and distributors of PPPs are of a high standard in Germany. Very common schemes to disseminate knowledge are courses in winter and open field days during the growing season. During the season, the information is mainly transmitted via the earlier described online portals, monitoring systems, prognosis models, and DSS. The majority of farmers are well trained in farm management and all aspects of plant protection. Professional users of PPPs, advisors in plant protection, and distributors of PPPs have to renew their certification every three years. Details and education topics are specified by region and crop by each responsible authority in the Regulation on Professional Knowledge (Freier and Zornbach 2008). Based on a survey from Freier and Zornbach (2008), about 1,000 persons are engaged in the public plant protection services of the 16 federal states, or about 0.89 persons per 10,000 ha arable land. More than 65 % of these advisors and trainers have got a university or technical college degree. Public advice in plant protection is complemented by an increasing number of private consultants and consultants from the agrochemical industry. The producer associations run separate advice and training courses. Visible advertisements and advice from companies producing biological or biotechnical plant protection agents or other nonchemical alternatives are not as efficient as needed. Universities do not play a significant role in the direct advice to farmers.

The public plant protection services and their support tools are, compared with many other EU member states, still well positioned despite severe budget cuts over the last few years. Plant protection services have contributed to the compliance of PPP applications with the necessary minimum. Nevertheless, a further reduction in public funding for extension and advisory support risks future tasks and the goals of the NAP to increase the number of farms that work according to IPP guidelines.

The cooperation of plant protection and nature conservation extension services, or public and private extension services, should be further strengthened nationwide and build on existing experiences from several federal states to strengthen advice to IPP. In Germany, there is no professional umbrella organization of rural advisors. Private consultants are often small enterprises. The lack of coordination in the consultancy and the weak economic power of the clients in particular areas with mainly small farms in the south of Germany are serious constraints for efficient knowledge transfer and the uptake of IPP.

The basic conditions for the preparation and acquisition of legally required expertise of users and distributors of PPPs are of a high standard. Many engaged advisors from the plant protection services in the federal states mediate, in numerous events and winter training as well as through tailor-made publications, relevant knowledge. A stronger network of experts in the federal states and joint online offers can contribute to a better applicable knowledge in IPP.

18.5 Support and Incentives

18.5.1 Information and Knowledge Management

In Germany, there is exhaustive knowledge and many tools available for all levels of IPP (Hommel 2012). Nevertheless, widespread practical implementation of offered and available knowledge is still lacking, due to the time constraints of farmers and advisors during the season and farmer's attitudes to IPP and risk perception. Jörg (2011) pointed out that in regions with large farms, close cooperation between farms and public extension services can be observed. Such farms use innovative technologies and equipment. In contrast, in regions with specialty crops extension services do not reach all small farms which are mainly managed as part-time farming. But exhaustive information about authorized chemical PPPs is at least provided by advisory services in trainings and is available on several websites.

Germany has several institutions engaging in knowledge transfer, for example, public research institutes on the state and federal levels (e.g., Julius Kühn-Institut, Federal Research Centre for Cultivated Plants, http://www.jki.bund.de/en/startseite/home.html), the German Agricultural Society (DLG, http://www.dlg.org/about.html), the Information Service for Food, Agriculture and Consumer Protection (aid), the Association for Technology and Structures in Agriculture (KTBL, http://www.ktbl.de/index.php?id=135), the Andreas Hermes Akademie (AHA), the German Phytomedical Society (DPG, http://dpg.phytomedizin.org/en/dpg/), rural adult education schools, universities, and so on.

Information about nonchemical alternatives to PPPs and their conditions for use in plant protection in arable farming and horticulture are available, for example, on the internet portal ALPS (http://alps.jki.bund.de). ALPS, a German acronym for Alternatives in Plant Protection, offers an intuitive search for crop/pest combinations or single measures. It provides several thousand datasets on nonchemical measures in arable and horticultural crops.

Substances that can be used in plant protection as plant strengtheners are listed by the Federal Office for Consumer and Food Safety (BVL) in three categories: (A) increase of plant resistance against pests; (B) protection against nonparasitic damage; and (C) application in cut-off ornamentals (flower fresh hold methods). The list is available on the internet (Anonymous 2012c) and will be changed in the future due to new legislation.

International information, knowledge, or experiences in plant protection for farmers and advisors, not in the German language, are available (e.g., on the internet portal ENDURE Information Centre, EIC) but not used in their daily work.

The biannual Plant Protection Conference organized by the DPG and JKI is the highlight of the German plant protection community where researchers, advisors, and policy makers interact.

18.5.2 Demonstration

The introduction of innovative plant protection measures and crop- or sector-specific guidelines of IPP into farming practice represent important measures to obtain the goals of the NAP. The federal project “Demonstration Farms in IPP,” started in 2010, supports the implementation of IPP and communication of all stakeholders. To date, it is planned for 35 farms to become demonstration farms. These farms are to adapt their pest management, and to implement and demonstrate the new knowledge and technology in an IPP system. They receive excellent support and advice from the federal institute JKI and the plant protection services of the federal states. Demonstration farms will serve as a vehicle for knowledge transfer and showcases that will eventually foster the uptake by other growers and dissemination by advisors.

The demonstration farm project is funded by the federal government and demonstration farmers will be reimbursed in case of financial losses due to higher risks of newly tested IPP methods, for project-specific costs and knowledge transfer activities. Farms can apply and are selected according to the following criteria (Anonymous 2012d):

- Qualified, economically successful full-time farm;
- Plant protection based on using IPP principles;
- Utilization of all regional available extension and information services/media;
- Willingness to implement new decision-support systems and plant protection methods;

- Full and timely documentation of all disease/pest/weed incidences and use of plant protection products;
- Willingness to disclose farm data and cooperate with plant protection services to establish an individual farm management plan;
- Facilitation of on-farm demonstrations and farm seminars;
- Agreement to on-farm data collection and cooperation with extension staff.

The results obtained at those farms will feed into the public debate and function as a proof of concept.

18.5.3 Incentives

Farmers in Germany and other EU member states receive decoupled subsidies for agricultural production, that is, direct payments from the European Union. Mostly, the direct payments are combined with cross-compliance requirements that provide the basic rules for sustainability and relate to plant protection with regard to: (1) only the use of authorized or permitted PPPs in accordance with any requirements or conditions; (2) use of PPPs in accordance with the principles of good plant protection practice and, whenever possible, in accordance with the principles of IPP; and (3) apply record-keeping requirements for PPPs. German farms receive an estimated farm income from direct payments of European subsidies ranging from 25 to 75 % depending on the farm size, sector, and area (high subsidies for farms in unfavorable areas and with low production intensity). German federal states can add additional elements to the list of cross-compliance requirements. About 1 % of all farms are inspected every year. Within the Common Agricultural Policy (CAP) reform, there are proposals to include "greening" requirements to the direct payments to enhance environmentally friendly cropping measures, in particular, setting aside, for example, at least 7 % of arable land for biodiversity and nature preservation purposes, increasing crop diversity to at least three crops per farm, and prevention of conversion of permanent pastures. It is expected that the implementation of such areas will be very difficult to achieve in areas where small farms and a diversity of landscape elements already exist and would further limit efficient production whereas farmers in areas with highly productive farming would try to avoid converting land for nature preservation purposes. Additionally, it would cause more bureaucracy for farmers and require considerable inspection efforts. The whole system will be very difficult to control, as only few elements can be measured and controlled. Detected violations of greening requirements will be penalized by the reduction of direct payments.

Use of IPP guidelines or preference for individual measures, such as biological control measures to reduce use and dependency on chemical PPPs, are beyond legal requirements and therefore voluntary for farmers and advisors. The SUD says in Article 14: "Member States shall establish appropriate incentives to encourage professional users to implement crop or sector-specific guidelines for integrated pest management on a voluntary basis" (Anonymous 2009b). These incentives could be used to compensate higher costs and economic risks. Possible tools are direct payments, special insurance schemes, higher prices, specific labels or awards, additional advice, and so on. One challenge is that the market has to recognize IPP products and reward sustainable production.

In Germany, four main systems are in place to incentivize the voluntary use of specific measures in plant protection:

- Guidelines on the integrated production of producer organizations, particularly for fruits, vegetables, ornamental plants, and nurseries;
- Agroenvironmental programs of the federal states;
- The QS Quality and Security Ltd. (QS-System);
- GLOBALG.A.P.

Guidelines for controlled and integrated crop production are broadly applied in horticulture. Producer organizations have established growers' self-commitment in line with sustainable production. The requirements which are beyond the good plant protection practice in horticulture include the following main aspects:

- Record-keeping of all cultural and plant protection measures;
- Priority use of nonchemical plant protection measures, in particular beneficial organisms;
- Selection of PPPs specifically listed annually for controlled and integrated crop production;
- Application of beneficial-friendly and selective PPPs;
- Compliance with crop rotation to avoid coincidence of host and pest;
- Promotion of natural antagonists of dominant pests in the crop rotation to utilize the antiphytopathogenic potential, particularly in soils;
- Preferential use of resistant or tolerant cultivars.

The exhaustive description of control measures against most harmful organisms in the above-mentioned guideline consists of three parts: (1) control measures of common practice (state-of-the-art); (2) environmentally friendly alternatives or complementary measures (currently rarely used); and (3) future possibilities. The list of PPPs, updated annually, contains all PPPs that can be used and also considers resistance strategies in order to maintain availability of PPPs. All PPPs authorized in organic farming are also allowed in integrated production. Compliance with this guideline is controlled and checked by an independent commission.

The federal states support methods and measures of IPP and organic farming in their agroenvironmental programs. These methods and measures are financially supported in the framework of: (1) the "Joint Task for the Improvement of Agricultural Structures and Coastal Protection" (GAK), which provides support for single farm investments, management systems, energy savings, and rural development; and (2) the contract-based implementation of measures for specific protection, such as nature protection schemes with participation of the federal government, federal states, and the European Union (Thomas et al. 2009). The aim to reduce the use of PPPs and risks in agroenvironmental programs is now pursued almost exclusively with actions to support low-input farming systems: organic farming (all federal states), controlled and integrated crop production systems (two federal states), and promotion of nonchemical alternatives such as biological and biotechnical plant protection control measures in some federal states. In reality, support is mostly given to organic farms.

Support systems aim to stabilize widespread implementation of IPP and organic farming. Individual federal states focus their support, in particular, on the application of biological or biotechnical measures in maize, oilseed rape, sunflowers, fruit, grapes, and in greenhouse cultivation (Thomas et al. 2009). Furthermore, measures for the restriction of the application of PPPs, for example, the omission of herbicides in perennial crops, are supported. The support of biological and biotechnical control focuses on the application of *Trichogramma*, *Bacillus thuringiensis*, granulosis-viruses, *Coniothyrium minitans* or pheromone-procedures against European corn borer (maize), Colorado potato beetle (potato), *Sclerotinia* (oilseed rape, sunflower), winter moth (fruit), codling moth and summerfruit tortricid moth (pome fruit), and tortricid moths (grape). Until now, support for arable farmers has rarely been set up by the federal states, for example, the biological or biotechnical control of Colorado potato beetle and *Sclerotinia* is not supported by any federal state. Use of *Trichogramma* to control the ECB in maize is only supported in Baden-Württemberg and Rhineland-Palatinate. In perennial crops such as fruits and grapes, there is more commitment from federal states; Saxony-Anhalt has included many measures in its program. Baden-Württemberg, Rhineland-Palatinate, and Saxony offer support in fruit-growing and grape-growing, and Hessen exclusively for grape-growing (Thomas et al. 2009).

The modular principle, where farmers can combine different cultivation and nonchemical plant protection measures, has become more and more popular. It is noteworthy that the modular measures that promote production technologies and which complement each other for example, a diverse crop rotation, intermediate cropping, direct tillage, environmentally friendly fertilization, and application of biological or biotechnical PPPs can be applied on the same field (Thomas et al. 2009). Unfortunately, the co-financing of many federal states for the agroenvironmental schemes (up to 50 %) or other European programs has been reduced, or programs were even stopped due to budget limitations.

The QS Quality and Safety GmbH was founded in 2001 and it is applied in the vegetable and fruit sectors and potato production chains. Farmers commit for a certain time to a contract and obtain higher profits and access to attractive markets. The main goal of the QS system is the prevention of exceeding maximum residue levels (MRLs) of PPPs in products. The guideline includes a number of IPP measures, of which at least four have to be implemented and are controlled. Such IPP relevant measures are:

- Use of disease-tolerant or resistant cultivars;
- Support of beneficial organisms (hedges, bird perches, stone mounds, nest boxes, etc.);
- Use of beneficial organisms (predatory mites, parasitic wasps, etc.);
- Use of control techniques (glue rings, lime plates, magnifier, pheromone traps, apple scab warning device, etc.);

- Use of certified sprayers;
- Use of resistance strategies of PPPs;
- Mechanical or thermal weed control, use of mulch material (foil, straw, bark);
- Use of crop protection nets or fleece;
- Protection of the field hygiene (fast and thorough disposal of crop residues);
- Protection of the storage hygiene (fast and thorough disposal of crop residues and materials, room disinfection, etc.);
- Examination of soil-borne pathogens (nematodes, *Verticillium*, etc.) before new seeding or planting;
- Site-specific cultivar selection;
- Partial-field or field margin treatments;
- Well-regulated crop rotations and crop-free periods.

The standards of GLOBALG.A.P. (G.A.P. means good agricultural practice) are applied in Germany, particularly in the vegetable and fruit sectors and result in the voluntary implementation of IPP guidelines in those sectors (Meinert 2006). German growers fulfill those standards easily because the national good plant protection practice requirements are often above GLOBALG.A.P. standards. Nevertheless, the GLOBALG.A.P. control schemes motivate farmers to adhere to the farm management plans. It has to be mentioned, however, that those requirements primarily focus on MRL levels and the cosmetic appearance of the produce whereas sustainable production with regard to IPP elements is secondary.

18.6 Measurement and Control of IPP

18.6.1 Plant Protection Control Program

The plant protection control program is a national task force to monitor the trade and use of PPPs and is thus an indicator of regulatory compliance. Its results are published in annual reports by the Federal Office for Consumer and Food Safety (BVL). The data are obtained from farms or companies based on a risk-based approach of changing the focus of inspections, and therefore trends regarding failure rates cannot be derived from these data. New legal provisions and current incidences may lead to changes in control practice.

The use of PPPs is controlled in approximately 5,000 farms per year which corresponds to approximately 1.5 % of all farms. In summary, whether the professional user is competent, uses only inspected equipment, and the PPPs are used only in authorized indications with consideration of the legal requirements and conditions of use are controlled. In some years, the mandatory documentation and waste disposal of PPPs are controlled as well. Violations of forbidden uses on paved areas and the illegal placing of PPPs on the market are often evident in the annual reports (Hommel 2012).

Table 18.6 Treatment frequency index (TFI) scores in main winter crops from 2007 to 2011. (Freier et al. 2012)

Crop	Herbicide					Fungicide					Insecticide				
Year	‘07	‘08	‘09	‘10	‘11	‘07	‘08	‘09	‘10	‘11	‘07	‘08	‘09	‘10	‘11
Wheat	1.9	2.0	1.8	1.8	2.0	1.9	2.2	2.0	1.9	1.8	1.2	1.0	1.0	0.8	1.1
Barley	1.5	1.7	1.6	1.7	1.7	1.1	1.3	1.3	1.3	1.4	0.9	0.7	0.3	0.3	0.4
Oilseed rape	1.6	1.8	1.7	1.6	1.8	0.5	0.8	0.9	0.9	1.0	2.3	2.3	2.8	2.8	3.1

Table 18.7 Average PPP dose reduction relative to the authorized standard application rate in winter crops. (Freier et al. 2012)

Crop	Category	2007 (%)	2008 (%)	2009 (%)	2010 (%)	2011 (%)
Wheat	herbicide	67	69	68	69	76
	fungicide	58	60	57	57	56
	insecticide	87	89	91	92	96
Barley	herbicide	60	65	68	70	72
	fungicide	56	54	52	52	54
	insecticide	92	95	90	94	92
Oilseed rape	herbicide	73	74	75	75	75
	fungicide	90	85	85	83	80
	insecticide	97	101	101	100	98

18.6.2 Network of Reference Farms

The Network of Reference Farms, a component of the NAP, was started in 2007 and exists as a joint project of the Federal Ministry of Food, Agriculture and Consumer Protection (BMELV), the plant protection services in the federal states and the Julius Kühn-Institut (JKI). The project focuses on surveying representative farms to obtain annual data on PPP uses in major crops and other information relevant to crop protection. All PPP treatments are evaluated to determine the actual PPP use intensities (based on the TFI) and the necessary minimum of PPP use, as determined by experts at the plant protection services.

The following parameters are used to explain differences in TFI scores between farms, within a region or between regions: field and farm size, soil quality, previous crop, tillage, sowing date, cultivar resistance, and the use of decision-support systems. The data are pooled for four regions (north, east, south, and west) and for Germany in total. In arable farming, the number of farms and fields surveyed annually is about 75 and 700, respectively. A total of 4,183 (2007), 5,216 (2008), 5,665 (2009), 6,147 (2010), and 6,160 (2011) datasets from arable crops have been statistically analyzed to date.

For example, looking at data from 2007 to 2011 in arable farming, the TFI did not reveal any trends in arable cropping (Table 18.6). The high intensity of insecticide use in oilseed rape is analyzed in order to identify mitigation potentials (e.g., to improve extension and decision-support systems).

Dose reduction is widely used in herbicide and fungicide treatments (Table 18.7). Increasing pest resistance is the main reason why insecticides are often used at the

Table 18.8 Percentage of PPP uses in main crops corresponding to the necessary minimum. (Freier et al. 2012)

Crop	2007 (%)	2008 (%)	2009 (%)	2010 (%)	2011 (%)
Winter wheat	88.7	85.8	89.8	89.2	91.8
Winter barley	94.8	84.9	86.0	90.6	93.8
Winter oilseed rape	87.7	81.8	87.4	89.3	91.4
Field vegetables	83.4	89.8	86.7	87.3	94.4
Apples	94.5	94.6	91.7	95.3	95.7
Grape	99.5	95.5	98.3	97.5	96.0
Hops	100	96.6	98.8	82.5	94.0

full authorized doses. Behind the concept of the necessary minimum, there is the following rationale: in a cropping region under similar conditions, TFIs on a particular crop, in a particular season, vary between farms (cf. Fig. 18.3). Many observed farms do not exceed the necessary minimum, presumably related to factors such as adoption of good plant protection practices, farmer experience, extension services, and appropriate decision-support systems. There are also some farms, characterized by higher TFI than in an average regional farm which are deemed as unjustified. The interesting part is in understanding the factors explaining justified and nonjustified PPP uses. For example, a fungicide application prior to the appropriate date is categorized as unnecessary, whereas the following application(s) needed to correct this mistake is(are) defined as necessary. The evaluation takes into account a number of factors including profitability and the feasibility of using alternatives. Selected experts endeavor to carry out this retrospective evaluation from the point of view of the farmer; only taking into account the knowledge available to the farmer at the time of decision making. Later developments or efficiency of measures are not included in the evaluation procedure to identify the necessary minimum. One interesting aspect of this analysis is its propensity to elicit a dialogue between the experts and farmers or their advisors. A main advantage of the expert assessment within the perspective of the necessary minimum, which is a complex and dynamic variable, is that problems or bottlenecks in PPP uses can be realistically identified and counteracted. Experts and researchers analyze these differences and look for explanations that are translated into areas for improvement in terms of future training, extension, demonstration, and research activities.

Based on the necessary minimum, an estimated TFI range can be defined for each PPP group in a particular crop and in a certain region, for example, fungicide use in winter wheat in the region WEST: 1.0–2.3 (2007), 1.5–2.9 (2008), 1.4–2.5 (2009), 1.2–2.2 (2010), and 1.1–2.3 (2011).

The data in Table 18.8 show that all PPP use and application rates (in farms of the reference farm network) were justified and the majority corresponded to the necessary minimum.

The necessary minimum is also used as a communication tool, for example, with farmers and advisors during winter training courses or extension field days. It is used in annual reports to show the TFI range for particular crops and regions. The TFI range also indicates PPP use rates above the necessary minimum in regions, crops, pests, or PPP categories which require attention. The percentage of PPP uses above such a region- and year-specific range represents a mitigation potential and provides clues to advisory, training, and demonstration activities in subsequent years.

18.7 Research and Innovations

The current program of the federal government to support innovations in plant protection and plant breeding comprises: (1) research, development, and demonstration projects aiming to place innovative technical and nontechnical products on the market; (2) projects to increase the ability to innovate, including knowledge transfer; (3) investigations of the social and legal conditions for innovations; and (4) identification of future innovation fields. About 35 million EUR (about 46 million USD) per year are available. Plant breeding and plant protection are separately funded topics in the program. The current program supports essential measures of the NAP including plant breeding, development of nonchemical plant protection measures and biological control, the preparation of tools for the prognosis and DSS, as well as the improvement of the application technology.

Main areas of the federal program are:

- Availability of biological, chemical, and other plant protection measures;
- Improvement of the resistance management of PPPs;
- Availability and improvement of existing DSS, management systems, geographic information systems (GIS), supported measures, and further tools for the situation-specific and partial-field application of PPPs (so-called precision farming);
- Plant protection equipment and use, especially with consideration of loss and drift reduction, saving of PPPs and resource protection;
- Availability of fast, sensitive, and specific diagnosis tools for pests;
- Procedures for precise determination of host–pest interactions and plant resistance and defense mechanisms;
- Development of crop- or sector-specific IPP guidelines, also in consideration of elements of biodiversity and water protection;
- Procedures to quickly identify PPPs, especially with a view to detecting counterfeit products;
- Implementation and optimization of networks, including internet-based solutions, between economy, advice, practice, and research to increase technology and knowledge transference in the area of plant protection.

In addition to the research programs initiated by the federal government, there are also activities to support innovations in plant protection in individual federal states. For example, Baden-Württemberg supported a research project from 2006 to 2011 about strategies to control *Monilia* disease in plums, in particular the reduction of this disease in the postharvest period. Based on pest epidemiology results, effective control strategies in the pre- and postharvest period were developed. Through cultural measures, an optimized use of fungicides, a careful harvest, as well as suitable storage conditions, the storage life of the fruits could be clearly extended.

Another example of the development of biological plant protection measures is the control of the Western corn rootworm, *Diabrotica virgifera virgifera*, with entomopathogenic nematodes of the species *Heterorhabditis bacteriophora* that can parasitize larvae and reduce damage. In Baden-Württemberg, a project from 2009 to 2011 was carried out in order to develop reliable procedures for the application of the nematodes. Investigations into persistence should clarify whether the nematodes can survive the period from application until the appearance of the pest larvae in the soils. In order to examine the effectiveness of the nematodes under high infestation pressure, experiments were done in southern Hungary where the Western corn rootworm occurs in high abundance.

18.8 Conclusion

The use of plant protection products in Germany is regulated by a strong legal framework. Integrated plant protection (IPP) represents an important element ensuring sustainability and an essential tool for pest and disease resistance management. Public expectations that farmers go beyond legal requirements in their plant protection activities are supported by the national action plan for sustainable use of plant protection products (NAP) where crop- or sector-specific IPP guidelines and their continuous update are considered key elements and respond to the dynamic concept of IPP. The implementation of these voluntary guidelines integrating the required system changes into a long-term approach are challenges and need to be supported by research, knowledge transfer, demonstration farms, incentives, public extension services, education, and training programs. Investments in more research and development, in particular the transfer from fundamental to applied knowledge, are continuously needed. The data from the nationwide network of reference farms, the TFI, and information about the necessary minimum deliver valuable information about the current state of PPP uses in Germany and can initiate discussions about innovative plant protection. The overall challenge is to find a balance between the economic interests of farmers (and society) and the ambitious implementation of IPP guidelines to encourage the majority of farmers voluntarily to implement IPP. Incentives or financial compensation for the initial changes might foster the change of farmer behavior and reduce perceived economic risks.

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Chapter 19
Experiences with Implementation and Adoption of Integrated Pest Management in Denmark

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Contents

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Abstract In 1986 Denmark adopted, as the first country in Europe, a pesticide action plan calling for 50 % reduction in pesticide use. The first pesticide action plan was later followed by three other pesticide action plans and recently the Danish government announced the fifth pesticide action plan covering the period 2013 to 2015. As a result of the long-standing public pressure to reduce pesticide use numerous research and advisory activities have been initiated to provide farmers with the knowledge and tools required to meet the goals. This chapter: (1) provides an overview of the content of the pesticide action plans; (2) presents the research and advisory activities supported by the pesticide action plans; (3) gives examples of the IPM tools that are available to Danish farmers; and (4) describes the most recent political initiatives including the new Pesticide Load Indicator that will replace the Treatment Frequency Index.

Keywords Pesticide action plan · Treatment frequency index · Pesticide load indicator · Decision-support system · Crop protection online · Experience group · Farm-level action plans · Demonstration farm · IPM website · IPM point system

19.1 Introduction

In Denmark the public debate on pesticide use in agriculture, and its possible adverse effects on the environment and human health, began in the early 1980s. The debate lead to a political action plan in 1986 calling for a 50 % reduction in the agricultural use of pesticides before January 1, 1997 compared to the average use for 1981–1985. Denmark was the first country to pass a pesticide action plan through the parliament but Sweden and The Netherlands followed shortly after.

The pesticide action plan was the first of a total of four pesticide action plans named Pesticide Action Plan I, Pesticide Action Plan II, Pesticide Plan 2004–2009, and Green Growth covering the period from 2010 to 2015. Recently, the Danish government announced a fifth action plan entitled “Protect Water, Environment and Health.” Contentwise it can be seen as an addendum to Green Growth, reiterating the targets, but also introducing a new indicator, the Pesticide Load Indicator, that will replace the indicator used hitherto.

It was not until the implementation of Green Growth in 2009 that the term integrated pest management (IPM) appeared in the pesticide action plans. Before the focus had been solely on pesticide use reduction. That IPM was introduced as a term and a goal in 2009 was a direct response to EU Directive 2009/128 on establishing a framework for community action for the sustainable use of pesticides and the obligation of all EU member states to implement the eight IPM principles, before January 1, 2014 (see Chapter 17 in this volume).

In the first part of this chapter we present the content of the pesticide action plans preceding Green Growth focusing specifically on the research and advisory initiatives contained in the plans. Although IPM was not mentioned specifically in these pesticide action plans many of the activities initiated as part of these plans have paved the road for the adoption of the eight IPM principles. Thereafter the content of Green Growth, and in particular the IPM-related activities and the new national pes-

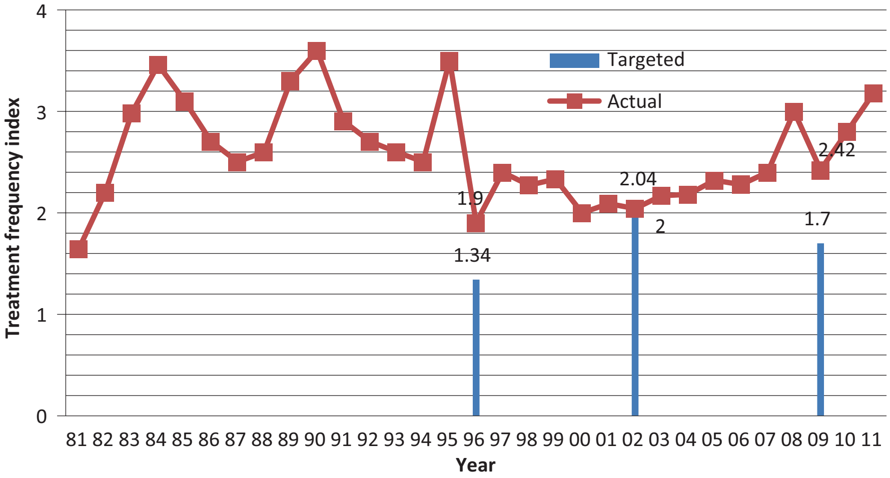


Fig. 19.1 Pesticide use, expressed as the Treatment Frequency Index, from 1981 to 2011. Solid columns indicate the quantitative targets set by Pesticide Action Plan I, Pesticide Action Plan II, and Pesticide Plan 2004–2009. Despite significant variations over the years the overall trend was a reduction in pesticide use until 2001 but since then pesticide use has been increasing.

ticide load indicator and its implementation, are presented and finally the content of the latest pesticide action plan "Protect Water, Environment and Health" is presented.

19.2 Pesticide Action Plan I and II and Pesticide Plan 2004–2009

With the introduction of Pesticide Action Plan I a new tool for expressing pesticide use, the Treatment Frequency Index (TFI), saw the light of day. Until then the yearly statistics on pesticide use only contained information on the total sales of active ingredients. In the 1980s many of the new active ingredients coming into the market were recommended at doses of grams per hectare and not in kilograms per hectare as the active ingredients they were replacing. Thus total sales of active ingredients could not be assumed to reflect pesticide use intensity any longer. A new indicator was needed and the TFI was launched. Calculation of the TFI is based on standard doses, hence the first step was to set a standard dose for each recommended use of each pesticide. Based on the total sales figures for a pesticide and an assumed allocation of the total sales on the various uses (based on expert knowledge) it is possible, for each pesticide, to calculate how many hectares could have been treated with the amount sold. This is done for each pesticide and by summarizing the figures for all pesticides one arrives at a figure reflecting how many hectares could have been treated in total. The TFI is calculated by dividing this figure with the total acreage cultivated in Denmark; i.e., the TFI is the number of times, on average, that each field was treated with a standard dose of a pesticide. As data are available on all uses of the pesticides, the TFI for various crop groups (e.g., winter cereals, spring cereals,

Table 19.1 Overview of Diseases and Pests in Major Arable Crops with Existing Thresholds

Crop	Disease
Winter wheat	Eyespot (Pseudocersosporella herpotrichoides)
	Powdery mildew (Blumeria graminis)
	Yellow rust (Puccinia striiformis)
	Septoria leaf blotch/Septoria glume blotch (Septoria tritici/Stagnosporium nodorum)
	Tanspot (Drechslera tritci-repentis)
Barley	Powdery mildew (Erysiphe graminis)
	Brown leaf rust (Puccinia hordei)
	Net blotch (Dresclera teres)
	Barley leaf blotch (Rhyncosporium secalis)
Triticale	Eyespot (Pseudocersosporella herpotrichoides)
	Powdery mildew (Erysiphe graminis)
	Yellow rust (Puccinia striiformis)
	Brown rust (Puccinia recondita)
	Septoria leaf blotch/Septoria glume blotch (Septoria tritici/Stagnosporium nodorum)
	Insect pests
Wheat, barley, spring oat, winter rye, and triticale	Aphids (various species)
	Cereal leaf beetle larva (Oulema melanopus)
	Wheat midge (Sitodiplosis mosellana) (only wheat)
Winter rye and triticale	Thrips (various species)
Pea	Pea weevil (Sitoria lineatus)
	Pea aphid (Acyrthosiphon pisum)
	Pea moth (Cydia nigricana)
Oilseed rape	Pollen beetle (Meligethes aeneus)
	Cabbage stem flea beetle (Psylliodes chrysocephala)
	Cabbage seed weevil (Ceutorhynchus obstrictus)
	Pod midge (Dasineura brassicae)
Sugar and fodder beet	Peach-potato aphid (Myzus persicae)
	Black bean aphid (Aphis fabae)
	Noctuid moths (Noctuidae)
Clover	Common clover weevil (Sitona hispidulus)

potato, etc.) can be calculated. Orchards, plantation crops such as Christmas trees, forest, and noncrop areas are not included in the yearly statistics on pesticide use.

Over the years modifications to the TFI have been introduced, for example, basing the statistics on the sales of active ingredients rather than commercial products, but the overall principles have stayed the same. In recent years the concept of TFI has been adopted by other European Union (EU) member states, including Germany and France.

All three pesticide plans had quantitative targets for the reduction in pesticide use. Figure 19.1 shows the actual TFI and the targets. Only Pesticide Action Plan 2 met the target but since 2002 pesticide use has been increasing. Following the failure to meet the quantitative target of Pesticide Action Plan 1 it was decided to appoint a committee (later named the Bichel Committee). The committee was given the task to review thoroughly the benefits and risks of pesticide use in Danish agriculture and propose new, and more realistic, quantitative targets for pesticide use reductions. The quantitative targets of Pesticide Action Plan 2 and Pesticide Plan 2004–2009 were the results of the work of the Bichel Committee. Explaining why the quantitative targets for Pesticide Action Plan 2 as well as Pesticide Plan 2004–2009 were higher than for Pesticide Action Plan 1.

The success in meeting the targets varies significantly between pesticide and crops. For example, herbicide uses in winter and spring cereals are almost at the same level as previously and recent years have even seen an increase in herbicide use in winter cereals. In contrast, fungicide use in cereals is much lower nowadays than previously (Jørgensen et al. 2008). More information on the experiences of reducing pesticide inputs in Denmark can be found in Jørgensen and Kudsk (2006).

Throughout the era of pesticide action plans, pesticide taxes have been used as an economic incentive to meet the targets. Originally the taxes were just a few percent of the value of the pesticide but later taxes were increased to 33% on herbicides, fungicides, and growth regulators and 54 % on insecticides. It has been discussed several times over the years to change taxation from an added value tax to a tax system reflecting the potential impact of the pesticides on human health and environment, but this did not happen until 2013.

The rationale behind the quantitative targets and the reasons for the observed trends in pesticide use over the years will not be discussed further. One significant outcome of the widening gap between the actual use of pesticides and the targets was a discussion on the relevance of regulating pesticide use through quantitative targets. In this context EU Directive 2009/128, highlighting that reducing the adverse impacts of pesticide use rather than reducing pesticide use itself is the goal and introducing IPM as one of the tools to meet this goal, was very timely.

19.2.1 Research Initiatives Supported by Pesticide Action Plans I and II and Pesticide Plan 2004–2009

19.2.1.1 Thresholds and Monitoring

The development of thresholds based on historical data and monitoring and forecasting systems were partly supported via the funding allocated for research on the pesticide action plans. Today, thresholds or forecasting models exist for the majority of the important diseases and insect pests in arable crops (see Table 19.1). For most diseases thresholds depend on the susceptibility of the variety and crop growth stage. For Septoria climatic conditions are also considered and for tanspot tillage (ploughing/noninversion) is considered along with the susceptibility of the variety and growth stage. Thresholds for pests only incorporate crop growth stage. The thresholds are an integral part of Crop Protection Online (CPO)—Diseases and Pests (see Section 19.2.1.2).

Another important IPM tool is the nationwide monitoring network run by the Knowledge Centre for Agriculture. Every week a number of fields are visited and monitored for a range of diseases and insect pests by the local advisors. The data are collected and made available to advisors and farmers via a website maintained

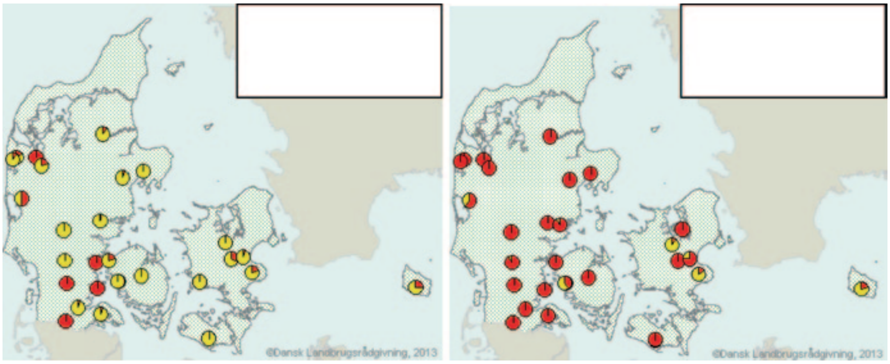


Fig. 19.2 Percent plants with Septoria (*red* part of the circles) and healthy plants (*yellow* part of the circles) in fields with susceptible winter wheat varieties. The left figure is based on the monitoring data collected from May 30–June 5, 2012 whereas the right figure shows the occurrence of Septoria in the same fields in the week of June 20–26, 2012. The figures show that Septoria spread to nearly all parts of Denmark during June and that disease severity increased (higher percentage of diseased plants). Monitoring data in combination with thresholds are used to provide farmers with advice on disease and pest control adjusted to local conditions.

by the Knowledge Centre for Agriculture (https://www.landbrugsinfo.dk/planteavl/plantevaern/varslingregistreringsnet/sider/startside.aspx).

On the website it is possible to follow the developments for a wide range of diseases and insect pests week by week. Several of the diseases and pests listed in Table 19.1 are among the ones monitored but also pests, where no thresholds are available (e.g., Colorado beetle, *Leptinotarsa decemlineata*), are included in the monitoring network. For certain insect pests the website provides a risk assessment rather than monitoring data (e.g., fruit fly, *Oscinella frit*). An example of the output provided to advisors and farmers is shown in Figure 19.2.

Every year a number of observation trials are conducted to assess the disease resistance of the cereal varieties currently grown by the farmers and the varieties being introduced to the market by the plant breeders. During the season the monitoring data are continually made available on the Internet and at the end of the season the results are available through SortInfo, a website providing information on yield, quality, disease resistance, and the like of all cereal varieties (http://www.sortinfo.dk/Oversigt.asp?Sprog=uk). The data from the observation trials are also used for grouping cereal varieties according to the level of resistance to the major diseases in Crop Protection Online (CPO).

19.2.1.2 Decision-Support System

Probably the most unique IPM tool developed is CPO, a decision-support system for pest control which nowadays is Web-based. The development of CPO was initiated around the time the first pesticide action plan was passed and the system has continuously been improved, partly financed by funding from the pesticide action plans and partly by the income from subscriptions.

CPO consists of two modules, one for cereal diseases and insect pests and one for chemical weed control. Both modules provide solutions to farmers often recommending pesticide doses lower than the standard dose. This is possible because CPO takes into account the parameters known to influence pesticide performance. Existing threshold and forecasting models are an integral part of the disease and insect pest module. In addition to threshold models also the level of resistance of the crop variety to foliar as well as seed-borne diseases is considered (based on data from the observation trials; see Section 19.2.1.1) calculating the required pesticide input.

For yellow rust (*Puccinia striiformis*) the virulence of the pathogen population is assessed every year allowing the farmers to plan their strategy in advance.

For herbicides, weed species, weed size, soil type, climatic conditions, crop competitiveness, and joint effects of herbicides are considered, and based on these input variables CPO produces a list of potential herbicide solutions, often recommending the use of less than the recommended dose. A demo version in English with a limited number of crops and herbicides is freely available on the Internet (http://130.226.173.215/cp/menu/Menu.asp?SubjectID=1&ID=demo&MenuID=10009999&language=en).

The development of CPO was only possible because data from numerous studies conducted under semi-controlled and fully controlled conditions have been available. The purpose of the studies has been to understand and quantify the subtle interaction among pesticides, pests, and crops and the research has benefited greatly from the research funding allocated via the pesticide action plans. Not only new data but also historical data have been valuable inputs developing threshold and forecasting models for diseases and pests. More details on the development of CPO can be found elsewhere (Rydahl 2003, 2004; Rydahl et al. 2003; Hagelskjær and Jørgensen 2003; Jørgensen et al. 2008).

19.2.1.3 Nonchemical Control

One of the IPM principles laid out in Directive 128/2009 states that nonchemical methods should be considered before resorting to chemical control. Over the years ample funding has been allocated to developing and refining tools particularly for mechanical weed control. Major progress has been made but in addition to interrow cultivation in row crops and in winter oilseed rape sown in rows, the uptake by farmers has been limited. More recent developments using tools equipped with sensors and precision guidance technology hold promise for a major advance in the adoption of nonchemical weed control technologies.

It is believed that future tightening of the data requirements for pesticide registration in the European Union as well as national legislation will lead to a situation where satisfactory weed control cannot be achieved with the available herbicides. This is already now the case for some vegetable growers and sugar beet growers are also experiencing increasing problems controlling weeds chemically. The vast experience on nonchemical weed control will benefit Danish farmers implementing integrated weed management practices in crops where herbicides no longer can stand alone as the only control option.

19.2.2 Advisory Initiatives Supported by Pesticide Action Plans I and II and Pesticide Plan 2004–2009

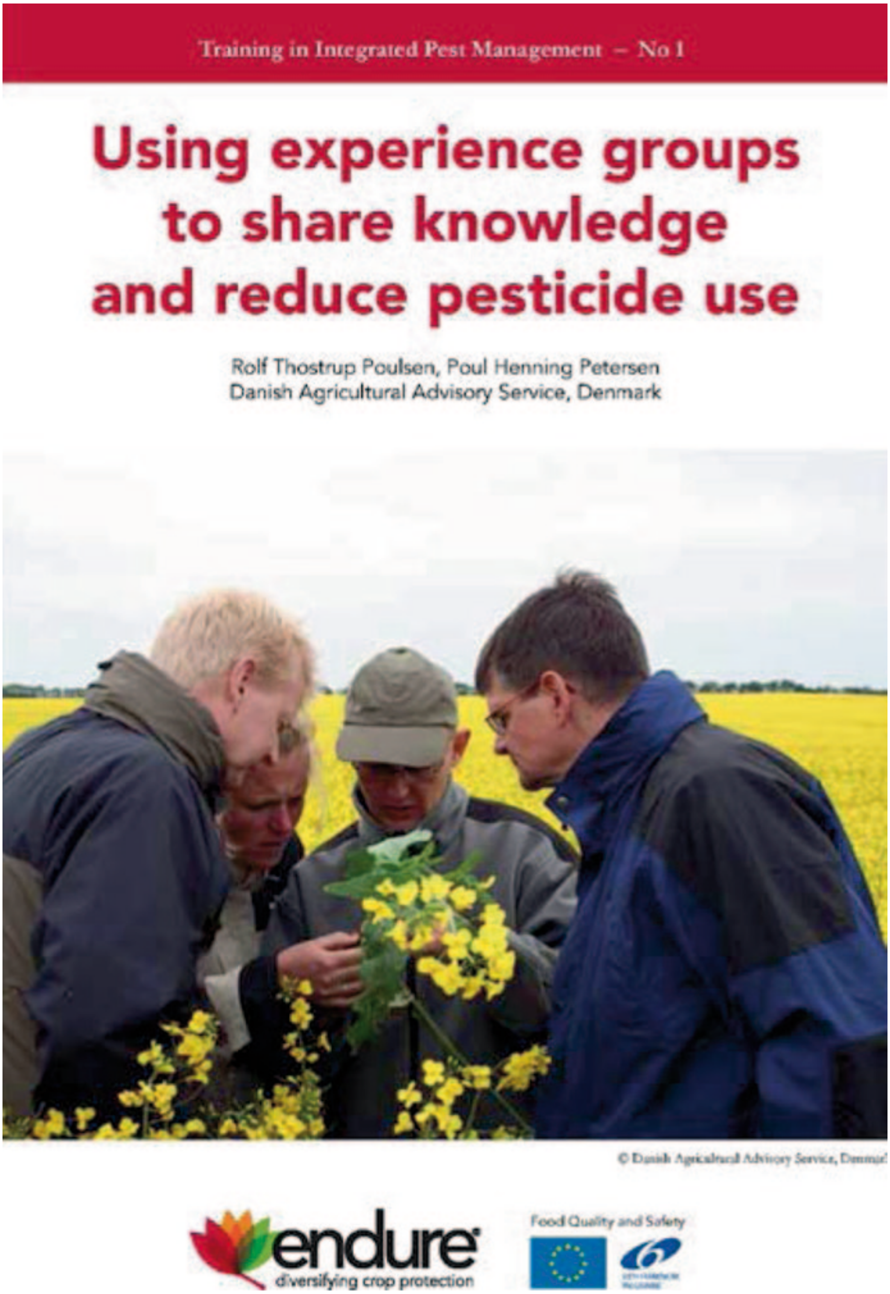
The Danish Agricultural Advisory Service (DAAS) is owned and run by the Danish farmers. It accounts for more than 85 % of the market share of advisory services in Denmark, and its operations are normally based on 100 % user payment; that is, advisory activities are not subsidized by the government. DAAS has been involved in the follow-up of all the Danish pesticide action plans so far and has received governmental support for these activities. Most activities have been carried out by the Knowledge Centre for Agriculture in close collaboration with (currently) 31 local advisory centers.

19.2.2.1 Experience Groups

Pesticide Action Plan I included a project named "Crop Protection Groups," running from 1989 to 1992, where group-based advisory activities on crop protection were developed. The groups consisted of 8–10 farmers per group visiting each other's farms during the growing season. Various available tools were tested and used by the members under facilitation and expert support of an adviser. An attempt was made to compare the pesticide use of the participating growers with the average. However, due to different ways of assessing on-farm and countrywide use, the results were inconclusive (Ersbøll et al. 1995). However, there is no doubt that this initiative paved the way for the so-called "ERFA groups" (experience groups) that are still viable today.

After the end of the project, many more groups were established. This participatory advisory method has been very popular among farmers, as it has: (1) stimulated participatory learning; (2) encouraged friendly competition among farmers to do as good a job as possible, that is, to reduce pesticide doses as much as possible; (3) made advice cheaper; and not least, (4) allowed for social interaction among growers. There are actually further benefits from this approach. The leaflet by Poulsen and Petersen (2009) gives an account of experiences and gives advice for establishment of experience groups (Figure 19.3).

The current trend in Denmark today is towards a decreasing number of experience groups due to the large structural changes towards larger farms in Danish agriculture. From 1987 to 2011, the average farm size in Denmark doubled from 32.2 to 64.9 ha (Statistics Denmark 2012, www.dst.dk). Furthermore, many small farms have rented out their land and the agricultural areas managed by professional farmers are much higher than areas indicated by the average farm size figures. Data from the national farm accountancy database show that the average size of man-



Training in Integrated Pest Management – No 1

Using experience groups to share knowledge and reduce pesticide use

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endure
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Food Quality and Safety

Fig. 19.3 Experience groups have been one of the successful outcomes of the work related to the Danish pesticide action plans. The ENDURE IPM Training Guide (see Chapter 17) contains a leaflet (Poulsen and Petersen 2009) that summarizes important lessons learned and provides instructions for starting up new experience groups.

aged units has more than quadrupled over the last 20 years, with a 2011 average of 205 hectares (Anonymous 2012a). With present farm sizes, many farmers think that they may spend their advisory costs more wisely by focusing on their own farm rather than meeting in other farmers' fields. This is probably the single most important barrier to further reductions in pesticide use in Denmark.

With the start of Pesticide Action Plan II, there was continued focus on—and support for—experience groups on 650 farms, but at the same time other advisory activities were initiated. The most important were advisory activities on 17 demonstration farms, farm-level action plans for pesticide use reduction on more than 5,000 farms, and strategies for nonchemical weed management on 15 farms.

19.2.2.2 Farm-Level Action Plans

These initiatives were based on the fact that a collective, nationwide pesticide reduction target had little meaning for the individual farmers. By expressing the national target of TFI below 2.0 into target TFIs for control of weeds, diseases, insect pests, and growth regulation in every crop, a farm-level target could be calculated and the pesticide use assessed and compared with that target. The advisers and farmers made action plans for each farm and did follow-up calculations of pesticide use during the years following.

One major challenge during these projects was to get in contact with farmers who had a potential for reducing pesticide use while maintaining satisfactory yields and pest control levels. On average the TFIs of 5,000 participating farms were 10 % under the national target. Most of the participating farms were already actively seeking advice on optimizing pesticide use and therefore had an advantage. During the project, much focus was given to targeting farmers with unfulfilled reduction potentials, but this proved to be a challenge. That most of the participating farms were already seeking advice on optimizing pesticide use explains why it was in general difficult to find examples where the pesticide use on a farm could be significantly reduced during the three-year period. However, it was easy to demonstrate that farms with TFIs much lower than the target had their TFIs increased as part of the optimization process during the project. Another interesting conclusion from the project was that the TFI seemed to increase with farm size, even when corrected for differences in crop rotations between smaller and larger farms. This was not surprising in that it is a challenge for a farmer or farm manager to keep up to date with recent developments in the various fields when small fields are scattered over a larger area as is often the situation in Denmark, and it highlighted that larger farms may have other demands for monitoring and decision-support systems than smaller ones.

The more ambitious goal of TFI < 1.7 introduced by the "Pesticide Action Plan-2004–2009" left many farmers demotivated by the moving target. At the same time, many farmers expressed that two decades of focus on reduced dosages in combination with a much higher frequency of autumn sown crops in the rotations had led to increases in abundance of grass weeds in particular, which called for special attention. It was therefore a challenge to continue with the farm-level action plans, and focus was again given to a number of demonstration farms where it could be determined whether greater attention and frequent visits by advisers during the season could help reduce pesticide use. Many success stories were reported from the demonstration farms, and obstacles to carrying out, for example, precision spraying in practice, were revealed. One major obstacle to reduced pesticide use in Denmark is the cost of detailed field inspections. The general salary levels are so high in Denmark that often the time and cost of detailed field inspections exceed the potential savings in pesticide costs. Other bottlenecks often mentioned by farmers are lack of time and/or lack of labor available for field inspections.

Another lesson learned is that it is difficult to maintain focus on, for example, pesticide use reduction over many years. In line with that, it has often been reported that after the end of an advisory program focusing on reducing pesticide use, the lack of continued attention has caused the pesticide use to increase again at the farm level.

19.3 Green Growth: The Fourth Pesticide Action Plan

The purpose of Green Growth was to ensure that a high level of environmental, nature, and climate protection goes hand in hand with modern and competitive agriculture and food industries, hence the scope of Green Growth was much broader than that of the previous pesticide action plans. One of the goals of the Green Growth agreement was a substantial reduction in the harmful effects of pesticides on human beings, animals, and nature. Several measures were proposed to reach this goal including 10 m permanent spraying-free buffer zones along all waterways, compulsory control of farmer's spraying equipment, and the creation of a framework for cultivation in accordance with guidelines for integrated pest management, including development of crop-specific guidelines, monitoring, and warning systems. Green Growth focused more on implementation of existing knowledge than generation of new knowledge, thus more funding was allocated for advice to farmers than for research.

Green Growth also stated that the TFI should be replaced by a new indicator reflecting pesticide impact on health and the environment and for a redesigning of the pesticide tax so that the pesticides potentially most harmful to health and the environment are subject to higher taxes than the less harmful pesticides. In order to meet these demands a new indicator called the Pesticide Load Indicator was developed. For more details on Green Growth see Anonymous (2009).

19.3.1 Pesticide Load Indicator (PLI)

The PLI consists of three main categories of indicators (human health; environmental fate, and environmental toxicity), each of which consists of several subindicators. Human health is based on the risk phrases of the product; environmental fate is composed of three subindicators: degradation, accumulation, and leaching; and environmental toxicity has 11 subindicators: short- and some long-term effects

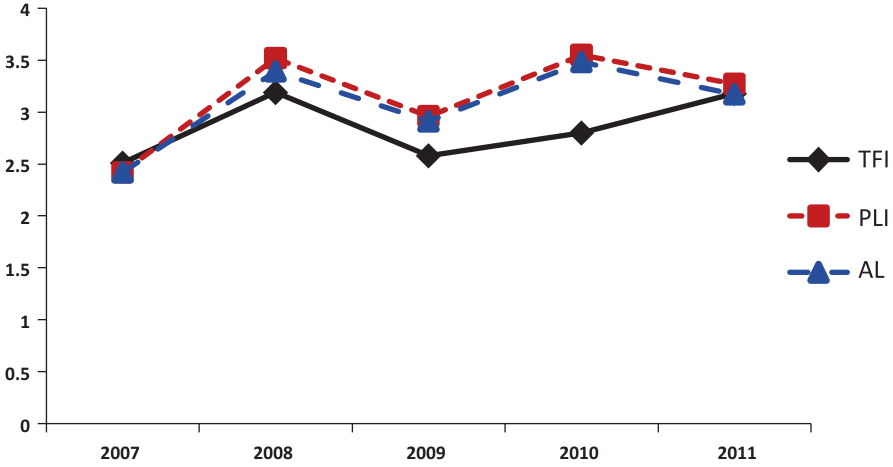

Fig. 19.4 Treatment Frequency Intensity (TFI), Pesticide Load Indicator (PLI), and Area Load (AL) from 2007 to 2011. From 2007 to 2010 a similar trend was observed for TFI and PLI although the increase in PLI from 2009 to 2010 was more pronounced than the corresponding increase in TFI. In 2011 PLI decreased despite an increase in TFI. The observed discrepancies between TFI and PLI were primarily caused by shifts in the use of insecticide active ingredients.

on mammals, birds, bees, earthworms, fish, aquatic arthropods (e.g., daphnia), aquatic plants, and algae. The calculation of the environmental load of a pesticide (environmental fate and toxicity) is based on the inherent properties of the active substance, derived from the Pesticide Properties Database (PPDB) (PPDB 2009). This database contains the data submitted for the EU assessment undertaken in connection with the evaluation and inclusion of active ingredients in the EU positive list.

For calculating the human health load every risk phrase is converted to a score ranging from 10 (e.g., for products that are harmful if swallowed) to 100 (e.g., for highly toxic products that can cause irreversible damage). Concerning environmental fate and toxicity of the active ingredient, the load for each subindicator is calculated on the basis of a reference value (the active ingredient with the highest load for a specific subindicator, e.g., the longest half-life or lowest LD_{50} value on daphnia). Thus for each active ingredient the ratio between each subindicator value and the corresponding value of the reference substance is calculated (always lower than 1). Furthermore, weights have been assigned to each of the environmental fate and toxicity subindicators. Using reference substances for each subparameter it is possible to summarize results for various subindicators.

The PLI can be expressed per unit product or per standard dose and be converted to describe the area load (AL) using the pesticide use data that is also used for calculating the TFI. The PLI can be broken down to a PLI by crop. Similarly the AL can be expressed by crop expressing the pesticide load per unit area of different crops. Figure 19.4 shows the TFI, PLI, and AI for the period 2007–2011. It can be seen that the PLI and AI are almost identical in all years reflecting that crop composition did not change significantly. In contrast, TFI and PLI/AE do not follow exactly the same trend between years reflecting that changes in the pesticide use pattern will affect TFI and PLI/AE differently.

The PLI will provide the basis for developing a guidance/point system to allow farmers making an informed selection among pesticides based on their properties. The PLI will also provide the basis for a new pesticide tax, replacing the current value-added tax, where the pesticides potentially most harmful to health and the environment are subject to the highest taxes. For more information on the PLI see Anonymous (2012b).

19.3.2 Research Activities Initiated by Green Growth

Green Growth stipulates that research should be initiated on integrated plant protection, decision-support systems and harmful pesticide effects. Research activities will be conducted partly as an on-going pesticide research program as well as within the framework of a new research program dedicated to monitoring, warning, and decision-support systems (MWD research program) that are considered to be crucial tools to enable farmers to adopt IPM.

A knowledge synthesis on monitoring, warning, and decision-support systems was carried out based on a literature survey and a technical evaluation of existing Danish systems (Axelsen et al. 2012). The authors recommended that the targets of future monitoring, warning, and decision-support systems should be: (1) insect pests (and slugs) in cereals and oilseed rape; and (2) diseases of potatoes, winter wheat, maize, and horticultural crops and fruit and berries. Further it was recommended to include basic biological studies including the dependence on climatic conditions as this information is missing in many of the existing systems.

The MWD research program was announced in the autumn of 2012. Three projects have been granted and they will start in 2013 and run for up to three years.

19.3.3 Advisory Initiatives Initiated by Green Growth

The following main advisory activities are undertaken to follow up the Green Growth action plan:

- Targeted IPM advice to farmers (two-year programs);
- Activities at seven IPM demo farms;
- A countrywide IPM reference website with various information materials;
- A self-assessment point system for measuring IPM uptake.

19.3.3.1 Targeted IPM Advice

The two-year targeted IPM advisory programs are offered to roughly 450 farmers at a time, allowing 1,300–1,400 farms to be covered over the six-year span of the initiative. Specially trained IPM advisers carry out these programs. The farmers are offered three advisory modules per season: winter planning (e.g., crop rotations, variety choice, and treatment plans), field visits in the main growing season (pest monitoring, decision support, etc.), and evaluation visits either before harvest or after the growing season. A subsidy of 80 % is taken from the pesticide tax revenues and given to farmers for these advisory programs, allowing advisers and farmers to take other subjects under consideration than they normally do. For example, local farm advisers say that it is easier to consider long-term implications of farming and discuss topics such as rotation planning and crop choice with this subsidy. So far, there has been considerable interest in participation in these programs, and the farms that enroll tend to be larger than average farms; the current average farm size is 234 ha. It is currently estimated that over the six years farmers managing approximately 15 % of Danish agricultural land will be covered, and it is hoped that the activities carried on at these farms will have a carryover effect on the advisory service and its offerings as a whole.

19.3.3.2 IPM Demonstration Farms

It is widely recognized that IPM is a dynamic phenomenon and that the targets should change as the opportunities evolve through, for example, technological development. Seven demonstration farms have been chosen to work more intensively with IPM and each focuses on a specific theme. Currently, the farmers/growers are focusing on: (1) using sensors for graduating fungicide and herbicide treatments in cereals and potatoes; (2) weed mapping and site-specific weed management; (3) local monitoring and forecasting of pests and diseases with focus on Septoria which is the main Danish cereal disease; (4) monitoring and decision support for late blight control in potatoes; (5) optimizing crop rotations and tillage to minimize grass weeds in grass seed production; (6) using pheromone mating disruption in an apple orchard; and finally (7) using natural enemies of various greenhouse ornamental pests (see Figures 19.5, 19.6 and 19.7).

Three of the arable farmers are working together in developing and testing a concept for growing variety mixtures of wheat on wide rows with the intention of opening up the crop for mechanical weed control, minimizing the need for fungicide inputs and, it is hoped, at the same time optimizing the utilization of nitrogen, a plant nutrient with restricted use in Denmark.

The farming press is generally very interested in publishing articles covering the activities at these seven farms, and opportunities and obstacles are brought out into the open. It is also expected that the activities on these farms will have an impact on other farmers/growers locally and countrywide.

19.3.3.3 Danish IPM Website

The IPM reference website is in the Danish language and has the address www.dansk-ipm.dk (Anonymous 2012c). It contains a wealth of material which is always

Fig. 19.5 Result of inter-row cultivation in spring barley, grown at 25 cm row distance. Treatment has been done with a camera-guided implement and has been fairly aggressive on weeds with only slight crop damage. In Denmark inter-row cultivation for weed management has established itself as a cost-effective tool in row crops such as maize and oilseed rape. However, it is not considered an attractive option in cereals, and development is still needed. Three demonstration farms are developing a concept for growing variety mixtures of winter wheat in wide rows to optimize protein content and to minimize pesticide inputs. Inter-row cultivation is an important tool in this system.

under further development. Every three months a campaign on a new IPM-related subject is launched and specific material developed for this campaign. Examples of campaigns carried out so far are: mechanical inter-row weed control (technical aspects), spray technology with the focus on biological effect and drift mitigation, pesticide resistance prevention and management, crop rotation planning, fungal diseases in cereals, beneficials in greenhouse production, and friends and enemies in the orchard.

For each campaign, different types of advisory materials are developed, with the focus on short messages that can be handed out to the farmer during an advisory visit. These short messages are called inspiration sheets (in Danish: *inspirationsark*). Another type of learning material is "test your knowledge" (in Danish: *test din viden*) which are small quizzes on each of the IPM topics in focus. They are multiple choice questions with images wherever feasible and with feedback explanations for both correct and wrong answers.

Furthermore, IPM toolboxes (in Danish: *IPM værktøjskasser*) have been developed and discussed with relevant stakeholders for all the major crops grown in Denmark. These toolboxes are currently being translated into crop-specific IPM guidelines adapted to Danish conditions and with more direct focus on operations to be done by the farmer/grower. Many IPM themes are best conveyed to farmers by using video material, and several video recordings on IPM may be found on the website.

A cross-cutting component has been the development of an IPM point system for farmers' self-assessment on their IPM uptake. The point system is currently

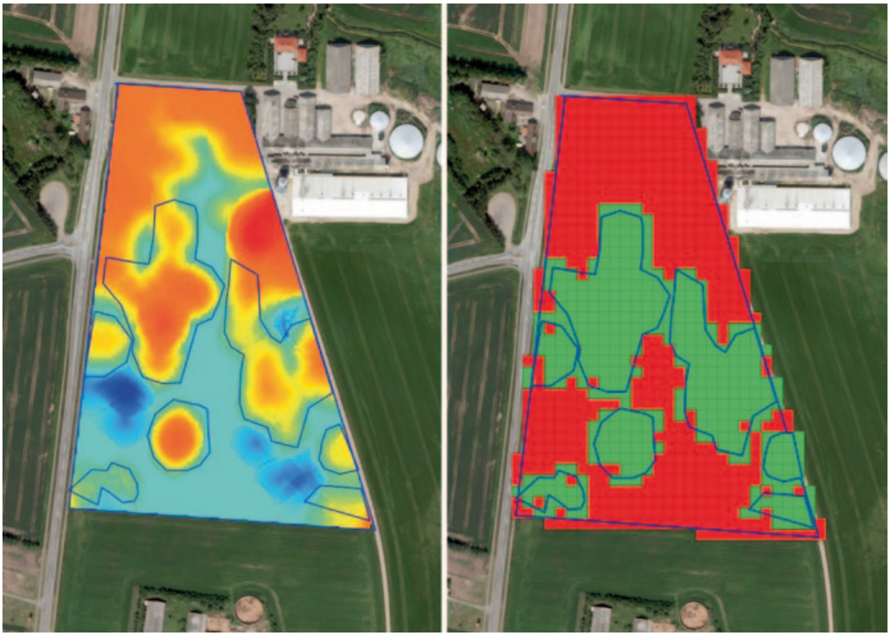

Fig. 19.6 The so-called Yara sensors (mounted on the tractor) are quite common in Danish agriculture where they are used for graduated application of commercial fertilizer. One demonstration farm looks at using the Yara sensor to graduate pesticide use, for example, fungicide dose in cereals where the highest dose is applied in areas where the canopy is dense. In this example, the map to the left shows the amount of "greenness" measured by the sensor in cereals before harvest. When inspecting the fields, this map showed a high degree of correlation with the infestation of the perennial weed, *Equisetum arvense,* and the combination of sensor measurements and field inspection allowed for creation of a simple application map (right) where green denotes full dose of MCPA and red areas denote approximately half-dose. This is an attempt to harvest the "low hanging fruits" with respect to precision farming.

being translated into English as a result of considerable interest from other European countries. The idea of the point system, currently implemented in an Excel spreadsheet, is to ask the farmer concrete questions which he answers in relation to current practice on his own farm. There are two components, one measuring current practice, and one measuring the awareness of IPM principles and other topics relevant to IPM. It is the intention that the point system will be used for measuring the impact of the targeted IPM advisory programs by asking farmers to complete the questionnaire at the beginning and again at the end of each advisory program. However, the questionnaire is accessible via the website and may be used by any farmer interested in benchmarking the state of IPM at her own farm against colleagues.

From the beginning of the Green Growth action plan, the Danish Agricultural Advisory Service has focused on making IPM very concrete to growers, focusing on initiatives that are ready to use in their fields, orchards, or greenhouses. From reading the eight IPM principles laid out in the EU framework directive, many farmers have responded that "IPM is just part of good farming practice," whereas others have stated that "IPM sounds like something very costly." IPM may be seen

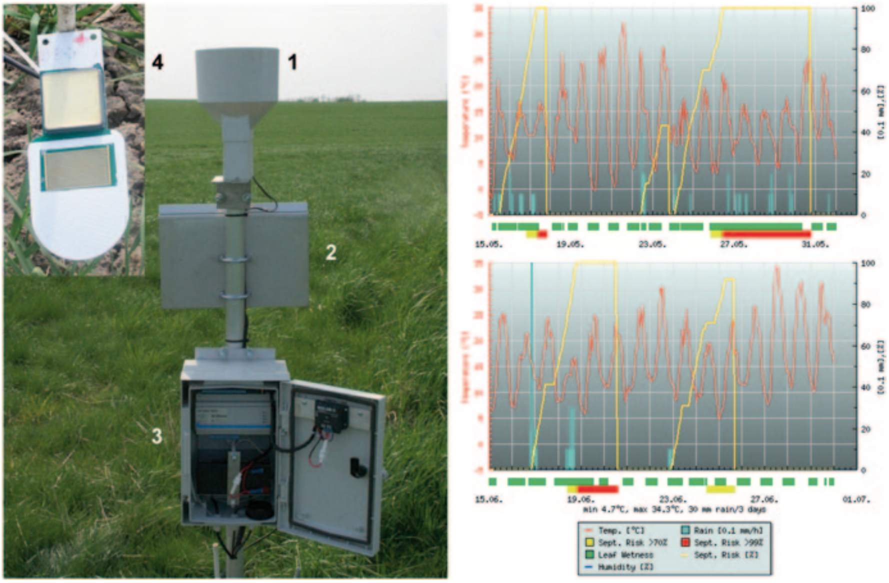

Fig. 19.7 Use of Septoria timer for local warning. Septoria tritici blotch is the disease causing the highest yield losses in winter wheat in Denmark. One demonstration farm focuses on using weather data for local forecasting/warning and tries different application strategies based on output from the national monitoring network as well as the Septoria timer. The picture at the left shows the Septoria timer measuring precipitation (1), temperature (3), and leaf wetness (4). The Septoria timer is powered by a solar panel (2). The graph at the right shows output from the Septoria timer which assists the farmer in making decisions about Septoria control. The Septoria timer has been made available by Bayer Crop Science.

as yet another political initiative limiting agricultural production by some farmers. For advisers it is therefore important to focus on the potential advantages in IPM as a set of tools that may come with a cost in the short term but will, it is hoped, be of benefit to the farmer in the longer term by, for example, delaying development of pesticide resistance, maintaining beneficials, and so on. In Denmark we focus on communicating IPM tools that are ready to implement and developing tools that are not currently widely adoptable together with the farmers. Thereby, the advisory activities will, it is hoped, create enthusiasm among farmers rather than opposition towards the idea of IPM. Even the most skilled and enthusiastic farmers tend to find that they can improve their current practice a bit.

19.4 Pesticide Strategy 2013–2015: The Most Recent Pesticide Action Plan

In the autumn of 2012 the Danish government launched the fifth pesticide action plan covering the period 2013–2015. In addition to reiterating the goals of Green Growth this plan serves two other purposes: introducing a new quantitative target for pesticide use and fulfilling the EU requirement to adopt a National Action Plan for reducing risks and impacts of pesticide use on human health and the environment.

Future reduction targets will be based on the PLI and the first target proposed is a 40% reduction in pesticide load by the end of 2015 compared to 2011 (see Figure 19.2). In contrast to the TFI, reductions in the PLI can be achieved by substituting high-risk pesticides with more benign pesticides without reducing pesticide use per se. The new quantitative target therefore leaves the farmer with more options to meet the reduction target than the TFI did.

The PLI will also be the basis for a new pesticide tax that will significantly increase the tax on products containing active ingredients with a high potential impact on human health and the environment. In contrast taxes on more benign pesticides will be lower than today. Overall the new pesticide tax will bring in substantially more revenue than the existing tax. The revenue will partly be used to reimburse the land taxes Danish farmers are paying. The remaining revenue will finance the wide variety of activities initiated as part of the national action plan including advisory and research activities.

As the impact of a pesticide is very much determined by the chemical group the pesticide belongs to, the new tax will not only change the price relations between pesticides but also between the various groups of pesticides. This could tempt farmers to increase the use of pesticides belonging to the groups of pesticides becoming cheaper but among those are unfortunately several (e.g., the sulfonylurea herbicides) where past experiences have shown that the risk of pesticide resistance is very high. Hence, Danish farmers, their advisors, but also researchers in Denmark are faced with a challenging task to meet the overall goal to reduce pesticide impact on health and the environment and at the same time apply sound anti-resistance strategies whenever the risk of pesticide resistance is high.

19.5 Concluding Remarks

Since the mid-1980s Danish farmers have had to cope with pesticide action plans setting quantitative targets for pesticide use. Faced with this demand, advisory services, as well as the institutions involved in crop protection research, have had their focus on reducing pesticide use. Thus many of the so-called “low hanging fruit” such as optimized pesticide doses and using disease-resistant varieties have already been “picked” making the challenge Danish farmers now face with EU Directive 2009/128 and national legislation including the new quantitative PLI-based target even greater. Add to this that national regulation particularly on groundwater protection has removed many products from the Danish markets or resulted in restrictions in their use dosewise or concerning the time of year they can be applied. Compared to previous years when targets were based on the TFI, the shift in focus from pesticide use/spraying intensity to pesticide impact and the focus on IPM has opened new possibilities for Danish famers to meet future demands.

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Chapter 20
Experiences with Implementation and Adoption of Integrated Pest Management in Italy

Tiziano Galassi and Maurizio Sattin

Contents

Abstract The optimization of crop protection strategies to reduce the risk and impact of pesticides on human health and the environment began in Italy in the early 1970s. An innovative approach for crop protection was first devised through specific research programs, the involvement of farmers and financial support from the Euro-

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pean Union (EU). A key step for integrated pest management (IPM) implementation was the application of the agroenvironmental measures (Reg. EEC no. 2078/92) that required definition of what was meant by IPM and which solutions could provide quantifiable benefits. Fundamental in that phase was the definition, in agreement with the European Union, of the principles and general criteria to be used in the implementation of IPM and the setting up of a National IPM Committee. From 1997 onwards, the National IPM Committee has been working to guarantee that the application of IPM evolves in full respect of the defined criteria. Since then IPM has spread progressively to 2 million hectares, involving 119 crops, and obtaining high implementation percentages, especially on the horticultural crops where pesticide inputs are very high. The regions have responsibility for the implementation of IPM. The system in Emilia-Romagna region is reported on, which involves more than 200 advisors as well as technical support for overseeing the implementation of IPM on around 80% of horticultural crops. Significant results have been obtained in the reduction of use of those pesticides with a high risk for human health and the environment.

Keywords IPM · Plant protection products · IPM guidelines · Pesticide use · Pesticide risk · Emilia-Romagna region · European legislation on plant protection products

20.1 Introduction

Italian agriculture is rather diversified due to a range of pedo-climatic and social conditions that result in the cultivation of a wide variety of crops. The usable agricultural area (UAA) is around 13 million ha (ISTAT 2012), major crops are durum and bread wheat *(Triticum durum* and *T. aestivum)*, maize *(Zea mays)*, vineyards *(Vitis vinifera),* olive groves *(Olea europaea)*, and orchards, that is, apples (*Malus domestica* spp.), peaches (*Prunus* spp.), pears (*Pyrus* spp.), and citrus fruits (*Citrus* spp.), but also tomatoes (*Solanum lycopersicum*) and potatoes (*Solanum tuberosum*). Although the area cultivated is not large, the high value of horticultural and specialized crops gives them an important role. The 2011 gross domestic product (GDP) of the Italian agriculture sector was €51.8 billion (equivalent to US $67 billion) (INEA 2012), producing about 80–85% of national requirements but with a decreasing trend in the last 20 years (MIPAAF 2012). Farm size is generally small, with almost 40% of UAA holdings smaller than 20 ha, and in terms of economic size 66% of farms have an ESU (European size unit, which is a standard gross margin of €1,200 (equivalent to US $1,563) that is used to express the economic size of an agricultural holding or farm) of less than 8 ha (Eurostat 2012). The recent sixth Italian census on agriculture, based on data collected in late 2010, highlighted that 6.1% of the national UAA is farmed organically (ISTAT 2012a).

Major crop protection problems in Italy are related to insect pests and diseases in orchards, fruit and horticultural crops, and weeds in arable crops (e.g., Vasileiadis et al. 2011). The intensive use of pesticides on several crops as well as the limited number of available active ingredients (a.i.), especially herbicides, make pesticide resistance a major issue (e.g., Alberoni et al. 2010; Criniti et al. 2008; GIRE 2012; Tirello et al. 2012), mainly where rotation of crops and pesticide mode of action (MoA) is not practiced.

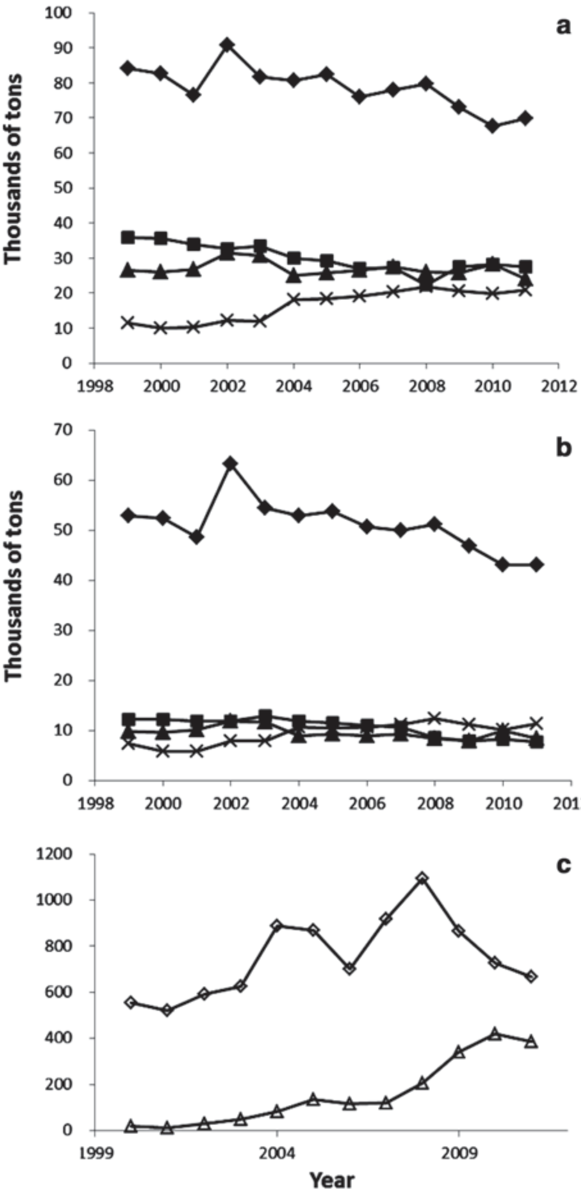

Fig. 20.1 Quantity of pesticides used in Italy from 1999 to 2011 in terms of products (**a**) and active ingredients (**b**), ♦=fungicides, ■=insecticides+acaricides, ▲=herbicides, ×=others (e.g., nematicides, fumigants, rodenticides, growth regulators). Tons (t) of biocontrol agents (BCA, Δ) and number of traps sold (thousands, ◊) during the same period is reported in (**c**).

In total, the amount of pesticide products used in Italy decreased from 158,100 tons in 1999 to 142,500 tons in 2011 (−9.9%), while during the same period the amount of a.i. decreased from 82,000 tons to 70,300 tons (−14.3%). In absolute values, fungicides is the category that decreased most (−17.0% and −18.5% in terms of products and a.i., respectively), followed by insecticides (−23.1% and −37.2% in terms of products and a.i., respectively; ISTAT 2010, 2011 and 2012a; Fig. 20.1a, b). Herbicide use also decreased, especially in terms of a.i. (−14.4%). The quantity of biocontrol agents (BCAs) has increased very substantially whereas the number of traps sold has fluctuated, although following an increasing trend, during the period 1999–2011 (Fig. 21.1c).

In relation to toxicity level, in the last 12 years the quantity of highly toxic and toxic products decreased by about 27%, unclassified products decreased by about 19%, whereas the quantity of noxious products sold increased significantly (+136%).

For about 20 years, the decision-making process for agricultural policy has been progressively devolved to the 20 regions and two autonomous provinces, with the Ministry of Agriculture retaining jurisdiction on general agricultural policy and coordination of regional policies.

Crop protection in Italy has been driven by pesticides for at least three to four decades. However, since the late 1970s many regions have started integrated pest management (IPM) programs, and in 1986 the Ministry of Agriculture began a national plan for integrated pest control (Galassi and Mazzini 2005).

The new EU legislation, also called the "Pesticide Package," represents a turning point and a boost for IPM (Barzman et al. 2014; see Chapter 17 of this volume). The directive on the sustainable use of pesticides specifically requires member states to take all necessary measures to promote low pesticide-input pest management and to draw up a National Action Plan (NAP) to address the directive and set specific targets to monitor success. Some level of IPM will therefore be compulsory in the European Union starting in January 2014.

20.2 IPM Implementation at National Level

IPM in Italy has a rather long history and its implementation has required the combined effort of several policy and decision makers at the European, national, and regional levels and the contribution of many stakeholders. The first research experience was acquired during the 1960s (Principi 1962, 1973) and the first practical experience of IPM implementation was gained on pilot farms in the early 1980s.

Start of IPM in a Coordinated Effort Among Regions, Italian Government, and European Union The key point for the development of IPM in Italy was the application of Regulation EEC no. 2078/92, which made funds available to farmers who implemented IPM through crop-specific guidelines. It was a difficult phase because a national framework was missing and for the European Commission it was very complicated to evaluate and approve all crop guidelines proposed by the regional administrations. There were no general principles, and reference criteria and guidelines proposed by the regions were very inconsistent with one another. For this reason the European Commission, in agreement with the Italian Ministry of Agriculture and the regions, decided to award subsidies to farmers who applied IPM according to the following procedure:

- Definition by the EU Star Committee of general principles and criteria to be followed in the definition of crop guidelines (EU Decision no. C(96) 3864).

- The setting up of an Italian National IPM Committee to guarantee that the crop-specific guidelines of the individual regions respected and were coherent with the principles and criteria defined in Decision no. 3864/96 and also that they justified the amount of the grants that the regional rural development plans awarded to the farmers who undertook to apply the agroenvironmental measures.
- Regional IPM regulations had to be submitted to and approved by the National IPM Committee.

The different IPM activities were accompanied by interventions to encourage biodiversity and increase ecological awareness through support for the development of areas of renaturalization, cover crops, and organic farming.

The system progressively developed, even if at different speeds in the different regions. IPM then evolved into a new production system, integrated production, which combines the sustainability of agricultural productions with the protection of human health and the environment as well as the improvement of the quality of agricultural products. Law no. 4 of 3 February 2011 was drawn up in this context, which instituted the national system of quality.

20.2.1 Principles and Criteria (EU Decision 3864/96)

The general principles and criteria defined by the STAR Committee (Committee on Agricultural Structures and Rural Development, it assists the European Commission with the administration of rural development measures) were to be in force only for the duration of Reg. 2078/92, but their application was renewed through the subsequent rural development plans and ministerial decrees that also periodically renewed the functioning of the National IPM Committee.

The IPM guidelines are indicated in the annexure to EU Decision no. C(96) 3864 of 30/12/96. Pests have to be controlled using products with minor impact on human health and the environment, in the lowest amount possible (therefore only if necessary and at the lowest doses), chosen among those with sufficient efficacy to obtain crop defense at economically acceptable levels and taking into account their persistence. Where different techniques or strategies are possible, those agronomic and/or biological techniques that can guarantee minimum impact must be preferred. Use of pesticides will be limited to where no effective alternative is available.

The technical guidelines must refer to the principles of IPM (Galassi 2008), taking into account that this is part of the wider strategy of integrated production. In this context the point of reference is the International Organisation for Biological and Integrated Control of Noxious Animals and Plants (IOBC/WPRS) guidelines in the document “Integrated Production—Principles and Technical Guidelines” (El Titi et al. 1993).

The technical guidelines include: (a) the pests recognized as dangerous for each crop; (b) the treatment criteria on the basis of which to evaluate the presence of the pests and the level of infestation (these criteria must be functional to justify the

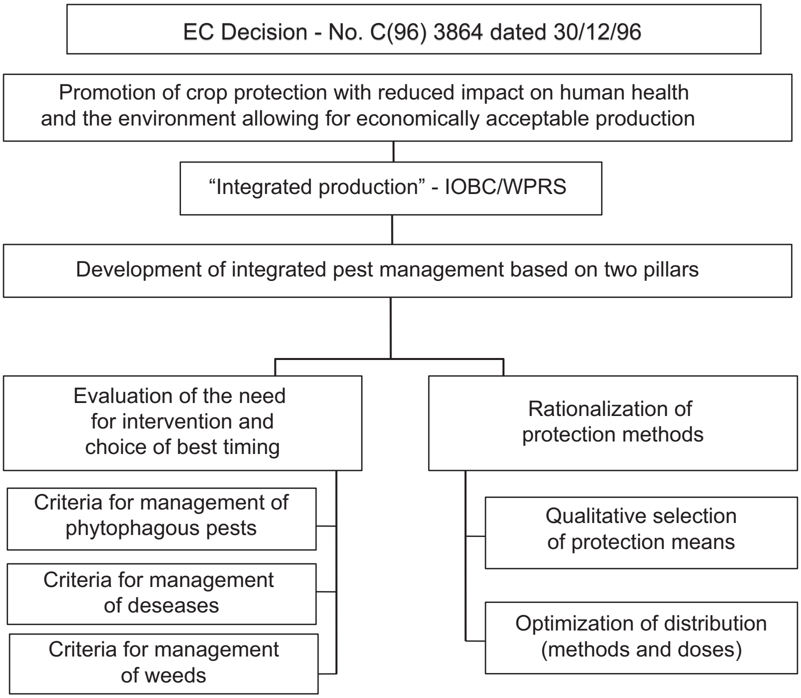

Fig. 20.2 Scheme of principles and criteria for IPM implementation in Italy.

recourse to control treatments); (c) the pesticides that can be used; and (d) notes on the use of pesticides and any limitations that may apply.

The technical guidelines are designed for pest management that based on the need to treat and choice of the best time, as well as identification of the control means (Fig. 20.2). The pesticide treatments must be justified by: (a) the damage risk; and (b) farmer's observations or local evaluations for homogeneous areas.

For insect control, the presence of the most troublesome phytophages at damaging stages and their relative density is determined, and "economic treatment thresholds" are defined. The presence of any natural antagonists is then assessed also in relation to the choice of the selective insecticide. The optimal treatment time is then identified. Integrated or biological control techniques and agronomic methods with low environmental impact must always be preferred.

The highly infectious nature of some diseases makes it almost impossible to subordinate the treatments to the presence of symptoms and therefore predictive evaluations have to be made, reserving the start of treatments to after the appearance of the symptoms only for pathogens at low epidemic risk. Disease control therefore requires the use of forecasting models.

Weed control has to be based on the knowledge of target weeds as well as the level of infestation. Mechanical and physical control means should always be preferred and chemical treatments localized (e.g., banded treatment along the crop rows where appropriate). In general, agronomic techniques and tools that reduce the dependence on and the quantity of pesticides should be preferred (e.g., crop rotation, tolerant or resistant crop varieties, adequate soil cultivation, natural products). The choice of pesticides should take various aspects into consideration: good efficacy against target pests, fit with the overall pest management strategy, minimize risk to human health and the environment by excluding or significantly limiting highly toxic and toxic products as well as those with a negative impact on water quality, preserve beneficials by using the most selective a.i., and minimize the risk of pesticide resistance.

Pesticides must be applied adopting techniques that allow the necessary amounts to be reduced to the minimum needed to obtain an acceptable efficacy, avoiding dispersion in the environment.

20.2.2 National IPM Committee

In order to guarantee adherence to the above-mentioned criteria, in 1997 the Ministry of Agriculture set up the National IPM Committee, which includes representatives of the ministry and a representative for each region and autonomous provinces. The committee regularly updates general and crop-specific national guidelines (Galassi 2012) and verifies that the regional regulations for IPM implementation are consistent with and respect the principles and criteria defined in the EU Star Committee Decision no. 3864/96. Since 2007, the regional regulations have also been used by the farmers who implement the EU Council Regulation establishing a common organization of agricultural markets and specific provisions for certain products (Single CMO Regulation, Council Regulation (EC) No. 1234/2007).

20.2.3 National IPM Guidelines

National IPM guidelines were defined by the National IPM Committee in 2007. The regions may also propose technical solutions that differ from the national guidelines. In this case the solutions must be to solve specific local problems, be supported by experimental results, and be verified and approved by the National IPM Committee. The national guidelines are split into general and technical guidelines for the 119 most important crops for Italian agriculture. They are updated annually, usually by September in the year of implementation. Minor integrations and modifications are normally made to the general guidelines, whereas the modifications to the crop-specific guidelines are more consistent, mainly due to the continual updating of available pesticides. All the guidelines are available on the rural network site of the Ministry of Agriculture (Rete Rurale Nazionale 2012).

20.2.3.1 General IPM Guidelines

The guidelines include criteria and agronomic solutions as well as strategies to be adopted for crop protection so as to reduce the impact on the environment and humans and obtain cost-effective production. In the case of extraordinary plant protection situations where products not listed for the crops are required, a farm-related derogation will be granted; if the event refers to large areas, there will be a territorial derogation.

A few relevant points of the guidelines are:

- Seed treatment and plant propagating material: all types of seed treatment and propagating material treatment are allowed with the use of appropriate products, except for the crops for which it is forbidden. The use of “certified” propagating material is preferred.
- Limitations and suggestions related to the use of plant protection products:
  - Where valid alternative methods are lacking, the use of toxic or highly toxic products is limited or not permitted.
  - Corrosive plant protection products are banned.
  - Where valid alternative methods are available, the use of Xn (harmful) products with risk phrases for chronic effects on man (carcinogenic effect—R40, reduce fertility—R60, cause damage to fetus—R61, risk of reduced fertility—R62, possible risk to fetus—R63, irreversible effect likelihood—R68) is limited or not permitted.
  - Chemical formulations Nc (not classified), Xi (irritant), and Xn (harmful) are to be preferred when, for the same a.i., toxic (T) or very toxic (T+) formulations are also available.
- Use of traps: this is mandatory when the treatment is conditional on the presence of captures. The farmers who do not install mandatory traps will not benefit from any derogation. Farmers are not obliged to install traps if areawide monitoring methods are provided or when there are alternative thresholds available, for example, plum (*Prunus* spp.) and *Hoplocampa* spp.
- Rotation is often imposed for arable crops and agronomic tools are always preferred.
- Pre-emergence herbicide treatments are discouraged.

20.2.3.2 Crop-Specific IPM Guidelines

Crop-specific IPM guidelines have been laid down for most crops cultivated in Italy. They were defined starting from the crop protection issues of the individual crops. The monitoring methods, level of hazard, and risk for the crop, pest control strategies, utilizable pesticides, and their limitations were considered for each pest. Each guideline was the result of a holistic process and evaluation of single elements and criteria. The crop guidelines cover 119 crops (17 fruits, wine and table grapes, 6 horticultural crops, 4 Liliaceae, 28 Cucurcitaceae, 6 Solanaceae, 10 legumes, 4 cabbages, 15 salads, 7 protected crops of fresh-cut vegetables, 17 arable crops, 12 seed crops, flowers and ornamental plants, and mushrooms).

Table 20.1 Potato IPM Guidelines for *Phytophthora infestans* and *Alternaria solani*

Disease	Criteria for Disease Control	Compulsury a.i.[a]	Compulsory Limitations of Use
Phytophthora infestans	*Agronomic Interventions* Use of seedling tubers that are definitely healthy. Choice of varieties that are not very susceptible. Elimination of plants born from seedling tubers that were left in the ground from previous years. Wide rotations. Balanced manuring. Adequate sowing distance to avoid excessive density of plants and of the development of the aerial parts. *Chemical Interventions* First treatment when the environmental and cultivation conditions are favorable for infection (rain, fog, high relative humidity, and temperature between 10 and 25°C) for the following applications; you can either repeat them after 6–10 days depending on the persistence of the products used, or follow the evolution of the disease on the basis of climatic parameters.	Copper products Dodina Fosetil Al Fluazinam Cimoxanil (1) Metalaxil-M (2) Metalaxil (2) Benalaxil (2) Benalaxil-M (2) Dimetomorf (3) Iprovalicarb (3) Mandipropamide (3) Zoxamide (4) Propineb (5) Pyraclostrobin (6) Famoxadone (6) Propamocarb Cyazofamide (7) Flupicolide (8)	(1) Maximum three times per year (2) Maximum three times per year with phenylamides (3) Maximum two times per year (4) Maximum three times per year (5) Maximum three times per year Suspend interventions 21 days before harvest (6) Suspend interventions 21 days before harvest, indipendement by the adversity (7) Maximum two times per year (8) Maximum three times per year
Alternaria solani	*Agronomic Interventions* Wide rotations. Use of healthy seedling tubers. *Chemical Interventions* Specific interventions against this pathogen are only necessary in the case of infection of young plants as the anti-peronospora products usually used are also effective against early blight.	Copper products Difenconazolo (1) Pyraclostrobin (2)	(1) Maximum three times per year (2) Maximum three times per year indipendement by the adversity

[a] When the same number is reported in brackets in addition to more than one a.i. the limitation of use reported in the third column refers to the total no. of treatments that can be done with the indicated a.i.

Fig. 20.3 An example of trap for insect monitoring: YATLORf for monitoring soil insects. (Photo by L. Furlan.)

The crop-specific IPM guidelines were developed in specific files. An example is reported in Table 20.1 which summarizes the guidelines for controlling *Peronospora* and *Alternaria* in potato. Each guideline contains advice as well as compulsory limitations. The doses of the a.i. are those on the label of the commercial products. Some important aspects considered in the crop-specific guidelines are briefly described below.

Monitoring and Forecasting Models

According to the general guidelines, pest monitoring is fundamental prior to treatment. Two monitoring levels have been defined: farm and areawide. The latter are valid for entire areas, with the use of traps and untreated fields to correlate the epidemic development of the pests with weather data and forecasting models. Territorial monitoring networks are used to check the spread of pests such as codling moth *(Cydia pomonella)*, tortricids *(Argyrotaenia pulchellana, Pandemis cerasana, Archips podanus)* and olive-fly *(Bactrocera oleae)*. Computerized monitoring networks have been created on a territorial basis in some areas, including Emilia-Romagna and the province of Trento.

The guidelines contain many references to pheromone traps, chromotropic traps, and territorial monitoring networks. The setting of traps is not mandatory when treatments have not been applied for a specific pest, when mating disruption is applied, or where there are territorial monitoring networks. Some regions have restrictions on the use of traps for the monitoring of elaterids. Indications and thresholds have been defined for the capture of larvae (vase traps) and adults (YATLORf type pheromone traps, Figure 20.3).

In relation to the forecasting models no specific indications are given at the national level, and the choice is left to the regions. However, some of these (e.g., Emilia-Romagna) provide compulsory indications on the type of models to be used (Table 20.2).

Table 20.2 Forecasting Models Included in the Regional Regulations of Emilia-Romagna Region

Crop	Pest	Model Type	Indication
Apple and pear	*Cydia pomonella*	Time-distributed delay model	Timing of the treatment
Apple and pear	*Pandemis cerasana*	Time-distributed delay model	Timing of the treatment
Apple and pear	*Argyrotaenia pulchellana*	Time-distributed delay model	Timing of the treatment
Apple and pear	*Cacopsylla pyri*	Phenological	Timing of the treatment
Apple and pear	*Erwinia amylovora*	Cougar blight	Timing of the treatment
Apple and pear	*Venturia inaequalis*	A-scab	Timing of the treatment
Apple and pear	*Stemphylium vesicarium*	BSP Cast	Timing of the treatment
Peach	*Cydia molesta*	Time-distributed delay model	Timing of the treatment
Plum	*Cydia funebrana*	Time-distributed delay model	Timing of the treatment
Peach	*Anarsia lineatella*	Time-distributed delay model	Timing of the treatment
Peach and plum	*Trips* spp	Time-distributed delay model	Timing of the treatment
Grape	*Plasmopara viticola*	DOWGRAPRI	Timing of the treatment
Grape	*Uncinula necator-Oidium tukeri*	POWGRAPRI	Timing of the treatment
Grape	*Lobesia botrana*	Time-distributed delay model	Timing of the treatment
Wheat	*Puccinia recondita*	RUSTPRI	Risk
Wheat	*Puccinia striiformis*	YELDEP	Risk
Wheat	*Septoria* spp	SEPTORIA	Risk
Wheat	*Erysiphe graminis*	POWPRI	Risk
Wheat	*Fusarium* spp.	FHB-Wheat	Risk
Sugarbeet	*Cercospora beticola*	CERCODEP	Timing first treatment
Strawberry	*Botrytis cinerea*	BOTRY	Timing of the treatment
Potato	*Phytophthora infestans*	IPI+MISP	Timing first treatment
Tomato	*Phytophthora infestans*	IPI+MISP	Timing first treatment

Agronomic Tools

Varietal choice and propagation material: The use of material from genetically modified organisms (GMO) is not allowed. The regional regulations can provide recommended lists of varieties. Varieties resistant and/or tolerant to the principal diseases are to be preferred, taking into account the market requirements for the produce obtained. Propagation material must be healthy and guaranteed genetically; it must also be able to offer guarantees on crop protection and agronomic quality.

For horticultural crops, material of the category “EC Quality” must be used. For tree crops, material of the category “certified” virus free or virus controlled must be used, if available.

Soil preparation before planting an orchard: This must aim at protecting and improving soil fertility and avoiding erosion and degradation. It must also contribute to maintaining the soil structure, favoring high biodiversity of the soil microflora and microfauna and a reduction of compaction, allowing the runoff of excess rainwater and avoiding water-logging. Soil maps should be used, if available. When soil tillage involves heavy operations such as deep plowing, earth movement, grinding of the bedrock, or deep ripping, these must be carefully evaluated.

Crop rotation or sequence: An agronomically correct crop rotation is fundamental for IPM. If IPM is adopted on the whole farm, a five-year rotation should be

Table 20.3 National Guidelines for Vineyards: X Indicates That a Pest Threshold Is Used

Pest	Thresholds				Thresholds				Models
	Pest		Damage		Phenology		Climate	Zone	
	Number	Presence	Number	Presence	Grape	Pest			
Plasmopora viticola	–	X	–	–	X	–	X	X	X
Uncinula necator	–	–	–	–	X	–	–	X	–
Botrytis cinerea	–	–	–	–	X	–	–	–	–
Trips	–	–	–	X	–	–	–	–	–
Scales	–	–	X	–	–	X	–	–	–
Lobesia botrana	–	–	X	–	–	X	–	–	X
Clysia ambiguella	–	–	X	–	–	X	–	–	X
Argyrotaenia pulchellana	–	–	X	–	–	X	–	–	X
Panonychus ulmi	X	–	–	–	X	–	–	–	–
Eotetranycus carpini	–	X	X	–	X	–	–	–	–
Scaphoideus titanus	–	X	–	–	–	X	–	X	–

adopted that includes at least three crops and a maximum of two consecutive years with the same crop. In particular cases (e.g., hills or mountains, rainfall of less than 500 mm per year, specialized crops), a rotation with only two crops in the five years is allowed; For rice, cropping for five consecutive years is allowed.

When replanting perennial crops it is advised to leave the field fallow for an appropriate period, during which an arable crop or cover crop can be grown. The residual roots of the previous crop should be removed and the planting layout changed.

Thresholds

The guidelines include numerous treatment thresholds such as: “pest numbers threshold,” that is, represented by a precise number of captured individuals (e.g., pear/*Cydia pomonella*); “treat above the indicative threshold of 2 adults captured per trap in 1 or 2 weeks;” “pest presence threshold,” that is, represented generically by the presence alone; “damaged numbers threshold,” based on the percentage or number of plants attacked; “damage presence threshold,” that is, represented generically by the presence of damage. Other “parameters” exist that limit the treatments on the basis of specific climatic and territorial conditions or qualitative characteristics of the plant and pest, such as plant and pest phenology, crop variety, climatic parameters, or else specific low- or high-risk areas. These “parameters” may be mandatory or not. As an example, Table 20.3 reports the use of the thresholds and other parameters as indicated in the regulations for vineyards: the mandatory thresholds are highlighted and the pests for which specific forecasting models are available are listed.

Use of Biocontrol Agents

Recommendations on the best application techniques for biocontrol agents are provided. Information is given on the efficacy of the different strains of *Bacillus thuringiensis* against individual pests.

The following biocontrol agents are also included for the control of various pests against which they are considered to have an acceptable efficacy:

- *Ampelomyces quisqualis* for the control of oidium in numerous crops
- *Beauveria bassiana* for the control of mites in numerous crops
- *Azadirachtin* for the control of aphids and aleurodids in numerous crops
- *Paecilomyces lilacinus* for the control of nematodes in numerous crops
- *Cydia pomonella granulo virus* (CpGV) for the control of *Cydia pomonella* and *Helicoverpa armigera*
- Entomopathogenic nematodes for the control of *C. pomonella*

Sexual disruption is recommended for the control of:

- *Cydia pomonella* on apple and walnut
- *Cydia molesta* on peach and plum
- *Anarsia lineatella* on peach
- *Cydia funebrana* on plum
- *Lobesia botrana* on wine and table grapevines

Limitations for Preventing Pesticide Resistance

General and specific measures for preventing pesticide resistance have been introduced in the guidelines. Resistance management guidelines provided by IRAC (IRAC—Insecticide Resistance Action Committee 2012), FRAC (FRAC—Fungicide Resistance Action Committee 2012), and GIRE (GIRE—Italian Herbicide Resistance Working Group 2012), as well as field experience and research programs have been considered. Measures aim at reducing pesticide selection pressure and optimizing pesticide efficacy. An example is given in Table 20.4, which reports the limitations introduced for the management of fruit crops.

Beneficial Insects

The guidelines contain references to numerous useful insects. Table 20.5 gives a summary of these. To protect the beneficials there are various solutions in relation to the different problems.

- The use of phosphoric esters is limited or excluded, especially on horticultural crops.
- The use of pyrethroids is limited on all crops and in some cases excluded.
- Among the pyrethroids preference is often given to fluvalinate (selective on bees and numerous useful insects).

Table 20.4 Resistance Management on Fruit Crops: Number of Fungicide, Insecticide, and Acaricide Treatments Allowed per Year and Mode of Action by the National IPM Guidelines

Fungicides

Fruit crop	QoI	Triazoles	Phenyl-Amides	Anilino-pyrimidines	Fludioxonil	Dicarbo-ximides	CAA	Quinoxyfen	SDHI (boscalid)
Kiwi	–	–	–	–	–	1	–		–
Apricot	2	3	–	2	2	–	–	3	2
Cherry	2	3	–	–	–	–	–		2
Strawberry	2	2	3	2	2	–	–	3	2
Apple	3	4	–	4	–	–	–	3	3
Pear	3	4	–	4	4	–	–		3
Peach	3	4	–	3	3	–	–	3	3
Plum	3	5	–	3	3	–	–		3
Wine grape	3	3	3	2	3	–	4	3	1
Table grape	3	3	3	2	3	–	4		1

Fungicides specific for grapes

Grape	Flupicolide	Fluazinam	Zoxamide	Spiroxamine	Cyazofamid	Metrafenone	Cymoxanil	Meptyl-dinocap
Wine grape	3	3	3	3	3	3	3	2
Table grape	3		3	3	3	3	3	2

Insecticides and acaricides

Fruit crops	Neonicoti-noids	Organopho-phates	Pyrethroids	Etofenprox	IGR[a]	Acaricides	Indoxacarb	Flonicamid
Kiwi	–	–	–	1	–	–	–	–
Citrus	1	4	1	1	4	1	–	–
Apricot	1	–	1	1	–	–	1	–
Cherry	1	1	–	1	–	–		–
Strawberry	1	0	1–2	–	–	1–2	–	–
Kaki	–	–	–	2	–	–	–	–
Apple	1–2	5	1	1	3	1	3	2
Olive	1	1–2	–	–	–	–	–	–
Pear	1	5	–	–	3	1–2	3	2
Peach	1–2	3	1–2	2	4	1	3	2
Plum	1–2	3	1–2	2	–	1	–	1
Wine grape	1	2–3	–	2	2	1–2	3	–
Table grape	1	3	3	–	2	1–2	3	–

[a] Inhibitors of chitin biosynthesis

Table 20.5 Some of the Benficials Used in IPM. X Indicates Inclusion in the National Guidelines, * Indicates that no commercial products are available

Beneficial organism	Target	Chestnut	Cucumber	Seed cucumber	Chicory	Water-melon	Valerian	Straw-berry in green-house	Straw-berry in field	Kaki	Lettuce	Seed lettuce
Amblyseius andersoni	Mites	–	–	–	–	–	–	–	–	–	–	–
Amblyseius californicus	Mites	–	X	–	–	X	–	X	X	–	–	–
Amblyseius cucumeris	Trips	–	X	–	–	–	–	X	X	–	–	–
Amblyseius swirskii	Trips - whiteflies	–	X	–	–	–	–	X		–	–	–
Anthocoris nemoralis	*Cacopsilla pyri*	–	–	–	–	–	–	–	–	–	–	–
Aphidius colemani	Aphids	–	X	X	–	X	–	X	X	–	–	–
Aphidoletes aphidimyza	*Aphys gossypii*	–	–	–	–	–	–	–	–	–	–	–
Chrysoperla carnea	Aphids	–	–	–	–	–	–	X	–	–	–	–
Diglyphus isaea	*Liriomyza spp.*	–	–	–	X	–	X	–	–	–	X	–
Encarsia formosa	*Trialeurodes vaporarium*	–	X	–	–	–	–	–	–	–	–	–
Eretmocerus eremicus	*Trialeurodes - Bemisia*	–	X	–	–	–	–	–	–	–	–	–
Eretmocerus mundus	*Bemisia tabaci*	–	–	–	–	–	–	–	–	–	–	–
Heterorabditis bacteriophora	*Othiorrhyncus*	–	–	–	–	–	–	X	X	–	–	–
Lysiphlebus testaceipes	*Aphids*	–	X*	X*	–	–	–	–	–	–	–	–
Macrolophus caliginosus	Whiteflies - *Tuta absoluta*	–	–	–	–	–	–	–	–	–	–	–
Necremnus artynes	*Tuta absoluta*	–	–	–	–	–	–	–	–	–	–	–
Orius laevigatus	Trips	–	X	X	–	–	–	X	X	–	–	–
Phytoseiulus persimilis	*Panonychus ulmi*	–	X	X	X*	X	–	X	X	–	–	–
Steinermena feltiae e carpocapsae	*Cydia pomonella*	X	–	–	–	–	–	–	–	X	–	–
Trichogramma maidis	*Ostrinia nubilalis*	–	–	–	–	–	–	–	–	–	–	–

Table 20.5 (continued)

Beneficial organism	Target	Small lettuce	Corn	Aubergine	Apple	Melon	Pepper in greenhouse	Pear	Tomato in green-house	Parsley	Rocket	Celery
Amblyseius andersoni	Mites	–	–	X	–	–	X	–	X	–	–	–
Amblyseius californicus	Mites	–	–	X	–	X	X	–	X	–	–	–
Amblyseius cucumeris	Trips	–	–	X	–	–	X	–	–	–	–	–
Amblyseius swirskii	Trips - whiteflies	–	–	X	–	–	X	–	X*	–	–	–
Anthocoris nemoralis	*Cacopsilla pyri*	–	–	–	–	–	–	X	–	–	–	–
Aphidius colemani	Aphids	–	–	X	–	X	X	–	–	–	–	–
Aphidoletes aphidimyza	*Aphys gossypii*	–	–	–	–	–	–	–	–	–	–	–
Chrysoperla carnea	Aphids	–	–	–	–	–	X	–	–	–	–	–
Diglyphus isaea	*Liriomyza spp.*	X	–	X	–	–	–	–	X	X	X	X
Encarsia formosa	*Trialeurodes vaporarium*	–	–	X	–	–	–	–	X	–	–	–
Eretmocerus eremicus	*Trialeurodes - Bemisia*	–	–	X	–	–	–	–	X	–	–	–
Eretmocerus mundus	*Bemisia tabaci*	–	–	X	–	–	–	–	X	–	–	–
Heterorabditis bacteriophora	*Othiorrhyncus*	–	–	–	–	–	–	–	–	–	–	–
Lysiphlebus testaceipes	*Aphids*	–	–	–	–	–	–	–	–	–	–	–
Macrolophus caliginosus	Whiteflies - *Tuta absoluta*	–	–	X	–	–	–	–	X	–	–	–
Necremnus artynes	*Tuta absoluta*	–	–	–	–	–	–	–	X	–	–	–
Orius laevigatus	Trips	–	–	X	–	–	X	–	–	–	–	–
Phytoseiulus persimilis	*Panonychus ulmi*	X*	–	X	–	X	X	–	X*	–	X*	–
Steinermena feltiae e carpocapsae	*Cydia pomonella*	–	–	–	X	–	–	X	–	–	–	–
Trichogramma maidis	*Ostrinia nubilalis*	–	X	–	–	–	–	–	–	–	–	–

- To protect *Anthocoris nemoralis* for *Cacopsylla pyri* control on pear trees, some products have been excluded that showed unsatisfactory selectivity: all the neonicotinoids (thiacloprid, thiametoxam, clothianidin, and imidacloprid) with the exclusion of acetamiprid, which on the basis of experimental results has demonstrated good selectivity; the use of emamectin is limited to two treatments per year although it also has some activity on *C. pyri* (this activity mitigates the repercussions deriving from the negative activity on *Anthocoris nemoralis*, but may indirectly favor the development of resistant strains).
- Indications are provided for greenhouse treatments so as not to interfere with the release of useful insects utilized as phytophage predators or to favor pollination.

Limitations for Environmental Protection

There are various solutions in relation to the different problems: in weed control the use of postemergence products is favored over those with residual activity (i.e., the use of pre-emergence herbicides on wheat is barred, the use of pre-emergence herbicides for sugarbeet and maize is recommended as banded application). The doses should be reduced while respecting the indications given on the product label. The use of phosphoric esters is also limited or excluded.

Compared to the maximum doses reported on the labels, an average reduction of 36% in horticultural crops and 6% in arable crops has been recorded.

Limitations to Quantitatively Minimize Residues in Food Products

Limitations on pesticide use have been introduced following information gathered by monitoring projects. Particular attention has been paid to dithiocarbamates. Many monitoring programs have been conducted, both privately and with the contribution of the ministry and regions and the results indicate that there is a substantial reduction in the quantity of pesticide residues in IPM products.

It was decided not to introduce any IPM strategy to support a reduction in the number of residues. This type of requirement, introduced by some European retail chains, has not been shown to reduce the risk of exposure to pesticides. These strategies are also not in favor of IPM, as they usually encourage: an increase in the use of pesticides with a wide action spectrum that are unfavorable to biodiversity while favoring the evolution of pesticide-resistant strains, as well as an increase in the use of pesticides with a worse toxicological profile than those adopted in the IPM programs.

Comparative Assessment of Pesticides

In the definition of the IPM national guidelines and regional regulations, there have been comparative assessments of pesticides for many years. This led to the most hazardous pesticides being excluded, which were later banned by the European Union during the revision process of Directive 91/414/EEC. The Italian IPM guidelines also excluded, and the European Union later banned, 76% of the products applied on apples, 83% of those applied on grapevines, 67% of those applied on pears, and 78% of those applied on peaches.

The differences between IPM and conventional pest management have been reduced recently because, thanks to the positive results from IPM, conventional management has also improved. There has been a reduction of 94% in the uses listed on the pesticide label of products with risk phrase R40 (Table 20.6) and 80% in the uses listed on the label of products with risk phrase R63 (Table 20.7). Tables 20.8 and 20.9 report the crops where pesticides with risk phrases linked to chronic effects on humans can be used following the IPM national guidelines.

20.2.4 Implementation of IPM in Italy

In the last 10 years the level of participation in IPM programs has varied in relation to the subsidies available. The level has also been very variable depending on the regions involved and the crops. It has been highest in the fruit and industrial horticultural crops with the highest pesticide inputs. It is estimated that crop-specific IPM guidelines are implemented on around two million ha, especially on orchards (nearly 100% in the Trentino–Alto Adige region and around 70% in the Emilia-Romagna region), processing tomatoes (95% in northern regions), and 70% of fresh-cut horticultural products, olive groves, citrus fruits, and table grapes in southern regions. The level of diffusion on vineyards has been very diversified, and the diffusion on arable crops such as wheat, maize, and sugarbeet has been rather limited.

20.2.4.1 Relations with the Large-Scale Retail Trade

In the horticultural and fruit sector the national guidelines and regional regulations of IPM have become a point of reference for the large-scale retail trade. Although better prices have not been obtained for the farmers, the “integrated” products, having become the standard required, are more easily marketed. At the start of the millennium every large retail chain demanded its own technical regulations, but since then, while maintaining some specific requirements, especially as regards pesticide residues, they have all progressively aligned themselves with the national guidelines and regional regulations.

The producers’ associations have also up to now promoted their own trademarks, with a moderate use of the collective trademarks proposed by the regional authorities. Nonetheless all the products fulfill the IPM requisites, which constitute the reference umbrella for all the promotional initiatives of quality products. The image of IPM consequently continues to be that of a system little oriented towards the consumers, who are in fact unaware of its existence, but fundamental in the trade relations between the producers’ associations and their buyers. An IPM product is now often considered a prerequisite.

Table 20.6 Pesticides with "Chronic" Phrases R40 or R68 on the Label Considered in the National Guidelines (NG)

a.i.	Out of NG	In NG	No. of Crops on PPP label	No. of crops on NG
Benthiovalicarb	x		3	0
Chlorotoluron	x		7	0
Chlorothalonil	x		17	0
Epoxiconazole	x		3	0
Folpet	x		5	0
Isoproturon	x		2	0
Kresoxim-methyl	x		8	0
Mepanipirim	x		3	0
Molinate	x		1	0
Propargite	x		8	0
Propaquizafop	x		1	0
Tepraloxydim	x		3	0
Valiphenal	x		1	0
Captane		x	5	4
Chlorprofam		x	29	11
Iprodione		x	37	3
Linuron		x	15	4
Profoxydim		x	1	1
Propyzamide		x	30	13
Pymetrozine		x	32	7
Tiofanato-methyl		x	9	1

Table 20.7 Pesticides with "Chronic" Phrases on the Label R62 and R63 Considered in the National Guidelines (NG)

a.i.	Out of NG	In NG	In NG: but only with alternative formulation	No. crops on PPP label	No. of crops on NG
Bromoxynil	x			2	0
Fenpropimorph	x			5	0
Oxadiargyl	x			0	0
Maneb	x			22	0
Protioconazole	x			2	0
Cyproconazole			x	15	0
Isoxaflutole			x	2	0
Miclobutanil			x	16	0
Tebuconazole			x	23	0
Fluazifop-p-butyl		x		44	5
Ioxynil		x		10	2
Mancozeb		x		12	2

Table 20.8 Fungicides, Insecticides, and Acaricides Included in the 2013 National Guidelines with Limitations

a.i.	Risk Phrase	Crop with Limited Use
Iprodione	R40	Kiwi, seed of sugarbeet, rocket, valerian
Captane	R40	Apple, pear, peach
Thiophanate methyl	R68	Peach
Mancozeb	R63	Grape, tobacco
Pymetrozine	R40	In greenhouse for: cucumber, melon, tomato, pepper, aubergine, courgette

In the grapevine sector, even if the area officially involved in the IPM programs is not very large, the wineries prefer to use the IPM standard for commercial reasons, not so much for the end user, but for the buyers.

The promotion of integrated products is more limited in the commodities sector, even if the major pasta producers have recently been favoring supply chain agreements in which the standard of reference is represented by the integrated production requirements.

20.2.4.2 The National Quality System

With the aim of promoting the products obtained following the integrated production regulations, the national system of quality was instituted in 2011 (law no. 4 of 3 February 2011 “Provisions relating to labelling and quality food”). The national system of quality offers the opportunity to promote integrated products with a national trademark. At the moment the producers’ associations and large-scale retail trade do not appear to have much interest in this, despite the fact that it could be very useful for accrediting Italian products on foreign markets.

20.2.4.3 Perspectives for IPM in Relation to the Italian National Action Plan (NAP) for the Implementation of Directive 2009/128/EC

The practices adopted up to now in Italy have anticipated some elements that have since been introduced with the new directive on the sustainable use of pesticides and with Regulation 1107/2009/EU:

- The principles and criteria of Decision EU 3864/96 are basically those in annexure III of Directive 128/09.
- The comparative assessment in the evaluation of pesticides and the criteria adopted in Decision 3864/96, are very similar to those in annex II of Regulation 1107/09 (points 3.6, 3.7, 3.8, and 4) for the evaluation of products that are candidates for substitution.

For these reasons there will be a system based on two IPM levels:

- Basic obligatory level with the application of the objectives in annexure III of the Directive. This involves a strong commitment of the regions and autonomous provinces to develop information services for farmers through meteorological networks, parasite monitoring, forecasting models, and territorial bulletins to support them in the application of the IPM principles and criteria.

- Voluntary level differentiated into:
  - Advanced IPM with the application of mandatory crop regulations such as rotations, farm and/or territorial monitoring, application of treatment thresholds, limitations in the choice of pesticides (i.e., those less hazardous for users, the environment, bystanders, and consumers), and number of treatments.

Table 20.9 Herbicides Included in the National Guidelines with Limitations

a.i.	Risk Phrase	Crop with Limited Use
Ioxynil	R 63	Garlic, onion, seed of onion
Propyzamide	R 40	Sugarbeet, lettuces and similar, chicory, valerian, alfalfa
Linuron	R40– R61– R62	Carrot and seed carrot, fennel
Chlorpropham	R 40	Chicory, lettuces, leek
Profoxydim	R40– R63	Rice

- Organic farming, the objective of which is to reach a doubling of the national UAA conducted according to the organic methods in Regulation (EC) 834/2007, by 2020.

20.3 IPM Implementation at Regional Level

20.3.1 The Role of the Regions in IPM Implementation

According to the Italian Constitution, agriculture is the concern of the regions and autonomous provinces. The application of IPM is therefore also devolved to these administrations, which acted autonomously until the end of the 1980s. They then collaborated in a multiyear plan for integrated pest control and subsequently for the application of the agroenvironmental measures and CMO regulation for horticulture crops.

The regions and autonomous provinces set up their own organizations individually and developed specific solutions to support the adoption of IPM on their territories. They are therefore each responsible for the application of regional IPM regulations. The system of the Emilia-Romagna region is presented as an example.

20.3.2 Experiences in Emilia-Romagna

The Emilia-Romagna region includes 9 provinces; it has an area of 22,445.5 km^2 and a population of 4,432,439. The density of 198 inhabitants per km^2 is very high given that much of the area is mountainous or hilly. The principal agricultural figures are: GDP €4,010 million (equivalent to US $5,213 million), no. of farms: 81,476, UAA 1,052,585 ha, and medium farm size 16 ha. In terms of GDP, livestock accounts for 43%, annual crops for 31%, and tree crops for 25%. Fruit crops are very important, covering approximately 75,000 ha (apples 6,000, pears 25,000, peaches 26,500, plums 5,000, apricots 5,000, cherries 2,000, kiwis 3,500, olives 3,500, persimmons 1,000). Vineyards cover 55,000 ha, horticultural crops 50,000 ha (processing tomatoes 24,000, potatoes 7,000), and arable crops about 400,000 ha (Calliera et al. 2013).

The Emilia-Romagna region started a rationalization of pest management in the early 1970s. The first group of advisors was employed in 1974 and by the end of the 1970s there were already more than 100 advisors who, with a regional contribution, worked with the farmers to promote the spread of integrated pest control. This then became integrated pest management and successively integrated crop production. Initially the new principles of pest control were applied on apple crops, then pear, peach, and grapevine. Since the end of the 1980s they have been applied on all the fruit crops in the region, on horticultural and arable crops, cereals in particular, and lastly on seed crops and protected crops for fresh-cut vegetables. IPM is currently applied on more than 80 crops. It has been considered as a single system divided into various components that must operate in an integrated and synergistic way. The components are discussed below.

20.3.2.1 Regional IPM Regulations

The regional IPM regulations are the key point for the application of IPM. In a commercial system it could be said that the technical guidelines are the product on which the whole system is based: they are the product to be sold, defended on the market against competition, and constantly improved through research and experimental activities. It is, therefore, fundamental that all the subjects who participate in the application of IPM are actively involved in the discussion that leads to the definition of the technical guidelines.

The regional technical guidelines are revised annually. All the stakeholders are consulted during the process, being systematically involved through no fewer than 40 meetings and no fewer than 400 contacts. Then, having heard the opinion of the National IPM Committee, the regional technical guidelines are issued at the end of December.

20.3.2.2 Research and Dissemination of Results

Research has always been of great importance for the definition of the regional IPM regulations. The investments in this sector have been substantial and up until the early 2000s research programs received funding of no less than €2 million annually (equivalent to US $2.6 million). With the critical financial situation of the last period, funds have been drastically cut back and are now around €500,000 per year (equivalent to US $650,000 million). The research programs are mainly focused on the following subjects: low impact solutions, evaluation of biological solutions, new strategies, comparison and selectivity of pesticides, pesticide resistance management, new problems, development of new forecasting models, ecotoxicological evaluation of pesticides, and herbicide persistence in the soil.

The research programs are strictly linked to the definition of the integrated production guidelines and immediate inclusion of the results in the crop guidelines is guaranteed. In order to speed this up the results are discussed at meetings of the IPM management group that are held during the winter.

20.3.2.3 Implementation of the Regional IPM Regulations

In the last few years the area involved in integrated production programs supported by the region has progressively diminished in relation to the contraction of available funds.

There is currently a total of 88,576 ha formally under contract, of which 32,638 are tree crops (25% of the UAA) and 27,417 are horticultural crops (51% of the UAA). According to data from the horticultural produce retail trade and pesticide retailers, IPM is practiced on between 70 and 80% of regional horticultural crops.

Technical Supports

The advisory service is supported by some fundamental technical supports:

- The meteorological network, which provides:
    - Weather data from around thirty meteorological stations
    - Five-day forecasts with hourly temperature forecasts for the next three days
    - Information with hourly data on the entire regional territory, divided into microareas (quadrants) of km 5 · km 5
- The territorial pest monitoring network that integrates farm monitoring with specific surveys on the main pests
- Support for the application of forecasting models on pest development

The models are run daily. The outputs are produced on each of the quadrants for which weather data are available and are published on the Internet (http://www.ermesagricoltura.it/Servizio-fitosanitario/Difesa-e-diserbo-delle-piante/Previsione-e-avvertimento-per-le-avversita-delle-colture/I-modelli-previsionali-utilizzati-in-Emilia-Romagna). The forecasting model results are little used by farmers, but are an important support for the coordinators and advisors who integrate them with the monitoring data for the bulletins.

Management of the Advisory Service

The advisory service is coordinated by the Regional Phytosanitary Service (hereafter called Service) and is managed by a group of high-level advisors employed either by the Service or free-lance but paid with public money. During the crop-growing season this group meets weekly to analyze the monitoring data, forecasting model results, and phytosanitary trends. When needed, the group seeks advice from specialists of the Service and/or research and academic institutions. In synergy with these regional-level meetings, meetings are held in all the provinces to analyze the crop protection situation, using the same approach as that utilized at the regional level.

At the end of each provincial meeting, bulletins are produced that provide information to farmers. The bulletins are normally weekly, becoming fortnightly in the periods with fewer phytosanitary problems. Around 240 are produced annually. The bulletins are available on the website: http://www.ermesagricoltura.it/Sportello-dell-agricoltore/Come-fare-per/Produrre-nel-rispetto-dell-ambiente/Fare-agricoltura-integrata-produzioni-vegetali/Bollettini-di-produzione-integrata-e-biologica

Technical assistance to farmers is guaranteed by a network of advisors whose number has varied over the years depending on the available funds. The advisors work in synergy with the provincial coordinators and attend the provincial meetings.

In the early years of IPM application the meetings with farmers were weekly and it was the advisors who conducted the monitoring on farms. Generally, one advisor supervised around 30 farms, that is, about 280 ha, which varied according to the complexity of the crops grown. Over the years the system has developed, the ability of the farmers to personally evaluate their crop protection situation has increased, the area under IPM has grown exponentially and the communication systems have improved. The work of the advisor has also evolved, passing from just integrated pest control to integrated production.

20.3.2.4 Some Results

Recently the difference between IPM and conventional production has been reduced because conventional farmers have also introduced some IPM solutions. The main differences between IPM and conventional production are:

- In IPM the amount of pesticide residues in the produce is lower.
- Residual herbicides are normally not used on fruit crops or on wheat and herbicide rates are generally lower.
- In relation to the crop, 20–35% reduction in the amount of pesticides used.
    - Improved impact on humans and the environment (between 70 and 90% reduction in pesticides with high acute toxicity, between 40 and 95% reduction in pesticides with high chronic toxicity).

In any case farmers in Emilia-Romagna have increased the application of organic pesticides:

- Apples and pears:
    - Spread of *Anthochoris nemoralis*
    - Roughly 30–35,000 doses/ha/year of granulosis virus for codling moth control
    - 800 ha treated with entomopathogenic nematodes for codling moth control
    - 9500 ha using mating disruption technique
    - Use of *Bacillus subtilis*-based products
- Peaches:
- Mating disruption technique used on 70–80% of the cultivated area
- Other crops:

- Mating disruption widely used on grapes and plums
- Beneficial insects often used in fields and greenhouses
- *Bacillus thuringiensis, Bacillus subtilis, Trichoderma,* and Azadirachtin frequently used on various crops

20.4 Concluding Remarks

IPM is now widespread in Italy and involves many stakeholders. It has not just been considered as a set of new technical solutions to propose to the farmers, but as an innovative approach through which to reformulate the management of crop protection. IPM has become the pillar on which to reinvent agriculture based on a holistic vision. Key steps of the process were the investments in research in the early stages, the setting up of the network of advisors for IPM implementation, and the direct involvement of the farmers by means of subsidies that have been made available through the agroenvironmental measures financed by the European Union.

It appears that the Italian IPM system is totally in keeping with the new EU "pesticide package." In this sense it is worth underlining some of the EU decisions that support the Italian approach:

- Annexure II of Reg. 1107/09 focuses attention on the toxicological characteristics of the pesticides, with a penalization of the more hazardous products.
- The IPM principles in annex III of the Directive 12/09/EU are in line with the principles adopted in Italy.
- The Directive 128/09/EU, as well as making IPM obligatory, also recognizes the advisability of operating on more than one level of IPM, with a higher level based on crop-specific guidelines.

The new EU legislative framework on pesticides allows a positive future to be predicted for IPM in Italy.

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Chapter 21
Integrated Pest Management Adoption in the Netherlands: Experiences with Pilot Farm Networks and Stakeholder Participation

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Abstract Integrated Pest Management in the Netherlands was developed in the 1980s and 1990s of the last century as a part of the wider concept of Integrated Farming. The potential proved to be very high in comparative farming systems studies proving that agrochemical inputs could be strongly reduced, notably pesticides. The Dutch government subsequently strongly advocated and supported the further development and implementation of "Integrated Farming" and "Integrated Pest Management" in practice. In the 1990s and 2000s, pilot farm networks were the cornerstone in the government strategy. The adoption of methods and techniques in practice however, progressed only slowly and unevenly. The support of the stakeholders in the agricultural community appeared to be essential to create sufficient momentum and ambition among farmers and contractors. The government's covenant on sustainable crop protection united in 2003 the stakeholders in a roundtable approach. At the same time, the national network project, Farming with Future,adopted a stakeholder management approach to mobilize the support and contribution of stakeholders in the development and subsequent introduction of Integrated Pest Management in practice. The results are promising.

Keywords Integrated pest management · IPM · Integrated production · Pesticides · Adoption · Stakeholder management · Incentives · Pilot farms · Farming systems research · Prototyping

21.1 Introduction

Intensification of agriculture after the Second World War based on reason, agrochemicals, and highly productive cultivars, not only led to a high degree of self-sufficiency in food production; it also directly led to a complex set of problems that marked the beginning of a long-lasting crisis that still continues. The key issues of these problems were and still are the endangered quality of the abiotic environment, mainly caused by over-use of pesticides and fertilizers, the decline of nature (biodiversity) and landscape caused by "improvements" in farm structure, scale enlargement, and land management. These problems lead to increasing social costs of agricultural production caused by pollution and overproduction. Moreover, due to restricted economic perspectives, rural areas are suffering from desertification, especially in marginal (mountain) areas in Europe. In the last decade questions and concerns regarding animal production, food safety, and animal health and welfare even intensified the discussion further.

The efforts of the European Union to come to grips with these problems initially focused on limiting farm inputs and production quantities, and evolved in the direction of measures to alleviate the impact of agriculture on the environment and ecology. During the early stages of this crisis (at the end of the 1970s and the beginning of the 1980s), the realization occurred that agricultural development was far from sustainable and that new approaches were badly needed. New sustainable farming systems were needed that were multi-objective: integrating "new" objectives such as quality of produce and production methods, quality of the abiotic environment, landscape and nature values, agronomic sustainability, and animal welfare into the old objectives. Ever since the 1970s agricultural research has been committed to meeting these challenges, with changing approaches and methodologies (see Sect. 21.2).

Dutch agriculture is one of the most intensive in the world in terms of input per hectare, but also one of the most productive in terms of yield per hectare. The end of the 1980s constituted the high-water mark for pesticide use; the related environmental issues were numerous, especially concerning the contamination of surface and ground water. Since then parties active in different domains, such as policy, practice, and research, have made substantial efforts to alleviate these problems and prevent new problems. In the policy domain, the first crop protection plan was adopted in early 1990, with a 50% reduction in active ingredient use as an ambitious target. The adoption of this plan was followed by continuous policy attention throughout the 1990s and the first decade of this century. Section 21.2.2 focuses on this topic and describes subsequent policies, incentives, targets, and results.

In the research domain, a new methodology came to maturity: farming systems research. Integrated farming systems (IP: integrated production) were developed on a semi-farm scale as multi-objective systems addressing and dealing with the complexity of challenges and objectives of sustainable farming systems. Integrated crop protection (ICP) was an integral part of these IP systems and developed in the farm context. For the Dutch situation, the history of integrated pest management (IPM) was and is strongly entwined with integrated farming, with the development and implementation of IP systems. Section 21.2 describes the development of IP and IPM in the context of farming systems research and government policy.

The efforts to disseminate IPM into practice with pilot farm network approaches are described in Part II, Sect. 21.3. However, facing the relatively slow adoption of IPM in practice, policy and research approaches increasingly shifted towards addressing the responsibilities of the stakeholders to take a real stake in this development. Subsequently, the research methodologies had to adapt to this challenge. In fact one could argue that IPM is a niche that has difficulties growing due to the repressive character of the dominant regime (see transition literature: for instance, Geels 2001). Increasing the use of IPM in practice then would mean opening up the regime, the network of stakeholders involved in crop protection. The active engagement of these stakeholders with this regime is described in Part III, Sect. 21.4.

21.2 Part I: Setting the Scene—Developing IPM and National Crop Protection Policies

In this part the initial development of IPM is described in Sect. 21.2.1 as part of a broader process of the development of integrated farming systems. In Sect. 21.2.2 the policy framework and background of crop protection are elaborated from the start in 1990 till now.

21.2.1 The Development of the Concept of Integrated Crop Protection

Section 21.2.1.1 describes the development of IPM in the context of the development of integrated farming systems. Section 21.2.1.2 focuses on the definition and description of the IPM strategy as state of the art.

21.2.1.1 Prototyping Sustainable Farming Systems in the Netherlands

The demand for new more sustainable farming systems became apparent as soon as the extent of the crisis became clear at the end of the 1970s and the beginning of the 1980s. Farmers needed new systems that could meet a wider range of objectives (see Sect. 21.1). This demand created renewed interest in the concepts of organic farming. Another concept was developed in research cycles, the concept of integrated farming or integrated production (IP) referring to both integration of objectives and integration of methods and means instead of solely relying on agrochemicals. This approach is based on agroecological principles. The concept originated from work on integrated crop protection (ICP) on a farm scale and was developed in fruit orchards (IOBC working group; Steiner 1977). Integrated production was a logical progression from integrated crop protection, especially because ICP can only be optimally implemented in the full context of the farm, hence in an integrated farming system (Vereijken 1989). The organic and integrated systems approach rapidly gained serious interest in the international research community. The first experimental farms that started developing these systems on a semipractical scale were the Lautenbach farm in southern Germany (El Titi and Landes 1992) and the Development Farming Systems (DFS) farm in Nagele, the Netherlands, where organic and integrated farming systems were developed and compared. The research focused on increasing performance, seeking new approaches to overcome old problems and unwanted side effects. The IOBC offered this movement an international platform in a study and working group on farming systems research (since 1986: Vereijken et al. 1986, Vereijken and Royle 1989, Wijnands 2006).

The methodology of designing, testing, improving, and disseminating integrated and ecological farming systems for arable farming was developed in a four-year European Union Concerted Action (Vereijken 1994, 1995, 1996, 1998, 1999). This methodology, called prototyping, can be characterized as a synthetic research/development effort that starts off with a profile of demands (objectives) for a sustainable farming system in agronomic, environmental, and economic terms, and ends with tested, ready-to-use prototypes that can be disseminated on a large scale. In contrast, common analytical research starts with a problem or a question and generates knowledge, often through single-factorial research. Prototypes can both be tested and improved on an experimental farm, or on a group of pilot farms. The first offers more degrees of freedom, but lacks the interaction with farm management and suffers from lack of "replicates" with respect to soil, farm, and management conditions. Moreover, if the initial tests are conducted on an experimental farm, they will have to be repeated with a small group of farmers at a later point in time. However, especially when systems appear to be very experimental, a first development phase on an experimental farm is necessary because systems can be fully implemented and tested on such a farm. A more detailed analysis of the problems and challenges encountered in this interactive way of working can be found in Wijnands (1992), Wijnands et al. (1998), and El Titi (1998). From 1985 to 2000, integrated and organic farming systems were developed on experimental farms all over Western Europe (Vereijken et al. 1986, Vereijken and Royle 1989, Vereijken 1995, 1996, Hani and Vereijken 1990). During the last part of this period, substantial experience was gained with developing these prototype systems in cooperation with commercial farms: innovative pilot farms (Vereijken 1997, Wijnands 1998, El Titi 1998). Experiences were shared in the international working group of the IOBC (see, for history, Wijnands 1996).

A European-sponsored project brought together Emilio-Romagna in Italy, Valencia in Spain, Switzerland, and the Netherlands in a four-year project to develop integrated and organic vegetable farming systems (Vegineco: see Sukkel and Garcia Diaz 2002a, b; Haan and Garcia Diaz 2002a, b; Haan 2002; Hopster and Visser 2002).

In the Netherlands, prototypes of integrated arable farming systems (IFS) were developed regionally at three experimental farms with region-specific crop rotations and cropping systems. The farms are located at Nagele (1979–2004) in the central clay area, at Borgerswold (1986–1995) in the northeastern sand area and at Vredepeel (since 1989) in the southeastern sand area, the major soil types in arable farming (Wijnands and Vereijken 1992). Farming systems research expanded to the more specialized vegetable-growing sector (see Table 21.1) and to flower bulbs and the nursery sector later in the 1990s.

21.2.1.2 Integrated Crop Protection: Strategies and Methods

The IOBC defines integrated production (IP) as a concept of sustainable agriculture based on the use of natural resources and regulating mechanisms to replace potentially polluting inputs. The agronomic preventive measures and biological/physical/chemical methods are carefully selected and balanced, taking into account

Table 21.1 Overview of farming systems research in arable and vegetable crops in the Netherlands in the period 1980–2000

	Location	Soil	Period 1	Period 2	IFS	OFS	CFS	ref
1. **Prototype development on experimental farms**								
arable farming systems	Nagele	clay	1979–1990		x	x	x	1
				1991–2004	x	x	–	1
	Borgerswold	sand/peat	1986–1995		x	–	x	1
	Vredepeel	sand	1989–1992		x	x	–	1
				1993–2004	x	x	x	–
	Kompas	sand/peat		1997–2004	x	–	–	–
	Kooijenburg	sand		1997–2004	–	x	–	–
vegetable farming systems	Zwaagdijk	clay	1990–1996		x		x	2
	Breda	sand	1990–1996		x		x	2
	Meterik	sand	1990–1996		x		x	2
				1997–2004	x	x		
	Westmaas	clay	1990–1996		x		x	2
				1997–2004	x	x		
2. **Pilot farms small scale**								
integrated arable farming	38 farms	all	1990–1993		x			3,4
integrated vegetable farming	18 farms	all	1996–1998		x			–
Ecological farming	25 farms	all	1998–2001			x		–
3. **Pilot farms large scale**								
integrated arable farming	500 farms	all	1993–1995		x			–
integrated vegetable farming	75 farms	all	1999–2001		x			–

OFS organic farming system, *CFS* conventional farming system, *IFS* integrated farming system, Conventional is the average actual farm approach in the region

Ref (*1*) Wijnands and Vereijken 1992; (*2*) Sukkel et al. 1998; (*3*) Wijnands et al. 1995; (*4*) Wijnands et al. 1998

the protection of health of farmers and consumers, as well as of the environment. Emphasis is placed on a holistic systems approach involving the entire farm as the basic unit, on the central role of agroecosystems, on balanced nutrient cycles, and on the welfare of all species in animal husbandry (Boller et al. 1998, 2004).

IPM (integrated pest management) is the part of IP focusing on insect pest, disease, and weed management. The objective of IPM as a strategic approach towards crop protection is to safeguard the quality and quantity of the production while minimizing the impact of pesticide use on human health and the environment. IPM applies to noxious species of phytophagous animals, plant pathogens, and weeds. Noxious species are those causing economic losses higher than their control costs. The term IPM is internationally widely accepted although integrated crop protection would be more comprehensive.

Inasmuch as almost all aspects of the management of a crop, or even a farm have a potential impact on the occurrence and development of insect pests, diseases, and weeds, an integral approach towards crop protection starts with taking these interactions into account. Agroecosystems are the basis for planning. The approach can also be characterized as agroecology: working with natural processes and regulatory mechanisms rather than relying on interventions alone. Just like IP, IPM takes the whole farm as its basic unit (Wijnands et al. 2012). The role of crop protection in integrated farming systems is, in addition to all the other methods, to efficiently control the residual harmful species with minimal use of well-selected pesticides. Integrated crop protection focuses on the real problems, namely the problems that remain after all other methods are designed and optimized.

The basic IPM strategy (see Table 21.2) focuses on minimizing the use and impact of pesticides. Therefore emphasis is given to preventive (indirect) measures which must be utilized to the fullest extent before direct control measures are applied (resistant varieties, cultural measures such as adapted sowing date and row spacing). Direct measures may only be taken if economically justified (decision-support systems (DSS) for a correct interpretation of the need for control: guided control systems, thresholds, signalizing systems, etc.) and the use of all available nonchemical control measures (mechanical weed control, genetic, physical, and biological control) should be part of the strategy. Pesticides are then only necessary as an additional measure. Methods with minimum use such as seed treatment, and row- or spot-wise application are preferred above full-field application. Appropriate dosages and when possible a curative approach (field- and year-specific), further reduce the input. Finally, pesticides should be carefully selected with respect to selectivity and exposure of the environment to pesticides (Wijnands 1997). All elements of the strategy should be carefully integrated in a coherent strategy to be fully effective. The different steps/elements of the strategy are described in more detail below and summarized in Table 21.2 (Wijnands et al. 2012).

- Prevention:
  - Includes the management of all those aspects that interact with crop protection from the more basic farm layout aspects (field size and shape, ecological infrastructures) over crop rotations, soil management, and fertilization to cultivar choice of crops, sowing date, and sowing density and other measures.
- Justification of direct control:
  - “Control” means management of the insect pest, disease, or weed population to maintain it below the level that causes economic losses. Decisions about the necessity to apply control measures must rely on the most advanced tools available, such as prognostic methods, monitoring techniques, scientifically verified thresholds, and decision-support systems.
- Control:
  - Direct plant protection may be used if otherwise economically unacceptable losses cannot be prevented by indirect means.
  - Preference is given to all forms of nonchemical control measures (biological, physical, etc.).

Table 21.2 Principles of IPM. Strategic objectives and management (Wijnands et al. 2012)

Principle	Explanation	Strategic Objectives	Management
1. Prevention and/or suppression of insect pests, diseases, and weeds	The incidence and severity of most insect pests, disease, and weed problems can be greatly lowered by applying agricultural measures that favor the competitive advantage of the crops against their harmful organisms	Prevent build-up of insect pests, disease, and weed populations	Crop rotation and soil management
		Escape periods of high insect pests, disease, and weed pressure	Timing of sensitive crop stages
		Optimize crop fitness against attacks	
		Make use of resistance, tolerance, and competitive ability	Fertilizing strategies, crop management, cultivar choice, etc
		Prevent spreading insect pests, diseases, and weeds	Field hygiene and adapted agricultural practice
		Keep your agroecosystem fit by supporting functional biodiversity	Enhance and protect beneficial organisms
		Design of the complete agroecosystem	Ecological infrastructure[a]
2. Monitoring of pest organisms and applying of economic damage thresholds	Assessing the necessity of intervention (control) based on knowledge about the real situation and the potential of losses leads to more targeted interventions	Know the insect pests, diseases, and weeds	Identify the sitespecific key pests, diseases, and weeds that require regular interventions
		Know the beneficial organisms	Identify site-specific key beneficial organisms
		Monitor insect pest, disease, and weed incidence:	Use monitoring traps and crop inspection Use intervention thresholds
		Define action threshold levels Define early warning systems	Forecasting models for pest and disease incidence, decision-support systems
3. Nonchemical control methods	Many interventions with pesticides can be replaced or supported by nonchemical alternatives	Optimize interference with insect pests, disease, and weed biology:	Mating disruption, sterile insect technique Use of biopesticides
		Use physical interference:	Crop covers such as nets, exclusion fences, mechanical weed control

Table 21.2 (continued)

Principle	Explanation	Strategic Objectives	Management
4. Chemical control methods	Pesticides chosen with minimum side effects and with minimal interference with preventive and nonchemical control methods	Select pesticides specifically targeted to harmful organisms and with minimal side effects, protect your allies (beneficial organisms)	Classify pesticides according to toxicity, ecotox etc., special emphasis on protection of key beneficial organisms
			Establish transparent criteria of preferred and less preferred pesticides
		Optimize application technique and timing	Use well-maintained and calibrated spraying equipment operated by trained persons
		Optimize the dosage of pesticide	Use weather and efficacy forecasts when available to optimize timing and dosage
			Consider row or spot applications
		Prevent development of resistance	Anti-resistance strategies based on sequence or combinations of active ingredients and alternation with other IPM methods
			Adapt application rates and frequencies
		Check efficacy	Small untreated areas, (zero treatment or “spray windows”)
5. Nonpermitted methods	Some interventions (mostly chemical) might be prohibited in IPM approaches because they interfere with the agroecosystem in a way that prevents sustainability	Avoid chemical soil disinfection	Soil health management (rotation, cultivar choice, crop choice, etc.)

[a] Utilization of ecological infrastructures inside and outside production sites to enhance supportive conservation biological control of key pests by antagonists

  - Pesticides may be used and integrated in the IPM strategy; however, they must be carefully selected based on their properties with respect to their impact on the environment, ecology, and human health. Detrimental effects on disease, insect pest, and weed antagonists must be avoided. Use should be minimized by reduced doses, reduced application frequency or partial applications, taking into account the risk for development of resistance in populations of harmful organisms.
  - Some control methods or pesticides may be banned for a specific IPM scheme.

Two aspects deserve special attention, the diversity of the farm ecosystem and the farmer himself.

- Biological diversity:
  - Includes diversity at the genetic, species, and ecosystem levels. It is the backbone of ecosystem stability, natural regulation factors, and landscape quality. Replacement of pesticides by factors of natural regulation cannot sufficiently be achieved without adequate biological diversity. Stable agroecosystems in which flora and fauna are diversified provide important ecological services to the farmer covered by the term "functional biodiversity".
- The farmer:
  - Plays a key role in IP systems and in IPM. His or her insight, motivation, and professional capability to fulfill the requirements of modern sustainable agriculture are intimately linked to his or her professional skills acquired and updated by regular training.

21.2.2 Government Policy on Integrated Crop Protection

In this section the government policy on crop protection is highlighted and the actions and results described. For the Dutch policy we distinguish two periods: the 1990s (Sect. 21.2.2.1 and 21.2.2.2) and the 2000s (Sect. 21.2.2.3 and 21.2.2.4).

21.2.2.1 The 1990s: The Multiannum Crop Protection Plan

In the 1980s the Netherlands had the highest pesticide use (measured in kg active substance per ha) in the world. Problems with water pollution and residues in drinking water enhanced the awareness that crop protection was running out of control. Nutrient use and emissions were also increasingly becoming a problem. In response to these problems, the government in The Netherlands adopted a policy of restructuring and sanitation of the national agriculture (Anonymous 1990).

- In arable farming and outdoor horticulture, the pesticide inputs had to be strongly reduced (50 % in 2000 compared to 1985–1988 in terms of kg active ingredients) and mobile and persistent pesticides were to be removed from the list of registered pesticides (Multi-Year Crop Protection Plan (MYCPP); Anonymous 1991). Integrated crop protection was to become the norm for crop protection. The gov-

Table 21.3 Short summary of crop protection policy objectives, actions, and results in the 1990s and the first decade of the new millennium in the Netherlands (after Buurma and Lamine 2008)

Period	1991–2000	2001–2010
Policy framework	Multi-Year Crop Protection Plan	Sustainable Crop Protection (Covenant Crop Protection)
The objectives	50 % volume reduction and 50–90 % emission reduction in 2000 compared to 1984–1988 Decreasing structural dependency	95 % impact reduction in 2010 compared to 1998
The actions	Restrictions on soil disinfection Phasing-out pesticides that cannot comply with stricter criteria Support development of IPM. Pilot farm networks	(Small: from 25–150 cm depending on crop) buffer zones/better nozzles Introduction safe pesticides Innovation and dissemination of IPM. Pilot farm networks
The results	49 % volume reduction 54–79 % emission reduction	2010: 86 % impact reduction (calculated) Still 50 % exceedances of pesticide threshold norm in surface water measurements

ernment was very encouraged by the initial results and potential of integrated crop protection applied in the context of the development of IAFS (Vereijken 1989; see Sect. 21.2.2.). The MYCPP had three targets (see also Table 21.3):

1. Volume reduction (50 % in terms of kg active ingredients).
2. Decreasing structural dependency, increased use of integrated crop protection methods and approaches, development of nonchemical alternatives.
3. Emission reduction (50–90 %) to soil, surface and groundwater, and air.

- The government simultaneously launched nutrient policies: The volatilization of ammonia had to be reduced significantly (70 % in 2000 compared to 1985) as well as N- and P-emissions into the North Sea (70 % in 2000 compared to 1985). Additionally, quality criteria for N and P in surface (2.2 mg N/l and 0.15 mg P/l) and groundwater (11.2 mg $N\text{-}NO_3^-$/l) were set. The use of organic manure was restricted in dosage (P-norm), timing, and application techniques. Legislation including levies on surpluses on nutrient balance sheets was implemented to restrict nitrate leaching to the groundwater and P-accumulation in the soil.

Consequently, the agricultural industry in the Netherlands had to adopt the quality of the environment as a major objective and integrate it with the conventional objectives of income and employment around 1990. The government considered such integrated farming systems as the best way to achieve a competitive, sustainable, and safe agriculture. By 2000, 100 % of farmers had to practice integrated farming (Anonymous 1991).

21.2.2.2 The 1990s: Actions and Results

The government supported their MYCPP policy plan with strong restrictions on the use of soil disinfection agents, for example, nematicides (only once in five years), and a fair attempt to restrict or even ban the use of the most polluting substances. This attempt was not very successful; the government was confronted with a large number of lawsuits from pesticide manufacturers as well as from the opposite side, the environmental NGOs, notably SNM and Milieudefensie. It appeared that the legal basis was not robust enough to restrict or even ban certain compounds. Dutch policymakers spent most of the 1990s trying to "repair" the legal basis for stricter pesticide approval and sanitation policy.

The development of ICP and IPM was supported by directing the focus of agricultural research towards the development of integrated farming systems and ICP/IPM approaches and methods. Through the intensive interaction between these two approaches, strong progress was made in the breadth and width of the portfolio of available techniques. In a national pilot farm network for arable farming the results of Integrated Arable Farming Systems from the experimental farms were tested in real-life situations on 38 farms all over the Netherlands (see Sect. 21.3.1.1)

The greater part of the targets for volume reduction and emission reduction were met. An overall volume reduction of 49 % was realized, thanks to an impressive (and higher than targeted) reduction in nematicides (85 %), which used to have a big share in total pesticide volume. The restriction of its use to once per five years led to an intensification of monitoring the populations and an increased use of resistant cultivars specific to the population present. However, the use of fungicides did not decrease; it even increased in the 1990s; the use concentrated in potatoes (*Phytophthora infestans*), flower bulbs (*Botrytis spp.*), and fruit (*Venturia spp.*). The diseases in question require repeated preventive sprays in short intervals. During the 1990s the aggressive *Phytophthora* type A2 was introduced leading to even stricter (shorter intervals) spraying schemes. In all cases there were no resistant or tolerant cultivars available.

The emission reduction amounted to 54 % for emission to the air, 79 % for emission to groundwater, and 79 % for emission to surface water (de Nie 2002). Yet, during the evaluation that was conducted at the end of the 1990s (Ekkes et al. 2001) the parties involved already foresaw that, even with a full implementation of the instruments from this policy period, the strict water quality criteria set by policy plans for national environment and water quality would not be met.

The government also concluded that farmers did not optimally comply with the rules regarding application of pesticides. This partially explained the recurring incidents in which residue norms and water quality criteria were exceeded. The MYCPP did also not manage to realize a paradigm shift in the approach towards crop protection. The dependency on pesticides remained the same.

During the MYCPP period the conviction grew that pesticide use in itself was not the problem; the impact of pesticide emissions to different compartments (air, groundwater, surface water) of the environment had to be reduced. Combined with the experiences from the previous period, this formed the basis of a new policy in the first decade of the twentieth century.

21.2.2.3 The 2000s: Sustainable Crop Protection

Around the year 2000, when renewal of the crop protection policy was on the agenda, the prevailing question that remained was how to further reduce the use and impact of pesticides in the coming period. In 2001, the government indicated that they believed all farms should practice integrated farming and that these efforts should be certified (Anonymous 2001). To obtain certification, farms would have to demonstrate and prove that they follow a certain approach towards ICP and take additional measures to control drift. Their efforts were to be monitored through random checks on mandatory self-assessment. New to this approach was that the government addressed the individual responsibility of the farmer. The main objective of the policy was to effectuate a strong reduction in the use and impact of pesticides and to improve compliance with the rules and regulations regarding pesticide use.

The policy proved to be one bridge too far; the approach was not successful and the certification idea died in the cradle. Certification demands for produce through international demands of retailers were introduced later. Moreover, the potential disturbance of the international level playing field created tensions, which led to a decrease in support for the policy from the (farming) community. The remaining impasse even decreased the likelihood that the objectives would be realized. New rounds of talks and reorientation of the policy eventually led to a new sustainable crop protection policy that proved to be far more successful over the next six years: the Sustainable Crop Protection Plan (Anonymous 2004).

The new approach took the shared responsibility of society, the farming industry, and the government as a point of departure. The pesticide problem could be not be solved by any of these groups individually. The government also addressed consumers in this plan, who could demonstrate what they wanted through their choices in the market. The government decided to form a coalition to attain the crop protection goals. This resulted in the so-called "Covenant Sustainable Crop Protection" (2003). This covenant was signed by farmers, companies in the chemical industry, water companies, and water boards. Initially the NGO SNM also participated, but they abandoned the covenant on sustainable crop protection when it became clear that the government would not implement an obligatory scheme for integrated crop protection. The covenant addressed each party's role and responsibility.

The targets from the earlier policies were maintained: the environmental impact reduction target remained at 95 % for 2010 compared to the year 1998. The impact reduction was defined as (1) 95 % less impact on surface water quality; (2) 95 % reduction in pesticide problems in the production of drinking water from surface water. In addition, a target of 50 % reduction in exceedances of the maximum residue limits (MRL) in agricultural products was formulated. The reference periods for the three goals were respectively 1998, 1998, and 2003.

21.2.2.4 The 2000s: Sustainable Crop Protection, Actions and Results

The main action lines distinguished in the Sustainable Crop Protection Plan were:

- Optimizing compliance and synergy between Dutch and EU approval procedures/criteria and environmental policies.
- Stimulating innovation and specifically adoption of IPM in practice (research/communication, role for every partner in the covenant).

Table 21.4 Matrix illustrating the results of the crop protection policy of the first decade of the new millennium in the Netherlands (van Eerdt et al. 2012)

Objective	Indicator	Trend—In Policy Period	Objective Achieved?
Ecological quality	Ecological quality surface water	Cannot be determined	No
	Environmental pressure on surface water due to agriculture	Large improvement	No
Drinking water quality	Problems related to drinking water quality	Large improvement is likely	No
Food safety	Exceedances of maximally permitted residue levels in food	Large improvement	Yes
Safe working conditions	Risk inventory and evaluation	Slight improvement	No
Maintaining economic prospects	Economic prospects (in relation to this policy)	Unchanged	Yes

The network Farming with Future (FwF) was started in this policy line (see Sect. 21.3.2), in addition to the continuation of research on elements of IPM. FwF worked closely together with the different partners of the covenant.

- Stimulating sustainable production chains, products, and consumer choices.
- Creating conditions for a sustainable and effective package of pesticides, eventually allowing temporal exceptions.

An important precondition for these objectives was the wish that Dutch agriculture could maintain a competitive international position. Changing coalitions of the covenant partners undertook actions along different lines. Several important elements for environmental impact reduction, such as the obligatory buffer zones and the obliged use of low spray drift equipment, had already been implemented a few years earlier. The sanitation policy for pesticides, which was first used in the Netherlands in the early 1990s and was used throughout the European Union at the beginning of the new millennium, became the most efficient tool for counteracting problems. On top of that, the industry introduced new pesticides with better environmental performance (less leachable and persistent, lower ecotox) that also greatly contributed towards attaining environmental impact reduction goals.

The policy period from 2004 to 2010 was thoroughly evaluated (van Eerdt et al. 2012). Over this period Dutch crop protection had become safer for both humans and the environment. Fewer pesticide residues were found in food products and surface water quality had improved (see Table 21.4). The target to maintain the competitive position of Dutch agriculture and horticulture had been achieved (Schoorlemmer and Spruijt 2011).

Despite these improvements, policy targets on surface water and occupational safety were not met (see Table 21.4). Voluntary measures and mandatory regulations saw to it that growers substantially reduced ecological risks to surface waters, but there was insufficient compliance with such regulations. This is one of the reasons why concentrations of pesticides in surface waters were often found to exceed statutory standards.

21.2.2.5 The 2010s: Sustainable Crop Protection, National Action Plan in EU Context

At the end of the last policy period it became clear that the quest for more adoption of ICP/IPM in agriculture was becoming an EU-wide issue by the drafting of the Directive 2009/128/EC on sustainable pesticide use (SUD 2009). The Dutch policy resulted in substantial progress; nevertheless the remaining water quality problems were still manifold. The problem proved to be persistent.

Improvements might be achieved by addressing the most-polluting substances. Continuation of existing policies—in combination with more attention for reducing emissions of substances that cause the greatest problems—can help to improve surface water quality substantially in the short term. For the long term, the focus could be on investments in larger system innovations, and in less-polluting substances and nonchemical methods, such as the use of biological control, which can be defined as the reduction in population densities of harmful organisms by exploiting one or more natural enemies of those organisms.

In 2012–2013 a national action plan was drawn up pursuant to Directive 2009/128/EC on sustainable pesticide use. The action plan describes sustainable plant protection policy in the Netherlands for The 2013–2018 period (Anonymous 2013).

21.3 Part II: Farming Systems—Prototyping and Pilot Farm Networks

In Part II the approaches and projects are described that aimed at the broader introduction of IPM in practice. Section 21.3.1 limits itself to the 1990s. Part III describes how approaches substantially changed during the 2000s. Sections 21.3.2 and 21.4.1 deal with the 2000s.

21.3.1 The 1990s: IPM Dissemination as Part of Integrated Arable Farming Systems

In this section the efforts to introduce IPM to the farming community are described, again in the Dutch situation in the context of integrated production. The pilot farm networks and their results of the 1990s are described in Sect. 21.3.1.1 and 21.3.1.2. In Sect. 21.3.1.3 the wider communication is described. The section ends with a reflection and outlook (Sect. 21.3.1.4).

21.3.1.1 Pilot Farm Network 1990–1993

To introduce, test, and evaluate integrated farming systems for arable farming in practice, a cooperative research project of the agricultural extension service and several research institutes was started in 1990. From 1990 till 1993, 38 pilot farms gradually converted to Integrated Production (IP). The goal of the project was to provide farmers with all necessary knowledge and guidance to ensure that they would not be hampered during implementation of new techniques. Therefore they were intensively supported by extension specialists who were specially trained for this task. The extensionists, in turn, were guided and backed up by research. An additional research program focused on quantifying farm data on different topics. In order to evaluate the approach, all farm data were recorded, analyzed, and evaluated. In order to obtain sufficient diversity of soil, farm, and management conditions, five regional groups of about eight farms each were selected in the major arable production areas in the Netherlands (Wijnands 1992). The farmers regularly met either in winter meetings to discuss results, exchange experiences, and develop plans for the next season or in summerfield excursions on each other's farms focused on field practices.

21.3.1.2 Results of the Pilot Farm Network

The conversion of the pilot farms to integrated farming was successful. Knowledge on how to adapt the experimental farm IFS prototypes to region- and farm-specific conditions was gained. A cropping guideline book could be published (Van Bon et al. 1994). The IFS approach resulted in considerable reductions (up to 70 % in comparison to farm-specific preproject references) in the input of pesticides (kg active ingredient/ha) and restored the balance in P in- and output. With respect to N, the surpluses on the nutrient balance sheet were decreased; however, the potential losses for N leaching were probably not adequately controlled. On average, the pilot farms met the crop protection policy targets for the year 2000 (an overall 50 % reduction in active ingredient input of pesticides; Anonymous 1991) for all categories of pesticides by 1993. In a number of regions and for some categories, these targets were even exceeded substantially. The IAFS approach had no negative influence on the profitability of the farms (Wijnands et al. 1995, Janssens et al. 1998).

The farmers experienced the IFS approach as a more crop-oriented way of farming that was clearly more challenging for their professional skills. The comments of the farmers indicate that the shift to IFS is a gradual learning process. The expertise needed for adopting IFS techniques was not always available in the beginning. The required management skills could only be learned though practical experience. The project gave the farmers the opportunity to experiment with new practices under the guidance of the extension worker. While testing and implementing IFS on their farm their expertise and craftsmanship increased. By increasing their knowledge and practical experience, farmers gained confidence in the IFS approach, which reduced the initial risk inherent in the adoption of new technology and new cropping strategies. As a result of this participatory learning process, the farmers elaborated the vision of sustainable farming, developed expertise in IFS, and gained the craftsmanship to apply it. The final individual farm strategies were specific for farm scale, soil type, and crops grown. All farmers signaled an increased labor demand for total farm management and operations. Apart from the amount of time required for learning, some of this extra time may be structural, especially with respect to planning and management tasks and field operations. A postproject assessment six years after the project ended revealed that most farmers were still practicing integrated farming and had become active ambassadors for the approach, participating in follow-up projects and regional activities around sustainable farming (Nieuwenhuize et al. 2001). Some of them converted to organic farming.

21.3.1.3 Communication: Study Groups and General Communication

Parallel to the pilot farm network, an intensive communication strategy was set up and applied to familiarize the agricultural community (extension, education, and farming industries) with integrated farming. The strategy consisted of a mixture of different approaches to create opportunities for the farming community to experience, meet, and read about integrated farming. The approaches included on-farm demonstrations, study groups, open gate days, and farmers' press articles, training of farmers, and training of extension officers. In the period 1992–1994, about 50 % of the Dutch extension service advisers working for arable farming were trained on IP. During the last year of the pilot farm network, a large-scale study group approach was initiated to disseminate the new methods and possibilities on an even larger scale. In the new project called Arable Farming 2000, 500 farmers participated from 1993 to 1995 (Anonymous 1992). Potato companies participated in this project. Their own fieldmen, trained for IP, guided their study groups. Other projects followed, for example the "star" project with 400 participants in the north of the Netherlands. Those projects were mainly financed by the government and by farmers' organizations. Their objective was to facilitate the change towards integrated farming methods, especially for crop protection and fertilization, in order to be able to reach the government's policy targets in these areas. The dynamics of these projects and dozens of others were instrumental for the introduction of IP and IPM in practice. Through extensive training resulting in the dissemination of information, integrated farming became a well-known concept in the farming community.

21.3.1.4 Reflection and Outlook

The chosen development model to develop IP systems on experimental farms proved to be fruitful and efficient. The experimental farms developed prototypes that offered sufficient perspectives for farmers. The pilot farm network was the practical test for the new approaches. Knowledge and experience was gained on how to apply the new strategies under varying conditions. This new knowledge then was communicated through a range of different approaches and through different media.

For the vegetable sector (outdoor) the same strategy was followed: with the start of a pilot farm network in 1996 (Sukkel et al. 1998), and a larger scale effort in 1999 (see Table 21.1). Other sectors followed at a later point in time, with efforts on experimental farms to develop new approaches, among other things to innovate crop protection strategies inspired by the IPM concept. Follow-up projects also involved farms in practice.

The Dutch model in the 1990s to develop and introduce IP was characterized by a strong government policy with clearly formulated objectives. Research organizations had a central role in the development of the prototypes. The "support" of farmers'organizations gave a framework for sustainable development. The top-down incentives were adequately supported by an interactive, bottom-up approach of implementation for these new systems. Farmers should be able to determine their own way to reach the, it is hoped, "common" objectives.

However, large-scale adoption of the new approaches was never realized. The most competitive and easy-to-handle elements of IP were adopted, but full strategies were rarely adopted. This is partly due to the lack of incentives from the market (no IP segment or premium position) and partly due to the absence of interest from the agrochemical advisory network to promote approaches that led to reduced use of pesticides. As a result, the problems with environmental quality persisted and even increased in certain areas. Nutrient emissions were becoming a particularly big issue in the EU-context (policy directives on N and water quality). The ministries of environment and agriculture therefore initiated a new large-scale program (Action Plan Nitrate Projects: 1998–2008) for research on minimizing nutrient losses on the farm and the interaction and communication with the common practices around 2000. This offered the opportunity for a second round of experimental development of new prototypes on experimental farms and for parallel testing and development of the systems on farms in a pilot farm network. This new approach is described in the next section.

21.3.2 The 2000s: IPM Dissemination, Pilot Farm Networks and Stakeholder Participation

In this section we describe the development of IP and IPM in the 2000s, as performed by the national project FwF. This project had three phases. The first phase, during which research simultaneously focused on experimental farms and on a pilot farm network, is described in Sect. 21.3.2.1. The second and third phases of FwF were based on another approach to help increase the use of IPM in practice. The division between these two approaches is marked by the transition to Part III. The change in approach is described in Sect. 21.4.1. In Sect. 21.4.2 we explain the set-up of the network, followed by Phase 2 and 3.

21.3.2.1 Farming with Future Phase 1: New Round of Prototyping

As described at the end of Sect. 21.3 (Sect. 21.3.1.4), the new N-projects framework initiated by the government around the year 2000 offered the opportunity to start the FwF project that encompassed both farming system research on experimental farms and a pilot farm network. The project dealt with arable, vegetable, nursery, and bulb crops (de Buck et al. 2000). The premise of the project was that through focused development of systems that can fulfill future demands with respect to environmental criteria and the interaction with practical farms, the implementation in practice could be accelerated.

The project ran in this set-up from 2000 to 2003, with 33 pilot farms and 4 experimental farms. The targets were extensively described (de Buck et al. 2000) and the project resulted in numerous publications (some 40 reports on different aspects of the farming system).

The project contributed to better insights in the nutrient dynamics of P and N in a farming system. In terms of integrated crop protection, the project focused on making progress in the reduction of use and impact. Only slight progress was made in terms of use, and in some cases the number of pesticide applications increased (low dose approaches). This can partially be attributed to the effect of scale enlargement of the farms in practice, which hampers mechanical weed control and reduces the willingness to monitor insect pest and diseases intensively on a parcel-to-parcel basis, but mainly it is due to the fact that the basic strategies for IPM were already developed in earlier projects, and the improvements that could be realized in research proved to be only incremental. More progress was made in terms of reducing impact by strongly focusing on substituting the pesticides with the worst environmental and ecological profiles. This approach called EEP, environmental exposure to pesticides (Wijnands 1997), is based on the published properties of the pesticides available (approved) in practice.

In 2003, at the end of the first four-year period of FwF, the state of the art in IPM methods and IPM adoption in practice was evaluated/assessed. It was clear that, in spite of substantial efforts in research and communication, the impact of the adoption of IPM measures was too low to contribute substantially to alleviate environmental problems. The main reason was the general lack of active support from the major stakeholders: manufacturers and traders of pesticides, suppliers, collecting industry, and even the farmer’s organizations.

21.4 Part III: The Adoption Challenge—Or the Stakeholder Conundrum

This conclusion was the point of departure for rethinking policy and research strategies. How could resources be put into action more effectively? And which concepts and models would optimize the chance that IPM would be adopted in the field? A design was made through interaction between research and policy for the next period of FwF. This is described in the last part of this chapter. The approaches and experiences of this last period of eight years seamlessly connect to the current European situation and discussion, thus we therefore describe this period in more detail.

The baseline analysis and the major hypotheses/assumptions of the new design are treated in Sect. 21.4.1. In Sections 21.4.3 and 21.4.4 the road test and dissemination of new knowledge is described, and Sect. 21.4.5 focuses on stakeholder management. Section 21.4.6 focuses on the results and Sect. 21.4.7 contains the final discussion.

21.4.1 Changing Approaches to the Adoption Challenge

When looking back over the last 25 years, it is clear that not only in the Netherlands, but all over Europe and the world, substantial research efforts were undertaken to work on the different elements of a more integrated crop protection approach, notably the prevention aspects, the need of control verification and control methods without pesticides, or with limited impact of its applications. Many of these methods are, with some exceptions such as the pheromone techniques for codling moth (*Cydia pomonella*) in orchards, insufficiently utilized in practice (Thomson et al. 2009). The practical approach largely remains unchanged, building mainly upon the input of pesticides, albeit on a much more rational base than 20 years ago. There seems to be no real incentive for farmers to adopt sustainable approaches. Recently (the last five years), the retailers' quest for products with low residue levels contributed to a change in approaches, although in practice it provoked keener use of pesticides rather than a reduced one. The fact is that the main reduction of the impact on surface water in the Netherlands has been achieved through obligatory crop-free zones, restrictions on spraying equipment, and the sanitation of authorized pesticides (MNP 2006).

This poses the questions of how the current approach towards crop protection in practice might be changed, how integrated crop protection can become the basis for crop protection in practice, and how the remaining environmental quality problems can be solved and new problems prevented.

FwF and the ministry formulated a general hypothesis at the end of 2003: active involvement of stakeholders is needed to attain a breakthrough in the way of working on the adoption challenge. There are many organizations, both in the private and public sector, with stakes in the crop protection business either as manufacturer, trader, and user or as other organizations having to deal with (on a different scale of governance, water boards, drinking water companies) the emerging problems surrounding sustainable crop protection. All the involved parties and their mutual relations are referred to here as the crop protection system. The stakeholders are influential when it comes to farmers' practices. They have many opportunities to contribute to sustainability; however, they only use a limited part of their virtual resources. In the crop protection system other interests are often more prevalent than sustainability.

An additional and entwined aspect is the "status" of the new IPM knowledge itself. Knowledge created in a research setting is mostly handed down/over for dissemination with traditional methods. This "cold" selling of knowledge seems to be one of the reasons for the laborious introduction of new IPM knowledge in practice. Because we already had experience with interactive knowledge development with farmers, we extended this notion to the hypothesis that new knowledge will be accepted better in practice if this knowledge is co-developed with farmers, advisors, and related stakeholders in a practical setting. At the onset of the project in 2004 (see Sect. 21.3.1.1 for a description) we therefore had two related working hypotheses:

1. First, that the introduction and implementation of new sustainable crop protection methods in practice can be substantially ameliorated by an approach in which new knowledge is developed and disseminated in practice jointly with all relevant stakeholders in a so-called road test.

2. Second, that sustainability in crop protection becomes a real perspective and not a utopian idea when stakeholders see sustainability as part of their responsibility and start using their professional potential to contribute to the realization of it (see also Box 21.1). The project uses the stakeholder management methodology to act on this premise.

Box 21.1 Stakeholders in Crop Protection: Interests and Perspectives

Stakeholders are in the position to influence the attitude and behavior of farmers, either directly because they are farmyard visitors such as advisors and commercial employees from suppliers and/or collecting industries, or indirectly because they deal and communicate with the agricultural sector and put the wider market and societal context into perspective. Think of the water boards and the NGOs, for example. In questionnaires, advisors are often cited as most important source of reliable information for farmers, followed by colleagues and farmers' journals.

Moreover, all stakeholders have at least a partial interest in the developed technologies, depending on their core business and their mission. Water boards have an interest in promoting emission-reducing techniques and methods that substitute polluting pesticides with other means of crop protection. Farmers' unions are interested in technical and economic benefits that derive from the new methods. Pesticide traders and suppliers are not interested in the promotion of mechanical weed control, but might well be interested in new pesticide technology, new application techniques, or new decision-support systems. See also Table 21.5 for an overview of stakeholders and their interests.

It is obvious that stakeholders all can contribute towards the desired process of sustainability in crop protection. They can convince farmers of the usefulness and the need for sustainability and they can recommend good practices. Stakeholders directly or indirectly determine the preconditions needed to attain sustainability (laws, regulations, collaboration methods, and how problems should be tackled, etc.) both today and in the future. Together they form the "regime" in the crop protection system. Regime is a term taken from transition theory (Geels 2001, Rotmans et al. 2001) and it represents the entire system of institutions, their networks, relationships, and procedures. Together they "determine" the culture, how things are done, and what the dominant procedures are: the written and unwritten rules. It is characteristic for the transition in agriculture that traditional values and certainties in the regime are disappearing. Under the influence of new issues and themes such as socially accountable entrepreneurship and sustainability, stakeholders in the regime are searching for a new interpretation of their changing roles and relationships. FwF wants to facilitate the stakeholder's quest and wants to promote any opportunity to stimulate the utilization of sustainable practices in the field.

Table 21.5 Overview of major stakeholders in the crop protection network and their interests

Major stakeholders	Interests
Water boards and drinking water companies	Safeguarding water quality: clean surface water, no contamination with pesticides above well-defined thresholds
Farmers' organizations	Minimize costs: low cost strategies: economic interests of their members
	Limit restrictions for the farmer as entrepreneur
	Maintain availability of a broad package of crop protection chemicals
	Sustain quality and quantity of production; robust production.
	Corporate social responsibility
	Complying with increasing market demands for more sustainable produce
Pesticide traders	Maintain availability of a broad package of crop-protection chemicals. Solutions for their customers
Pesticide manufacturers	Maintain market position: careful use of their products, good product stewardship, avoiding problems with ecology, environment, and human health prolongs their longevity
	Corporate social responsibility
Governments	Minimize impact of pesticide use on public health, biodiversity, etc
	Stimulate IPM adoption
Markets	Certify (sustainable) production/cropping standards: market-driven, upgrade performance of farms
	Reduce public/consumers' concern and risks
NGOs	Reduce use and impact of pesticides

21.4.2 The Farming with Future Project, Phase 2 and 3: National Network to Support Broad Adoption of IPM

FwF phase 2 and 3 was a national project that ran from 2004–2010 and was executed by Wageningen UR and DLV Plant (advisory organization). It was financed by the Ministry of Environment and the Ministry of Agriculture, Nature and Food Quality. The project was an important instrument for one of the action lines of the Covenant Sustainable Crop Protection, namely to stimulate innovation and knowledge circulation on integrated crop protection (see Sect. 21.2.2.4).

The objective of the project was to stimulate the application of integrated crop protection in all plant production sectors in the Netherlands, ranging from glasshouses over bulb and nursery trees to vegetables, fruit, and arable crops, thus contributing to sustainable crop protection.

For every sector, the project provided a dedicated team consisting of researchers and advisors who proactively engaged stakeholders in the quest for more sustainability in crop protection. Over 25 professionals worked together in the FwF team. The core activities were testing and improving selected new methods and techniques, knowledge dissemination, organizing and facilitating problem solving, coalitions around specific problems and stakeholder management aimed at the enrollment of the stakeholders. Enrollment is the term for the process in which stakeholders decide to take more and more responsibility for their contribution to sustainability. The approaches are explained in detail in Sect. 21.4.5.

In the first period of the project, from 2003 until 2007, the best practices were road tested in cooperation with 35 study groups of farmers, distributed across all sectors with more than 400 participants. Stakeholders were actively involved in testing new solutions. In 2008, the approach changed because fixed groups did not offer enough flexibility to select an optimal approach per best practice. From 2008 onwards, the project worked with changing coalitions of partners (including farmers), depending on the best practice that was tested.

21.4.3 Testing and Developing New Knowledge in Everyday Farming Practice

This section deals with the first hypothesis of the FwF project for Phase 2 and 3, namely that IPM adoption in practice can substantially be ameliorated by an approach in which new knowledge is developed and disseminated in practice together with all relevant stakeholders. Section 21.4.2.1 describes how the agenda for this new knowledge was set. Section 21.4.2.2 describes how the road test of new knowledge is conducted. In Sect. 21.4.3 the cooperation with stakeholders in knowledge dissemination is described.

21.4.3.1 Setting the Agenda for the Road Test of Promising New Technology

At the onset of FwF phase 2 the Dutch ministry of agriculture envisioned and developed a “production” chain of new crop protection methods with FwF. The chain starts with regular, basic, and applied research. The approach selects best practices, promising methods in terms of potential to become feasible and effective applications in practice. Best practices are integrated crop protection measures that are not yet used in practice but have the potential to contribute to a reduction in environmental impact. They arise, in general, from current or finished research. These promising methods then were to be road tested, developed further towards practical application in a practical setting involving all stakeholders.

Best practices can become good practices. The term “good practices” can be defined as effective and feasible measures that can be widely used in the field. A best practice only becomes a good practice if it is attainable for 70–80 % of all growers. The good practices are then communicated together with all relevant stakeholders.

The best practices were selected from all on-going research. Farmers’ organizations and researchers compiled the shortlist in workshops per sector (every two years 2004, 2006, and 2009). These lists were published in standardized formats, both on paper and on the Internet. The list of best practices involved totally new principles, new routines, new biological control agents, new decision-support systems (DSS),

Table 21.6 Examples of best practices road tested in 2009

Crop group	Best practices
Arable crops	Precision agriculture, biomass sensing on the sprayer to determine dosage of herbicides when defoliating potato crop before harvest, control strategies for diseases in cereals and carrot, weed control in maize and DSS for *Thrips* in onion and leaf mould in sugar beet
Vegetables	Strawberries: control of *Phytophthora*, testing Trianum (new biological agent), biological soil disinfection, ridge cropping. Also DSS for *Stemphyllium* in asparagus in decision-support systems and DSS for *Thrips tabaci* in leek with attractants (odors)
Flower bulbs	Methods to control emission of pesticides, monitoring systems for quality of plant material, control of specific problem weeds, and carbon filter to minimize emission of pesticides used in storage
Nursery trees	Mechanical weed control, methods to control emission of pesticides, integrated control of mites in ornamental crops
Fruit	Emission control (venturi nozzles), integrated control of codling moth and fruit tree canker
Greenhouse crops	Focused on new emission-reducing techniques in total production process as well as substrate crops and systems with soil

but also adjustments to existing routines, as for instance, for mechanical weed control equipment, or adjustments in existing DSS, and so on. Not all best practices are revolutionary inventions; they are mostly clever new techniques (see Table 21.6). FwF was the national project that focused on the road test of the selected best practices and the subsequent dissemination with full participation of stakeholders.

21.4.3.2 Road Testing: Involving Different Expertise, Farmers, and Stakeholders

FwF stimulated and initiated the collaboration among researchers, advisors, entrepreneurs, and others for the road test. It brought different professional skills and expertise together, confronting the formal knowledge of the researchers with the more tacit knowledge of the entrepreneurs. The context of a real farm added extra scrutiny to the test when it came to feasibility and practicability. The extensive experience advisors had with the practice of crop protection under a wide range of varying farm and management conditions added a sort of preview (ex-ante test) for the practical application.

FwF tried to find the right mixture of stakeholders and farmers for every best practice. The project itself naturally brought advisors and researchers to the test. It was important that the involved parties were motivated and committed to the test. New and often temporary coalitions were formed among agribusiness, water boards, suppliers, machine manufacturers, entrepreneurs, and other groups of stakeholders. The tests and demonstrations were done on one or a number of farms in practice, or in some cases on the experimental farms of Wageningen UR. The test period varied from 1–3 years. FwF had the overall lead in this process.

The “recipe” for the eventual resulting good practices was easy to write thanks to the practice test. The resulting good practices were robust, feasible, and ready for use. This process can be described as “knowledge co-creation,” referring to the process of sharing, applying, and developing knowledge in an interactive process, among stakeholders, practitioners, and scientists, usually within heterogeneous groups (see also Regeer and Bunders 2009).

21.4.4 Knowledge Dissemination by and with Stakeholders

In this section it is argued and demonstrated that communication with full involvement of all relevant stakeholders is both effective (Sect. 21.4.4.1) and efficient (Sect. 21.4.4.2).

21.4.4.1 Effective

FwF focused on involving stakeholders in the road test and the subsequent dissemination and communication of the feasible and effective road tested technology, because stakeholders are in the position to influence the attitude and behavior of farmers, as described in Box 21.1. Moreover, they have the professional skills to contribute to finding new solutions.

When stakeholders disseminate knowledge in their professional capacity either through direct contacts or in meetings organized by them or their magazines, it puts knowledge in the perspective of the business relation with the farmers. It thus enhances relevance of the knowledge. It also creates the opportunity to advocate the new methods or highlight them as contributing to the desired development of sustainability. Whenever new approaches and methods are put in the wider context of why they are needed, the communication will have more impact. The stakeholder can create more impact by clearly stating the new direction and the strategy to be followed. The stakeholder can clarify and point out that the new approaches are needed as part of an overall strategy to address the challenges. The more this is the case the more effective the communication will be in terms of influence on the farmers’ behavior.

One of the current problems is that farmers receive very mixed signals from their partners and surroundings, based on the different ways that their partners handle their interests. If the common interest of sustainability were more important, the messages would converge more. And if different stakeholders advocated the same new methods and techniques, knowledge dissemination would be more effective. The more stakeholders have the same message, especially in terms of urgency and strategy, the more powerful the communication will be.

The “trick” for FwF was to get stakeholders engaged, involved, and to let them work together with other stakeholders in fitting coalitions per tested new technology.

21.4.4.2 Efficient

Knowledge dissemination by or together with stakeholders is not only more efficient in terms of utilizing resources, but also in terms of money and manpower and in terms of optimal use of all available means of communication. Stakeholders have a significant impact on sustainable ways of working, because they are part of the everyday production chain.

Efficient here is used in the sense of the cost-effective approach. Traditional linear push-based communication is restricted to a few methods, such as giving presentations and executing demonstrations. Although cooperation with stakeholders on different occasions required extra resources, people were reached in a more meaningful way.

Together with relevant stakeholders across all sectors, FwF organized hundreds of activities to disseminate and communicate knowledge on sustainable crop protection. Activities varied from articles in journals to demonstrations, workshops, manifestations, and so on. These activities sometimes resulted in surprising coalitions, such as producers of pesticides working together with water boards. Thousands of entrepreneurs were reached by these activities every year.

21.4.5 Stakeholder Management Mobilizes Stakeholders

In this section we focus on the second hypothesis of Phase 2 and 3 of FwF, namely that strong involvement of stakeholders is necessary to realize more sustainability in crop protection. The project uses the stakeholder management methodology to act on this premise. The approach is described in this section starting with the dialogue with stakeholders, connecting interests and new perspectives (Sect. 21.4.5.1) and a description of the process and the final aim: the enrollment of stakeholders (Sect. 21.4.5.2).

21.4.5.1 The Dialogue, Connecting Interests and New Perspectives

The crop protection system contains a large number of different stakeholders (Table 21.5), each of them with their own interests and preferred ways to handle their interest. They all have their own perspective on the challenges in crop protection, the possible solutions, and their role in it and contribution to it. The network of key players often is referred to as the regime (transition literature). The regime determines how things are done and dealt with, resulting in the dominant practices that become routines.

In the current crop protection system other interests often prevail over the sustainability issues. The interests of the stakeholder can be described and structured using an interest ladder approach (hierarchical organized list of key interests and description, in analogy with the participation ladder; Arnstein 1969). The challenge is to get the sustainability issues higher on the ladder of interest of the stakeholders. Without the active involvement of the stakeholders in crop protection the intended sustainability in crop protection will not be realized. Only when stakeholders develop and gain a perspective on sustainability that relies on their own individual responsibility, can stakeholders be mobilized to contribute to the intended change. Stakeholder management aims to do just this (see Box 21.2 for methodological aspects).

The stakeholder managers of FwF established contact with the most important stakeholders in the crop protection network in the region and sector where they are active. This approach started in 2004; by 2008 the network of contacts amounted to more than 200 separate organizations. FwF was accepted as an informed partner with excellent expertise in the field of crop protection. The stakeholder manager informed the stakeholders about the objectives of the project and the goal of contributing to the sustainability of crop protection.

The stakeholder manager continued throughout the project to show his personal commitment to sustainability and explicitly gave attention to it as the driver for the goal of the project. He communicated what sustainability meant in various forms, but also gave attention to un-sustainable situations based on evidence. In the dialogue the stakeholder manager invited the stakeholders to elicit how they felt about sustainability, what it meant to them, how they contributed to it and how it was embedded in their business. Thus through the dialogue he gained insight into their outlook on sustainability and the way the stakeholder acts on it. In the dialogue the stakeholders will often at first only show what their position on the topic is. The stakeholder manager has to dig deeper to find underlying interests. It is important to explore the underlying interests because a stakeholder manager has to align the interest of the intended change with the interests of the stakeholder.

The dialogue proved to offer an excellent starting point for the exploration of possible collaborations. Many points of interest that offered opportunities for further action usually emerge during these talks, and are elaborated on later. In most cases it is helpful to keep the management funnel in mind (see Fig. 21.1). In any bi- or multi-lateral process of finding solutions for a specific challenge that suits the different stakeholders, it is often relatively easy to agree on a problem, or an objective, especially when the time horizon is mid or long term. It is often much harder to agree on solutions and operational choices. Most conflicts arise around solutions. Solutions have to fit all sorts of criteria that stakeholders have. The stakeholder manager has to acquire all possible information on the criteria. The better criteria are known, the more likely a solution can be arrived at that fulfill the criteria. An interest can be looked after or be acted upon in different ways. Stakeholders usually have a preferred response.

The stakeholder manager is responsible for showing the stakeholder that there are more ways to respond. She can show this better if she knows what is at stake and what criteria have to be fulfilled for the particular stakeholder. To work with this possible variation in response, but still in line with the criteria helps the stakeholder manager with finding scenarios in which several stakeholders can work together.

The approach described above can help to connect the deliverables, the interests of the intended change, and those of the stakeholder. Do not forget, they are

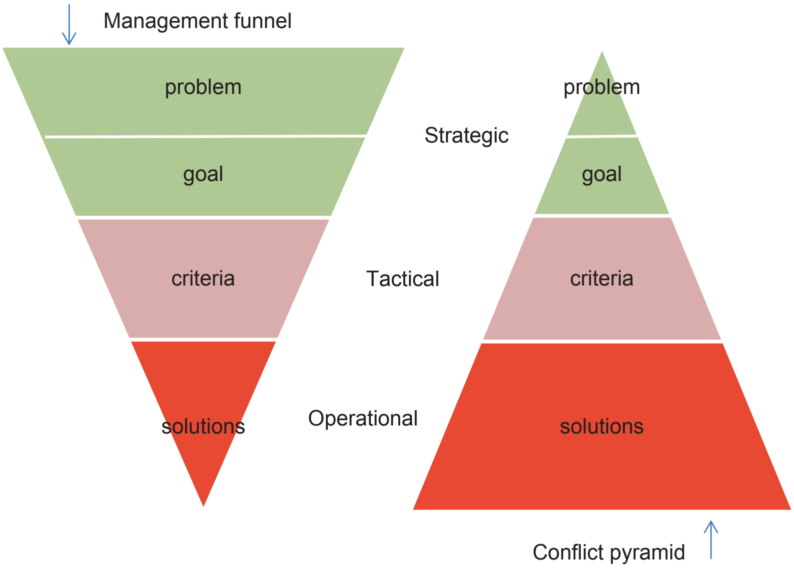

Fig. 21.1 Management funnel and conflict pyramid (after Vandendriessche and Clement 2006)

stakeholders, and thus the outcome of the change is not leaving them indifferent, because eventually it will affect them too. Connecting these interests is easier when the stakeholder starts reflecting on his role and position. New perspectives help sustainability creep up the ladder of his interests, finding new coalition partners in the interests on the ladder. See Sect. 24.4.1.

21.4.5.2 Stakeholder Enrollment, Taking Responsibility

Stakeholder enrollment is the terminology for the gradual process in which stakeholders take responsibility for the change process. The stakeholder management in FwF aims at just this! After the initial dialogue, an intensive period of work starts for the stakeholder manager. Finding ways to contribute to the intended change, finding ways to connect the interest of change and that of the stakeholder, is a search process that requires hard work. How responsibility for sustainability can be substantiated over time in actions was obviously not immediately clear to every stakeholder. It was an exploration in which they found out which activities fit their business and which activities did not. Moreover, what fits usually changes over time (see also Sect. 21.4.5.1 about criteria). Fortunately, stakeholders could, in the context of the FwF project, experiment with new behavior and new actions on a relatively small scale. Stakeholders could build up experience with new ways of acting, facilitated by the stakeholder managers. This lowered the initial threshold for action. Stakeholder management can be seen as a guided exploration of new options, innovative ways of working that encompass a sustainable future of crop protection.

The stakeholder managers of FwF stimulated enrollment in several ways:

1. By exerting continuous pressure on stakeholders to take positions to explain themselves, to explore what can be done, to react to others, by showing and communicating what others do, by involving them in multilateral talks, and the like.
2. By ensuring that the stakeholder takes position in the change (from liberty of choice to responsibility of choice; see Box 21.2). Stakeholders have a stake in the change; they cannot stay indifferent. Stakeholder management is a way to conquer this indifference. Again, the best way to do this is to connect the change with the interests of the stakeholders.
3. By consulting the stakeholders continuously about their ideas, their experiences, and their knowledge and expertise in the field of crop protection to help them decide how to proceed.
4. By involving stakeholders in a multilateral problem-solving setting, for example, with respect to water quality problems.
5. By committing the stakeholders to the development of new crop protection practices and the dissemination of that new knowledge.

Stakeholder management used in a well-defined project like FwF, in a clearly defined area and in a confined period of time, functions as a pressure cooker. The intended change is put on the agenda. The continuous attention given to the intended change, the continuous pressure and publicity create the preconditions for the stakeholders to reflect on their position, how they deal with sustainability, and what it means for them, and so on. Stakeholders are invited to show their cards on sustainable crop protection and interests are discussed out in the open, resulting in more people taking responsibility for their actions around sustainable solutions. This lowered the threshold for applying good practices.

Specifically, the necessity to repeatedly and explicitly explain what the stakeholder does to bring sustainability further and the confrontation with other interests and perspectives stimulates reflection on a deeper level. The confrontation with other interests in heterogeneous groups, the common exploration of perspectives on problems and solutions, stimulates stakeholders to re-evaluate what the stakes are and how to deal with them, what sustainability means for the organization and how they act on it. Experimenting with new ways of action also helps and strengthens the learning process (Argyris and Schön, 1996). This approach works better if the addressed problems are more specific and concrete. In FwF we have seen that the confrontation of different interests often leads to surprising opportunities for individual and coordinated actions (Fig. 21.2).

Enrollment grows when the reflection of stakeholders on their role leads them to a different view of their interests, committing to the responsibility for change. This is the basis for a change in behavior. The newfound values have to find a way into the entire organization, which can take some time and deserves much attention. During the collaborate phase the stakeholder managers help in this respect, based on the questions of the stakeholders (see Box 21.2). Finally, the newfound attitude and behavior have to be transferred to the partners and find a new institutional equilibrium/embedment. The FwF project formally ended although, in terms of stakeholder management, the collaborate phase was just beginning to develop.

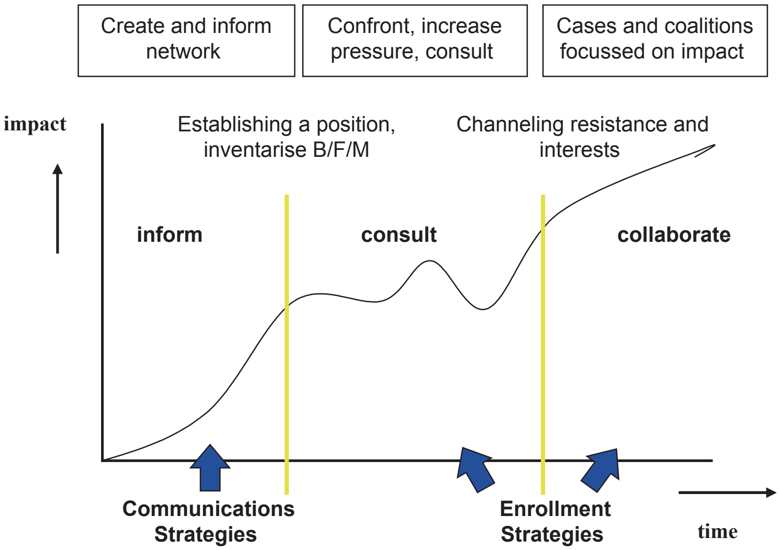

Fig. 21.2 The stakeholder management process in three phases with some characteristics B/F/M stands for respectively Blockers, Floaters and Movers, see text Box 21.2

Box 21.2 Stakeholder Management

Stakeholder management is a methodical approach to initiate and facilitate processes of change by effectively influencing stakeholders to act on their interest in line with a well-defined intended change target. The term "stakeholder" is used in connection to the intended change (Donaldson and Preston 1995). A stakeholder is a person who has a vested interest in the outcome of the intended change yet to be implemented. Stakeholder management is not open ended; ultimately it is the outcome of the change process that counts for every stakeholder (Freeman 1984). The term "management" is not used in terms of control, but rather in terms of organizing, initiating, stimulating, and facilitating. Stakeholder management is divided in three phases: the inform, the consult, and the collaborate phase.

Inform phase:

- In the inform phase the stakeholder manager communicates to all stakeholders the need to change and the change objectives, in our case, sustainability in crop protection. The final target of the intended change gives direction. Stakeholders determine what the stakes are, how they interfere with their interests, and what their position in relation to this target/goal should be. From this moment on the stakeholder manager obtains a perspective on the interests of the stakeholders by assessing their attitude and behavior towards a sustainable way of working.

- It is important to know which of the stakeholders supports the goals and is willing to do something (movers), which ones postpone taking a position (floaters), and which ones oppose the change because they have an opposite and therefore conflicting interest regarding the change targets (blockers).
- The stakeholder manager maps the position of the stakeholders and their interests in a network and stakeholder analysis. It is essential to know the position of the stakeholders and to re-evaluate it regularly inasmuch as that position can and will change. The attitude towards the objective determines the possibilities for action for the stakeholder manager and the sequence of actions in time. He needs to understand the force field around the intended change to be able to influence a successful process.
- The stakeholder manager starts working with the movers to initiate new actions towards the change in search of a leading coalition.

Consult phase:

- In this phase the stakeholder manager consults the stakeholders about the change and their contribution. She uses three basic principles to influence stakeholders, namely exerting pressure to become active by using confrontation, providing insight in the problems and possible solutions, and tempting stakeholders to become involved by stressing the need for their unique contribution (see also Cialdini 2001). The final aim is to encourage stakeholders to re-evaluate their position and interests and stimulate them to become involved.
- In this phase, the stakeholder manager and the movers produce breakthrough solutions and modes of actions, and movers are encouraged to find new feasible ways to contribute to the intended change.
- New activities are initiated, during which stakeholders could gain experience in their new role: what fits and what does not, what they can do, and what do they want to do. The stakeholder manager is everywhere and always present; he is facilitator, broker, and accelerator at the same time.
- The blockers are specifically addressed and confronted in this phase. Their cooperation is needed to ensure a sustainable change. Without their cooperation they can sabotage the change. Moreover, their objections have to be dealt with to strengthen the solutions of the movers.

Collaborate phase:

- In this phase the elaborated scenarios and products of fruitful collaborations are introduced to effect the change.
- The consult phase produces a new sustainable way of working that fits the everyday reality of the stakeholders.
- In the collaborate phase the stakeholders take over the responsibility for the change; it becomes their change. The role of the stakeholder manager therefore changes. She retreats to a more supportive role to coach the

enrolled stakeholders in their activities to embed the change in their organizations and to introduce it in their network.
- The stakeholder manager keeps working on the embedment of the change in the institutional networks. The stakeholder manager conducts activities in consultation with the stakeholders.
- In this last phase floaters will follow what now has become the general trend, accepted by movers and some blockers who changed their position and became movers who allow the new way of working to be implemented. The new order invites them to contribute.

The stakeholder manager guides the stakeholders through the three phases from what could be called "the liberty of choice to the responsibility of choice." The intended change is necessary; stakeholders have interests that are linked to the change. The change cannot be realized without their professional input and support. During the course of the process towards the intended change it is no longer possible to be indifferent, to watch from the sideline. The stakeholder has to get involved or at least make a conscious decision on their role and position. In the process, coordinated forms of action evolve from the elaborated scenarios into feasible ways to contribute to the intended change in a coordinated manner in line with their own interests.

Stakeholder enrollment is the name for the process in which the stakeholders become problem owners of the change process. An enrolled stakeholder has a positive attitude towards the change, sees a role for his organization and works hard to find feasible ways to contribute to the change by his actions and by influencing others in his network to also become involved. It is important to note that enrolled stakeholders realize their own version of the change, not the personal solution of the stakeholder manager. This ensures that the new way of working will last, because it is linked to their everyday reality.

The stakeholder manager uses the above-described methodical approach towards facilitating change. The stakeholder manager is committed to the change and has a personal drive to contribute to it. In addition to project management skills he or she also needs excellent process management skills.

21.4.6 Results Farming with Future 2004–2010

In this section the results of the project are discussed.

21.4.6.1 Evaluation Scheme: Activities and Results

The key activities of FwF were designed to primarily focus on and accelerate the development of new knowledge relevant for IPM, and increase the adoption in prac-

Table 21.7 Main results farming with future (2004–2010)

Output	Best practices: 100 tested methods, 80 good practices, described, which were made available and actively communicated in many ways
	Dialogue stakeholders: initially more than 200 separate contacts resulted in regular contact and common activities with more than 100 of them on a regional or national scale
	Knowledge sharing/communication: hundreds of activities, reaching thousands of farmers
Outcome	Change in behavior and attitude of stakeholders
	More open dialogue between them, more coalitions, more actions
Impact	Increasing application of good practices in practice
	Less problems in the areas with water-coalitions

tice, building upon the two hypotheses that road tested knowledge with the involvement of stakeholders' help and that stakeholder involvement increases the adoption rate (see Sect. 21.4.1). In short:

- Contributing expertise to the biannual selection and subsequent description of best practices (see Sect. 21.4.3.1)
- Arranging and conducting the road test (set-up, partners, experimental design)
- Stakeholder analysis of the network, prioritizing the parties to be engaged
- Informing the selected group of stakeholders, engaging them in dialogue, actively using stakeholder management methodology to enroll them
- Initiating, facilitating, and participating in communication and dissemination activities by the stakeholder partners of FwF

The results of FwF are described here using the "input–output/outcome–impact" typology (see also logic model theory, McLaughlin and Jordan 1999). The output refers to simple countable products and activities. Outcome refers to the first effects of that output. Impact refers to the way in which the outcome finally results in changes of end effects. For example, FwF publishes new good practices (output), leading to more application in practice (outcome), leading to an improvement of, for instance, water quality (impact). The results of FwF are described in this manner in Table 21.7. In the next three sections we elaborate on these aspects.

21.4.6.2 Output

The **output** of FwF could fairly easy be documented: the activities undertaken and the products made. Some details on the three main aspects are:

- *Road test*: In the period from 2003 until 2010 more than 100 best practices were road tested. Around 80 of them have grown into robust good practices; others were impeded by obstructions (work load, risk, implementation, etc.) and need further development in research and/or in the field. The successful good practices were documented in a series of flyers. Not all best practices could be transformed into a good practice. Some techniques proved to be too challenging, too labor intensive, or not practical enough. They were handed back to the research institutions for a possible makeover and other adjustments. Some methods were very feasible, but were not viable in economic terms, or at least not at the moment. These techniques were shelved, but might be used in the future. Some mechanical control methods may, for instance, become a very attractive alternative due to the ever-decreasing availability of herbicides for smaller crops.

The judgment whether a technique or a method is a best or good practice was done by extension specialists from FwF in dialogue with the agricultural organizations.

- *Network*: The network of stakeholders was established from 2004 on and intensified in the period 2008–2010. By 2008, the network of contacts amounted to more than 200 separate organizations. On a national level the management team of the project had regular meetings with national organizations of the most relevant stakeholders (water boards, traders, manufacturers, and farmers' organizations).
- *Communication*: Together with relevant stakeholders across all sectors, FwF organized hundreds of activities to disseminate and communicate knowledge on the good practices in sustainable crop protection, with activities varying from articles in journals to demonstrations, workshops, manifestations, and the like. These activities reached thousands of famers.

21.4.6.3 Outcome

The **outcome** was harder to establish. Two outcomes were targeted by the project: the change in attitude and behavior of stakeholders and the increased adoption in practice of the good practice. Both cannot easily be documented.

- *Stakeholder behavior and attitude*: We reported to the steering committee twice per year. We not only documented all our activities, but also recorded all contacts with the stakeholders and their progression. Documenting all FwF activities that were used as a platform for the communication on IPM/ICP and the good practices offered a good insight as to the extent to which stakeholders engaged. We summarized our observations for every stakeholder group. This was checked against the informed view of the stakeholder representatives themselves in the steering committee. This gave the necessary feedback and fixed the state of the art.

  From the analysis of the change in behavior and attitude, it became apparent that in every stakeholder group individual organizations and companies were changing their attitudes and behavior. They increasingly deployed new initiatives to address sustainability. In many cases they asked the project FwF to assist them, for instance, by providing relevant knowledge or facilities.

  At the end of the project we asked the different teams in FwF (dealing with different crop groups) to select a handful of developments in their stakeholder network of which they were proud, to nominate successes. We used a fixed format to describe the success, what the success was, what were the drivers, how was it was realized, who was involved, what did they do, and how FwF was connected to this. One could call this subjective, and yes it is, but by describing and analyzing the progression as logical steps with the involvement of FwF, it became clear whether the relation with FwF was profound and robust.

- *Adoption rate of good practices*: The degree to which the good practices as developed by FwF (and remember they are all documented, what best practices were selected for the road test and what the outcome was) were used in the field and evaluated annually. The annual evaluation was an expert judgment conducted through deliberation between our extension specialist and the advisors from the pesticide trade companies and the agricultural organizations. All good practices were sorted into three categories: less than 30 %, between 30 % and 80 %, or more than 80 %. We used this distinction to focus our actions. If the adoption rate was higher than 80 % no additional action was needed in terms of dissemination. If the rate was between 30–80 % then focused attention was needed to increase adoption, and if the rate was less than 30 %, additional action would be considered. The annual evaluation shows that the use of good practices in practice (the application degree) was increasing over the years. The majority of the good practices shifted from the bottom category to the middle category and only a few to the highest level.

21.4.6.4 Impact

Impact is difficult to assess and can only be measured in specified cases where high levels of control are established on the project conditions.

- We worked on improvement of water quality in two regions on a limited regional scale, in close cooperation with the water boards and other stakeholders. An accompanying monitoring and research program was set up to be able to monitor progress. All relevant stakeholders were involved in a platform, and the process of joint fact-finding was facilitated. They acknowledged the problem, discussed how their interests could best be served, and developed scenarios for a common approach to solving the problem. This approach delivered excellent results in terms of awareness, a changing attitude and behavior of stakeholders, and results in a decrease of water quality (monitored).
- As far as the impact of increased use of good practices is concerned: it is a premise of FwF that a higher degree of application would contribute to the objectives of the project, sustainable crop protection.

21.4.6.5 Reflection on the Job

FwF is not a linear project in the sense that specified actions yield specified results. The outcome of the project is uncertain and dependent on many aspects that are not under the control of the project itself. Therefore an open minded reflection on the state of the art was continuously necessary along the way to find or design the best possible next steps. FwF was supported in this process in a number of specific cases by a monitor, an expert in monitoring and evaluation processes. In FwF we used the Reflexive Process Monitoring approach (van Mierlo et al. 2010). The reflexive approach helps to keep the project activities focused on addressing the key issues for sustainability. Moreover, it supports the "social learning" approach by giving direction to activities and approaches that stimulate learning processes on different levels. These monitoring approaches helped us to support decisions on the best possible next step in the process and helped to evaluate the process and result over a longer period.

21.4.7 Reflection and Outlook

21.4.7.1 Concerning Knowledge Development

The chosen approach for knowledge development and dissemination in the FwF project appears to be effective. The project functions as a transfer point for promising knowledge on sustainable crop protection methods and supports stakeholders in transforming their ambitions into concrete activities. One could also use the term knowledge circulation or co-creation to refer to this process of sharing, applying, and developing knowledge further in an interactive process usually within heterogeneous groups. An important aspect within knowledge circulation is the interchange of scientific and tacit knowledge found within the different parties involved (Mode-2 approach, Gibbons et al. 1994).

This approach has clearly contributed to a new élan and new dynamics in the knowledge flow from research into practice, a knowledge flow that in recent years gained in breadth (more actors involved) and in focus (on sustainability and solving problems).

21.4.7.2 Concerning Stakeholder Management

Project managers, facilitators, process managers, consultants, and others who work as change agents, increasingly use the words "stakeholder management" to describe their activities. This accentuates that they are consciously dealing with the interests and agendas of different stakeholders. These approaches are mostly used to create common ground for change, often used in the corporate world (Evan and Freeman 1993, Donaldson and Preston 1995, Clarkson 1998, Goodijk 2001).

The stakeholder management method described here is more extensive. It is a powerful instrument for facilitating change in the regime as part of the transition process, an approach for complex transition problems in the public domain with involvement of many different stakeholders, both public and private in the interface between public and private interests. Stakeholder management draws from and builds upon social science knowledge and uses best practices as developed over the last years in practice. The systematic approach does not stop with creating a common basis, but aims to create new movement in a network of stakeholders, by organizing a critical mass who want to get involved in the intended change, after which this leading coalition will, over time, successfully influence the other stakeholders.

Stakeholder management initiates, stimulates, facilitates, and supports the process of stakeholders to take responsibility for the intended change and to act on it based on their interests and perspectives. The portfolio of activities will change over time, as will the way the stakeholders deal with each other in their networks. Stakeholder management works best when different stakeholders with different interests are connected to each other through a professional network (Andriof et al. 2003). Key elements of a successful network approach are working with heterogeneous groups of stakeholders and unlikely coalitions (to provide spontaneous, mostly novel, perspectives on a challenge or problem); the development of mutual trust and social cohesion (openness, honesty, transparency); a communal perspective for the future (ownership); and good process management (facilitation utilizing a range of creative work methods and inspiring environments for joint learning; Wals 2007; Loeber 2003). This forms the basis for an increasing congruency in the actions, in increasing coordination. Stakeholders can and will act in their interests, however, by the dialogue with others these actions become more congruent with a common understanding of the solutions to be realized (congruency; see also Grin and van de Graaf 1996),

Stakeholder management is perfect for dealing with immaterial interests such as sustainability. The stakeholder manager appeals to others to commit to the higher aim of these immaterial interests (more value driven). The issue of sustainability as such is a key issue for the development of agriculture.

One aspect deserves to be singled out here with respect to the work ethics and belief of the stakeholder manager herself.

- First of all, the stakeholder manager has to be self-consciousness with regard to her role. The stakeholder manager has to realize that he or she has no formal power to superimpose the change; she knows that she has to mobilize the current key players, the existing regime. She also knows that she has to retract and change her role once the change is in the collaborate phase and the stakeholders take over.
- Second, the stakeholder manager has to realize that the stakeholders together hold the key to the sustainability of crop protection for the future. They will have to use their professionalism to realize sustainability. And the stakeholder manager has to realize that he can only begin to imagine what can be achieved when the stakeholders choose sustainability and start acting on it. Like one of the stakeholders of FwF, a mover, once said, “If everyone (he meant all involved parties) would have the will to do what they can do, then we could take substantial steps towards more sustainability.” From the experience with FwF it became very clear that when stakeholders get involved in the change and do what they can do, results follow. Those results inspire others to get involved or do more.

21.4.7.3 The Adoption Challenge and the Stakeholder Conundrum, Some Answers

Even 80 years after the introduction of chemicals in agriculture and 50 years after Rachel Carson's *Silent Spring* (Carson 1962), reducing the use and impact of pesticides still remains a challenge (Sustainable Use Directive European Union, SUD 2009). Every European country has to produce National Action Plans to operationalize the general objective. IPM is the norm, but it is still not widely used. There are more feasible and effective IPM methods developed in research than applied in practice. This problem, this void between knowledge and application, referred to as the adoption challenge, was discussed at an international OECD meeting in Berlin in 2010 (OECD 2012). There the overriding tendency was to attribute this lack of adoption to the complexity of IPM methods, the increased risk perception of IPM by farmers, and the associated higher labor demand (perceived). Surprisingly, the arguments used in the analysis did not change over 25 years' time; see the Vereijken article "From IPM to IP" (Vereijken 1989). The answers that were formulated can be classified as "doing more of the same," more research, more extension.

The hypothesis of the authors of this chapter, however, as already addressed in FwF is that it is mostly a question of lack of engagement and involvement on the part of the stakeholders. They have the power to change reality and to contribute substantially to sustainability. This issue was already addressed in the reflection in the last section. It is "simply" a question of taking responsibility and learning to operate in a network with coordinated actions, focusing on congruency (Grin and van de Graaf 1996).

A supplementary and brief analysis of the incentives for adoption demonstrates our hypothesis. Based on the IPM experience of the IOBC and listening to all presented case studies at the OECD meeting, the following four groups of incentives can be distinguished:

1. *Financial/technical—individual famers*. Crop protection issues on the farm are better solved by IPM (technical result and/or financial result). When the benefits are clear, new methods find a fast track to implementation and almost no additional dissemination will be necessary. Then also initial feelings of risk (related to the end result of crop production and control of pests, diseases, and weeds) when applying new technology will be overcome.
2. *Commodity—community agribusiness*. All over the world there are regions where the local economy is dependent on one commodity. Recurring, unsolvable, or increasing problems affecting quality and quantity of production will have negative effects on all involved. In these cases IPM solutions will be supported by all involved and adopted on a broad scale, as, for example, was the case for the control of sugar cane borer, *Diatraeas accharalis* with the parasitoid *Cotesia flavipes* in sugar cane production in Brazil (Bueno and Lenteren van 2002). Other examples have shown that, when different economic pillars in the same region have a negative interaction due to pesticide use and impact, common solutions can also be found and will be implemented (see, e.g., rice stem moth, *Chilo suppressalis,* in the Ebro estuary in Spain; Ramoneda et al. 2006)

3. *Market options and demands—individual farmers/cooperatives*. Farmers' cooperatives, or producers, can decide to distinguish their product and production by adopting or establishing supralegal requirements under a certified label. These can, and in some cases do, include advanced levels of IP (see the wine Oregon example, Wijnands et al. 2012). On the other hand, the ever-increasing demands from retailers reflected in, for instance, GLOBAL GAP, can and will eventually lead to premium segment fresh food with certified higher performance in different sustainability areas. This is an opportunity for IPM inclusion.
4. *Policy—regulation/stimulation individual famers, general or region specific*. In the EU context support for agriculture is connected with obligations on the part of the farmer. In the so-called pillar I, this concerns EU-wide obligations, in Pillar II, however, regions might implement so called agroenvironmental measures. Again, that IPM programs can be part of this has already been demonstrated in many European regions (Keenleyside et al. 2011).

These examples show that public intervention can support IPM adoption, but also confirm that stakeholders are in a position to change the crop protection regime on farms. A more informed and better-designed public policy, taking these incentives into consideration, probably could increase the incentives' effectiveness.

Returning to the stakeholders. It is our conviction that they hold the key to more sustainability, and are the key to solving what we called earlier the adoption challenge: the challenge to increase substantially the adoption of IPM methods in practice. This is why we called this the stakeholder conundrum; it is a highly complicated puzzle that seems to only have a conjectural solution for most people. We, however, are convinced from what we experienced in FwF, that the puzzle can be solved to the great gain of society and that the key to the solution lies in applying the stakeholder management method as described.

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Chapter 22
Experiences with Implementation and Adoption of Integrated Pest Management Strategies in Sweden

Agneta Sundgren

Contents

Abstract Sweden has a variety of cultivation types. The most intensive cultivation is located in the southern part of the country, and in the north there is mostly grassland. The main crops are cereals (winter wheat and spring barley), oilseed, ley (cultivated grassland), sugar beet, and potatoes. The major horticultural crops are carrots, onions, iceberg lettuce, strawberries, and apples.

The first national program to reduce the risks to human health and the environment posed by the agricultural use of pesticides was introduced in 1986. Its goal was to reduce the use of pesticides by 50% of the average use in 1981–1985. In the following program, the goal was to reduce the quantities another 50%, down to 25%. The later programs have had goals concerning the reduction of risks rather

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than pesticide quantities. The current proposal for the National Action Plan is the sixth in Sweden and is written in accordance with Directive 2009/128/EC on sustainable use of pesticides.

In total, 1,765 tons active substances in pesticides were sold in 2011 in Sweden. There has been a decrease from the average of 4,528 tons sold per year over the period of 1981–1985.

Important factors that have made the reduction possible are: the transition to less hazardous pesticides, the reduction of the use of pesticides, and the introduction of special measures to protect human health and the environment. Special strategies for weed control have been adopted and the control measures for insect pests and diseases have been adjusted so only what is necessary is being applied on a year-by-year basis.

Measures that have been and are still maintained to be important in order to keep pesticide use low are: information and advisory services, mandatory training, legislation and control, and research and development.

Keywords Pesticide · Reduced pesticide use · Environment · Integrated pest management

22.1 Introduction

Sweden is a long country, comprising very different climates. It extends from the 55th to the 69th latitude. In the northern part of Sweden, the winter lasts for about seven months (i.e., the average temperature is under 0°C) and in the southern part, the winter lasts for two to three months. The average temperature in northern Sweden is −2°C and in the southern part it is +7°C. There is snow for 240 days a year in the northern part and for 30–40 days in the extreme southern part of Sweden (Adelsköld 1991).

In 2010, Swedish agriculture had 71,000 agricultural holdings with an average area of 37 ha of arable land. There has been a rapid development towards bigger holdings in recent years. The arable land area in Sweden is 2.6 million ha and the area of grazing land is 0.5 million ha (Jordbruksverket 2012a). Sweden has varying types of cultivation, with the most intensive cultivation in the southern part; more pesticide-intensive crops are cultivated in the south. In the north, there are mostly grasslands that do not need much pesticide treatment. Table 22.1 shows the most important crops with acreage and average yield in 2011. The yields differ greatly between the southern and northern part of the country.

Cereals and ley (cultivated grassland) are the dominant crops. Oilseed production is located in the south and middle of Sweden. Potatoes are grown in the entire country. Sugar beets are grown in the southern part (Jordbruksverket 2012a). Cereal production is largely dominated by wheat, as shown in Table 22.1. Winter wheat is grown mainly on the plains districts of southern and northern Götaland and Svealand. Cereals are not grown in the northern part of Sweden. The dominant

Table 22.1 Arable Land by Crops and the Average Yields in Sweden in 2011. (Source: Jordbruksverket 2012a)

Crop	Area (Thousand Hectares)	Yield (kg/ha)
Wheat	417	
winter wheat	350	5,630
spring wheat	67	3,980
Rye	24	5,290
Barley	328	4,350
Oats	181	3,940
Mixed grain	19	3,060
Triticale	24	4,460
Potatoes	28	29,130[a]
Sugar beet	40	62,900
Ley, other fodder	1,195	5,040
Oilseed (winter and spring rape, winter and spring turnip rape)	95	–
Winter rape	57	3,070

[a] Yield in table potatoes.

disease pests on wheat are leaf blotch (caused by *Septoria tritici*), yellow leaf spot (caused by *Dreschlera tritici-repensis*), and ear blight (caused by *Fusarium avenaceum)*. In some years and in some varieties, yellow rust (caused by *Puccinia stiiformis*) has become a big problem. The most important insect pest, which can cause significant problems, are grain aphids (*Sitobion avenae*). Spring barley is the second most important cereal in Sweden, and is grown all over Sweden. Important disease pests are leaf blotch (caused by *Rhynchosporium secalis*), net blotch (caused by *Drechslera teres*), brown rust (caused by *Puccinia hordei*), and powdery mildew (caused by *Erysiphe graminis*). In some years, birdcherry aphids (*Rhopalosiphum padi*) may cause problems.

Oilseed cultivation (mainly winter rape) has decreased over the last few years. Disease pests that may cause problems are sclerotinia disease (caused by *Sclerotinia sclerotiorum*) and verticillium wilt (caused by *Verticillium dahliae*). Pollen beetles (*Meligethes aenus*) can be a problem as well.

In potatoes, the worst disease pests are potato late blight (caused by *Phytophthora infestans*) and black scurf and stem canker (caused by *Rhizoctonia solani*). Sugar beets need to be treated for weed control, but can also be attacked by different fungi, such as *Cercospora* and *Aphanomyces cochlioides*. Insects that can be a problem are black bean aphids (*Aphis fabae*).

Other important crops to protect against insect pests and diseases are the horticultural crops. In Table 22.2, the main crops in horticultural production are shown.

The cultivation of vegetables is concentrated in the southern part of Sweden. Carrots are also grown on the island of Gotland and in the middle part of Sweden. Strawberries are grown in the whole country. In carrots and onions, weed problems require treatment with pesticides from day one of sowing. On carrots,

Table 22.2 Main Crops in Horticultural Production in Sweden in 2011. (Source: Jordbruksverket 2012b)

Crop	Hectares 2011	Yield (kg/ha)
Carrots	1,927	54,500
Onion	1,017	41,600
Iceberg lettuce	1,128	25,800
Strawberries	2,130	5,900
Apples	1,371	15,100
Greenhouse tomatoes and cucumbers	100	Tomatoes: 39 kg/sqm Cucumber: 44 kg/sqm

carrotfly (*Psila rosae)* and carrot psyllid (*Trioza apicalis*) are important insect pests and some fungi attack carrots during storage. In onions, downy mildew (caused by *Peronospora destructor*) is a big problem. Lettuce is attacked by many kinds of aphids and downy mildew (caused by *Bremia lactucae*). In strawberries, grey mould (caused by *Botrytis cinerea*) and powdery mildew (caused by *Sphaerotheca alchemillae*) may cause problems. In apples, apple scab (caused by *Venturia inaqualis*) and many insects may cause problems. In greenhouses, biological control is widely used against insects and the diseases that cause treatments with pesticides are mainly grey mould and powdery mildew.

22.2 History of Pesticide Action Plans

Sweden has a history of making National Action Plans about pesticides. There have been five National Action Plans dealing with pesticides in Sweden; for references see Table 22.3. The first one was written in 1986. The latest action plan was enacted for the period of 2010–2013, and was presented in August 2008 (Sundgren et al. 2008). According to Directive 2009/128/EC on sustainable use of pesticides (European Parliament 2009), a proposal for a new National Action Plan was drafted in 2012. It will become the sixth National Action Plan in Sweden. The name "National Action Plan" comes from Directive 2009/128/EC; in Sweden we used to name them programs on pesticides or plant protection products. According to Directive 2009/128/EC, all countries in the European Union have to adopt National Action Plans with the goal to reduce the risks and impacts of pesticide use on human health and the environment, which is also the aim of the entire directive.

In the first program, there was a goal of reducing the quantities of pesticides used. In later plans, reducing the quantities is still maintained as a goal, but reducing the risk became more important. The latest changes to the program include different ways of reducing the risks of pesticides. Regulations and economic incentives are combined with activities such as an extension services, information available in different channels, education, and research and development. These measures have been the emphases from the beginning.

Table 22.3 Goals in the Programs About Pesticides in Sweden. (Source: Söderberg 2008)

Period	Goal
1987–1990	50 % reduction in pesticide use by weight (baseline 1981–1985)
1991–1996	75 % reduction of quantity of pesticide use (baseline 1981–1985)
1997–2001	75 % reduction in pesticide use (baseline 1981–1985). Goals on reduced risks. The reduced risks are expressed as indicators of reduced risks to health and the environment should be bigger than the quantities used (see Section 22.3.2 for details about how to measure that)
2002–2008	Reduced risks expressed as indicators of human health and the environment
2008–2013	Reduced risks on both national and farm levels
2013–2017	A proposal of a National Action Plan to be developed with the same goals as previously

The first program on how to reduce the risks to human health and the environment as a consequence of the agricultural use of pesticides was developed as a result of a request to some Swedish authorities by the Swedish government. The Swedish Board of Agriculture developed the program together with the Swedish Environmental Protection Agency (equivalent to the U.S. EPA) and Swedish Chemicals Agency. The Swedish Board of Agriculture has been responsible for activities on reducing the use of pesticides and has also been the main coordinator of all programs.

The rationale for the first program was the decision by the Swedish government to reduce the use of agricultural pesticides by 50% in five years, between 1986 and 1990, as compared to the average use in the previous five years (1981–1985). Public concern regarding the negative effects of the use of pesticides in agriculture led to the Swedish government's decision to reduce the quantities of pesticides used. Discussions about the involvement of environmental quality in agricultural policy had already begun in 1977, when environmental factors were considered together with the efficacy of agricultural production and the supply of cheap food to consumers.

The overall goal for the first program (Emmerman 1986) was to reduce the risks to human health and the environment. The action to reduce the risks has involved some key elements:

- Phase out unacceptable pesticides (e.g., lindane, atrazine, and paraquat) and change over to pesticides that are less hazardous to health and the environment (Emmerman 1990).
- Use of comparative assessment and the precautionary principle.
- Reduction of the use of pesticides.
- Special measures to protect health and the environment, for example, mandatory training of farmers and information campaigns.
- More frequent controls of pesticide residues.

In the next program, which came about in 1991, the goal was another reduction of pesticide use by 50%, which would mean that the pesticide use per year in agriculture would be 25% of the average use per year between 1981 and 1985. In later plans, the reduction of quantities used is still maintained as a goal, but the reduction of risks to the environment and health has become more important. To reduce the quantities further has been difficult to achieve, and the later programs have stated that there must be an attempt to find a balance between the competitiveness of Swedish agriculture and the relevant Swedish Environmental Objectives,[1] such as “A Non-Toxic Environment” (Anonymous 2013a). There are 16 environmental quality objectives, adopted by the Sweden’s parliament. They cover different areas, with the goal of promising a healthy living environment to future generations. Co-operation among different Swedish authorities, farmers, industry, and scientists is one of the factors that have made the Swedish pesticide programs successful. This cooperation has guaranteed that the pesticide user information is correct, up-to-date, and that it reaches the farmer. Together, the Swedish authorities, farmers, industry and scientists have also been able to agree on the measures, giving advice and carrying out research and development.

Table 22.3 is a summary of the goals of the programs enacted in Sweden thus far. The goals set for reducing pesticide quantities by weight for the first three programs are in reference to the average value of quantities used per year for the period of 1981–1985.

22.3 Present Situation

22.3.1 Pesticide Use

The quantities of pesticides sold and used in Sweden from 1981 until 2011 are presented in Figure 22.1. The quantities sold are being reported every year, whereas the quantities used have been investigated and reported more irregularly. Between 1988 and 1992, pesticide use was investigated every year, between 1993 and 1998 it was studied every second year, and after that pesticide use was reported only in 2006 and in 2010. These infrequent observations in recent years render it difficult to deduce

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[1] “A Non-Toxic Environment is the Environmental Objective,” in Sweden has 16 stated goals to achieve concerning existing environmental problems.

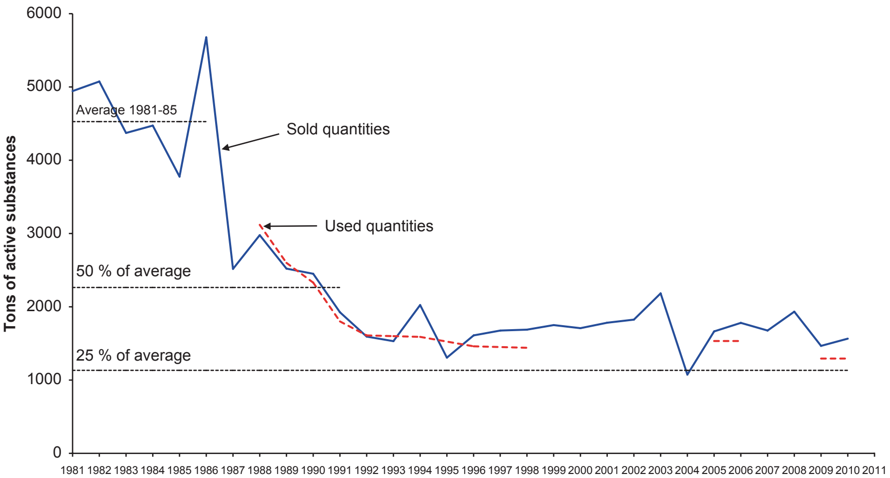

Fig. 22.1 Rate of decline of plant protection products (active ingredients) sold and used from 1981 to 2011 in Sweden. The lowest dotted line (25% of average) indicates the goal of pesticide use that the Swedish government set up in 1991. (Source: Swedish Chemicals Agency, Peter Bergkvist).

the latest trends in use for different crops. The survey on quantities of pesticides used provides more details than the survey on quantities sold. There is also a difference in the amounts sold and used. The reasons for this can be that it is hard to find information for the period between sale and use, how much pesticide is in the farmers' store, or perhaps some systematic error occurs in the collection of data. When comparing the numbers, it is the surveys of pesticide use that give more details, and they should be compared to data from the comparable surveys on use and not with the surveys on quantities sold. In some years, there have been special peaks in the quantities sold (1994 and 2004) which are caused by changes in taxes that have made farmers buy more in a particular year and stock up until the following year (Figure 22.1).

There were steep reductions in the amount of pesticides from 1986 to 1996, but since then it has been more difficult to reduce the amount sold and used. Partly, the reduction was a consequence of the use of other substances in lower doses, but it is also due to the reduction of doses for many pesticides and a change in the areas of cultivated crops. Over the last 10 years, the quantities of pesticides sold per year have been about the same, that is, around 1,800 tons active ingredients for 2011. The reduction observed in 1996 compared to the average use between 1981 and 1985 refers mainly to herbicides.

The reduction in the use of herbicides was about 1,800 tons a.i. in cereals, and that reduction came from reduced areas of cultivation (which explains 30% of the reduction), increased use of sulfonylureas as herbicides, which are efficient at much lower doses than the traditional phenoxy acids (which explains 40% of the reduction) and more adjusted and lower doses (explaining the remaining 30% of the reduction) (Emmerman and Franzén 1998). For weeds, there has also been a special strategy that explains one part of the reduction. The strategy is of a long-term nature; the level of weed seed in the agricultural fields must be kept low. In cereals, research has shown that the best yields are obtained when herbicides are used at half the recommended dose, at a 70–75% herbicidal efficacy. Test results show that it is important to use herbicides every year to keep the level of weed seed low. If other control methods (such as changed rotation) are not employed, it is best to use a low dose every year. This has been an important strategy for pesticide reduction (Emmerman 1997). For insect pests and diseases, the strategy has mainly been to adjust the control measures to what is necessary for each individual year. This has been achieved by different measures, such as giving advice on the right time to spray and information on how to control the insect pests and diseases and learning more about how to prevent them.

When studying the latest statistics for plant protection products from 2010, Sandberg (2011) found that 0.74 kg of active ingredients were applied per ha on average. The largest part of this figure comprises the use of herbicides, which made up about 75% of the active substance used (per hectare, 0.56 kg of active ingredients). Concerning fungicides and insecticides, the variation in quantities over the years is large, because the quantities used are strongly correlated with weather conditions. The use per ha is greater in professional horticulture, potatoes, and sugar beets than in traditional agricultural crops such as cereals and oilseed. Fungicide use averaged 0.37 kg active ingredients per ha and insecticides 0.04 kg active ingredients per ha in 2010. Most of the fungicides were used in cereals, but when the figure is converted to display use per ha, potatoes emerge as the crop that is most treated. Even apples are treated with quite a lot of fungicides, but the cultivated area is very small. Concerning insecticides, spring rape is the most heavily treated crop.

Pesticide use in some important crops in 2010 are shown in Table 22.4. When compared to the previous survey from 2006, the total quantities used have increased but the arable land treated with pesticides has also increased, which makes the dose per ha decrease from 0.75 kg a.i. in 2006 to 0.74 kg a.i. in 2010. Of the total quantity of pesticides used, herbicides in cereals make up the biggest part. The dose per ha has decreased by 20%, however, from 2006 through 2010, probably because the use of low-dose herbicides is still widespread. The crop that receives the most treatment is sugar beet, where the dose per ha has increased since 2006 due to changes in herbicides. In this case, the change has been towards herbicides that need to be used in higher doses. Potato is also a crop where the dose per ha is high. Here, the quantities used per ha have decreased due to fungicides that can be used in lower doses. There has also been much effort to adjust the control of potato late blight to necessary application timing and dose through decision-support systems. Table 22.4 shows pesticide use in some important crops in Sweden in 2010 as kg active ingredient (a.i.) per ha.

22.3.2 Environmental and Health Risks

The Swedish University of Agricultural Sciences has been monitoring concentrations of pesticides in water. There has been a reduction of pesticide concentrations in water (Nanos et al. 2012).

Table 22.4 Pesticide Use in Some Important Crops in Sweden in 2010. (Source: Sandberg 2011)

Crop	Pesticide Use a.i. (kg/ha)
Wheat	
Winter wheat	0.61
Spring wheat	0.40
Rye	1.25
Barley	
Winter barley	0.77
Spring barley	0.45
Oats	0.33
Mixed grain	0.53
Triticale	0.49
Table potatoes	3.41
Sugar beet	3.79
Ley, other fodder	0.37
Winter rape	0.95
Spring rape	0.46
Carrots	2.50
Onion	5.73
Strawberries	5.75
Apples	5.94

Evaluating the environmental and health risks is difficult, but there is an attempt to standardize measurements of risks known as the PRI Nation[2] (Pesticide Risk Index; Bergkvist 2004). Data on hazard and exposure are scored and combined with data on the intensity of pesticide use. These scores consist of a value for environmental impact and one for its impact on health. There is a national environmental monitoring program for agricultural land and air. The environmental monitoring program is comprised of surveys of plant protection products found in surface water, groundwater, rainwater, and sediments. Figure 22.2 shows the outcome of regular analysis in a part of Sweden where advice has been given to the farmers. The advice has included information on where to fill and clean spraying equipment, how to store pesticides, and the inspection of spray equipment (Andersson et al. 2012). The combination of regular observations and giving advice to the farmers concerning the handling of pesticides has been successful in reducing the concentrations of pesticides found in water.

22.3.3 *Old Spraying Equipment but Well-Protected Users and Safe Handling*

Many of pesticide sprayers are old and not sufficiently provided with equipment to make them work easier and safer. The latest survey on the use of plant protection products (Sandberg 2011), shows that the sprayers are better in many ways compared to the earlier survey. It concludes that 55% of the sprayers are more than 10 years old, but the equipment on the sprayers better than previously reported.

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[2] Pesticide Risk Index Nation is the use index for the whole country. There is also a PRI Farm that would be an index for only one farm.

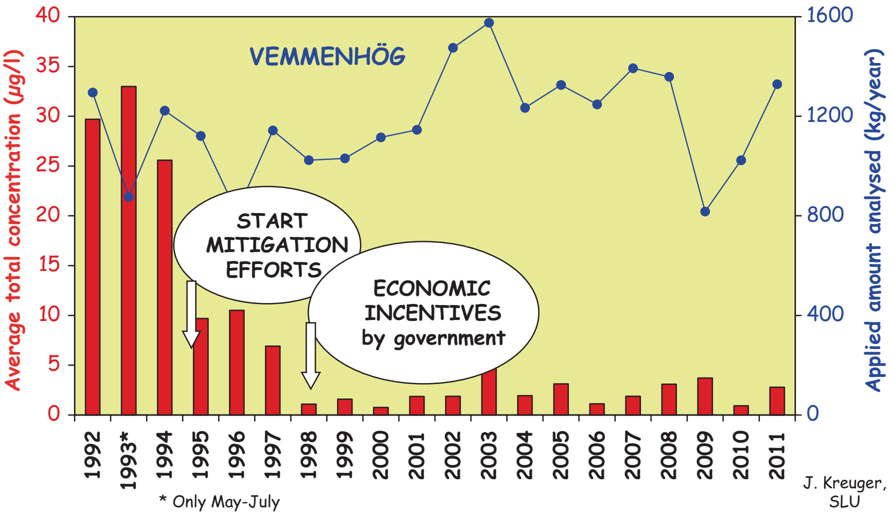

Fig. 22.2 Average of total pesticide concentration (bar graph) in water from the area of Vemmenhög (southern Sweden) during the period of May–September during the years 1992 and 2011. Amounts of pesticides used are included in the graph (scatterplot). (Source: Jenny Kreuger, Swedish University of Agricultural Sciences. With permission.)

A tank with clean rinsing water making it possible to rinse the applicator or to rinse the sprayer after use was available on 76% of the sprayers. Remote control to make it possible to fold out the spraying boom without getting out of the tractor was available on 78% of the sprayers, which was considerably more than in 2006. It also concludes that 99% of the professional users wear some kind of protective gear when applying pesticides. The kind of protective gear most commonly used was gloves (more than 90%) (Modig 2007), but only about 70% of the users wore a disposable apron or other kind of protective clothing for single use. The survey also inquired as to where the sprayers were being filled, and most farmers reported using the manure-plate, a place where there is biological activity similar to that in the field, or a special place where sprayer remainders/discharge is collected, a so-called biobed; these are the places that are recommended. In previous surveys, there were farmers who answered that they filled their sprayers in the courtyard, which is not recommended, and is considered hazardous.

There has been a great deal of effort to disseminate information on the handling of pesticides. A special campaign (“Focus on Pesticide Use”) in cooperation between The Federation of Swedish Farmers, the pesticide industry, the Farmers Supply and Crop Marketing, and the authorities (Swedish Board of Agriculture, Swedish Environmental Protection Agency, and the Swedish Chemical Agency) has been providing information on safe pesticide handling. The Federation of Swedish Farmers (LRF) is in charge of this project, and has been going on since 1996. The cooperation among these organizations has been very successful and there is a website (Anonymous 2013b) with useful information for farmers. The campaign has distributed information through brochures, courses, leaflets, and announcements in the press.

The focus of the campaign has been:

- Safe filling and cleaning of sprayers;
- Safe storage of pesticides;
- Safe distance—surface runoff;
- Safety distance—wind drift.

This initiative has even created 14 films on how to protect oneself from the risks to human health when using pesticides, how to fill the sprayer, and how to decide the safe distance for wind drift when using pesticides, and more films are under development. Anonymous (2013b) provides a link to this website and the films. The Swedish Work Environment Authority has also been in charge of a project that provides advice on protective gear. A website and a brochure give advice (in Swedish) on what is considered basic protection in different spraying situations (Dalin 2013).

All the authorities mentioned above have their own part in regulating the use of pesticides. The Swedish Board of Agriculture is responsible for the mandatory training of professional users of pesticides, the Swedish EPA is responsible for the regulation on where pesticides can be employed, the Swedish Chemical Agency is responsible for the approval and registration of pesticides for use in Sweden, and the Swedish Work Environment Authority is responsible for issues relating to the work environment.

Most of the companies selling pesticides in Sweden are members of an organization called "Svenskt växtskydd" ("Swedish Crop Protection Association"), and their members represent industry in "Focus on Pesticide Use." LRF organizes farmers and corporations within Swedish agriculture and forestry. LRF is a farmers' interest and business organization for the green industry (Anonymous 2013c).

22.3.4 Food Residues

The Swedish National Food Agency continuously collects samples of food to analyze for the presence of pesticide residues. They do so to ensure that there are no residues exceeding the maximum residue limits and to confirm that non-approved pesticides are not present in the estimate of consumer exposure to pesticides.

Generally, there are few Swedish samples that contain residues that exceed the maximum residue limit (MRL). Every year, approximately 1,500 samples are taken of different types of products, such as fruits, vegetables, baby food, juices, cereal grains, and cereal products. In Sweden, less than 2% of samples have exceeded the MRL since 1996 (except for 2006 when it was about 2%), whereas samples from other countries have exceeded the MRL more often. In 2010 (Jansson et al. 2011), only 1% of the Swedish samples and 4% of the samples originating from other European countries exceeded the MRL. In fruits and vegetables imported by Sweden from non-European countries, residues exceeded the MRL in 7% of the samples. In 42% of the Swedish food samples, residues that could be detected but that did not exceed the MRL. In horticultural produce from other European countries, residues were found in 60% of the samples, and in produce imported from outside of Europe, this figure was 70%. In Figure 22.3, the magnitude of residues in fruits and

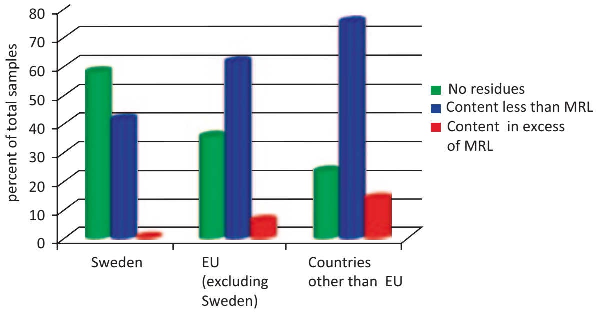

Fig. 22.3 Residues in fruits and vegetables in 2010 including the percentage of random samples of fruits and vegetables that contained pesticide residues. The fruits and vegetables originated from Sweden, from Europe outside of Sweden, and from countries outside of Europe. (Source: The Swedish National Food Agency; A. Jansson, unpublished data. With permission.)

vegetables in 2010 from Sweden, Europe outside of Sweden, and countries outside of Europe is shown.

22.4 Current Goals and How We Intend to Continue the Work

The current goals are:

- Reduced pesticide risk, as measured by risk indicators. The risk should be trending downwards both at the national level and at the level of individual farms.
- Almost no presence of residues in water shall be found. This applies to both surface and ground water.
- Low levels of residues in domestic vegetable crops shall be found, but there shall be no risk to consumers.
- Little risk to those who use plant protection products, by virtue of appropriate design of protective measures and work routines.
- Sustainable cropping systems shall be developed, and all growers shall apply integrated plant protection or organic farming (Sundgren et al. 2008).

22.5 Measures Taken to Reach the Goals on Sustainable Use of Pesticides

Integrated pest management (IPM) is one of the most important ways to reach the goal of the sustainable use of pesticides. According to Directive 2009/128/EC, all professional users of pesticides will be working in accord with the principles of IPM or organic cultivation by the year 2014.The measures planned to reach that goal are a combination of national regulations, improved information, and advisory services.

Many of the planned actions are already in place. There is a lot of experience, information, and advisory services that can be used in this work. Our Regional Plant Protection Centers are one of the points of reference that will be used in this work. There has been mandatory training for professional pesticide users since the 1960s: four days, including a one-day additional training course every fifth year. In the Rural Development Program, there have been some measures that aim to accomplish our environmental target, the so-called "Giftfrimiljö" (a nontoxic environment). There have also been long-term efforts in research and development with the goal being the safe use of pesticides.

The most important things to learn more about which have been identified and are part of ongoing projects are: threshold values (new and revised ones); the combination of mechanical and chemical regulation of weeds, crop rotation, pests that attack apples and carrots during storage, and knowledge about cultivars.

22.5.1 Information, Education, and Advisory Services

The mandatory training for professional users of pesticides will be revised and some parts of the training will be improved according to the Directive 2009/128/EC. One of the four days of the mandatory training will probably be an "IPM-day". Most users, however, will attend one day of a further training course. Some part of that course will contain information about IPM and where to find more information, but it will also be possible to attend the day dealing with IPM on a voluntary basis. Even those farmers who are hiring someone to use pesticides on their farms or a worker on a farm will be invited to this training about IPM. Authorities intend to provide education via the Internet, even though this idea has not yet been fully realized.

Sweden will make further improvements to the information given by the regional Plant Protection Centers. The regional Plant Protection Centers belong to the Swedish Board of Agriculture. They work with forecast and warning services about insect pests, diseases, and weeds, and there are about 20 people involved in these activities. Most of them are experts in plant protection in agriculture, but there are also some individuals specialize in horticultural issues and some who specialize in weeds. The regional Plant Protection Centers act as coordinators in the Swedish advisory system (Anonymous 2011). They work with forecasts and warnings and strategies for plant protection, and provide basic information to advisers, which is of great importance. They also identify areas of research and development, conduct courses, and document reports on the actual situation in the field. In addition, their work include the analysis of the current situation. The target group of these experts is advisory officers working in different organizations and these officers can receive the information in different ways. Subsequently, the advisory officers can apply the knowledge in their direct interaction with the farmers. The aim of the warning systems is to give information on the actual situation for different insect pests and diseases, to detect early attacks in order to raise awareness, and follow developments throughout the season. The data can be found on the website of the Swedish Board of Agriculture in Swedish (Anonymous 2013d). The information is disseminated in different ways, such as information messages on the Web, but also through telephone meetings with the advisory officers.

22.5.2 Record Keeping

Keeping records about which pesticides have been applied, time and dose of application, and where they have been used has been made compulsory for spraying outdoors since 1996. It is also compulsory to list the precautions that have been taken to protect the environment when filling and cleaning the spraying equipment, and to document the spraying distance maintained to protect the areas outside of the field. Since 2011, it is a requirement in Regulation (EC) No. 1107/2009 to record some of this information. There will probably be a need to document the plant protection problems that motivated the pesticide treatment. When checking the success of the pesticides applied, this information can be useful.

22.5.3 Knowledge Support

Extension services aimed at environmental issues are developed and provided by the Rural Development Program, in the shape of individual advice, training, field excursions, pilot cultivations, and written information. The mandatory training for use of pesticides is also an important way of informing sprayer operators. These measures have had a good impact and have an important part to play in maintaining the progress made thus far reducing the risk related to pesticide use. The system in use to keep this work progressing has been successful.

22.6 Ongoing Measures and Future Work

For the future, there is great need of knowledge and research and development about IPM. Even though Sweden has come far in reducing of pesticide use and increasing information on risks when using pesticides, further improvements will be necessary. We need to combine methods where, for example, biological control or mechanical weeding can be used in combination with chemical methods. We also need new and improved threshold values for the most important insect pests. Working to improve decision-support systems is also needed. The information provided to farmers will be developed in different ways; work is progressing on how to give more and better information via the internet and in the form of web-based education.

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