P. Parvatha Reddy

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Foreword

Even though the intensive crop production practices adopted in achieving green revolution (using heavy doses of fertilizers, indiscriminate use of pesticides and herbicides) led to enormous gains in food production and improved world food security, it had negative impacts on production, ecosystems, and the larger environment (causing environmental damage, pollution, reliance on fossil fuels), putting future productivity at risk. The food production in the developing world must be doubled, in order to feed the world's growing population that is expected to reach 9 billion by 2050. Since there is no scope to increase the land available for cultivation, the increase in production should come from sustainable intensification of agriculture – getting more crops out of the same amount of farmland with less environmental impact. In order to achieve Sustainable Development Goals (SDGs) (which last until 2030) set forth by the UN (to end hunger, achieve food security and improved nutrition, and promote sustainable agriculture), the increased food production should be achieved through environment-friendly and economically sustainable manner.

More than 30% of crops worldwide are blemished, damaged, or destroyed by agricultural pests – insects, mites, weeds, nematodes, and disease pathogens (fungi, bacteria, viruses). The crop losses due to pests viewed in terms of food security would represent the equivalent of food required to feed over one billion people. For over last five decades, chemical control has been the prevailing pest control strategy, resulting in safety problems and ecological disruptions. Hence, there are renewed appeals for economically acceptable, effective, and eco-friendly alternative pest management strategies, which reduce pest damage while avoiding the cost and negative externalities associated with inorganic pesticides.

One of the emerging strategies in crop protection, "Agroecological Pest Management", is being recognized in the present-day context. The new paradigm emphasizes on the incorporation of ecological principles into pest management while ensuring high productivity and profitable harvests without causing harm to the environment. The restructuring of the crop production system to incorporate preventative ecological measures that keep organisms from reaching pest status is the long-term pest management strategy. The use of biological processes has been given emphasis to regulate pest populations (as an alternative to direct control via synthetic pesticides) through the redesign of cropping systems via plant species' spatial and temporal diversification, while also preserving and improving the soil health (fertility, biological activity, structure, etc.) in agroecological pest management.

The information on agroecological pest management is very much scattered, and there is no book at present which comprehensively and exclusively deals with the above aspects in agriculture emphasizing on food security. This book, *Agro-ecological Approaches to Pest Management for Sustainable Agriculture*, outlines a new paradigm which aims to increase productivity through increasing efficiency and reducing waste, while conserving resources, reducing negative impacts on the environment, and enhancing the provision of ecosystem services. The use of ecologically based pest management strategies can increase the sustainability of agricultural production while reducing off-site consequences. The preventive strategies rather than reactive strategies form the basis of agroecological pest management. In order to build a farm's natural defenses, the preventive practices based on above- and below-ground habitat management (crop/soil management) should be given primary focus in cropping program, followed by planned (problems not solved by preventive practices – planned supplemental pest/soil management practices) and reactive (problems not solved by planned practices – reactive inputs for pest management/reduce plant stress) strategies. The book also highlights the underlying principles and outlines some of the key management practices and technologies required to implement agroecological pest management.

I compliment Dr. P. Parvatha Reddy for his meticulous contribution on a very potential topic of agroecological pest management. This book will be of immense value to the scientific community in agriculture as a whole and to those who are involved in crop protection in particular. The material can also be used for teaching postgraduate courses. It can also serve as a very useful reference to policymakers and practicing farmers.

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Preface

The green revolution (using heavy fertilization and indiscriminate use of pesticides) during 1960s has led to enormous gains in food production and improved world food security. However, intensive crop production has had negative impacts on production, ecosystems, and the larger environment, putting future productivity at risk. The world's population is expected to reach 9 billion by 2050; therefore, there will be a need to raise food production by almost 100% in developing countries. An estimated 80% of the required food production increases will thus need to come from land that is already under cultivation, through higher productivity. Hence, new and more environmentally sustainable and economic approaches are demanded and sought to meet future societal needs.

Pests (insect and mite pests, disease pathogens, nematodes, and weeds) are the important limiting factors in crop production and productivity. They are responsible for significant crop losses to the extent of 26–40% of the attainable yield every year in major food and cash crops. The present modern agricultural systems are reliant on agrochemical inputs for pest management. Overreliance on pesticides disrupts parasitoid and predator populations, causes outbreaks of secondary pests, exposes farmers to serious health risks, has negative consequences for the environment, causes development of pesticide resistance, leaves pesticide residues in food products, decreases effectiveness of many pesticides, adds to increased costs, and pollutes the air, soil, and water. Hence, there is an immediate need for alternative pest management strategies to overcome the above limitations, and to provide sustainable and eco-friendly production systems. The use of ecologically based pest management strategies can increase the sustainability of agricultural production while reducing off-site consequences. Agroecologically based pest management makes full use of natural and cultural practices and methods, including host resistance and biological control. In order to stabilize the population of pest species throughout the food web, the new designs should concentrate on managing the farm environment through ecosystem enhancements (i.e., landscape ecology), crop attributes, or other means.

This book, *Agro-ecological Approaches to Pest Management for Sustainable Agriculture* deals with optimal resource use for pest management with high productivity and enhanced ecosystem services. This alternative paradigm has been shown to work in many parts of the world, and is biologically and ecologically as well as economically more efficient in producing the required outputs of goods such as edible and nonedible biological products and of water while at the same time taking care of other essential ecosystem services that regulate soil, crop, and ecosystem health, protect habitats and biodiversity, drive carbon, nutrient, and hydrological cycles as well as conserve stocks of carbon, nutrients, and water, and protect soils and landscapes from erosion and other forms of degradation. The important aspects of agroecological pest management such as conservation tillage, crop residue management, addition of organic amendments, nutrient management, crop diversity, crop rotations, cover crops, plant breeding, agroforestry, biofumigation, habitat management, cultural approaches, push-pull strategy, cultivar mixtures, and precision agriculture are dealt in a very comprehensive manner in this book.

The book will be of immense value to scientific community involved in teaching, research, and extension activities related to crop protection. The material can be used for teaching postgraduate courses. It can also serve as a very useful reference to policymakers and practicing farmers. Suggestions to improve the contents of the book are most welcome (e-mail: reddy_parvatha@yahoo.com). The publisher, Springer India (Pvt.) Ltd., New Delhi, India, deserves commendation for their professional contribution.

Bangalore, Karnataka, India P. Parvatha Reddy
February 5, 2017

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About the Author

Dr. P. Parvatha Reddy obtained his PhD degree jointly from the University of Florida, USA, and the University of Agricultural Sciences, Bangalore.

Dr. Reddy served as the director of the prestigious Indian Institute of Horticultural Research (IIHR) at Bangalore from 1999 to 2002, during which the institute was honored with the "ICAR Best Institution Award." He also served as the head of the Division of Entomology and Nematology at IIHR and gave tremendous impetus and direction to research, extension, and education in developing biointensive integrated pest management strategies in horticultural crops. These technologies are being practiced widely by the farmers across the country since they are effective, economical, eco-friendly, and residue-free. Dr. Reddy has about 34 years of experience working with horticultural crops and is involved in developing an F1 tomato hybrid "Arka Varadan" resistant to root-knot nematodes.

Dr. Reddy has over 250 scientific publications to his credit, which also include 30 books. He has guided two PhD students at the University of Agricultural Sciences, Bangalore.

Dr. Reddy is serving as chairman of the Research Advisory Committee (RAC), Indian Institute of Vegetable Research, Varanasi, and as senior scientific advisor of the Dr. Prem Nath Agricultural Science Foundation, Bangalore. He had also served as a member of the RAC of National Centre for Integrated Pest Management, New Delhi; the expert panel for monitoring the research program of National Initiative on Climate Resilient Agriculture (NICRA) in the theme of horticulture including pest dynamics and pollinators; the RAC of the National Research Centre for Citrus, Nagpur; and the Project Directorate of Biological Control, Bangalore. He has also served as a member of the Quinquennial Review Team (QRT) to review the progress of the Central Tuber Crops Research Institute, Trivandrum; All-India Co-ordinated Research Project (AICRP) on tuber crops and on nematodes; and All-India Network Research Project (AINRP) on betel vine. He is the honorary fellow of the Society for Plant Protection Sciences, New Delhi; fellow of the Indian Phytopathological Society, New Delhi; and founder president of the Association for Advancement of Pest Management in Horticultural Ecosystems (AAPMHE), Bangalore.

Dr. Reddy has been awarded with the prestigious "Association for Advancement Pest Management in Horticultural Ecosystems Award," "Dr. G.I. D'souza Memorial Lecture Award," "Prof. H.M. Shah Memorial Award," and "Hexamar Agricultural Research and Development Foundation Award" for his unstinted efforts in developing sustainable, biointensive, and eco-friendly integrated pest management strategies in horticultural crops.

Dr. Reddy has organized the "Fourth International Workshop on Biological Control and Management of *Chromolaena odorata*," "National Seminar on Hi-tech Horticulture," "First National Symposium on Pest Management in Horticultural Crops: Environmental Implications and Thrusts," and "Second National Symposium on Pest Management in Horticultural Crops: New Molecules and Biopesticides."

Agro-Ecological Pest Management – An Overview

1

Abstract

The emerging paradigm in crop protection—agroecological approaches to pest management for sustainable agriculture—emphasizes on the incorporation of ecological principles into pest management while ensuring high productivity and profitable harvests without causing harm to the environment. The restructuring of the crop production system to incorporate preventative ecological measures that keep organisms from reaching pest status is the long-term pest management strategy. The use of biological processes has been given emphasis for agroecological crop protection through biodiversity while also preserving as well as improving soil health (fertility, biological activity, structure, etc.). The preventive strategies [above- and below – ground habitat management (crop/soil management)] rather than reactive strategies form the basis of agroecological pest management.

Keywords

Agroecosystems • Biodiversification • Ecological principles • Crop protection

1.1 Introduction

The United Nations Food and Agriculture Organization has predicted that food production needs to increase by 70% globally in order to feed the population of over 9 billion by 2050. Since there is no scope to increase the land available for cultivation, the increase in production should come from intensification of agriculture—getting more crops out of the same amount of farmland. Earlier, the conventional agricultural intensification (the so-called "Green Revolution") relied on monoculture along with heavy inputs such as pesticides, inorganic fertilizers, and fossil fuels to achieve a decline in global hunger. Despite this production increase, nearly 800 million people continue to suffer from hunger and malnutrition around the world. Ecological

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principles were continuously ignored, as the agricultural intensification progressed, that resulted in negative externalities. In order to achieve Sustainable Development Goals (SDGs) (which last until 2030) set forth by the UN, the increased agricultural production should be achieved through environment-friendly and economically sustainable manner.

The innovative methods of increasing yields while reducing chemical inputs (inorganic fertilizers and pesticides), incorporating trees into the farm landscape, and capturing carbon (ecological intensification of agriculture) are already being discovered and implemented by researchers and farmers. The implementation of these potential agroecological pest management practices needs to be scaled up across the globe to increase food production and productivity. Even if these agroecological practices (specifically nitrogen mineralization and biological control of pests) are adopted in only 10% of farmland worldwide, the economic value of ecosystem services could exceed the input costs of pesticides and fertilizers. Insect pollination, an important ecosystem service provided by the insects that benefits farmers, can compensate for low levels of fertilizer application.

The intensive use of land, water, biodiversity, and nutrients more efficiently for enhancing crop production in an eco-friendly and economically sustainable manner is known as sustainable intensification (Godfray and Garnett 2014). The ecological principles and practices such as conservation tillage, crop residue management, agroforestry, cropping systems, habitat management, precision agriculture and diversification, and breeding resistant cultivars, can be used more intensively in a sustainable manner for increasing crop production (Voora and Venema 2008; Juma et al. 2013).

The precise and strategic way of utilizing inputs (nutrients, pesticides, seeds, or water) sparingly and effectively with minimal negative externalities is called precision agriculture (Agriculture for Impact 2013). Soil testing, microdosing, and seed spacing are some of the methods used in achieving precision agriculture.

The maintenance of diversity of both flora and fauna is emphasized in agroecological pest management (Mori et al. 2013). Development of diverse agroecosystems for soil and crop protection through integration of trees, livestock, and crops is called sustainable farming (Fig. 1.1).

Multiple benefits of diverse agroecosystems like agroforestry include crop protection, soil fertility improvement, biomass accumulation, soil and water conservation, and tree integration.

Production of more food from the same piece of land with less environmental impact, (sustainable agriculture), is variously referred to as “agriculture durable,” “agroecological intensification,” “alternative agriculture,” “doubly green revolution,” “evergreen agriculture,” “evergreen revolution,” “green food systems,” and “greener revolutions” (Royal Society 2009).

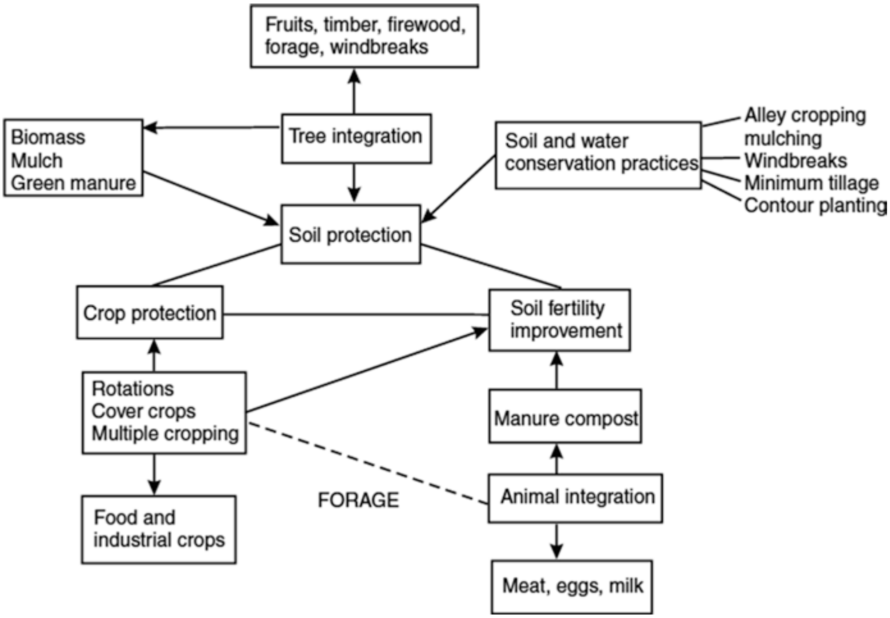

Fig. 1.1 A diversified agroecosystem to achieve pest management for sustainable agriculture (Altieri 1987)

1.2 Ecology and Agroecology

1.2.1 Ecology

The interrelationship between biological processes due to organisms and their environment is called ecology.

1.2.2 Agroecology

The application of ecology to agroecosystems, which involves interrelationships among crops, pests, man and environment in relation to social, economic, and ecological aspects is called agroecology (Dalgaard et al. 2003). Agroecological pest management principles give more emphasis on biological processes to prevent utilization of external inputs (Deguine et al. 2008).

The advantages of agroecology include the following:

- Achieving enhanced food production with improved product quality
- Enhancing functional redundancies, perennial cover, plant diversity, and presence of trees
- Based on local natural resources

- Improving the efficiency of food production by “closing the nitrogen cycle” and enhancing positive externalities to the environment
- Enhancing input-use efficiency
- Achieving improved social status of farmers
- Addressing climate-change resilience by appropriate selection of crops and enhancing ecosystem function and resource efficiency
- Restoring soil health by adopting agroecological approaches
- Closing the gaps in yield and environmental sustainability
- Eliminating production constraints through farmer participation
- Improving soil nutrition to enhance crop yields
- Achieving energy and technological sovereignty
- Integrating trees in agriculture.

1.3 Agroecological Pest Management

Sustainable management of crop pests and diseases by using natural regulation strategies is called agroecological pest management. It needs to enhance farmers’ livelihood and improved performance of agroecosystem, through biodiversity and proper utilization of natural agroecological processes. Agroecological intensification is based on input-use efficiency, eco-friendly pest management, microirrigation, and environmental protection to enhance food production in a sustainable manner. There is a need to avoid excessive use of fossil fuels, pesticides, and water. This is an innovative approach which emphasizes on biological processes regulated by organisms for pest management (Griffon 2013).

The creation of multifunctional sustainable agroecosystems is the aim of agroecological pest management (Tittonell 2014). The utilization of nature’s resources without exploiting them unsustainably in order to better understand the ecological processes is the prerequisite (CIRAD 2014).

The core attributes that are reflected in sustainable agroecological intensification production systems are as follows:

- Utilization of crop varieties and livestock breeds with a high ratio of productivity
- Unnecessary use of external inputs to be avoided
- Use of agroecological strategies such as allelopathy, nutrient cycling, natural enemies, and biofumigation
- Avoiding negative externalities and enhancing protection of environment
- Minimizing greenhouse gas emissions, dispersal of pests, pathogens, and weeds, enhancing clean water, carbon sequestration, and biodiversity

1.4 Goals

The fundamental goals of agroecological pest management include the following:

- Safety of the food produced for the farmers and public

- Profitability through input-use efficiency and avoiding external inputs as for as possible
- Durability by way of adopting long-lasting and sustainable practices

1.5 Basis and Principles

More than 30% of crops worldwide are blemished, damaged, or destroyed by herbivores (insect and mite pests), fungal, bacterial, viral, and nematode diseases, and weeds. They are responsible for significant crop losses to the extent of 26–40% in important cash and food crops such as soybean, wheat, cotton, maize, rice, and potato (Table 1.1) (Oerke 2006).

Over the last 50 years, the main strategy utilized for pest management was through chemical methods, resulting in safety problems and ecological disruptions. Hence, there is a need for economically acceptable, environmentally friendly alternative pest management strategies for future crop protection.

Monoculture of crops is the main cause for erosion of genetic biodiversity and is responsible for the worsening of most pest problems (FAO 2001; Altieri and Letourneau 1982). The monoculture of annual crops such as cotton, maize, rice, soybeans, and wheat has occupied 91% of cropland. Crop monoculture is also the main reason for enhanced susceptibility of crops to diseases and pests. Huge quantities of pesticides are being used every year to manage pests on these crops globally (FAOStat 2014). Hence, agroecologically based pest management strategy is the need of the hour.

Crop protection has been evolving since the 1970s based on the principles of agroecological strategies for pest management (Bottrell 1980). This is one of the emerging strategies in crop protection that is being recognized in the present-day context (Gurr et al. 2004; Clements and Shrestha 2004; Nicholls and Altieri 2004). The new paradigm emphasizes on the enhanced production utilizing the principles of agroecological pest management without causing harm to the environment. The restructuring of crop production is the long-term sustainable pest management strategy.

Table 1.1 Current global losses (%) due to various categories of pests in major crops

Crop	Animal pests	Weeds	Pathogens	Viruses	Total
Cotton	12.3	8.6	7.2	0.7	28.8
Maize	9.6	10.5	5.8	5.2	31.3
Potato	10.9	8.3	14.5	6.6	40.3
Rice	15.1	10.2	10.8	1.4	37.5
Soybean	8.8	7.5	8.9	1.2	26.4
Wheat	7.9	7.7	10.2	2.4	28.2
Average	**10.8**	**8.8**	**10.0**	**2.5**	**32.1**

Source: Oerke (2006)

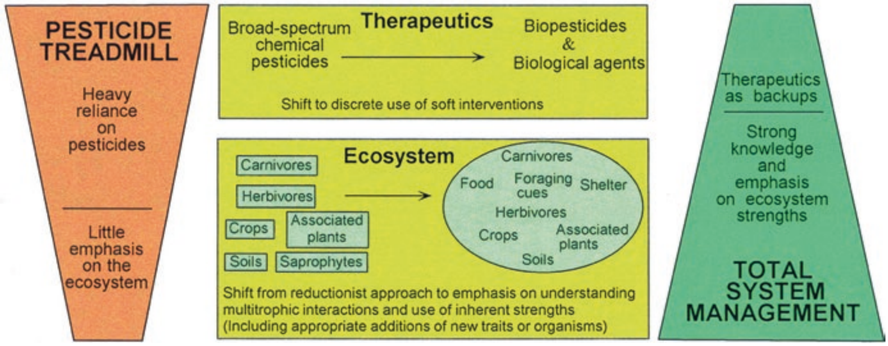

Fig. 1.2 Agroecological intensification of pest management

The use of biological processes has been given emphasis for alternative pest management strategy through biodiversity, while also preserving and improving soil health (fertility, biological activity, structure, etc.) in agroecological intensification of crop protection (Ratnadass et al. 2012).

Agroecological intensification relies on developing methods to enhance the natural enemies of crop pests to increase crop yields substantially. Some scientists believe that genetically modified crops fit into the gambit of agroecological intensification to fulfill the objective of food security (Birch et al. 2011).

Habitat management, which increases the population of pollinators and biological control agents within agroecosystems, helps to manage crop pests (Fig. 1.2) and thereby enhances crop production.

According to the vision of agroecological intensification, preventive tactics, habitat manipulation, and biological control are the principal components for pest management, while the reactive tactics based on chemical control should be given less priority.

In order to implement an agroecologically based approach to crop protection, cropping systems like intercropping, cover and green manure cropping, trap cropping, companion planting, and crop rotation should be employed to keep pest population below injury thresholds (Lewis et al. 1997). Use of crop cultivars resistant or tolerant to pests, cultivar mixtures and multiline cultivars, biofumigation, allelopathy, and precision agriculture also need to be promoted.

The successful agroecological pest management strategies include the following:

- Enhancement of biological processes due to organisms
- Use of crop cultivars resistant or tolerant to pests
- Attraction of natural enemies through habitat management and cropping systems
- Soil management practices to encourage beneficials such as antagonists, earthworms, etc.

The benefits of biodiversity can be obtained in an agroecosystem by improving farm design and soil biology, nutrient recycling, moderating microclimates,

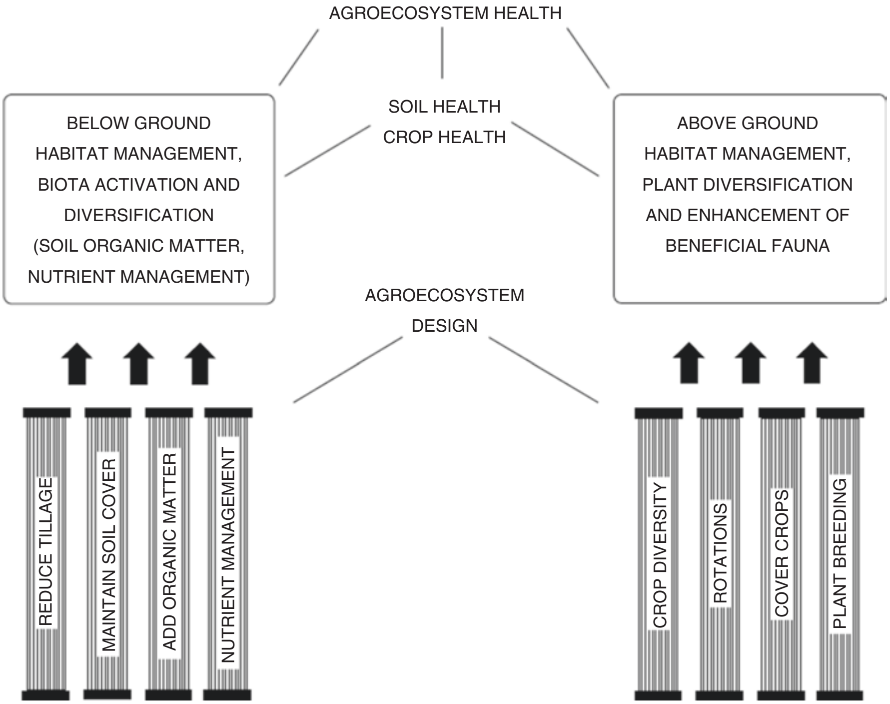

Fig. 1.3 The pillars of sustainable intensification of crop protection

detoxifying noxious chemicals, and regulating hydrological processes to enhance the highly functional diversity of crucial organisms (Fig. 1.3).

1.6 Key Elements of Agroecological Pest Management

Preventive strategies rather than reactive strategies form the basis of agroecological pest management. In order to build the natural defenses, the preventive practices based on above- and below-ground habitat management (crop and soil management) should be given primary focus in the cropping program. This should be followed by planned strategies for supplemental pest and soil management to solve those problems not solved by preventive practices as well as reactive strategies such as inputs for pest management or reduce plant stress for problems not solved by planned practices.

1.6.1 Crop Management

The pests should be stressed and/or natural enemies should be enhanced by using habitat management employing the following cultural approaches:

- Crop selection based on locality
- Use of well-adapted local and native varieties with resistance or tolerance to biotic and abiotic stresses
- Inclusion of atmospheric nitrogen-fixing and allelopathic or biofumigation crops in the cropping sequence to improve soil nutrition and pest management
- Use of cover crops which can manage weeds and other biotic stresses
- Habitat management both within the field and at field boundaries to encourage natural enemies
- Management of proper crop sanitation
- Adoption of agroforestry system to enhance biodiversity
- Creation of unfavorable conditions using crop spacing, intercropping, and pruning

1.6.2 Soil Management

These practices include below-ground habitat conservation and enhancement and maintenance of soil nutrition and pH levels. They encourage useful organisms like earthworms and soil antagonists in soils. Soil management practices include preventive, supplemental, and reactive options.

1.6.2.1 Preventive Options

These practices include:

- Enhancing organic biomass through cover or green manure cropping that encourages biological processes in the soil
- Promoting conservation tillage which improves the soil's physical, chemical, and biological properties
- Providing balanced crop nutrition
- Preventing soil acidity or salinity
- Encouraging soil antagonists for biological control of pests

1.6.2.2 Supplemental Options

If preventive options fail to achieve satisfactory pest management, the following supplemental options have to be undertaken:

- Application of biopesticides and inundative release of predators or parasitoids.
- Prune to reduce humidity under canopy to prevent pathogens
- Management of weeds which act as alternate hosts for pests
- Careful scheduling of irrigation to maintain adequate soil moisture
- Leave mulch soil cover by mowing rather than incorporating cover or green manure crops
- Intercrop legumes within cereals

1.6.2.3 Reactive Options

Even after following preventive and supplemental options, if satisfactory pest management is not achieved, the following reactive options have to be undertaken:

- Alleviate soil compaction by chisel plow or subsoiler
- Soil or foliage application of nutrients to rectify deficiency symptoms

1.7 Benefits and Limitations

1.7.1 Benefits

1.7.1.1 Increasing Species Diversity

Compensatory growth and pest protection are enhanced due to increased species diversity. The complementary resource use is facilitated by several spatial and temporal plant species combinations to provide intercrop benefits such as supply of additional nitrogen by legumes for the growth of cereals. The full use of available resources is made for a desirable compensatory growth.

1.7.1.2 Enhancing Longevity

The more stable pest–enemy complexes can be established by perennial vegetation that provides more habitat permanence. The soil can be protected from erosion by including perennial species that shade the soil surface. The nutrients can also be captured because of biomass accumulation through aerial parts and roots of the plant.

1.7.1.3 Imposing a Fallow

Fallowing and growing cover or green manure crops during fallowing restores biological processes that enrich soil nutrients and regulate pests.

1.7.1.4 Enhancing Soil Organic Matter

Enhancing crop biodiversity provides substrate to beneficial soil microorganisms which in turn help in biological control of pests.

1.7.1.5 Increase Landscape Diversity

Enhancing landscape diversity improves pest management. Landscape diversity can be increased by sequential cropping system, which in turn spreads the risk of complete crop failure among and within the various cropping systems.

1.7.1.6 Saving on Cost of Inputs

The costs of pesticides, inorganic fertilizers, farm machinery, and manpower can be saved by following agroecological intensification of crop production. Pimentel et al. (2005) reported that organic corn or soybean farming approaches used about 30% less fossil energy as compared to conventional systems.

Saving on cost of inputs has been reported to increase production levels due to the presence of specific biological control agents for a determined pest (Pesticide Action Network North America 2009). For example, tapioca mealy bug was effectively managed by introduction of the parasitic wasp *Apoanygyrus* (= *Epidinocarsis*) *lopezi* in unsprayed fields (FAO 2016).

1.7.2 Limitations

- Biological control agents have not been identified for some very serious pests. In such cases, the farmers resort to use of chemical pesticides.
- Agroecological intensification is knowledge intensive and requires thorough understanding of the production system. Hence, it is not easy to implement.
- Biological control agents are slow to act, and may not be able to provide significant pest control. It can be used as a component in integrated pest management.
- Since no single biological control agent is effective under diverse conditions, there is a need for the use of two or more natural enemies.

1.8 Conclusions

Key ecological services to agroecosystems can be provided by encouraging the diversity and abundance of aerial and soil biological processes (Altieri and Nicholls 2000). There is a need for exploitation of synergy and complementarity of agroecosystems through integration of annual and perennial crops (agroforestry) in enhancing biodiversity. Good agricultural practices based on agroecological principles like enhancing natural enemies, soil fertility, conservation of water, and soil’s physical, chemical, and biological properties to increase crop productivity should be followed (Gurr et al. 1998).

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Conservation Tillage

2

Abstract

This chapter presents both beneficial and detrimental effects of no-till systems on pest management. Reduced tillage alters pest dynamics considerably. Conservation tillage system commonly leads to enhancing grass weeds and volunteer cereals, while reducing broad-leaved weeds. Under reduced tillage systems, damage due to thrips is reduced, while slug and cutworm problems are increased. More natural enemies, such as annelids, parasitic wasps, and predatory ground beetles, are observed in conservation tillage fields. The incidence of foliar diseases may increase, while soil-borne diseases may decrease in reduced tillage systems over time due to increased biological activity and growing numbers of beneficial microorganisms. Pest management in reduced tillage systems can be as effective as in conventional systems, but requires a higher level of management. Key cultural practices for pest management under conservation tillage include crop rotation, scouting, pest identification, variety selection, field sanitation, proper planting procedures, and irrigation management.

Keywords

Conservation tillage • Insect pests • Diseases • Weeds • Crop rotation

2.1 Introduction

Conservation tillage is an innovative and sustainable agricultural production system providing greater economic and environmental advantages. The economic advantages include increased cropping intensity and diversity, coupled with reduced operating costs in machinery operations, fuel, and labor, as well as savings in time. The environmental benefits include improvement in soil health and resilience and soil's physical, chemical, and biological properties, restoration and enhancement of wildlife habitat, increased soil organic matter and activity of soil organisms, and

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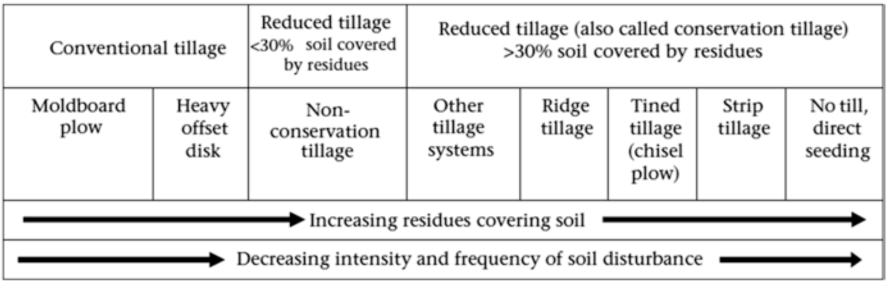
Table 2.1 Effects of tillage systems on tillage intensity and residue coverage

Classification	Primary tool(s)	Tillage intensity	Residue coverage
Clean till	Moldboard plow	High, soil inversion	<30%
Clean till	Heavy offset disk	High	<30%
Reduced till	Chisel plow, disk	High	<30%
Conservation tillage (high residue farming)			
Reduced till, Minimum till, mulch till	Chisel plow	Moderate	>30%
Strip till	Strip-till implement	Nonuniform, moderate to none, 15–30 cm deep	60–80%, bare soil in planted strip
Zone till, vertical till	Gang of coulters on planter, row cleaners	Nonuniform, moderate to none, 2.5–5.0 cm deep	60–80%, bare soil in planted strip
No till (direct seeding)	Planter with row cleaners	None	60–80%, 0–80% in planted strip
No till (direct seeding)	Planter without row cleaners	None	80–100%



Conventional tillage		Reduced tillage <30% soil covered by residues	Reduced tillage (also called conservation tillage) >30% soil covered by residues				
Moldboard plow	Heavy offset disk	Non-conservation tillage	Other tillage systems	Ridge tillage	Tined tillage (chisel plow)	Strip tillage	No till, direct seeding

→ Increasing residues covering soil →

→ Decreasing intensity and frequency of soil disturbance →

Fig. 2.1 Effect of tillage systems on residues covering soil and intensity and frequency of soil disturbance

reductions in soil erosion, nitrate leaching, fuel use, and agricultural greenhouse gases (GHGs) emissions.

Reduction in volume of the soil that is tilled in order to maintain residue cover on the soil surface in the cropping systems is called conservation tillage farming. Depending on the specific amount of residue on the previous crop, the current crop, and soil and climate factors, soil surface residue cover provides many benefits of conservation tillage. The various types of conservation tillage include no tillage or direct seeding, reduced tillage, strip tillage, ridge tillage, and vertical tillage. Table 2.1 shows the range of tillage practices.

The range of tillage systems, from high-disturbance systems to very-low-disturbance systems are presented in Fig. 2.1.

The features of conservation tillage are as follows:

- Application of pre-planting non-pollutant desiccant herbicides and use of cover crops for weed management
- Use of pre- and postemergence herbicides to control weeds
- Management of insect pests, diseases, nematodes, and weeds through crop rotation which is fundamental to conservation tillage

Conservation tillage farming systems are being followed by an increasing number of farmers from different regions to suit their conditions and crops for the management of insect pests, diseases, and weeds.

2.2 Weed Management

Under conservation tillage, the need for vigilance in weed management is increased as the tillage is reduced. Tillage can kill weeds by preventing germination and burying weed seeds. Even if seeds do germinate, the seedling emergence can be prevented when seeds are buried deep in the soil. Weed management is heavily dependent on herbicides in conservation tillage system. The crop residues must be spread uniformly for effective application of residual herbicides. In recent times, great strides have been made in the development of herbicides for their economic feasibility, effectiveness, and environmental friendliness. Additional weed management methods such as flame weeding, mechanical crushing or hand picking, mowing, rolling and crushing without soil disturbance, and cover crops and residues are promising. There is low emergence of weed seedlings (by blocking sunlight, decreasing temperatures, and providing habitat to insects that eat weed seeds), because seeds are not exposed by tillage and the soil surface is covered with crop residues. Better weed suppression is generally achieved with higher levels of soil-surface residues (Chauhan et al. 2006). The rates of herbicide application can be reduced by spot treatment with postemergence herbicides (spraying just where the weeds are) or banding the herbicides over the rows instead of broadcasting them.

Weed ecologists opine that for no-till systems, there should be zero weed tolerance (Pollock 2011, Shrestha et al. 2006). Achieving zero weed tolerance requires the following:

- The potential shift in weed species that are often associated with reduced tillage should be understood.
- Cultural and other nonchemical methods should be used for weed management.
- More reliance is placed on herbicides and in enhancing their efficacy in weed management.

Conservation tillage system commonly leads to enhancing grass weeds and volunteer cereals while reducing broad-leaved weeds, though small-seeded, broad-leaved weeds like lamb’s quarters and pigweed may still be a problem (Wrucke and Arnold 1985). In general, it is difficult to manage grass weeds than broad-leaved weed in cereals, while it is impossible to control volunteer cereals. In a trial on weed

Table 2.2 Effect of reduced tillage treatment without the use of herbicides on weeds in winter wheat at Midlothian

Tillage system	Weed number/m^2				
	Annual meadow grass	Volunteer oilseed rape	Common chick weed	Forget-me-not	Field pansy
Plow	548	24	44	4	36
Reduced tillage	1168	0	544	0	0

management in winter wheat at Midlothian, annual meadow grass increased while many broad-leaved weeds decreased in number in reduced tillage system as compared with conventional plowing (Table 2.2).

Under conservation tillage, all weed seeds are left on the soil surface under the crop residue. The small-seeded weeds germinate and grow under these environmental conditions which are more conducive, while the large-seeded weeds remain in soil.

The weed growth is suppressed by the release of chemicals (glucosinolates including isothiocyanates) during the decomposition of crop residues, which is called allelopathy, and can be important with residues from *Brassica* crops and rye (Haramoto and Gallandt 2004).

There is often a shift in the weed populations in reduced tillage systems (without fall tillage) away from summer annual weeds toward winter annuals, biennials, and perennial weeds (Kapusta and Krausz 1993). Burndown and postemergence herbicide application in the fall, spring, or both, or by rotating to herbicide-resistant crops can be employed to manage these weeds. Since the tillage is practiced in potatoes, onions, or carrots as part of the crop rotation, the perennial weeds will probably not be a problem in these fields.

The burndown herbicides applied before planting, at planting, or after planting, kill the existing weeds. In order to manage both early- and later-germinating weeds, the use of split applications may be followed (that is, apply one-third of the labeled herbicide rate early and the remaining two-third at planting). The late-germinating summer annual weeds that would otherwise compete with the crop can be managed by the use of residual soil-active herbicide mixed with the last burndown application.

In reduced tillage, the timing of herbicide applications is more important to strike the right balance between treating weeds when they are small and treating after as many weeds as possible have germinated. Besides application of a mixture of soil-active and burndown herbicides early, one or more postemergence herbicide applications may be required to achieve complete weed management.

Proper rate of herbicide application also plays a major role in weed management in reduced tillage systems. The amount of soil organic matter, crop residue level, timing, and size or density of weeds affect the rate of herbicide application. The factors can affect herbicide activity under reduced tillage and, therefore, the needed rate should include the following:

- Increased rates of soil-applied herbicides (within the labeled range) with increased soil organic matter levels (not residue)
- Increased rates of soil-applied herbicides with increased thickness of crop residues
- Increased rates of more persistent herbicides for early preplant applications
- Increased rates of soil-applied herbicides when spraying larger or more numerous weeds

For weed management in some of the specialty crops grown in the far western USA for which selective herbicides are not available, the adoption of reduced tillage may be limited. Creamer and Dabney (2002) suggested the use of high-residue cultivators that allow tillage for weed management while preserving some residue cover, in such situations.

As the reduced tillage systems rely on herbicides for weed management, the development of herbicide-resistance in weeds is of great concern. The problem of herbicide-resistant weeds can be overcome by rotating herbicide modes of action using labeled tank mixes and maximum labeled rates. In the irrigated regions, herbicide rotation should always be used with less diverse rotations.

2.2.1 Stale Seed Bed + Glyphosate Strategy

The stale seed bed technique (delayed sowing) can be adopted for the management of weeds in spring, but is perhaps most useful in winter cereals. This technique has a major impact on early-emerging grass weeds (such as meadow grasses, Italian rye grass, barren or sterile brome, volunteer cereals, and rape black grass) and volunteer crop populations in the following crop. The stale seed bed technique needs about a 4-week gap after harvest to allow the weeds to germinate, along with adequate moisture. The weeds are most cost effectively managed by spraying with a low dose of glyphosate (Fig. 2.2).

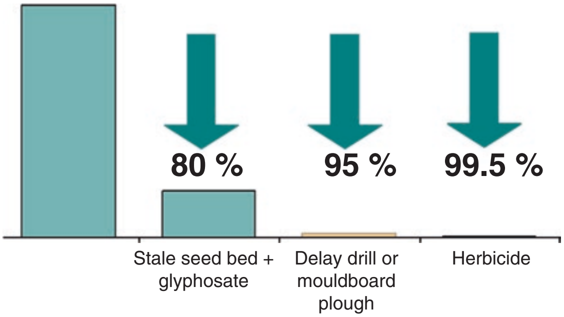


Fig. 2.2 Effect of stale seed bed + glyphosate strategy for management of sterile brome weed

2.2.2 Crop Rotations + Stale Seed Bed

Grass weeds in the oilseed rape and beans can be managed by winter crop rotations along with a stale seed bed approach (allowing a gap of 4 weeks between rape harvest and planting of beans). The grass weeds can also be managed by following spring cropping in the rotations.

2.2.3 Integrated Weed Management

Under conservation tillage systems, the use of integrated weed management (IWM) methods could reduce weed densities (Blackshaw et al. 2005a, b). In order to reduce the reliance on herbicide methods, Awada et al. (2014) suggested that the IWM systems that include crop rotation, seeding date (early spring), seeding rate (100% or 150% recommended rate), fertilizer application (fall or spring), and in-crop herbicide rate (50% or 100% of recommended rate) have the potential to lessen weed populations. The problems of herbicide-resistant weeds, the potential for injury to rotational crops from herbicide carryover, and public concerns regarding the environmental and health effects of pesticides can be solved by the reduction in herbicide use under IWM systems. The use of IWM systems under conservation tillage systems has been found economical and profitable (Smith et al. 2006; Upadhyay et al. 2006).

2.3 Insect Pest Management

There will be a shift in the number and type of insects in a field by following reduced tillage. However, the pest problems need not necessarily increase (Stinner and House 1990). The pest-insect dynamics was considerably altered by reduced tillage. Many natural enemies such as annelids, parasitic wasps, and predatory ground beetles are observed in conservation tillage fields (Chan 1987). Under reduced tillage systems, damage due to thrips is reduced, while slug and cutworm problems are increased.

Some specific pests that overwinter in crop residue or in the soil and become active during early stages of crop growth can be more numerous in reduced tillage. By following reduced tillage for a number of years, the insect population may decrease because of increased survival of natural enemies such as spiders, rove beetles, ground beetles, and ants, which can contribute to insect pest management. The predatory ground beetle populations can be increased by the provision of alternative food sources such as weeds and volunteers by buildup of ground beetle populations that will prey on slugs. The slug population can also be managed by employing metaldehyde slug pellets to ensure that the newly sown crop does not get damaged by slugs.

In some instances where the weeds act as alternate hosts for pests, proper management of weeds (especially of grassy weeds) can facilitate pest management.

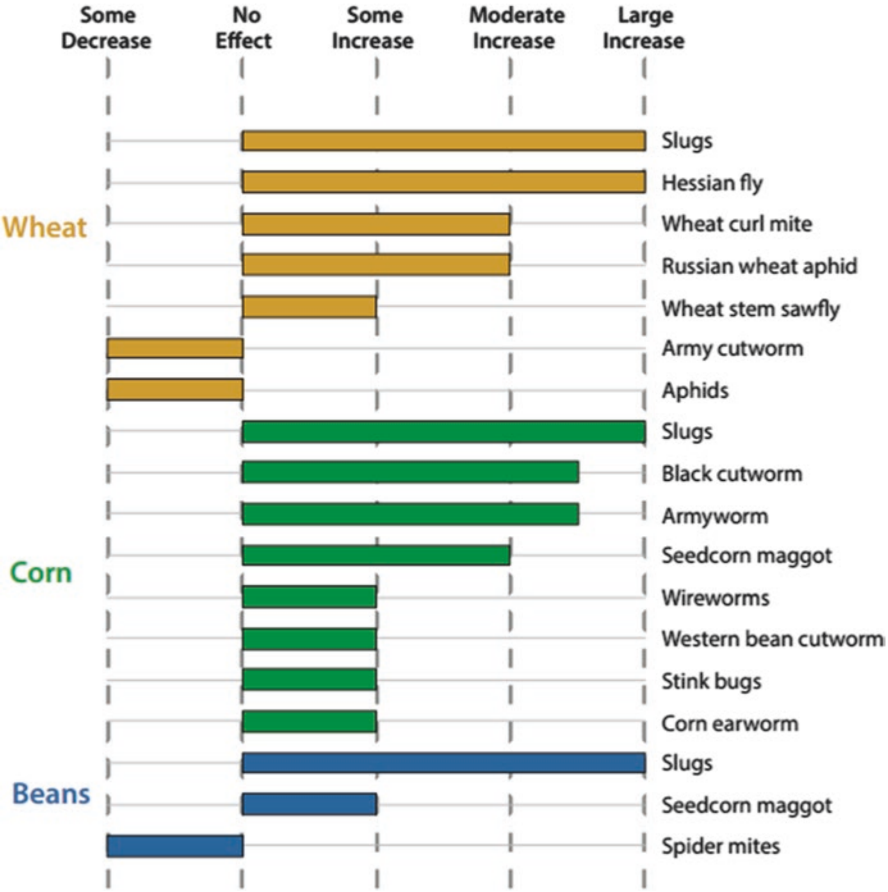


Fig. 2.3 Effect of reduced tillage on pests of wheat, corn, and beans (Adapted from Conservation Tillage Systems, MWPS-45, MidWest Plan Service 2000)

Under long-term adoption of reduced tillage systems, the pest management can be achieved by enhancing the natural-enemy population in conjunction with targeted use of pesticides.

The effects of reduced tillage on some pests can be generalized, even though each combination of crop and pest is unique (Fig. 2.3).

- Freshly incorporated crop residues or green manures favor seed corn maggots than dead crop residues which simply cover the soil (Hammond 1984).
- In fields with grassy weed infestations, reduced soil disturbance and delayed germination due to cool soil, wireworms are most likely to increase and cause damage (All et al. 1986).
- In low-lying wet areas where unincorporated crop residue and cool, wet conditions prevail, slugs can cause extensive damage to crop seedlings. The slug

population can be managed by employing metaldehyde slug pellets (control can be expensive).
- Unincorporated crop residues in reduced tillage favor black cutworms.
- When planting or crop development is delayed in no-till fields, the corn earworms may become a major problem.
- Winged aphid infestations can be present in new crop stands (since they are attracted to bare ground) but not after canopy closure.

In plots where corn is planted into a grassy sod or wheat residue, the wheat curl mite can also move from green grass to emerging corn and can infect crops with viral diseases like High Plains disease. The viral disease can be managed by killing any grasses with herbicides several weeks before planting. Alternatively, pesticide seed treatments can also be employed under high-risk conditions. Pesticide seed treatments may have been more frequently used in reduced tillage and are the preferred control method for many insects in no-till systems.

Stinner and House (1990) reported that 43% of insects and their damage decreased with reduced tillage, compared with 28% where the number or damage increased, while the remaining 29% showed no difference. Pest management should not be an impediment for adopting conservation tillage systems.

2.4 Disease Management

The effects of reducing tillage on disease pressures are variable, depending on the disease (pathogen virulent or avirulent), the environment (favorable or unfavorable), and the crop (susceptible, tolerant, resistant). It is difficult to predict the incidence of a disease problem in specific crops and in particular climates (Krupinsky et al. 2002). In general, the incidence of foliar diseases may increase, while the soil-borne diseases may decrease in reduced tillage systems (Table 2.3) over time due to increased biological activity and growing numbers of beneficial microorganisms (Bockus and Shroyer 1998). Likewise, diseases favored by higher soil temperatures and drier soils may be seen less often, while pathogens that thrive in cool, wet soils may become more of a problem. Under reduced tillage conditions, the stem base *Fusarium* disease levels were highest. Elimination of crop monocultures

Table 2.3 Effect of conventional and zero tillage on leaf spot and root disease severity on wheat (Bailey et al. 1992)

	Disease severity				
	Leaf spots*			Root rot^{a}	
Tillage type	*Septoria nodorum*	*Septoria tritici*	*Pyrenophora tritici-repentis*	*Cochliobolus sativus*	*Fusarium* spp.
Conventional tillage	3.0^{a}	10.0^{a}	2.1^{a}	71^{a}	76^{a}
Zero tillage	3.2^{a}	12.0^{b}	4.4^{b}	42^{b}	86^{b}

*Means followed by the same letter are not significantly different using an LSD test at $P = 0.05$

Table 2.4 Effect of tillage type on the incidence of take-all and eyespot diseases and yields of wheat

Tillage type	Take-all (%)	Eyespot (%)	Yields (t/ha)
Reduced tillage	37	31	9.6
Plow	42	37	8.7

Table 2.5 Effect of tillage type on the occurrence of postemergence damping off of cotton in a peanut–cotton rotation (Johnson et al. 2001)

Tillage type	Damping-off in cotton*	Tomato spotted wilt virus on peanut*
Conventional tillage	13.5^a	24.6^a
Minimum tillage	1.6^b	14.2^b
Reduced tillage	2.9^b	14.2^b

*Means within a column followed by the same letter are not significantly different using Fisher's Protected LSD (0.05)

and improving the diversity of crops in rotations can help to manage the diseases of cereal and oilseed crops.

The severity of take-all disease in wheat is lower under reduced tillage system, when the soil structure is good, and there is no increase in cereal volunteers (Table 2.4). Similarly, in reduced tillage crops where there is more trash on the soil surface, lower level of common eyespot disease was observed because of the presence of higher population of antagonists (Table 2.4). Likewise, the wheat crop yields were also higher in the reduced tillage areas as compared to conventional tillage system (Table 2.4).

The wheat crop grown under reduced tillage and crops in close rotations will be at risk from early attacks of powdery mildew and yellow rust since volunteers are more likely to occur. Hence, the yellow rust, powdery mildew, and net blotch diseases can be prevented from spreading by controlling volunteers. The *Cephalosporium* leaf stripe is rare under conventional tillage system, but can become a major problem in wheat under reduced tillage. Two to three years of crop rotation of wheat and preferably barley, oats, grasses, and volunteers with nonhosts is the best way to manage the disease.

In a peanut–cotton rotation, the postemergence damping off of cotton was lower in the minimum or reduced tillage treatments than in the conventional tillage systems (Table 2.5). Similarly, the tomato spotted wilt virus (TSWV) disease incidence was 42% lower in peanut across all years under reduced and minimum tillage than under conventional tillage in a peanut–cotton rotation (Johnson et al. 2001) (Table 2.5). Since there are no effective single control measures for TSWV in peanut, this finding is very significant. For the management of TSWV disease, conservation tillage was recently added as a risk-reducing option against this potentially devastating viral peanut disease. This benefit is directly correlated to less incidence of damage from thrips, the vector of TSWV (Brown et al. 2001).

The opportunity for reducing the development of damping-off diseases can be promoted by good seed germination and quick emergence of seedlings, besides planting at the proper depth and spacing. Planting into soils that are warm enough to promote good germination and quick emergence will reduce the opportunity for development of damping-off diseases. If the environmental conditions are favorable for disease development, seed treatment with fungicides should be considered as an option.

For early planted crops like peas, conservation tillage may offer the opportunity to prolong the period before irrigation, which may in turn, reduce soil-borne diseases by keeping the soil drier early in the crop's development.

The ergots shall remain on or near the surface under reduced tillage conditions that may become a problem during the second year. The risk of disease carryover between cereal crops may increase due to the presence of cereal volunteers. Hence, the option of plowing needs to be considered in order to bury the ergots on the surface where disease levels become high.

If volunteer cereals and grass weeds are left unchecked, the threat of barley yellow dwarf virus (BYDV) in cereals may be increased as these will harbor aphids (and possibly BYDV). The volunteer cereals and grass weeds acts as a "green bridge" between the previous crop and the next. Hence, in order to reduce the risk of aphids and BYDV in cereals, the weed management either before sowing or postemergence may be required.

Under reduced tillage systems, the microbial activity may be increased due to the creation of an environment that shall be more antagonistic to *Cochliobolus sativus* (Tinline and Spurr 1991). The antagonistic populations such as mycophagous amoebae and fungi that feed on *C. sativus* may be favored by the cooler soil temperatures associated with reduced tillage in some parts of Canada which may kill *C. sativus* "resting" spores (Duczek 1986; Duczek and White 1986). In reduced tillage systems, it may be comparatively easy to displace *C. sativus* due to intense microbial competition in the rhizosphere, since *C. sativus* has a low competitive saprophytic ability and can only become established if it is the initial invader (Tinline 1977; Herman 1984).

Many diseases can be avoided or their damage reduced by preventing soil from becoming too wet by managing soil moisture through controlled irrigation.

The critical factor for successful disease management under reduced tillage is by following diverse crop rotations which prevent the probability of disease inoculum buildup over time. The integration of crop rotation with cultural, chemical, or biological controls should be used in cases where the disease is not completely managed through crop rotation.

Other recommendations for limiting the risk of diseases under reduced tillage systems include the following:

- Insect pest management to prevent the spread of viral infection and to avoid wounds which become infection points for pathogens
- Management of adequate soil fertility and pH
- Management of plant-density recommendations for the crop and the variety

- Weed management to enhance air movement within the crop canopy and limit disease development

Specific recommendations for corn diseases are as follows:

- Management of seed rots and seedling blights by planting when soil temperatures are above 52 °F.
- Management of ear and stalk diseases by selecting hybrids with good stalk strength and rotation with nongrass crops.

2.5 Nematode Management

Zero till rice and zero till wheat with and without crop residues integrated with *Sesbania* sp. showed low population densities of *Meloidogyne graminicola*, root gall index, and wide nematode to root biomass ratio and thereby serve as better options for the management of *M. graminicola* (Table 2.6).

2.6 Nonpesticidal Management Practices

Nonpesticide practices become more important under conservation tillage. Crop rotation, field sanitation, irrigation management, proper planting techniques, and variety selection are some of the essential practices that can be adopted for pest management in reduced tillage.

2.6.1 Crop Rotation

Insect pests, diseases, and weeds can be managed by diverse crop rotation that forms the backbone of an integrated strategy. The likelihood of developing herbicide-resistant weeds can be prevented by following strategic crop rotation (including

Table 2.6 Effect of resource-conservation practices on population of *Meloidogyne graminicola* on rice plants grown in soil samples collected from wheat fields

Resource conservation practices	J2 population at harvest	Nematode biomass (μg)	Root biomass (μg)	NB: RB Ratio	Root gall index
Zero till rice + zero till wheat (without residue)	4317	2426	156,973	1:65	5.0
Zero till rice + zero till wheat (with residue)	4102	1639	60,110	1:37	5.0
Zero till rice + zero till wheat with *Sesbania*	800	787	79,043	1:100	2.5
CD ($P = 0.05$)	15.28	17.21	15.52	–	–

herbicide-resistant crops when deemed useful) that allows the use of different groups of herbicides to manage different problem weeds. The decline of weed seed bank is possible by allowing sufficient time gap between similar crops. The insect pests with limited mobility and that live in the soil are effectively managed by crop rotation. The strategic choice of crop sequence in a diverse rotation can be utilized to manage several plant pathogens that survive in or on crop residues. The population of pathogens will decrease to tolerable levels by giving sufficient time gap between diverse crops (for further details on crop rotation see Chap. 15).

2.6.2 Field Sanitation

Field sanitation plays a major role in pest management under reduced tillage systems. Management of volunteer small grains and weedy grasses in and around direct-seeded corn fields 3–4 weeks before planting is necessary, since these weeds can serve as hosts for viral diseases and their insect vectors, and as a “green bridge” for soil-borne pathogens. The problem weeds can also be managed by keeping the field borders free from these weeds.

2.6.3 Proper Planting Procedures

The farmers should not exceed the recommended seeding rate for a given crop and variety, in order to maintain the plant density such that humidity levels determined for the crop canopy are maintained adequately. Appropriate plant density along with efficient weed control, facilitates good air movement through the crop canopy and prevents disease development.

In reduced tillage systems, getting the crop off to a good start by rapid germination and emergence shall reduce the potential for development of damping-off diseases (which may be promoted under the wetter soil conditions), and will make the crop more competitive with weeds. The importance of planting at the proper spacing and depth, and with adequate available nutrients cannot be overlooked. In conventional tillage conditions, use of seed treatments with pesticides for the management of soil-borne pests is also important.

2.6.4 Irrigation Management

The optimization of soil moisture through controlled irrigation is another method that can be used to control soil-borne diseases by avoiding saturated conditions after irrigation under reduced tillage. The amount of soil splashed onto the crop from rain or irrigation is reduced by soil-surface residue cover resulting in white mold disease management in beans under reduced tillage systems.

Management of diseases caused by *Phytophthora* spp. is based on limiting susceptibility through drainage and irrigation. The most important factors that increase the severity and spread of *Phytophthora*-incited diseases include excess irrigation and rainfall and the duration of free water in soil or on foliage or fruit because it is during this time that propagules proliferate and infect (Erwin and Ribeiro 1996). Further, the propagules such as zoospores, cysts, and chlamydospores travel in the soil through irrigation water, rainfall run-off, and movement of soil. Hence, orchards should be established preferably in sloping land that is well drained and not subject to flooding. The soil should be ideally drained to a depth of 1.5 m. Proper drainage can be provided by mounding of the soil around the tree (Broadley 1992). In order to prevent free water from contacting the plants, the row crops should be planted on raised beds. The plants should be irrigated less frequently so that free water drains away to reduce the rate and extent of buildup of inoculum (Lutz et al. 1989). To prevent waterlogging in areas where rainfall is the main source of water, optimal horizontal and vertical drainage are necessary.

The irrigation water, particularly the recirculated water, can potentially introduce propagules of plant diseases. Pathogens such as *Pythium dissotocum* and *P. rostratum* have been detected in irrigation water from holding ponds in Colorado (Pottorff and Panter 1997). *Olpidium brassicae*, the fungal vector of Lettuce Big Vein Virus and Lettuce Ring Necrosis Disease, both limit the development of recirculated nutrient film (NFT) production of lettuce (Vanachter 1995).

2.6.5 Variety Selection

One of the practical and economical strategies for pest management includes utilization of crop varieties that are resistant or tolerant to insect pests and diseases. While choosing the varieties, herbicide tolerance should also be considered. The seeds of several commercial pest-resistant and herbicide-tolerant varieties are supplied by various seed companies for use by the farmers.

2.6.6 Scouting and Pest Identification

Regular is very critical before planting and through crop emergence and growth to catch insect pests, diseases, and weeds at the proper growth stage before reaching damage threshold and treating them with the right pesticides or herbicides. The diagnosis and proper identification of insect pests, diseases, and weeds is very crucial for their management.

The effect of different tillage systems for management of pests, diseases, and weeds of cereals is presented in Table 2.7.

Table 2.7 Effect of different tillage systems on management of weeds, diseases, and insect pests (including predators) of cereals

Weeds diseases/insect pests/predators	Plow	No-till	Reduced till
Weeds			
Grass weeds (excluding wild oats)	−−−	++	+++
Wild oats seed bank	0	−	0
Volunteer crops	−	++	+++
Broad-leaved weeds (excluding cleavers)	++	−−	−
Cleaver seed bank	0	0	0
Perennial weeds	−/+	++	++
Herbicide-resistant grass weeds	−−	+++	+++
Diseases			
Take-all on wheat	++	−	−
Common eyespot	++	−	−
Fusarium	−	+	+
Cephalosporium leaf stripe	−	++	++
Insect pests			
Slugs	−	+	+[a]
Aphids	−	+	+
Predators			
Predatory ground beetles	−−	+++	++

−: decrease, **+**: increase, 0: little or no effect

[a] In conjunction with increased predation by ground beetles

2.7 Conclusions

Pest management in conservation tillage systems may present a challenge. The alternative pest management strategies such as planning and field scouting, applying timely solutions, and using crop rotation have been used by successful farmers. The keys to success in conservation tillage include foresight and flexibility. The timeliness of all production practices, a formal field scouting protocol to identify problems, and the proper selection and implementation of control strategies are required for successful pest management in conservation tillage systems. The essential components in profitable conservation tillage production systems include preventative IPM strategies coupled with early detection of problems and reactive treatments. Identification of pest-free seed beds well in advance of planting, optimal application dates for agronomic practices, and judicious use of preventative and reactive chemical control strategies are the prerequisites for an effective pest management strategy under conservation tillage.

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3

Crop Residue Management and Organic Amendments

Abstract

Cultural practices like the type and quantity of crop residues and incorporating organic amendments to soil have a direct impact on plant health and crop productivity. These practices influence the release of biologically active substances from both crop residues and soil microorganisms. Organic mulches like straw suppress annual weed seedlings, conserve moisture, and add organic matter as they break down, but they are more labor-intensive to apply. All organic mulches are useful for suppression of insect pests in comparison to bare soil. The presence of more crop residues can form a physical barrier for the completion of the life cycle of certain pathogens, like *Sclerotinia* spp., or prevent pathogens from being spread through soil movement by agricultural equipment, water, or wind. The crop residues have a direct correlation with the nematode population in soil, and prevent the nematode spread over long distances, and bring down the soil temperature which results in a slower development of the life cycle of nematodes. The application of crop residues, composts, manures, and organic amendments that are rich in nitrogen may reduce pests by releasing allelochemicals generated during product storage or by subsequent microbial decomposition. Introducing crop residue management and organic amendments takes time, but the benefits accumulate across successive years improving weed suppression and pest management.

Keywords

Crop residues • Organic amendments • Insect pests • Diseases • Nematodes • Weeds

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3.1 Introduction

Plant health and crop productivity are influenced by incorporating organic amendments and managing type and quantity of crop residues. The factors that impact decomposition of organic amendments and crop residues include the crop type and residue quantity, depth of placement in the soil, allelopathic interactions between existing soil biota and time, and soil and climate factors. The lowering of pest population in the soil, reduction of their ability to survive, deprivation of their host, and creation of conditions that favor the growth of other microorganisms at the expense of the pest are some of the mechanisms through which pest control is attained by using organic amendments and crop residues. Management of insect pests, diseases and weeds by high residue farming system is being adapted by an increasing number of farmers from different regions to suit their conditions and crops.

Higher numbers of species that can cause damage to crops and also beneficial organisms that parasitize on eggs of certain pest species occur under high residue farming that is a more natural system (Gonzales and Dave 1997). The quantity of residues left on the surface and the crop rotation practiced determines new balances between different species. Weeds, insect pests, diseases and nematode pests can be managed using organic amendments and crop residues.

3.2 Weed Management

The better weed suppression is commonly achieved by higher levels of crop residues covering the soil surface (which can also hamper planting) and the effect is species-specific (Chauhan et al. 2006). The chemicals that suppress weed growth are released during the decomposition of crop residues (allelopathy) from Brassica crops and cereal rye (Haramoto and Gallandt 2004).

Straw mulch is generally used by the organic farmers, since it is readily available, provides good suppression of weeds, and saves fuel and labor costs. The reasons for suppression of some weeds by covering the soil surface with suitable mulch include:

- Blocking of sunlight (shading)
- Conserving soil moisture for enhancing crop growth and competitiveness
- Decreasing soil temperatures
- Physically hindering emergence of weeds
- Providing habitat for insects that eat weed seeds
- Reducing weed seed germination

Organic mulches such as hay, straw, leaves, and chipped brush are most effective on weeds emerging from seed and least effective on aggressive perennial weeds emerging from rootstocks, rhizomes, or tubers. The later-emerging weeds (until the crop has passed through its minimum weed-free period) can be managed by organic mulch applied immediately after the final cultivation. Some of the benefits of

Fig. 3.1 Effect of hay mulch on suppressed emergence from a large weed seed bank of galinsoga (*Galinsoga* spp.) and other annual broadleaf weeds in broccoli, onion, and garlic

organic mulches include lowering the soil temperatures, conserving soil moisture by slowing evaporation while allowing rainfall to penetrate, and improving soil quality. The crop residues are left in the field after harvest as soil surface cover that helps to build soil organic matter as it breaks down. The fruit quality in pumpkin and other vine crops is improved by organic mulch that prevents fruit-soil contact.

Application of a thick layer of mulch (of hay, straw, or leaves) on soil surface blocks the light stimulus, thereby reducing seed germination in many agricultural weeds such as annual bluegrass (*Poa annua*), black nightshade (*Solanum nigrum*), common chickweed (*Stellaria media*), common lambsquarters (*Chenopodium album*), common purslane (*Portulaca oleracea*), common ragweed (*Ambrosia artemesiifolia*), hairy galinsoga (*Galinsoga ciliata*) (Fig. 3.1), and some pigweeds (*Amaranthus* spp.) (Egley 1996). The weed seed germination is also deterred by organic mulches that lower soil temperature and dampen daily fluctuations.

The interception of light which is essential for photosynthesis and for physically hindering seedling emergence is possible by organic mulch. The mulch effect can easily suppress the dicot (broadleaf) weed seedlings that are fairly delicate. The small-seeded broadleaf weed seedling emergence can be suppressed for at least several weeks by hay, straw, or cover crop residues at 7.5–12.5 tons per ha (5–10 cm thick, loosely packed), while the germination of larger-seeded species such as common cocklebur or velvetleaf (*Abutilon theophrasti*), and some grasses, whose shoots are protected by a pointed sheath (coleoptile), can be suppressed by a heavier mulch (12.5–17.5 tons per ha). The increased suppression of weeds in wheat can be achieved by enhancing the quantity of rice residue as mulch (Rahman et al. 2005).

Ninety-five percent of milkweed seeds, 68% of foxtail seeds, and 51% of dock seeds were suppressed using biofumigation with rapeseed. Integration of tarping for soil solarization before biofumigation with rapeseed suppressed 94% of dock and 100% of milkweed.

The emergence of several weed species with small seeds was affected to the extent of 20 to 95% and reduced growth of weed seedlings from 8 to 90% by addition of chopped residues of *Brassica hirta*, *B. juncea*, and *B. napus* to the soil under greenhouse studies on potato. Eight individual isothiocyanates, including methyl- and allyl-isothiocyanates (being the most inhibitory), were responsible for inhibition of germination and growth to various degrees of redroot pigweed and Barnyard grass, *Echinochloa crusgalli*. The fresh weight of redroot pigweed was reduced by more than 90% by addition of Meadow foam, *Limnanthes alba* seed meal at 1% or more by weight to the soil in greenhouse trials.

Soil surface cover with organic mulches alone cannot prevent 100% of weed emergence. Integration of organic mulches along with good crop rotation gives effective suppression of aggressive weeds such as nutsedge and morning glory.

3.3 Insect Pest Management

All organic mulches are useful for suppression of insect pests in comparison to bare soil. The habitat for spiders (which find mulch more habitable) are provided by hay and straw mulches that give 70% reduction in damage due to insect pests on vegetables. Under enough soil cover of organic mulches, even the presence of high numbers (100 larvae per m^2) of the plant-eating insects, like white grubs (*Cyclocephala flavipennis*), cannot cause enough damage to crops.

Straw mulch is responsible for reduction of the early-season Colorado potato beetle's (CPB's) ability to locate potato plants and for the suppression of its activity in potatoes due to the creation of a micro-environment that enhances the population of predators such as lacewings, lady beetles, and ground beetles. The reduction of defoliation and enhancement of potato yields by one-third compared to plots with no mulch was also noticed in these trials.

The development of snails and slugs (which can cause considerable damage to crops) is favored by the presence of residues on the soil surface that conserve the moisture. Heavy infestations of snails and slugs can be prevented by proper residue management. Snails and slugs can also be managed using the following practices:

- Application of ammonium nitrate (rich in nitrogen) at sunset: an efficient low-cost practice which enhances the decomposition of organic matter
- Slugs and snails are attracted to beer kept in a bowl
- Improvement of soil drainage in the field
- Removal of residues from the field with high risk of occurrence
- Use of effective chemicals (metaldehyde)

Significantly less population of thrips, mites, and leaf curl index and improved growth parameters and chili yield was noticed in plots treated with vermicompost at 2.5 t ha^{-1} followed by four sprays with 5% neem seed kernel extract (NSKE) and Neemazal at 2, 5, 7, and 11 weeks after transplanting alternatively; or application of neem cake at 0.5 t ha^{-1} followed by 5% NSKE and Neemazal at 2, 5, 7, and 11 weeks after transplanting alternatively (George 2006).

The increased number and diversity of natural enemies of aphids that predate on them was observed when soil was covered with organic mulches which may also interfere with the visualization mechanism of aphids, when identifying the possible host plants. The aphids may also find it difficult to distinguish the host plants due to reflection of the sunlight in a different way by soil cover as compared to bare soil (Cunha Fernandes 1997).

3.4 Disease Management

The presence of fresh vegetative crop residues on the soil surface provides the most essential medium for growth and survival of pathogens. The favorable habitat is provided for disease-causing organisms that develop better in cooler and moister environments by the presence of more crop residues. Hence, special attention is required for solving the pathogen inoculums survival problem by way of biological destruction or decomposition of crop residues by microorganisms until the residues are fully mineralized through proper crop rotations. The type of crop, differences in C/N ratio, different climatic conditions, etc. affect the decomposition of crop residues. From plant pathological point of view, crop rotation means refraining from planting the same crop until complete decomposition of crop residues occurs that consequently eliminates pathogens from the field.

On the other hand, the presence of more crop residues can form a physical barrier for the completion of the life cycle of certain pathogens, like *Sclerotinia* spp., or prevent pathogens from being spread through soil movement by agricultural equipment, water, or wind (Costamilan 2000). Similarly, the lowest incidence of *Tilletia indica* (Karnal bunt) infection was noticed in wheat planted into no-till rice residue (Sharma et al. 2007).

The incidence of foliar disease of tomatoes planted in a dead mulch of hairy vetch was reduced, had higher yields, and lived longer than tomatoes planted in live mulch. Similarly, the Fusarium wilt in watermelon was reduced by 26% when a dead mulch of hairy vetch was used (Stone 2012).

Besides crop residue management, disease management strategies should also focus on other alternative measures which include:

- Resistant varieties
- Rotation of crops
- Seed treatment with chemicals
- Shallow seeding (2–3 cm deep)
- Soil compaction prevention
- Soil drainage improvement

Reduction in tillage practices (more crop residues) increases the disease incidence, while integration with crop rotation drastically reduces the pathogen population, as is the case with oats and vetch rotation (Fig. 3.2) (Viedma 1997).

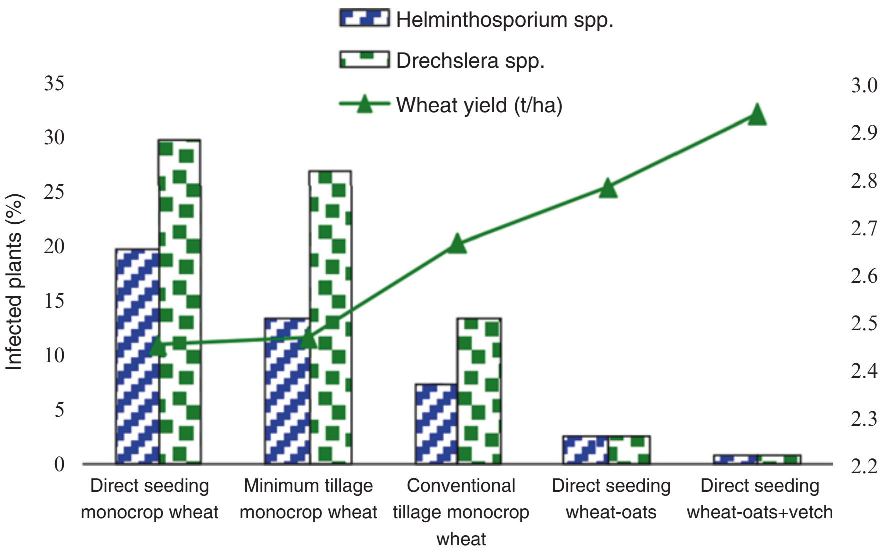

Fig. 3.2 Effect of integration of crop residues with crop rotation on disease incidence and yield (Viedma 1997)

There is a positive influence on the reduction of virus diseases with crop residues, since the vector that transmits the virus (i.e. the aphids) is influenced. The number and diversity of natural enemies that predate on aphids are provided with habitat by the soil cover. The soil cover may also interfere with the visualization mechanism of aphids in distinguishing the possible host plants, as the cover reflects the sunlight in a different way compared to bare soil (Cunha Fernandes 1997).

The soil cover with crop residues enhances soil biological biodiversity that provides the agro-ecosystem with naturally occurring microorganisms that suppress certain disease-causing pathogens. Increased levels of organic matter enhance the population of biological control agent, *Gliocladium virens* which controls damping-off pathogens. Similarly, the bioagent *Pseudomonas fluorescens* has been associated with a decrease in “take-all” disease (*Gaeumannomyces* spp.) in wheat, while *Agrobacterium* limits the growth of *Fusarium* spp. (Hiddink et al. 2005). The resistance against plant pathogens that infects both the roots and upper parts of crops including plant pathogenic nematodes is inducted by the well-known plant growth-promoting rhizobacterium, *P. fluorescens* (Shennan 2008).

The antagonistic potential of soil microorganisms against crop diseases is enhanced by the maintenance of high levels of organic carbon in the soil by mulching or the application of animal manures. Soil cover with *Gliricidia sepium* biomass mulch is effective against pathogens near the soil surface due to release of root leachates (which contain phenolic substances like protocatechuic acid) with known fungistatic properties (Inostrosa and Fournier 1982; Ramamoorthy and Paliwal 1993). Soil mulching with *Gliricidia sepium* biomass reduced the incidence of rust and late leaf spot in groundnut (Schroth et al. 1995). Rao et al. (2000) have extensively discussed the effects of mulches against crop pests.

Rice can withstand attacks by pathogens like Striga or blast disease caused by *Magnaporthe grisea*, since mulching reduces evaporation and contributes to better water nutrition of crops (Scopel et al. 2004; Husson et al. 2008; Sester et al. 2008).

The spore germination of *Cochliobolus sativus* is prevented in soils with high levels of organic matter (Chinn 1967). Drastic reduction (approximately tenfold) in sporulation of *C. sativus* on wheat and barley residue left on the soil surface was noticed in the Canadian prairies after 10 months (Duczek et al. 1999). However, reduced level of sporulation continued for at least 20 months. The lower plant parts especially the sheaths, stems, and crowns that took longer to decompose than the leaves supported greater sporulation. Reduced tillage possibly contributed to reduced disease potential of the pathogen as nitrate levels are lower under reduced tillage systems, since *C. sativus* appears to be more dependent on NO_3-N than on NH_4-N.

The incidence of Verticillium wilt and common scab of potato was considerably reduced under field conditions by soil application of bone meal, soy meal, and poultry manure at 37 t ha^{-1}incorporated to a 15 cm depth (Lazarovits et al. 1999; Conn and Lazarovits 1999).

Lumsden et al. (1986b) reported that the incidence of lettuce drop caused by *Sclerotinia minor* was reduced in field for the next 4 years due to soil application of composted sewage sludge for 2 years. The suppression of *Pythium* and *Rhizoctonia* damping-off was due to enhanced soil microbial activity (Lumsden et al. 1986a).

The pathogens' population was reduced by soil application of organic amendments such as cellulosic soil amendments, compost, farm yard manure, mature crop residues, oil cakes, and vermicompost. During the decomposition of organic amendments in soil, certain chemicals are released which are toxic to pathogens. Besides, the reduction in numbers of pathogens may also be due to the stimulation of predaceous and parasitic fungal population. The bacterial biocontrol agents such as *Bacillus* spp., *Enterobacter* spp., *Flavobacterium balustinum*, *Pseudomonas* spp., *Streptomyces* spp. as well as fungal species including *Gliocladium virens*, *Pencillium* spp., and several *Trichoderma* spp. colonize the compost during the curing phase after heating.

The consistent natural suppression of damping-off and root diseases caused by *Pythium* and *Phytophthora* spp. can be achieved by the application of compost in potting mixes. The suppressiveness of potting mixes to other pathogens such as *Rhizoctonia* and *Fusarium* spp. can be increased by enriching the compost with specific antagonists like non-pathogenic *Fusarium oxysporum, Trichoderma* spp., and *Verticillium biguttatum*. The enriched composts produced are up to three times more suppressive to pathogens when compared with the non-amended naturally suppressive compost.

Under protected greenhouse conditions, the soil-borne diseases such as Fusarium wilt of bell pepper (*F. oxysporum* f. sp. *vasinfectum*) and cucumber (*F. oxysporum* f. sp. *cucumerinum*) can be managed by drenching the soil with non-aerated compost tea (Ma et al. 2001). The reliable composted bark media which are as effective as modern synthetic fungicides have been developed for different crops (grown in

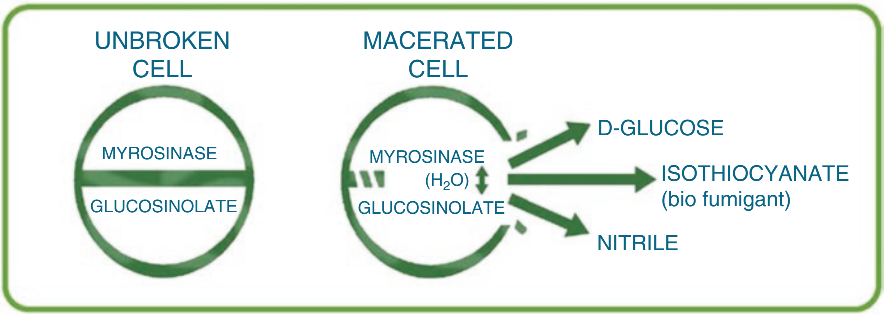

Fig. 3.3 Glucosinolate hydrolysis to release isothiocyanate

composted bark amended substrates) to manage root rots caused by *Pythium* and *Phytophthora* spp.

The incidence and severity of diseases such as *Aphanomyces eutiches* on pea, *Fusarium oxysporum* f. sp. *melonis* on melons, *Phytophthora capsici* on bell pepper, *Rhizoctonia solani* on bean, and *Sclerotinia minor* on lettuce were considerably reduced by soil application of composted sewage sludge to soil (10% by volume). Similarly, the incidence of damping-off of pea cultivars (smooth skinned and wrinkled) caused mainly by *Rhizoctonia solani* and *Pythium ultimum* was significantly reduced in field plots by soil amendment with composted sewage sludge (7–10 t ha^{-1}) (Lewis et al. 1992).

Soil application of composted cotton-gin trash was effective in reducing the incidence of southern blight (*Sclerotium rolfsii*) of tomatoes between 3 and 23%, as compared to 61 and 67% in infested plots without compost. Likewise, the viability of onion white rot pathogen, *Sclerotium cepivorum* was reduced, which was as effective as a standard fungicide treatment (tebuconazole) (Coventry et al. 2006). Similarly, Tsror (Lakhim) et al. (2001) reported that the application of cattle manure compost at 60 m^3 ha^{-1} reduced the incidence of potato black scurf (*Rhizoctonia solani*) disease between 18.6 and 62.3% in comparison to controls with no compost added. The factors responsible for reduction of diseases and higher potato tuber yields include the presence of organic matter, organic nitrogen, and increased nutrient availability (Davis et al. 2001). Addition of organic amendments to the soil enhances beneficial microbial populations and results in soil-sanitization effects and, in some cases, may replace crop rotation (Mathre et al. 1999).

3.4.1 Biofumigation

Stapleton (1998) defined biofumigation as an agronomic practice that releases volatile biotoxic compounds into the soil atmosphere during the decomposition of organic amendments. The isothiocyanates (ITCs) (related to the active ingredient in the commercial fumigants metham sodium and dazomet) are the most common volatiles produced during the breakdown of Brassicas that are highly toxic to pathogens (Fig. 3.3) (Delaquis and Mazza 1995).

The volatile chemicals (allelochemicals) released while decomposing *Brassica* tissues such as biologically active green manures are utilized to manage soil-borne pathogens. The myrosinase enzymes at neutral pH hydrolyze glucosinolates (GSLs) to release ITCs following tissue damage. Most researchers believe that GSLs [sulfur containing chemicals (thioglucosides)] that are produced as secondary metabolites by Brassicas are responsible for providing the resistance against pathogens. Substantial quantities of ITC can be produced using black mustard (*B. nigra*) and Indian mustard (*B. juncea*) (Tollsten and Bergström 1988) and could be utilized in a biofumigation cropping system. The take-all disease (*Gaeumannomyces graminis*) in cereal rotations can be managed by the use of Brassicas such as canola (*Brassica napus*) as break crops.

Biofumigation involving GSL-containing plants can be utilized under field conditions as rotation crops, or intercrops, by incorporating fresh plant material as green manure, or utilizing processed plant products high in GSLs such as seed meal, or dried plant material treated to preserve ITC activity. Pathogens such as *Botrytis cinerea, Cladosporium fulvum, Didymella lycopersici, Fusarium oxysporum,* and *Rhizoctonia solani* can be managed by the biofumigation products (Urbasch 1984). Similarly, tomato pathogens such as *P. ultimum*, *R. solani*, and *S. rolfsii* are suppressed using volatiles from various Brassica species (Charron and Sams 1998, 1999; Harvey et al. 2002). Likewise, diseases like *Verticillium* in potato; *Pythium, Fusarium,* and *Rhizoctonia* root rots in beans; *Pythium* in lettuce; pink root in onion; *Aphanomyces, Pythium, Rhizoctonia,* and *Fusarium* root rot in peas; and cavity spot and *Fusarium* in carrot can be managed by incorporating Brassica crops' green residues as green manures (Sanders 2005) (for further details on biofumigation see Chap. 4).

3.5 Nematode Management

A large number of studies have demonstrated the use of organic amendments (like sawdust, oilcakes, sugarcane bagasse, bone meal, sewage sludge) for management of plant-parasitic nematodes (Akhtar and Malik 2000; D'Addabbo 1995; Litterick et al. 2004; Stirling 1991). The recent overview of the organic materials that have been most effective for nematode management has been reviewed by Oka (2010). Since large amounts of organic amendments have to be applied to soil for effective nematode management, the practice might be too expensive to adopt under field conditions.

Chitinous materials like crushed shells of shrimps and crab should be applied to the soil in order to enhance the population of "nematode-trapping" fungal species. After the complete decomposition of the shell material, these fungi will feed on chitin-containing nematode eggs (Yepsen 1984).

In general, the crop residues have a direct correlation with the nematode population in soil. The soil surface cover with crop residues prevents the spread over of cysts over large distances and brings down the soil temperature which results in a slower development of the life cycle of nematodes (at 23 °C the life cycle takes 24 days, while at 18 °C the same life cycle takes 40 days).

The incidence of plant-parasitic nematode populations is considerably reduced by soil application of bone meal, soy meal, and poultry manure at 37 t ha^{-1} incorporated to a 15 cm depth under field conditions (Lazarovits et al. 1999).

The root-knot nematode, *M. javanica* can be managed by maintaining high levels of organic carbon in the soil through mulching with crop residues or the application of animal manures to enhance the antagonistic potential of soil microorganisms such as the fungus *Pochonia chlamydosporia* and the bacterium *Pasteuria penetrans* (Page and Bridge 1993).

The lesion nematode *Pratylenchus coffeae* on tea bush is satisfactorily controlled by soil application of the Guatemala grass, *Tripsicum laxum* at 20 to 30 tons per ha (Loos 1953). The slow wilt/pepper yellows (*Radopholus similis*) and the root-knot nematode (*M. incognita*) population on black pepper (Ichinohe 1980) were managed by mulching with Guatemala grass. Another species of lesion nematode *Pratylenchus loosi* population on tea declined by incorporation of large quantities of green manure such as loppings from dadaps, *Tephrosias,* and marigolds. Bhattacharya and Rao (1984) reported that soil mulching with sugarcane and banana trash reduced the burrowing nematode *R. similis* and the lesion nematode *Pratylenchus* sp. in banana roots.

Mulching of kacholam with neem and chromolaena green leaves at 5 kg/m^2 15 days before planting rhizomes, reduced root galling (1 as compared to 5 in control), root-knot nematode population both in soil (80.4–81.8%) and roots (86.14–89.60%) and increased the rhizome yield (160.7–143.3%).

Amendment of soil with sheep and chicken manure reduced the citrus nematode (*Tylenchulus semipenetrans*) population. The infestation level of *Globodera rostochiensis* in potato roots was reduced and development of nematodes in plant roots was slowed down by application of Farm Yard Manure (FYM) and compost to nematode-infested soil that imparted some type of biochemical resistance to the plants by nutrients from these manures.

The nematodes on turf grass (*Belonolaimus longicaudatus* and *Hypsoperine graminis*) were effectively controlled by organic N in the form of sewage sludge than inorganic N from ammonium nitrate.

3.6 Conclusions

Crop residue management practices and various forms of organic amendments are responsible for suppression of weeds and economic management of insect pests, disease pathogens, and nematode parasites. However, the level of understanding of the mechanisms involved in pest management is still very much limited. The decomposition of crop residues results in biological and chemical processes that can directly affect the pest's ability and survival through the restriction of available nutrients and the release of natural antimycotic substances with varying inhibitory properties. The increased soil microbial activity and the likelihood of increased competition effects in the soil is contributed by the Carbon released from crop residues. The effect of addition of organic amendments to soil for pest management are generally slower acting than chemical pesticides, but incremental, may last longer, and their effects can be cumulative. The evaluation of information on the impacts of crop residues and organic amendments on whole soil ecosystems is vital. Better tools are needed to overcome the problem of batch consistency, if residue management and organic amendments are to operate reliably.

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Biofumigation

4

Abstract

In order to reduce the need for chemical fumigation, especially in tight rotations, the use of certain crops as biological fumigants ahead of crop production to manage soil-borne pests is receiving considerable interest in recent times. The crops that have shown the potential to serve as biological fumigants include plants in the mustard family (such as mustards, radishes, turnips, and rapeseed) and sorghum species (Sudan grass, sorghum-Sudan grass hybrids). The crops from the mustard family show some promise to reduce soil-borne pests by releasing naturally occurring compounds called glucosinolates in plant tissues (roots and foliage). When chopped plant tissues are incorporated in the soil, they are further broken down by enzymes (myrosinase) to form chemicals (glucosinolates) that behave like fumigants. Isothiocyanates are the breakdown products of glucosinolates, which are the same chemicals that are released from metam sodium (Vapam) and metam potassium (K-Pam), commonly used as chemical fumigants. A cyanogenic glucoside compound called "dhurrin" breaks down to release toxic cyanide when sorghum plant tissue is damaged.

Keywords

Glucosinolates • Isothiocyanates • Myrinose • Biofumigant crops

4.1 Introduction

Soil-borne pathogens (fungi, bacteria), nematodes, and weeds are important limiting factors in the production of crop plants. Preplant soil disinfestations, using pesticides or other physical or biological methods, are one of the principal strategies employed by the farmers growing high-value horticultural crops to manage these pests. Out of the several soil fumigants used for disinfestations of soil, methyl bromide (MB) is the most effective chemical used by farmers around the globe, which

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has an excellent broad spectrum pesticide activity against most potential soil pests. However, MB was identified as a risk to the stratospheric ozone layer in 1992 and was targeted for worldwide phaseout by 2005 by means of the Montreal Protocol, an international treaty (USDA 2000). Among the potential alternative control methods being touted to replace methyl bromide, biofumigation is recognized as the most useful of the nonchemical soil disinfestation methods.

4.2 Biofumigation

The agronomic technique that makes use of some plants' defensive systems is known as biofumigation. Stapleton (1998) defined biofumigation as an agronomic practice that releases volatile biotoxic compounds into the soil atmosphere during the decomposition of organic amendments. The *Brassicaceae* (cabbage, cauliflower, kale, and mustard) (Fig. 4.1), *Capparidaceae* (cleome), and *Moringaceae* (horseradish) are some of the main plant families in which this system is found. These family members contain secondary plant metabolites called glucosinolates (GSLs), which are believed to be involved in plant defense. When tissues are damaged, glucosinolates are enzymatically broken down by myrosinase to produce nitriles, thiocyanates, isothiocyanates (ITCs), and other products (Fig. 4.2). Isothiocyanates, the predominant breakdown products related to the active ingredient in the commercial fumigants metam sodium and dazomet, have biocidal activity on fungi, bacteria, nematodes, and weeds (Delaquis and Mazza 1995; Mithen et al. 1986; Isshiki et al. 1992). Substantial quantities of biofumigation products can be produced for field application. Biofumigation cropping system involving black mustard (*Brassica nigra*) and Indian mustard (*Brassica juncea*) produces high levels of ITC (Tollsten and Bergström 1988) and can be utilized for the management of soil-borne pests.

The volatile chemicals (allelochemicals) released while decomposing Brassica tissues, such as biologically active green manures, are utilized to manage soil-borne pathogens. The myrosinase enzymes at neutral pH hydrolyze glucosinolates (GSLs) to release ITCs following tissue damage. Most of the researchers believe that GSLs

Fig. 4.1 Brassicas help in controlling soil-borne pathogens

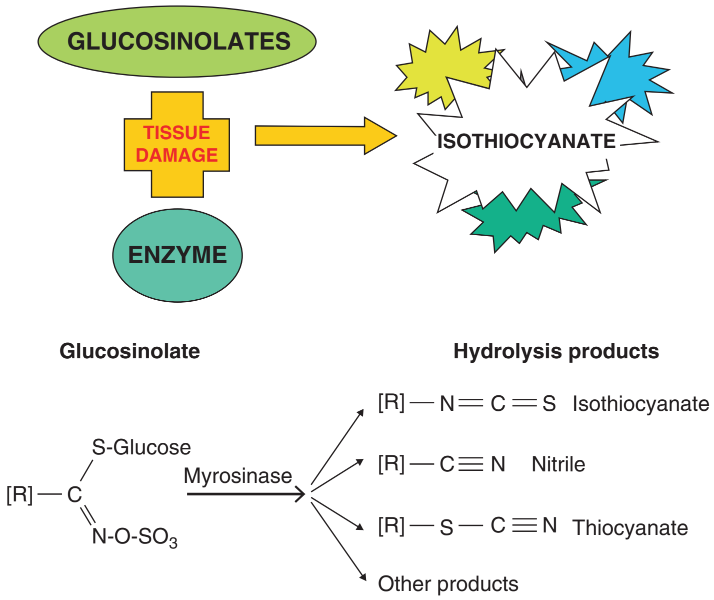


Fig. 4.2 Glucosinolate hydrolysis to release isothiocyanate

(sulfur-containing chemicals [thioglucosides]) that are produced as secondary metabolites by Brassicas are responsible for providing the resistance against pathogens. Substantial quantities of ITC can be produced using black mustard (*B. nigra*) and Indian mustard (*B. juncea*) (Tollsten and Bergström 1988) and can be utilized in a biofumigation cropping system. The take-all disease (*Gaeumannomyces graminis*) in cereal rotations can be managed by the use of Brassicas such as canola (*Brassica napus*) as break crops.

The evaluation of the effectiveness of glucosinolate-containing plants as biologically active rotation and green manure crops for controlling several soil-borne pathogens has been experimented at a full-field scale in a number of countries (the USA, Australia, Italy, the Netherlands, and South Africa) over the past few years. The "biofumigation" seed market is significantly growing year after year, in view of its effectiveness for the management of soil-borne pathogens. Since soil incorporation of the dehydrated plant tissues and/or defatted meal pellets has also been found to have biofumigation effect, the new potential has also been found for their production and use. Integration of biofumigation along with soil solarization can be used as an integrated approach to methyl-bromide replacement in agriculture.

4.3 Benefits

- Enhances water holding capacity of the soil.
- Increases soil microbial populations.
- Improves soil microbial community structure.

- Improves soil texture (physical, chemical, and biological soil characteristics).
- Increases nutrient availability through weathering of soil mineral components by the production of acids by microorganisms during the decomposition of the green manure.
- Increases water infiltration rate.
- Produces a delayed, but remarkable increase of potentially mineralizable nitrogen (N).
- Provides organic biomass to the soil.
- Reduces runoff and preserves nitrogen.
- Reduces wind erosion.
- Reduces soil compaction.
- Significantly suppresses weeds, nematodes, and soil-borne plant pathogens.

4.4 Modes of Utilization

Biofumigation involving GSL-containing plants can be utilized under field conditions as rotation crops, or intercrops, by incorporating fresh plant material as green manure, or utilizing processed plant products high in GSLs such as seed meal or dried plant material treated to preserve ITC activity.

The pathogens such as *Botrytis cinerea*, *Cladosporium fulvum*, *Didymella lycopersici*, *Fusarium oxysporum*, and *Rhizoctonia solani* can be managed by the biofumigation products (Urbasch 1984). Similarly, tomato pathogens such as *Pythium ultimum*, *R. solani*, and *Sclerotium rolfsii* are suppressed using volatiles from various Brassica species (Charron and Sams 1998, 1999; Harvey et al. 2002). Likewise, pathogens like *Verticillium* in potato; *Pythium*, *Fusarium*, and *Rhizoctonia* root rots in beans; *Pythium* in lettuce; pink root in onion; *Aphanomyces*, *Pythium*, *Rhizoctonia*, and *Fusarium* root rots in peas; and cavity spot and *Fusarium* in carrot can be managed by incorporating Brassica crops' green residues as green manures (Sanders 2005).

4.4.1 Crop Rotation/Intercropping

The root exudates of growing plants throughout the season, or the leaf washings or root and stubble crop residues are responsible for biofumigation by rotation crops or intercrops. The suppression of weeds and pathogens in both natural and managed agro-ecosystems may be due to both GSLs and ITCs that have been detected in the rhizosphere of intact plants. The effective management of Verticillium wilt (*Vertcillium dahliae*) on strawberry production systems can be achieved by crop rotation with broccoli (Brassica vegetable) (Subbarao et al. 2007). In both infested and noninfested sites, the higher reduction of *V. dahliae* microsclerotia and higher vigor and yield of strawberry occurred following broccoli or Brussels sprout rotation crops compared with lettuce (for further details on crop rotation see Chap. 15, and on intercropping see Chap. 8).

Fig. 4.3 Growing and incorporation and mixing of green manures in soil of plant material using tractor-drawn implements

4.4.2 Incorporation of Biofumigants

Growing of crops specifically for soil incorporation with the aim of converting GSLs to ITCs is the most recognized use of biofumigant plants. Thorough maceration of plant tissue is required before rapid incorporation into soil and addition of water (if necessary) to ensure complete hydrolysis in order to achieve high levels of ITC release (Matthiessen and Kirkegaard 2006; Kirkegaard 2009). Covering the soil with plastic mulch or sealing the soil with a roller is beneficial, as some ITCs are quite volatile (Kirkegaard and Matthiessen 2004).

4.4.3 Green Manuring Cover Crops and Trap Crops

Soil incorporation with biofumigant green manures or plow downs integrated with crop rotations was responsible for higher concentrated release of biocidal GSL-hydrolysis products at the time of incorporation (Fig. 4.3). Management of root-knot nematodes and increase in yield (17–25%) on potato were observed by the incorporation of rapeseed (*Brassica napus*) green manures through the release of GSLs (Mojtahedi et al. 1993). Similarly, the population of *V. dahliae* was reduced to a greater degree by green manures of Indian mustard (*B. juncea*), canola (*B. napus*), and radish (*Raphanus sativus*) than a range of cereals but not more than a clover/ryegrass mixture (Harding and Wicks 2001). Likewise, Larkin and Griffin (2007) reported that the mustard green manure was most effective in suppression of common scab (*Streptomyces scabies*) of potato (for further details on green manuring cover crops, see Chap. 7).

Jaffee et al. (1998) suggested that certain specific Brassica green manures can also be used as trap crops for nematode management (for further details on trap crops see Chap. 9).

4.4.4 Processed Plant Products

The high-GSL materials suitable for soil amendment for the management of nematode, fungi, and weeds in high-value horticultural crops include the Brassicaceous seed meals or oil cake by-products (which remain after pressing rapeseed or mustard seed for oil) that contain sufficient intact myrosinase to ensure effective hydrolysis of the GSLs upon wetting. Soil incorporation of dried and ground postharvest residues of Brassica vegetables gave effective suppression of common scab (*Streptomyces scabies*) of potato (Gouws and Wehner 2006). Similarly, incorporation of a range of Brassica amendments at 5 kg fresh material/m^2 significantly increased the suppression of bacterial wilt (*Ralstonia solanacearum*) in potato crops. Likewise, both high-GSL rapeseed meal and low-GSL rapeseed meal were responsible for apple replant disease suppression caused by *Rhizoctonia solani* and *Pratylenchus penetrans* (Mazzola et al. 2001).

4.5 Biofumigation Crops

4.5.1 Brassica Plant Species

4.5.1.1 Rapeseed (Fig. 4.4)

The spring-type rapeseed species *B. napus* and winter-type or biennial rapeseed species *B. rapa* are used as biofumigation crops for the management of plant-parasitic nematodes and weeds. The glucosinolates are the breakdown products responsible for pest suppression with rapeseed cover crop. Soil incorporation of rapeseed can add 80–120 lbs. of residual N per acre.

Fig. 4.4 Rapeseed

Fig. 4.5 *Sinapis alba* and *Brassica juncea* used for biofumigation

4.5.1.2 Mustard (Fig. 4.5)

White or yellow mustard (*Sinapis alba* or *Brassica hirta*, respectively), brown or Indian mustard (*B. juncea*), and black mustard (*B. nigra*) are used as biofumigation crops for the management of weeds and potato diseases. In a wheat/mustard (white and oriental)-potato system, potato early dying (*Verticillium dahliae*) was suppressed and the yields increased (equivalent to fumigated soils). It also improved water infiltration in soil along with a cost savings of about US$66/acre. Mustards contain very high levels of glucosinolates as compared to the true Brassicas and add up to 328 lbs. of residual N per acre.

4.5.1.3 Radish (Fig. 4.6)

The oilseed and forage radish (*R. sativus*) add 140–170 lbs. of residual N per acre.

4.5.1.4 Turnips (Fig. 4.7)

Turnips (*B. rapa* var. *rapa*) alleviate soil compaction and provide many macrochannels that facilitate water infiltration.

4.5.1.5 Rocket

Rocket (*Eruca sativa*) traps root-knot and cyst nematodes; has excellent tolerance to cold and drought; and has good disease, nematode, and weed suppression characters.

Fig. 4.6 Daikon radish at full canopy closure

Fig. 4.7 Wild turnip

4.5.1.6 Processed Brassica Amendments

Lazzeri et al. (2004) reported that incorporation of Brassica-derived isothiocyanate-rich materials such as seed meals (Fig. 4.8) or oils as soil amendments provide biofumigation effects.

The details of different Brassica plant species that are used for biofumigation are presented in Table 4.1.

Fig. 4.8 Brassica seed meal used for biofumigation

4.5.2 Non-Brassica Plant Species

4.5.2.1 Grasses

The decomposition of residues of various Graminaceous crops of agronomic importance, such as barley (*Hordeum vulgare*), wheat (*Triticum aestivum*), triticale (*X. triticosecale*), and oats (*Avena sativa*), exhibited significant deleterious effects on soil-borne plant-parasitic nematodes (Stapleton 2006). A powerful nematicide (dhurrin that degrades into hydrogen cyanide) was observed in Sudan grass and sorghum (Luna 1993; Forge et al. 1995; Wider and Abawi 2000).

4.5.2.2 Garlic and Onions

Sulfur volatile compounds are released during degradation of *Allium* tissues (garlic, onion, and leek) such as thiosulfinates and zwiebelanes that are mainly converted in soil or in *Allium* products (extracts) to disulfides (also produced by *Brassicaceae*) which exhibit biocidal properties. The three disulfides, dimethyl disulfide (DMDS), dipropyl disulfide (DPDS), and diallyl disulfide (DADS), show a good potential for inhibition of various fungal pathogens like *Aphanomyces euteiches*, *Colletotrichum coccodes*, *Fusarium moniliforme*, *F. oxysporum radicis cucumerinum*, *Phytophthora cinnamomi*, *Pythium aphanidermatum*, *Rhizoctonia solani*, *S. rolfsii*, and *Sclerotinia slerotiorum.* The DMDS was the most toxic disulfide against termites.

The products released during decomposition of garlic and onion residues in moist soil inhibited four important agricultural weeds such as black nightshade (*Solanum nigrum*), common purslane (*Portulaca oleracea*), London rocket (*Sisymbrium irio*), and barnyard grass (*Echinochloa crus-galli*). The herbicidal effects of onion and garlic residues were by far more potent at soil temperatures of 39 °C, while the inhibitory effect was mild when tested at 23 °C (Mallek et al. 2007).

Table 4.1 Brassica plant species used for biofumigation

Species	Selection	Sowing time	Biomass yield (t/ha)	Contents in GSLs (μmol/g dry matter)	GSLs yield (Moles/ha)	Main GSLs/ITCs	% N content in dry matter	Biocidal activity
Brown mustard (*B. juncea*)	ISCI 20	Autumn	93.8 ± 1.1	12.9 ± 0.4	201 ± 10	Singrin/2-propenyl-ITC (= allyl-ITC)	1.5	3
		Spring	46.5 ± 10.6	25.8 ± 0.4	246 ± 32.5		2.0	
	ISCI 61	Autumn	133.5 ± 23	11 ± 1.1	183.6 ± 26	-do-	1.4	2
		Spring	60 ± 14.1	17.7 ± 2.3	213 ± 35		2.0	
	ISCI 99	Autumn	109 ± 16	16.9 ± 0.5	300 ± 49.9	-do-	1.2	4
		Spring	54.5 ± 9.5	33.6 ± 1.6	333.8 ± 41		1.6	
Turnip weed (*R. rugosum*)	ISCI 4	Autumn	84 ± 33.2	27.6 ± 3.2	562 ± 158	Cheirolin	1.9	4
		Spring	65.3 ± 21.4	24.7 ± 1.0	160.7 ± 45		2.8	
Rocket (*E. sativa*)	Nemat	Autumn	87 ± 19.2	9.4 ± 0.6	186 ± 15	Glucoerucin/4-methylthiobutyl-ITC	1.5	1
		Spring	45.3 ± 4.2	12.9 ± 2.5	107.2 ± 8.5		2.0	
Black mustard (*B. nigra*)	ISCI 27	Autumn	102.8 ± 25	17.1 ± 0.3	255.5 ± 8.1	Singrin/2-propenyl-ITC (= allyl-ITC)	0.9	4
		Spring	46 ± 15.5	20.7 ± 0.2	204.5 ± 61		1.5	

4.6 Pest Management

4.6.1 Diseases

The soil-borne plant pathogens such as *Botrytis cinerea*, *R. solani*, *F. oxysporum*, *D. lycopersici*, and *Cladosporium fulvum* have been suppressed using volatile plant chemicals by biofumigation (Urbasch 1984). The tomato pathogens like *P. ultimum*, *R. solani*, and *S. rolfsii* were suppressed by volatiles from several Brassica species (Charron and Sams 1998, 1999; Harvey et al. 2002).

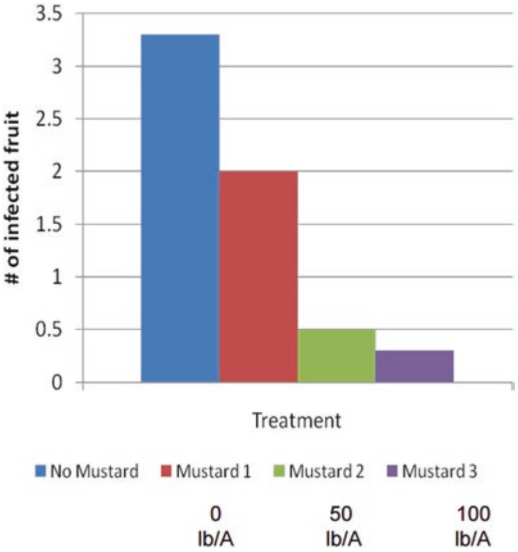
Biofumigation with yellow and oriental mustard reduced the infection of lettuce with *S. minor* (cause lettuce drop disease) by 91% and 68%, respectively (Fig. 4.9). Integration of biofumigation (with yellow mustard) with soil solarization (by covering soil with plastic for 3 weeks) gave almost 100% lettuce drop control and produced the biggest lettuce heads.

Biofumigation with Brassicas reduced Phytophthora fruit rot infections by 75% and 56–72% (Fig. 4.10), and improved yields in squash by 14–21% and 30–36% as compared to untreated controls and a fungicide treatment, respectively, in studies conducted at Georgia and New York.

Soil incorporation of green residues with oriental mustard cover crop suppresses some pathogens like *Verticillium* in potato; *Pythium*, *Fusarium*, and *Rhizoctonia* root rots in beans; *Pythium* in lettuce; pink root in onion; *Aphanomyces*, *Pythium, Rhizoctonia*, and *Fusarium* root rot in peas; and cavity spot and *Fusarium* in carrot (Sanders 2005).

Fig. 4.9 Effect of biofumigation with mustard (cv. Caliente) on damping-off and *Sclerotinia* diseases of lettuce. *Left* – Control: "damping-off" and Sclerotina, *Right* – Caliente treated: minimum disease and weeds

Fig. 4.10 Effect of biofumigation with mustard on Phytophthora fruit rot incidence in squash



Direct biocidal effects have most commonly been observed in Brassica green manures containing high levels of glucosinolates. Fungicidal activity depends on glucosinolate content and method of incorporation. There are many such examples including control of *R. solani* in vegetable crops (Villeneuve et al. 2004).

Biofumigation with Fall Raab (*B. rapa*) gave effective management of bacterial wilt (*R. solanacearum*) of tomato and gave the highest fruit yields. The above treatment also gave 40% and 19% higher marketable tomato fruits than plots with the rye (control) and Indian mustard cover crop, respectively.

Biofumigation with mustard (cv. Caliente) gave effective management of Fusarium wilt in beans and enhanced pod yields (3603 lbs./acre as compared to 2615 lbs./acre in control) (Fig. 4.11).

Incorporation of Brassica plant tissue (*B. juncea*) showed significant reductions in *R. solani* (responsible for pre- or postemergence damping-off of seedlings) population in greenhouse assays, leading to the highest disease reductions in field tests (Larkin et al. 2006).

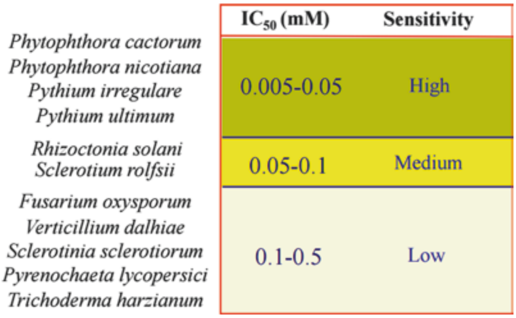
Gamliel et al. (1993b) showed that population reduction of *S. rolfsii* (causes southern blight) occurred in soil amended with dried cabbage residue (*Brassica oleracea* Capitata group). The germination of *S. rolfsii* was reduced by 38–55% by incorporation of cabbage residue into the soil at a rate of 2% (Stapleton and Duncan 1998). Soil amendment with bok choy (*B. oleracea* var. *chinensis*), broccoli (*B. oleracea* var. *italiensis*), and cabbage significantly suppressed sclerotial germination compared to the nonamended control.

In a controlled experiment, incorporation of 2% Brassica tissue into the soil significantly reduced the survival of *Pythium ultimum* (Stapleton and Duncan 1998).

The sensitivity of certain soil-borne fungi to thioglucosinolates-derived products is presented in Fig. 4.12.

Fig. 4.11 Effect of biofumigation with mustard (cv. Caliente) on Fusarium wilt and yield of French bean

Fig. 4.12 Sensitivity of some soil-borne fungi to thioglucosinolates-derived products



	IC_{50} (mM)	Sensitivity
Phytophthora cactorum *Phytophthora nicotiana* *Pythium irregulare* *Pythium ultimum*	0.005-0.05	High
Rhizoctonia solani *Sclerotium rolfsii*	0.05-0.1	Medium
Fusarium oxysporum *Verticillium dalhiae* *Sclerotinia sclerotiorum* *Pyrenochaeta lycopersici* *Trichoderma harzianum*	0.1-0.5	Low

4.6.2 Nematode Pests

The soil-borne plant-parasitic nematodes are generally suppressed by the cultivation and incorporation of cover/rotation crops, particularly *Brassicaceae* plants. Even though glucosinolates are thought to play an important role in nematode suppression, various studies have shown that nematode-control efficacy and nematode reproduction in treated soils are not correlated with glucosinolate contents in plants (Potter et al. 1998; McLeod and Steel 1999). Other factors like nonglucosinolate compounds (other sulfur-containing compounds) (Bending and Lincoln 1999), as well as biological and physiological factors, may also be involved in nematode suppression (Mazzola et al. 2001). The biofumigation works better in sandier soils with low organic matter content.

Integration of soil incorporation of *Brassicaceae* plants (biofumigation), combined with soil tarping using plastic film in hot seasons, enhances the nematode-control efficacy by elevating soil temperatures due to soil solarization effect and preventing rapid emission of volatile nematicidal compounds from the soil to the atmosphere (Gamliel and Stapleton 1993a; Ploeg and Stapleton 2001). The synergistic effect on nematode-control efficacy has been noticed by combinations of sublethal soil temperatures (30–38.8 °C), which render nematodes more sensitive to toxic compounds or to antagonistic microorganisms, and the biofumigation effects that release toxic volatile compounds. The nematode-control efficacy can also be enhanced by the combination of biofumigation with non-*Brassicaceae* plants (such as pepper plant residues) and soil solarization.

Cultivation of different mustard species (e.g., *B. juncea var. integrifolia* or *B. juncea var. juncea*) in nematode-infested fields and their soil incorporation at flowering give effective management of nematodes. The nematicidal compounds released during the decomposition of incorporated plant parts in a moist soil kill nematodes. The new crop can be planted or sown 2 weeks after incorporating the plant material into the soil (it takes about 2 weeks for the plant material to decompose and stop releasing phytotoxic substances, i.e., chemicals poisonous to plants).

4.6.3 Weeds

About 95% of milkweed seeds, 68% of foxtail seeds, and 51% of dock seeds are killed by biofumigation with rapeseed alone. Weed suppression can be enhanced by integration of rapeseed biofumigation with soil tarping for solarization that killed 94% of dock and 100% of milkweed. However, the germination of foxtail weed seeds was stimulated (twice as many foxtail seeds germinated over control) with high temperatures under tarps.

The reduction in emergence of several small-seeded weed species from 20 to 95% and reduced growth of weed seedlings from 8 to 90% were observed on potato by soil incorporation of *Brassica hirta*, *B. juncea*, and *B. napus* chopped residues in greenhouse trials. Among eight individual isothiocyanates tested, methyl- and allyl isothiocyanates were most inhibitory for germination and growth of redroot pigweed (*Amaranthus retroflexus*) and barnyard grass (*E. crus-galli*). In greenhouse studies, the reduction of more than 90% in fresh weight of redroot pigweed was noticed by soil incorporation of meadowfoam, *Limnanthes alba*, seed meal (Boydston et al. 2004).

4.7 Integration of Biofumigation and Solarization

Integration of biofumigation (primarily by adding various composts, manures, teas, and other organic amendments to the soil) with soil solarization (tarping with plastic films) has been found more effective (synergistic effect) for pest (weeds, diseases, and nematodes) management by most organic growers. Higher levels of pest control are achieved over shorter periods or at lower temperatures by integration of both the components.

The suppression of sclerotial germination of *S. rolfsii* ranged from 86.5 to 99.9% when biofumigation with Brassicas was combined with a diurnal temperature treatment with a maximum of 38 °C and minimum of 27 °C (Stapleton and Duncan 1998). The suppression of sclerotial germination with Brassicas amendment and without the diurnal treatment ranged from 2 to 65%, while the nonamended control plus diurnal temperature treatment suppressed germination by 5.8%. Thus, the difference in suppression between amended and nonamended soil can be attributed to the Brassica amendments. Similarly, Stapleton and Duncan (1998) reported that integration of Brassica soil amendment with a diurnal temperature treatment with a maximum of 38 °C and minimum of 27 °C reduced the survival of *P. ultimum* ranging from 96.5 to 100%.

Deadman et al. (2006) reported that populations of *Pythium aphanidermatum* were significantly reduced after biofumigation with postharvest cabbage residue used as the Brassica amendment and soil solarization.

4.8 Conclusions

Biofumigation has tremendous potential for management of a range of soil-borne diseases, nematodes, and weeds. However, in order to implement the technique more widely to address the main issue of variability in levels of disease control, much more evidence-based research and development is needed. Besides potential disease control and provision of multiple benefits to farmers, it is most likely that biofumigation will be promoted. It will form just one component of an integrated strategy for the more intractable soil-borne diseases that could include other approaches such as biological control. An incentive scheme perhaps as a component of common agricultural policy (CAP) reform could also be a way forward, to overcome social and cultural reticence in the use of biofumigants and to promote adherence to recent European Union (EU) directives on pesticide usage.

More emphasis needs to be placed by researchers on the following aspects:

- Identifying the most appropriate biofumigant for a particular target pathogen.
- Selecting or breeding of new high-GSL Brassica lines adapted to the local environmental conditions.
- Separating out the effects of the growing biofumigant crop and the incorporation phase, standard measurement of GSLs/ITCs.
- Understanding the relative importance of ITCs compared to other potential mechanisms of control (e.g., benefits related to organic matter incorporation such as increased microbial community activity).

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Fertilizer Management

5

Abstract

Plants need 16 essential nutrients (9 macronutrients and 7 micronutrients) for their growth and development. These nutrients can be supplied to plants through organic manures or inorganic fertilizers. In general, the incidence of pests is increased by excessive use of nitrogenous fertilizers, while the application of phosphate and potassium fertilizers reduced the incidence of certain pests. Among several research studies reviewed for over 50 years, the application of nitrogenous fertilizers enhanced pest damage in 63% of cases, while low pest damage was reported in 37% studies. Foliar spray of potassium and phosphate fertilizers was responsible for the management of aerial pathogens in apple, cucumber, grapevine, maize, mango, nectarine, and rose. Plant susceptibility is indirectly affected by micronutrients, since their deficiency makes the plants susceptible to pests. The role of macro- and micronutrients on susceptibility/resistance to insect, mite, and nematode pests and disease pathogens is discussed.

Keywords

Macronutrients • Micronutrients • Insect pests • Diseases • Resistance • Susceptibility

5.1 Introduction

The universal practice in realizing full-yield potential in commercial crop production is through properly balanced plant nutrition by integration of organic manures with inorganic fertilizers. The quantity, quality, yield of crops, and levels of the incidence of pests (insects, diseases, nematodes, and weeds) have been associated with macro- and micronutrients.

The plants require 16 essential nutrients (9 macronutrients such as C, H, O, N, P, K, Ca, Mg, and S; and 7 micronutrients like B, Cl, Cu, Fe, Mn, Mo, and Zn) for

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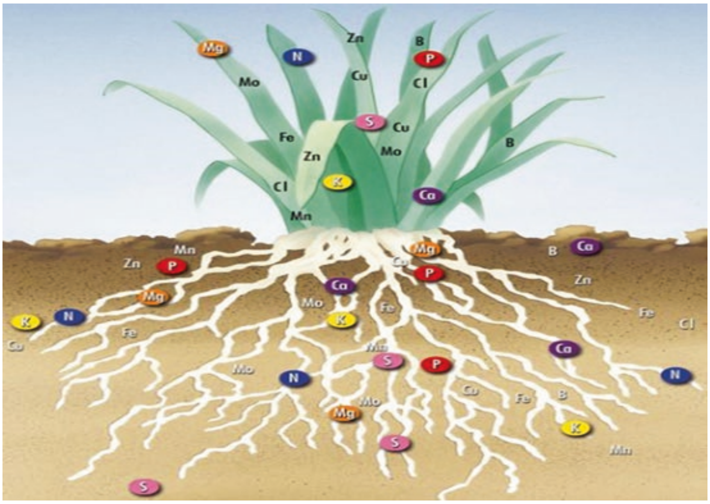

Fig. 5.1 Nutrient requirements for plant growth and development

normal growth and reproduction (Fig. 5.1), which are sourced mainly through inorganic fertilizers.

The feeding, longevity, and fecundity of phytophagous pests are influenced by plant nutrition supplied through chemical fertilizers.

Fertilization is responsible for enhancing resistance to crop pests. The damage caused by herbivores can be reduced using micronutrients and plant hormones (from seaweed extracts) sprays. Indiscriminate use of fertilizers by farmers, especially at higher doses, critically affects the pest incidence. For example, large pulses of available nitrogen are responsible for compromising crops' resistance to pests.

In general, the incidence of certain pests (aphids and mites with sucking mouth parts) is increased by excessive use of nitrogenous fertilizers, while the application of phosphate and potassium fertilizers reduced the incidence of certain pests (Perrenoud 1990). Reuveni and Reuveni (1998) reported that aerial pathogens in several crops like apple, grapevine, mango, nectarine, and rose can be managed by the foliar application of phosphate and potassium fertilizers through induction of systemic resistance.

The foliar application of phosphate and potassium fertilizers is responsible for the management of leaf pathogens in several crops like apple, grapevine, corn, mango, nectarine, and rose (Reuveni and Reuveni 1998). The reaction of a plant to pathogens in one or other way by the application of P and K may be due to the following reasons:

- Pathogen multiplication, development, and survival are affected directly.
- Food supply for the pathogen is directly affected due to internal metabolism of the plant.

- Toughens the leaf cuticle, promotes healthy plant growth, and imparts resistance.

Marschner (1995) reported that the plant's physiological aspects are impaired when a crop is affected by pests. Some pests can hyperaccumulate nutrients which adversely affect them, while some others may not be able to utilize them (Huber and Graham 1999). Likewise, other pathogens compete with crops for nutrients (Timonin 1965).

Several soil-borne pathogens infect roots and reduce their ability to supply essential crop requirements (Huber and Graham 1999). The nutrient deficiency or toxicity can also be induced by infection from pathogens. The essential nutrients in leaves may be decreased (except that the concentration of P is increased) by vascular pathogen infection (Huber and Graham 1999).

Heavy applications of fertilizers to cotton increased population of boll weevil larvae (Anthonomus grandis) nearly three times as compared to unfertilized checks (Adkisson 1958).

The development of plant disease is influenced by fertilizer application probably due to dense stands which create humid conditions favorable for pathogen infection. Hence, there is a need to apply recommended doses of fertilizers for obtaining higher yields as well as for pest management.

The effect of each major and minor nutrient on susceptibility/resistance to insect, mite and nematode pests and disease pathogens is discussed below.

5.2 Macronutrients

5.2.1 Nitrogen

5.2.1.1 Insect Pests

The occurrence of pests is generally increased with high levels of nitrogen in plant tissues (Phelan et al. 1995). Among several research studies reviewed for over 50 years, the application of nitrogenous fertilizers enhanced pest damage in 63% of cases, while the low pest damage was reported in 37% studies (Table 5.1).

The total nitrogen (N) in the fertilizers is a major factor which influences the susceptibility of crops to pest damage (Slansky and Rodriguez 1987; Scriber 1984; Mattson 1980). For example, van Emden (1966) reported direct correlation between foliage N and the incidence and severity of peach-potato aphid in paddy. Similarly, Comstock mealybug (*Pseudococcus comstocki*) on apple, corn earworm (*Heliothis zea*) on cotton, fall armyworm (*Spodoptera frugiperda*) in maize, and psylla (*Cacopsylla pyricola*) on pear are the other examples where there is a direct correlation between N level and susceptibility to herbivores (Luna 1988). Likewise, rose-grain aphids (*Metopolophium dirhodum*) on winter wheat and thrips (*Frankliniella occidentalis*) on tomato are also influenced by higher N levels (Brodbeck et al. 2001).

Table 5.1 Insect and mite pests that increase at high levels of nitrogen

Common name	Scientific name	Crop/s
European red mite	*Panonychus ulmi*	Apples
Two-spotted spider mite	*Tetranychus telarius*	Apples, peaches, beans, and tomatoes
Clover mite	*Bryobia praetiosa*	Peaches and beans
Greenhouse thrip	*Heliothrips haemorrhoidalis*	Beans
Green peach aphid	*Myzus persicae*	Brussels sprouts and tobacco
Green bug	*Schizaphis graminum*	Oats and rye
Corn leaf aphid	*Rhopalosiphum maidis*	Sorghum
Spotted alfalfa aphid	*Therioaphis maculata*	Alfalfa
Diamondback moth	*Plutella xylostella*	Cabbage
Cabbage butterfly	*Artogeia rapae*	Rape
Cabbage aphid	*Brevicoryne brassicae*	Brussels sprouts, Kale, and cabbage

Source: Phelan et al. (1995) and Letourneau (1988)

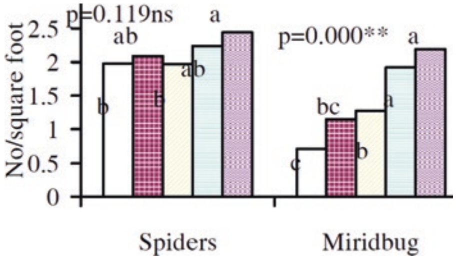

Fig. 5.2 Increase of natural enemy (spiders and mired bug) population due to application of higher doses of nitrogenous fertilizers

In contrast, Klostermeyer (1950) reported that the incidence and severity of corn earworm (H. zea) were reduced by the application of nitrogenous fertilizers.

The outbreak of insect pests of rice was clearly emphasized by nitrogen fertilization. There was a direct correlation of nitrogen application with occurrence of insect pests including stem borer (SB). These rice pests could cause yield loss significantly at higher dose of N. The losses due to brown plant hopper (BPH) feeding are compensated by higher percentage of nitrogen in rice leaf (through external application) that enhanced photosynthesis to produce more nutrition (Chau 2000). The most abundant population of BPH and leaf folder (LF) was induced at higher nitrogen application. Interestingly, the higher numbers of biological control agents were also noticed at higher level of N (2.44 and 2.19 adults per square feet, respectively) (Fig. 5.2).

5.2.1.2 Diseases

The effect of nitrogenous fertilizer application on the disease incidence and severity is not clearly understood. In some cases N application is responsible for increase in disease incidence and severity, while in others reverse is the trend (Marschner 1995; Hoffland et al. 2000; Carballo et al. 1994; Celar 2003; Harrison and Shew 2001).

Table 5.2 Effect of high N level on increased disease severity

Crop/s	Disease	Scientific name	References
Wheat	Stem rust	*P. graminis*	Howard et al. (1994)
Wheat	Powdery mildew	*E. graminis*	Büschbell and Hoffmann (1992)
Tomato		*O. lycopersicum*	Hoffland et al. (2000)
Cabbage	Club root	*Plasmodiophora brassicae*	Kiraly (1976)
Tobacco	Tobacco mosaic virus	TMV	Singh (1970)
Tomato	Bacterial speck	*P. syringae*	Hoffland et al. (2000)
Maize	Smut	*Ustilago maydis*	Kostandi and Soliman (1991)

Table 5.3 Effect of high N level on decreased disease severity

Crop/s	Disease	Scientific name	References
Bell pepper and tomato	Bacterial spot of pepper and tomato	*Xanthomonas vesicatoria*	Chase (1989)
Potato and tomato	Early blight	*Alternaria solani*	Blachinski et al. (1996)
Chrysanthemum	Fusarium wilt	*Fusarium oxysporum*	Woltz and Engelhar (1973)

The increased N application enhanced the incidence of foliar diseases in grain crops. The increased disease severity of powdery mildews and rusts in grain crops by the application of nitrogen fertilizer is attributed to enhanced crop canopy development, which increases the humidity favorable for disease development (Hoffland et al. 2000). Similarly, the powdery mildew (*Oidium lycopersicum*) and the bacterial speck (*Pseudomonas syringae* pv. *tomato*) of tomato (Hoffland et al. 2000), and the stem rust (Puccinia graminis) and powdery mildew (*Erysiphe graminis*) of wheat are the other examples where there is a direct correlation between N level and susceptibility to diseases.

The effect of high levels of N on increased disease severity in certain crops is presented in Table 5.2.

On the contrary, Huber and McCay-Buis (1993) reported that the severity of winter wheat and barley root disease was decreased by the application of nitrogenous fertilizers. Likewise, the severity of fungal pathogens such as *Botrytis cinerea*, *Xanthomonas* spp., *Fusarium* spp., and *Alternaria* spp., and vascular wilt of tomato was also reduced by N application (Agrios 2005; Vidhyasekaran 2004).

The effect of high levels of N on decreased disease severity in certain crops is presented in Table 5.3.

Further, the severity of vascular wilt of tomato is not affected by N application (Hoffland et al. 2000).

Plants grown with high N supply were found susceptible to obligate pathogens (Kostandi and Soliman 1991; Hoffland et al. 2000), while they were resistant to facultative pathogens (*B. cinerea*). Higher susceptibility of obligate fungal parasites at high N rates may be due to promotion of new growth and significant increase in amino acid concentration, which makes the plants more susceptible to disease pathogens (Robinson and Hodges 1981). The metabolism of the plant also changes the defense system of the plants against infection by pathogens due to lower lignin and phenolic contents. Further, silicon content also decreases at high N rates (Volk et al. 1958). Hence, high N rates increased host susceptibility to obligate parasites. The lower levels of N increased the defense of the plants resulting in better protection against pathogens (Wilkens et al. 1996; Hoffland et al. 1999).

The presence of nitrification inhibitors and the form of nitrogen play an important role in plant diseases (Harrison and Shew 2001; Celar 2003). Application of high ammonical nitrogen ($NH_4^+ - N$) decreased blast, black root rot, southern stem blight, and head blight pathogens, while high nitrate nitrogen ($NO_3^- - N$) reduced gray mold, root rot, and damping-off pathogens. Similarly, application of $NO_3^- - N$ increased soil salinity and micronutrients resulting in decrease of Fusarium wilt pathogen, while $NH_4^+ - N$ fertilizer increased the availability of micronutrients including zinc and reduced the losses from take-all disease (*Gaeumannomyces graminis*) of wheat. The soil pH, micronutrient availability, and plant's phenolic content, which are precursors of lignin, are also affected by the form of N.

5.2.2 Potassium

5.2.2.1 Diseases

In general, Foliar-applied potassium (K) is associated with reductions in disease. Mann et al. (2004) reported that wheat pathogens such as *Blumeria graminis* and *Septoria tritici* are controlled by the application of potassium chloride. The chloride ions are more important than potassium in imparting disease resistance. The application of potassium toughens the leaf cuticle and promotes healthy plant growth resulting in plant resistance to disease pathogens (Prabhu et al. 2007).

Huber and Graham (1999) reported that potassium increases the host resistance. Crop physiological aspects like metabolic functions play a major role in increasing susceptibility to disease in the K-deficient plant. Potassium also promotes tissue hardening and stomatal opening pattern and thus preventing disease attack (Marschner 1995). The different sources of K do not influence the crop response to diseases. Besides, the plant susceptibility to diseases is also affected by the balance between N and K.

Application of K is responsible for managing several disease pathogens like *Xanthomonas oryzae*, *Rhizoctonia solani*, *Sclerotium oryzae* (sexual stage: *Magnaporthe salvinii)*, *Helminthosporium oryzae*, *Mycosphaerella henningsii*, *Cercospora canescens*, *Mycosphaerella arachidis*, *Cephaleuros parasiticus*, *P. graminis*, *Sphacelia sorghi*, *Xanthomonas citri* pathovar *malvacearum*, and *Cochliobolus sativus* (Sharma and Duveiller 2004; Sharma et al. 2005). The decrease in severity of leaf blight, *C. sativus*, and the increase in grain yields of wheat were achieved by K fertilization (Sharma and Duveiller 2004; Sharma et al.

Table 5.4 Effect of K level on disease severity

Crop/s	Common name	Scientific name	References
Rice	Bacterial leaf blight	*X. oryzae*	Chase (1989)
Wheat	Stem rust	*P. graminis*	Lam and Lewis (1982)
Tobacco	Tobacco mosaic virus	TMV	Ohashi and Matsuoka (1987)
Potato and tomato	Early blight	*A. solani*	Blachinski et al. (1996)
Peas	Fusarium wilt	*F. oxysporum*	Srihuttanum and Sivasithamparam (1991)
Wheat	Tan spot	*Pyrenophora tritici-repentis*	Sharma et al. (2005)
Cucumber, muskmelon, and zucchini squash	Powdery mildew	*E. graminis*	Menzies et al. (1992)

2005). The intensity of various infectious diseases caused by obligate and facultative pathogens has been reduced by K fertilization (Table 5.4).

5.2.2.2 Nematodes

Application of high rates of K (2 and 6 kg of K_2SO_4 per tree) significantly reduced the population of *Xiphinema* and *Pratylenchus* in cherry orchards (Kirkpatrick et al. 1959a). The population of these nematodes was negatively correlated with leaf potash (Kirkpatrick et al. 1959b).

The number of root galls by *Meloidogyne javanica* in tomato was significantly reduced by increased levels of potash (Gupta and Mukhopadhyaya 1971). The soil amended with 20% fly ash increased tomato growth (35%), and reduced southern root-knot nematode index (one as against four in control), nematode population in soil (80% reduction), and egg mass production (egg mass index one as against four in control). The reduction in nematode population and increase in plant growth might be due to toxic compounds (polycyclic aromatic hydrocarbons, dibenzofuran, and dibenzo-*p*-dioxin mixtures) present in fly ash and micronutrients (N, K, Ca, Mg, Na, B, SO_4), respectively.

Sivakumar and Meerazainuddin (1974) reported that the *Rotylenchulus reniformis* population multiplication on ladies finger was reduced by the application of potash alone or potash in combination with phosphorus or nitrogen.

5.2.3 Phosphorus

5.2.3.1 Diseases

The reduction in disease incidence and improvement in plant health are generally observed by phosphorus (P) fertilization. The induction of resistance to pathogens in Cucumis sativus, Vicia faba, and Vitis vinifera (Mucharromah and Kuc 1991;

Walters and Murray 1992; Reuveni and Reuveni 1995) has been observed with foliar application of phosphate salts.

P fertilization was found effective for the management of fungal diseases in seedlings (Huber and Graham 1999) and damping-off in Triticum vulgare (Huber 1980). Likewise, the incidence of root rot and soil smut in corn was reduced by P application (Huber and Graham 1999). Similarly, the management of several crop disease pathogens such as U. maydis, *Pythium graminicola*, *X. oryzae*, *Peronospora tabacina*, *Tobacco leaf curl virus*, *Diaporthe phaseolorum* var. *sojae*, *Barley yellow dwarfvirus*, *Cochliobolus stenospilus*, *Podosphaera xanthii*, *Sphaerotheca pannosa* var. *rosae*, *Erysiphe necator*, *Oidium mangiferae*, *S. pannosa*, *S. fuliginea*, *Exserohilum turcicum*, *Puccinia sorghi*, and *Magnaporthe grisea* has been achieved by application of P (Huber 1980; Huber and Graham 1999; Kirkegaard et al. 1999; Reuveni and Reuveni 1998; Reuveni et al. 2000).

In contrast, the incidence of certain fungal disease pathogens like *Sclerotinia sclerotiorum*, *Bremia lactucae*, and *Urocystis agropyri* is increased by the application of P (Huber 1980).

5.2.3.2 Insect Pests

Soil application of 30 and 45 kg P_2O_5 ha^{-1} significantly ($P < 0.05$) reduced the damage by aphids (*Aphis craccivora*), flower thrips (*Megalurothrips sjostedti*), and legume pod borer (*Maruca vitrata*), and consequently higher grain yields were obtained in cowpea cultivars IT91K-180, IT95M-118, and TVU 1890 (Asiwe 2009). The wireworm populations often tend to increase in soils with low phosphorous.

5.2.4 Calcium

5.2.4.1 Diseases

Calcium (Ca) enhances the plant resistance by the following ways:

- Marschner (1995) found that Ca prevents leakage of amino acids and sugars from the plant cells which are required by the disease pathogens for infection.
- The losses from both physiological disorders and fruit rotting can be effectively prevented by treatment of fruits with Ca before storage. Similarly, application of Ca to the root zone of groundnut protects and eliminates the occurrence of root rot disease pathogens (Huber 1980).

Several pre- and postharvest disease pathogens can be prevented by the treatment with Ca (Rahman and Punja 2007; Woltz et al. 1992; Biggs 1999). Disease resistance to storage diseases can be enhanced by maintaining increased calcium concentrations in storage organs (Cheour et al. 1990).

Graham (1983) reported that resistance to certain plant diseases such as damping-off of seedlings, white mold, gray mold, and vascular wilts is provided by Ca through a putative mechanism.

5.2.4.2 Nematodes

Soil incorporation of Ca CN_2, Na CN, and urea cyanamide can be employed to control nematodes (*Meloidogyne* spp.) probably by the release of hydrogen cyanide (HCN) or NH_3, which are toxic to the nematodes.

5.2.5 Sulfur

5.2.5.1 Insect Pests

The common scab, *Streptomyces scabies*, of potato is effectively managed by the application of elemental sulfur. Soil application of elemental sulfur is also effective in decreasing black scurf, R. solani, disease of potatoes (Kilkocka et al. 2005).

5.2.5.2 Mites

Sulfur also acts as an acaricide that can be used for effective management of mites.

5.3 Micronutrients

The important role played by micronutrients in plant metabolism affects the membrane stability and also phenolics and lignin contents (Graham and Webb 1991). Plant susceptibility is indirectly affected by micronutrients, since their deficiency makes the plants prone to pest attack. Micronutrient-deficient plants exhibit an impaired defense response.

5.3.1 Manganese

5.3.1.1 Diseases

Manganese (Mn) is important for imparting tolerance to disease pathogens (Huber and Graham 1999; Heckman et al. 2003). Several crop disease pathogens like *G. graminis*, *Drechslera tritici-repentis*, *S. scabies*, *F. oxysporum* f. sp. *vasinfectum*, and postharvest sclerotinia soft rot of squash can be managed by manganese fertilization (Heckman et al. 2003; Simoglou and Dordas 2006; Keinath and Loria 1996; Agrios 2005; Huber and Graham 1999). The factors which contribute to plant resistance by manganese application include the presence of phenolic polymers (lignin and suberin) resistant to enzymatic degradation (Agrios 2005; Huber 1996; Hammerschmidt and Nicholson 2000; Krauss 1999; Vidhyasekaran 1997).

Mn content in wheat seeds is indirectly correlated with the take-all disease (Huber and McCay-Buis 1993). Some common cultural practices like sequential cropping, addition of organic matter to soil, and application of gypsum and water that promote availability of manganese to plants thereby control common scab disease (*S. scabies*) of potato.

5.3.2 Zinc

5.3.2.1 Diseases

Zinc was found to have variable effects on disease as it can have a positive or negative effect on the host (Grewal et al. 1996). Graham and Webb (1991) reported that in most cases it acts directly to decrease the incidence of pathogens, for example, scab and take-all diseases of wheat are managed by soil application of Zn (Grewal et al. 1996). Cakmak (2000) opined that Zn-superoxide dismutase is responsible for imparting resistance to crop plants against disease pathogens. The mode of action of Zn in increasing disease resistance is discussed by Mengel and Kirby (2001).

Zn deficiency in plants encourages pathogen development (Marschner 1995). For example, powdery mildew diseases are aggravated by low zinc level (Bolle-Jones and Hilton 1956).

5.3.2.2 Insect Pests

Hagen and Anderson (1967) reported that the occurrence of maize beetle is increased in zinc-deficient plants due to reduced pubescence on maize leaves.

5.3.3 Boron

5.3.3.1 Diseases

Low boron (B) level is very common in the whole world (Blevins and Lukaszewski 1998; Brown et al. 2002). Application of B reduced the incidence and severity of club root of cabbage, root rots, powdery mildews, vascular wilts, TMV, and take-all disease in several crop plants (Graham and Webb 1991). The spread of *E. graminis* was more rapid in B-deficient wheat (var. Kenya) plants (Schutte 1967). The reduction in disease severity by B application might de due to its function in promoting cuticle strength to resist pathogen infection (Brown et al. 2002). The mechanisms of action of B in imparting resistance to crop plants against disease pathogens have been discussed by several authors (Brown et al. 2002; Dordas and Brown 2005; Blevins and Lukaszewski 1998).

5.3.4 Iron

5.3.4.1 Diseases

The requirement of Iron (Fe) is higher in several plant pathogens including *Fusarium* spp. as compared with higher plants. Certain disease pathogens such as *P. graminis tritici*, *Ustilago tritici*, banana anthracnose, pear and apple black rot, and cabbage seedling blight can be reduced by Fe application (Graham 1983; Rohmeld and Marschner 1991). The disease suppression effect of Fe might be due to its antimycosis effect or synthesis of siderophores (Graham and Webb 1991).

In contrast, the addition of Fe in nutrient solution was not able to suppress disease pathogens such as *G. graminis* and *Colletotrichum lindemuthianum*.

5.3.5 Chlorine

5.3.5.1 Diseases

Application of fairly large amounts of chlorine (Cl) is responsible for inducing tolerance to crop disease pathogens (Mann et al. 2004). A number of disease pathogens such as *Fusarium verticillioides* and *E. turcicum* on maize; stripe rust, *Septoria* leaf spot, and take-all in wheat; and downy mildew of millet can be managed by the application of Cl (Mann et al. 2004).

Chlorine may be indirectly involved in disease suppression by competing with NO_3^- absorption and influence the rhizosphere pH, resulting in suppression of nitrification and increased availability of Mn. In addition, the host tolerance to pathogens is increased by Cl ions mediating in reduction of Mn oxides and increasing Mn availability for the plant.

5.3.6 Silicon

5.3.6.1 Diseases

The fact that disease severity in crop plants is reduced by the application of silicon (Si) is well known. Soil application of silicon (Si) is responsible for improved growth of rice and sugarcane plants, improved disease tolerance, and higher production (Alvarez and Datnoff 2001; Seebold et al. 2004). Crop diseases, such as brown patch, greasy spot, gray leaf spot, and powdery mildew on turf grasses, can be managed by Si fertilization (Alvarez and Datnoff 2001; Seebold et al. 2004; Zhang et al. 2006).

Miyaki and Takahashi (1983) reported that supplementation of silicon in nutrient solutions of cucumbers had considerably reduced the incidence of *Podosphaera fusca* in cucurbits. Belanger et al. (1995) reported that the application of silicon suppressed above- and belowground diseases in cucurbits.

The modes of action of silicon on pathogens as suggested by Alvarez and Datnoff (2001), and Brescht et al. (2004) include:

- Silicon-mediated resistance occurs due to phytoalexin accumulation and the presence antifungal compounds in both dicots and monocots.
- Penetration of fungal hyphae is restricted because of the creation of a physical barrier by silicon.

5.4 Conclusions

In general, the incidence of insect and mite pests and disease pathogens including nematodes is increased by the excessive use of nitrogenous fertilizers, while the application of phosphate and potassium fertilizers reduced the incidence of certain pests and diseases. Hence, optimum plant nutrition makes the crop plants to resist the pest and disease attack and increase the crop productivity (Luna 1988).

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6 Agro-Forestry

Abstract

The pest incidence and abundance are influenced by agro-forestry practices through both top-down regulation (by increased natural enemies) and bottom-up factors (moderation of microclimate, soil nutrients and water content). In general, the higher abundances of natural enemies and lower abundances of pests are brought about by agro-forestry practices. The crop type decides the effects of agro-forestry on invertebrate pests and diseases. Agro forestry was associated with lower pest abundances and less plant damage in perennial crops such as coffee, cocoa and plantain, while these effects were not significant in annual crops like maize, rice and beans. In conclusion, agro-forestry is beneficial in terms of pest, disease and weed management because the combination of trees and crops provides greater niche diversity and complexity in both time and space than polyculture of annual crops.

Keywords

Natural enemies • Polyculture • Weeds • Insect pests • Diseases • Plant damage

6.1 Introduction

The loss of biodiversity and associated ecosystem services are mainly due to deforestation and agricultural intensification. These negative effects can be reversed by the restoration of tree-cover through agro-forestry that complements the protection of pristine forest ecosystems (Tscharntke et al. 2011). Agro-forestry is defined as an intentional combination of trees (woody perennials) with agricultural crops (herbaceous crops), pastures (grasses) and/or livestock on the same land by spatial arrangement/temporal sequence to create sustainable farming (intensive land use) systems (Nair 1993). The beneficial effects of agro-forestry include biodiversity conservation and improved soil fertility (Matata et al. 2011; Sileshi et al. 2014); increased

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plant diversity, crop production, and protection; and diversification of income benefits. In this system, forestry trees are planted with wide spacing, and high-value crop plants are grown in between tree rows. The trees provide correct shade to crop plants, and they also give additional income (selling of tree products). The smallholder farmers in developing countries get food security through agro-forestry by improved soil health, provision of firewood, building material, fodder and fruits (Sileshi et al. 2014). Agro-forestry influences other ecosystem services delivered by biodiversity, including pest management (Sileshi et al. 2008b; Karp et al. 2013).

The strategy to reduce the risk of pest and disease outbreaks includes the replacement of monoculture crops by more diverse agro-forestry systems that increases habitat complexity, which generally correlates positively with abundance and diversity of natural enemies due to top-down regulation both at the field (Letourneau et al. 2011; Iverson et al. 2014) and landscape levels (Chaplin-Kramer et al. 2011; Tscharntke et al. 2011). In contrast, trees may benefit pests directly by providing food resources or improving microclimate, or indirectly by enhancing host plant nutritional conditions or water availability (Sileshi et al. 2008a).

The increase in crop diversity is responsible for increase in natural enemies as well as reduction in herbivore population and crop damage (Letourneau et al. 2011). In polyculture systems that minimize intra-specific competition via substitutive planting, win-win relationships are likely to occur between per-plant yield of the primary crop and biocontrol (Iverson et al. 2014). The natural enemies are benefitted by the complex landscapes including natural habitat (Chaplin-Kramer et al. 2011).

6.2 Effect on Pests and Natural Enemies

In general, most aspects of natural pest management are benefitted by agro-forestry. Weed abundance was significantly less under agro-forestry (Fig. 6.1a). Nonparasitic weeds were significantly reduced (Fig. 6.1b), while suppression of parasitic weeds (Striga) was marginally significant under agro-forestry (Fig. 6.1a). Agro-forestry significantly enhanced natural enemies of pests more abundantly (Fig. 6.1a). Even though the pest abundance was not significantly affected, plant damage due to pests and plant diseases was significantly reduced by agro-forestry (Fig. 6.1a). Agro-forestry caused a significant reduction of both pest abundance and plant damage in perennial crops, while it had no effect in annual crops (Fig. 6.1c, d). However, there was no correlation between above- and below-ground pest abundance and plant damage (Fig. 6.1e, f). The positive effect of agro-forestry on pest control was translated into increased crop yield in two studies investigated (Ogol et al. 1999; Sileshi et al. 2005). Agro-forestry did not show any effect on natural enemy diversity in majority of studies (7 out of 11). Similarly, three out of seven studies did not show any effect of agro-forestry on predation and parasitism, while the remainder split evenly between positive and negative effects (Pumariño et al. 2015).

The reduction of pest problems in agro-forestry systems (Stamps and Linit 1998) may be due to the following reasons (Vandermeer 1989):

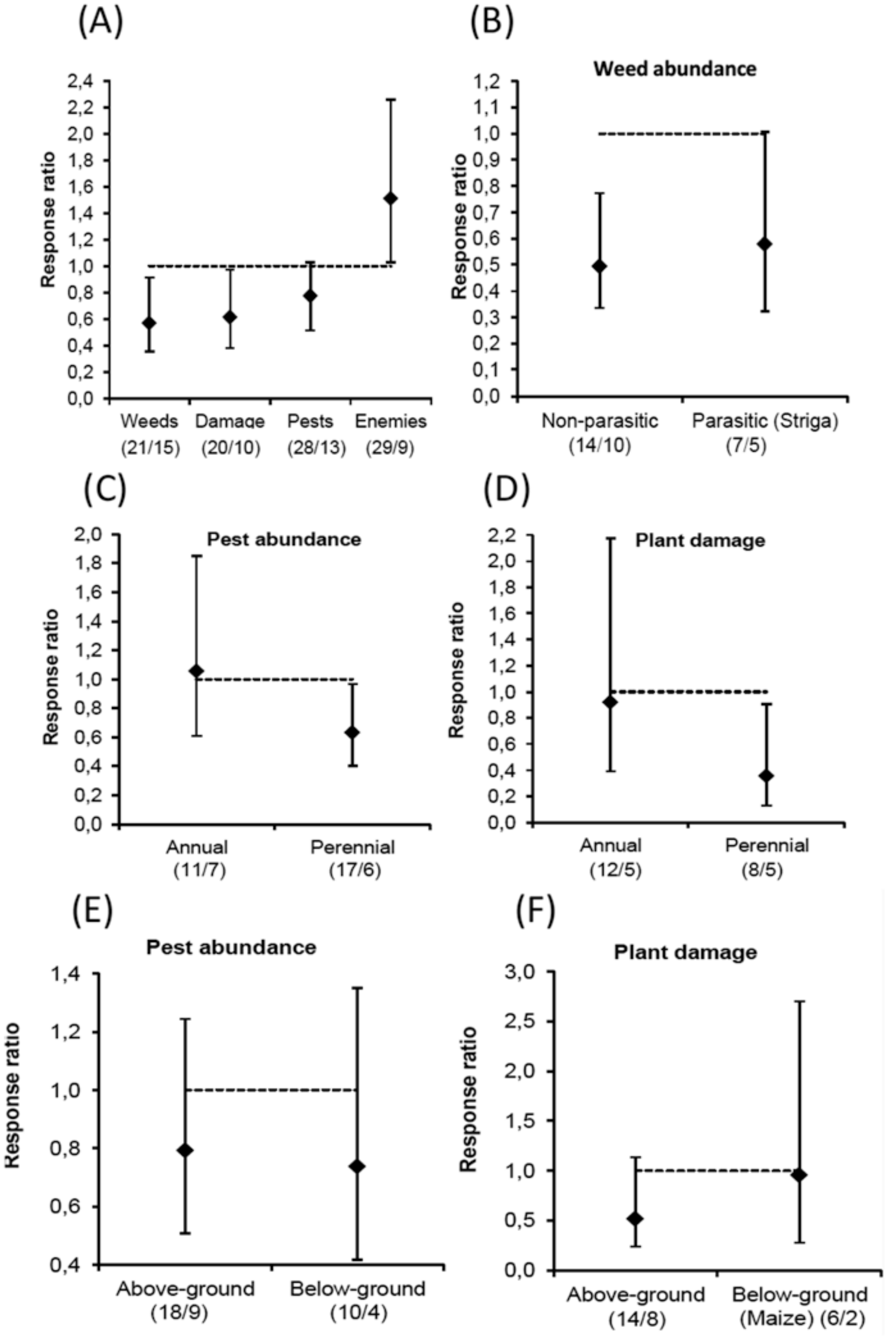

Fig. 6.1 Effects of agro-forestry on pests, diseases, weeds and natural enemies (*Lines* and *dots* represent back-transformed values of 95% confidence interval around mean effect sizes for the respective response variables. Numbers in parentheses represent the number of data points/studies for each category)

- Greater niche diversity and complexity makes it more difficult for pests to find their host plants.
- Plant species may act as trap or repellent crops.
- Higher plant diversity increases natural enemy population and pressure on pests.
- Provision of alternative food sources (e.g., flowers supply pollen, nectar) for adult parasitoids.
- Provision of sites for mating, oviposition and overwintering (Stamps and Linit 1998).

6.2.1 Insect Pests and Diseases

The tri-trophic interactions occur between the plants, herbivores and their natural enemies. The first trophic level include plant community (or producers) consisting of the trees, crops and weeds. A wide range of herbivores (i.e., primary consumers) may attack each plant species, which constitute the second trophic level. The third trophic level constitutes natural enemies (i.e., secondary consumers) which in turn attack herbivorous species. The natural enemies such as predators (arthropods and vertebrates), parasitoids (parasitic insects) and pathogens (bacteria, viruses, fungi, protozoa and nematodes) play a significant role in the population dynamics of pests of agro-forestry (Sileshi et al. 2001).

These tri-trophic interactions are affected in a variety of ways by the plant community, as represented in Fig. 6.2 and Table 6.1. The development of a greater stability in time and certain equilibrium is established between pests/diseases and their natural enemies (e.g., predators, parasitoids) in perennial cropping systems, which is an important component of biological and integrated pest management (Heitefuss 1987). For example, trees may directly influence the migration, host location and feeding of insect pests of the crop in addition to acting as refuge for natural enemies through their physical presence or by shading. The pest incidence may also be influenced by trees by acting as alternative hosts of a crop pest or vector of a pathogen. The demographic parameters of crop pests such as natality, longevity and mortality can also be influenced by trees through their indirect effects on the nutrition of the crop, which in turn may trigger changes in the migration, host location, feeding and demographic patterns of natural enemies. Shading due to trees reduces air circulation, leading to high humidity and an increase in disease incidence. In order to establish or conserve natural enemies through provision of refuge, a clear understanding is required of tri-trophic interactions associated with a given pest or pest complex.

The pest abundance and plant damage as affected by agro-forestry practices depend on the crop type considered (annual or perennial). Perennial cropping agroforestry system supports less pest abundance and plant damage possibly by the constant presence of shading by trees that decreased both the numbers of herbivore species and the rate of herbivory on cocoa pods (Bisseleua et al. 2013). Likewise, Jonsson et al. (2015) reported higher abundance of coffee berry borer (CBB) *Hypothenemus hampei* on coffee berries in low-shade compared to high-shade systems. The mechanisms operating behind the reduction in CBB abundance and plant damage under shade may include:

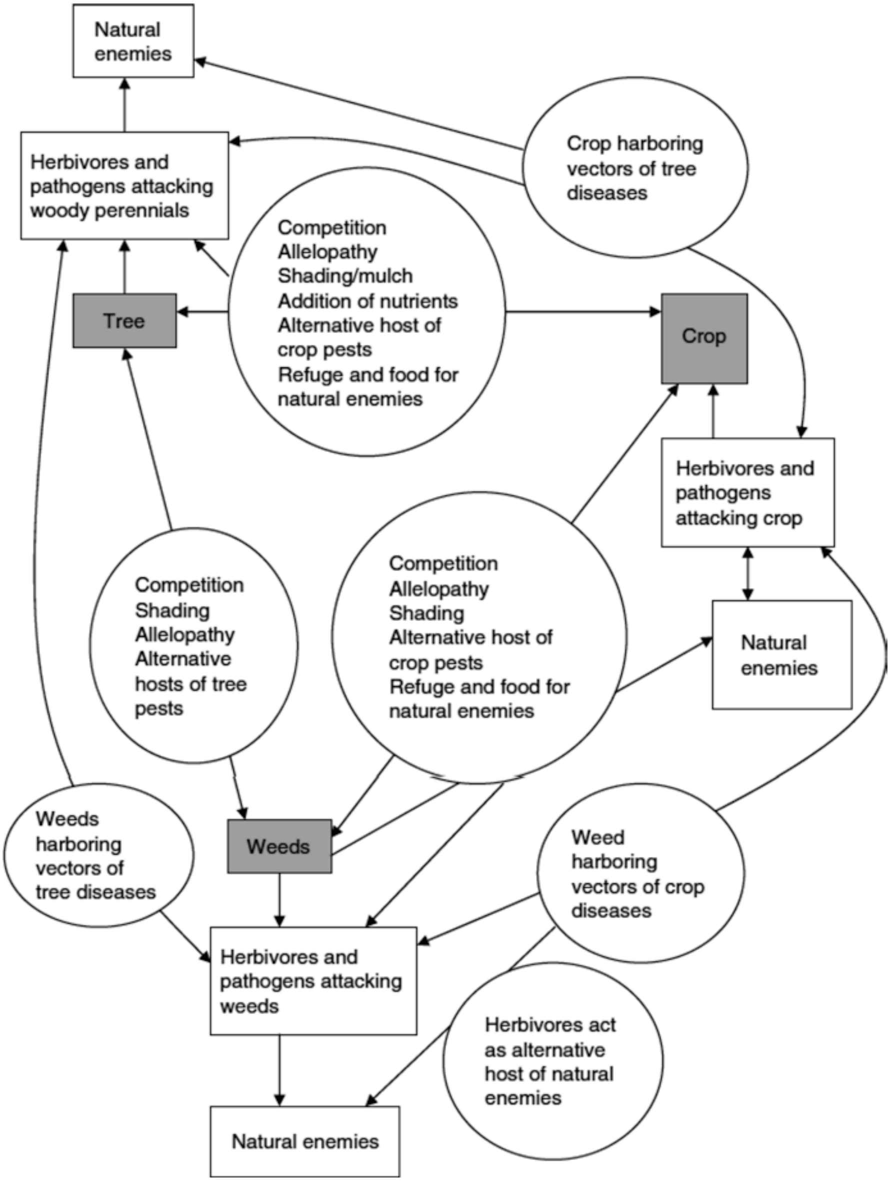

Fig. 6.2 Potential interactions between the plant community, herbivores, pathogens and natural enemies in a simultaneous agro-forestry practice (Sileshi et al. 2008b)

- More effectiveness of natural enemies of CBB, such as birds and parasitoid wasps under shade (Perfecto et al. 1996, Karp et al. 2013).
- CBB development rate reduction under shade (Jaramillo et al. 2009).
- Difficulty in location of oviposition sites by CBB females due to modification of biochemical composition and emission of chemical compounds from coffee berries (Jaramillo et al. 2013).

Table 6.1 Tree–crop interactions and their consequences on pests/diseases/nematodes/weeds in major groups of agro-forestry systems (Sileshi et al. 2008b)

Tree–crop interactions	Process	Possible effects
Sequential systems	Tree canopy shading/smothering the understory vegetation.	Reduction of annual and perennial weeds.
	Tree/shrub species may stimulate germination of parasitic weed Striga.	Weed seed-bank depleted.
		Striga population and its seed-bank are reduced.
	Trees producing allelopathic chemicals.	Reduction of weed populations
	Tree species profusely producing seed and volunteer seedlings.	Tree species becomes an environmental weeds.
		Increase costs of control.
	Tree in fallow or boundary planting harboring pests.	Increased pests damage in adjacent crop fields.
	Increases the pool of available soil nutrients, especially inorganic N.	Increased crop vigor to withstand some pests.
		Increased vigor inducing susceptibility to other pests.
	Tree fallows breaking the cycles of insects and pathogens.	Reduction in insect, disease, and nematode damage on subsequent crops.
	Trees serving as alternative hosts to insects, nematodes, and pathogens.	Increased pest damage on subsequent crops.
	Mulches increasing soil humidity and lowers soil temperature.	Increased soil-borne disease populations.
	Trees serving as refuge and food source for natural enemies.	Reduction of pest problems in adjacent crop fields.
Simultaneous systems	Trees dominating crops by competition for growth resources.	Reduced vigor inducing susceptibility to pests attack.
	Trees serving as refuge and food source for natural enemies.	Reduction of pest problems in adjacent crop fields.
	Tree lines act as mechanical barriers for the spread of insect pests, vectors, and pathogens.	Reduction of pest colonization.
	Trees improving microclimate in harsh environments.	Increased crop vigor.
		Buildup of pests and pathogens.
	Trees serving as alternate hosts to crop pests and disease vectors.	Increased pest damage on crops.
	Tree prunings are used as mulch.	Reduction of shade-sensitive weeds.
	Tree and crop sharing the same pest.	Increase in pest problems.
	Tree canopy and leaf litter keeping the ground covered for most part of the year.	Buildup of some disease.

Girma et al. (2000) reported that lower stalk borer (*Busseola fusca, Chilo* spp.) and aphid (*Rhophalosiphum maidis*) infestations were observed on maize with hedgerows as compared to maize monocrop. Similarly, alley cropping with *Leucaena leucocephala* significantly reduced the abundance of stem borers, stem damage and plant mortality due to maize stem borers (*Chilo partellus*, *C. orichalcociliellus, Sesamia calamistis*) than in a maize monocrop (Ogol et al. 1999).

Maize planted after *Tephrosia vogelii* + pigeon pea, *Sesbania sesban* + pigeon pea, and pure *S. sesban* showed lower termite damage (based on % lodged plants) as compared to maize grown after natural fallow (11 and 5 times more termite, respectively) (Sileshi and Mafongoya 2003).

In contrast, white stem borer *Monochamus leuconotus* on coffee was more common in shaded than in sun-exposed coffee plantations probably due to changes in microclimatic conditions (Jonsson et al. 2015). Likewise, MacLean et al. (2003) reported that increase in the herbivore numbers in some cases might be due to better soil quality and crop nutrition coming from hedgerow biomass. Besides the crop type, the effect of agro-forestry on pests and diseases also depends upon the actors like pest identity, microclimate and the microclimatic preferences of the pest (Schroth et al. 2000).

Avelino et al. (2006) found that shade was responsible for increase in coffee (*Coffea arabica*) rust (*Hemileia vastatrix*) incidence due to changes in microclimate, while the shade favored *Mycena citricolor* in Costa Rica (Avelino et al. 2007) but hampered *Colletotrichum kahawae* in Cameroon (Mouen Bedimo et al. 2008). The brown eye spot disease *Cercospora coffeicola* and mealy bug *Planococcus citri* incidence in coffee were reduced at 35%–65% shade, while simultaneously increasing the effectiveness of microbial and parasitic organisms without increasing the levels of rust pathogen *Hemileia vastatrix* or reducing yields (Staver et al. 2001). However, a heavy shade reduces flower initiation and the yield of coffee trees (*C. arabica*) and negatively affects the development of coffee rust (Avelino et al. 2006).

The changes in microclimate induced by the plant species diversity (PSD) may facilitate a particular process in the life cycle of a pest or parasitoid while hampering the same process in another pest or parasitoid or another process in the same pest or parasitoid (Avelino et al. 2004). The pod rot (*Phytophthora megakarya*) in cocoa is increased under heavy shading, while reducing the insect (*Sahlbergella singularis*) attack (Bigger 1981). Likewise, the intermediate levels of shade increase *Phytophthora* pod rot (Beer et al. 1998), while the fields exposed to full sunlight increased stem canker caused by the same fungus due to water stress. The humid conditions in agro-forestry systems may favor the effectiveness of entomopathogenic fungi due to PSD-induced changes in microclimate along with the absence of direct sunlight (Jaques 1983). Fargues et al. (1988) reported that the half-life and viability of the spores of the fungus *Nomuraea rileyi* were considerably increased in the shade. Smith (2012) (unpublished) based on preliminary data indicated that scab levels were less than half in the organic agro-forestry site (WAF) as compared to the organic orchard control (CLO) (Fig. 6.3). Copper or any other inputs were not used in WAF or CLO system.

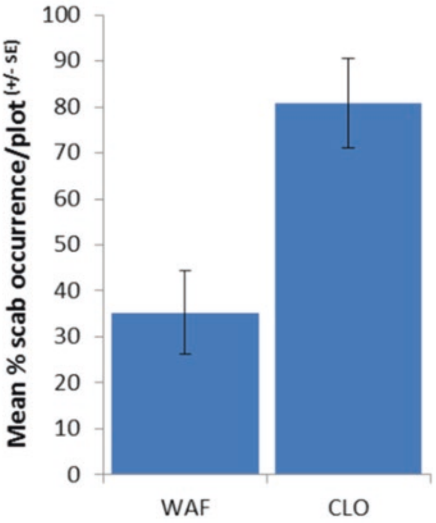

Fig. 6.3 Effect of organic agro-forestry system (WAF) and control orchard (CLO) on scab occurrence on pre-harvest apples (Source: Smith 2012 (unpublished))

Generalist predators such as spiders and ants which are natural enemies of mirid bugs (Way and Khoo 1990) are favored by the presence of different shade strata (Perfecto et al. 1996). However, ants act as vectors for *Phytophthora* diseases (Evans 1973). Perfecto and Vandermeer (1996) reported that a key mutualism exists between an ant (*Azteca instabilis*) and a scale insect (*Coccus viridis*) in a coffee agro-forestry system in Costa Rica. The architectural characteristics of the trees rather than the effects of microclimate are responsible for establishment of the predator *Azteca instabilis* nests in shade trees. Likewise, it is recommended to set up nests of weaver ants *Oecophylla* spp. (which control major fruit flies) and encourage their presence throughout the year by planting tree or shrub species with large flexible leaves or smaller abundant leaves in the vicinity of citrus or mango orchards (Van Mele and Cuc 2007).

6.2.2 Nematodes

The plant-parasitic nematodes that attack crops have also been shown to be affected by rotational fallows. A *Crotalaria agatiflora* cover-crop under rotational fallows decreased *Meloidogyne incognita* and *M. javanica* populations, while the root-lesion nematode (*Pratylenchus zeae*) populations increased to levels that could limit maize growth during the same time (Desaeger and Rao 2000).

Velvet bean (*Stizolobium deeringianum*), sesame (*Sesamum indicum*), castor bean (*Ricinus communis*), partridge pea (*Cassia fasciculata*), marigold (*Tagetes* spp.) and *Crotalaria* spp. possess properties antagonistic to nematodes and may be used to reduce nematode populations in the soil under rotational fallows (Rodríguez-Kábana 1992).

6.2.3 Weeds

The weed abundance is reduced under simultaneous agro-forestry systems mainly due to shading (Nestel and Altieri 1992). The organic material from the trees has been integrated into the soil under sequential agro-forestry systems, resulting in an improvement of soil nutrient availability to better plant growth that allows crops to out-compete weeds (Barrios et al. 1998; Sileshi et al. 2008a). The moderation of microclimate (decreases soil temperature) by trees (Nestel and Altieri 1992; Sileshi et al. 2008a; Barrios et al. 2012) prevents germination and emergence of striga (Carson 1989). Covering of the soil with litter from plants significantly reduced emergence of striga (Midega et al. 2013).

Sileshi et al. (2006) reported significant reduction in the incidence of *Striga asiatica* under rotational fallows (in sequential agro-forestry practices) of *Sesbania sesban* that persisted on subsequent maize for three consecutive cropping cycles compared with continuously cropped monoculture maize. Likewise, the number of *Striga hermonthica* seeds in the soil was reduced by 34% under *S. sesban,* while the *Striga* populations increased over the same period by 11% in monoculture maize plots (ICRAF 1993). The combined effects of *S. sesban* causing suicidal germination of *Striga hermonthica* (i.e., a "trap crop" effect) and improving soil inorganic N were responsible for reduction of *Striga* under *S. sesban* (Gacheru and Rao 1998).

6.2.4 Natural Enemies

The trees in multistrata agro-forestry can increase the abundance of natural enemies (Sileshi et al. 2008b). The parasitic wasp *Cephalonomia stephanoideri* and the entomopathogenic fungus *Beauveria bassiana*, which control the coffee berry borers, are favored by the shade trees (Beer et al. 1998). *Helopeltis* damage to cocoa can be managed by planting coconut in cocoa plantations to provide nesting sites for the predatory ants *Dolicoderus* and *Oecophylla* (Way and Khoo 1990). More diverse traditional agro-forestry systems enhance predator–prey ratio as compared to intensified systems (Klein et al. 2002). The abundance of soil fauna is enhanced when organic material from the improved fallows is incorporated into the soil in annual cropping systems, probably due to an improved living environment for ground and soil-based natural enemies (Barrios et al. 2005, 2012; Sileshi and Mafongoya 2006a). More below-ground natural enemies (particularly ants, carabid beetle larvae and centipedes) have been recorded in maize-based agro-forestry as compared to the corresponding monoculture (Sileshi and Mafongoya 2006b).

The heterogeneity of the habitat, the quality and quantity of bio-resources and regulation of ecological niches of various species in the community can be increased by planting ground cover plants and weeds in orchards that provide a variety of resources for predators and parasitoids, including shelter, food and information on the location of their herbivorous prey (Bugg and Waddington 1994; Liang and Huang 1994). The citrus red mite (*Panonychus citri*) can be managed by the weed *Ageratum conyzoides* growing in citrus orchards, which stabilizes populations of the predatory mites (*Ambleyseius* spp.) (Liang and Huang 1994). The population of generalist predators like lady beetles, ground beetles, hover flies, mirid bugs and lacewings are enhanced by understory vegetation as compared to clean-weeded orchards (Bugg and Waddington 1994). Understory weeds colonized by aphids can play an important role as reservoirs of polyphagous natural enemies such as lady beetles, hover flies and lacewings.

6.3 Conclusions

Agro-forestry systems may provide opportunities to noticeably increase plant and pest diversity which are beneficial for pest, disease and weed management due to higher habitat complexity (Letourneau et al. 2011; Iverson et al. 2014). More research is required in specific areas like basic research into the life histories of target pests and potential natural enemies, and mechanisms behind enhancement of pest management with agro-forestry practices. The future agro-forestry design practices should be determined by understanding what aspects of trees modify pest populations—shelter, food or host resources for natural enemies; temporal continuity; microclimate alteration or apparency (Rao et al. 2000). Future studies should assess the effects of agro-forestry in a broader range of crops, regions and types of agro-forestry systems, and disentangle the mechanisms underlying the effects of agro-forestry on pest management.

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Cover/Green Manure Cropping

7

Abstract

The cover/green manure crops can be considered as the backbone for any annual cropping system to be sustainable. They are responsible for sustainable farming because of enhancement of organic matter, improvement of soil structure, nitrogen fixation, nutrient enhancement, rooting action, soil and water conservation, soil microbial activity, and pest management. This chapter summarizes different management aspects of insect and mite pests (pollen and nectar source for predators, overwintering habitats for generalist predators, and understory cover crops in orchards), disease pathogens, nematode pests, and weed suppression using cover/green manure crops. The mechanisms involved in insect pest, disease, and weed suppression are also discussed.

Keywords

Insect pests • Diseases • Nematodes • Weeds • Pest management

7.1 Introduction

Cover/green manure crops are planted between main crops which are valuable tools for agricultural production and productivity. The major fertility management tools for organic farmers include cover/green manure crops. They are cultivated in order to improve the physical, chemical, and biological properties of soil, and to cover the soil surface. In fact, cover crops can act as an “ecological turntable” influencing various agro-ecological processes simultaneously. They can add or retain soil nitrogen (N), facilitate the availability of nutrients, improve soil organic matter, reduce nutrient leaching, improve soil structure and quality, enhance microbial activity, reduce soil compaction, improve water infiltration, enhance moisture retention, protect soil from erosion, and manage crop pests (insect pests, disease pathogens, nematode pests, and weeds), which positively impact yields over time (Fig. 7.1).

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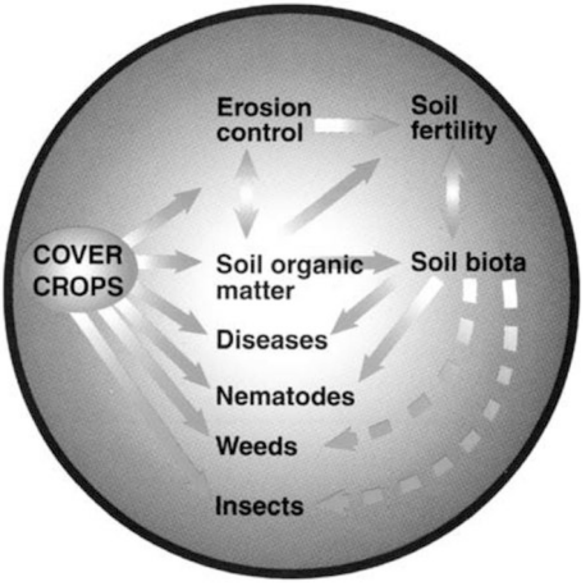

Fig. 7.1 Effect of cover cropping on multiple and interactive processes (Lansing 2000)

Pest management can be achieved by cover crops which are to play an increasingly important role.

Cover crops have a high potential for the management of insect pests, diseases, nematodes, and weeds. They can reduce pest infestations along with limited tillage and careful attention to cultivar choice, placement, and timing. Besides pest management, other benefits of cover crops include minimized reliance on pesticides, and as a result cut costs, reduced chemical exposure, protection of the environment, and increased consumer confidence in the food that is produced.

Under no-tillage production systems, soil surface cover with living crops can provide opportunities for regulating pest populations. Generation of substantial quantities of surface vegetation and residues generated by cover crops can enhance management of pests. Prevention of pathogen propagules dispersal through splashing and/or wind-borne processes helps in management of foliar diseases. Cover crops can disrupt emergence, suppress establishment, and affect the migration behavior of soil-inhabiting herbivores like the Colorado potato beetle, resulting in reduction of pest populations and elimination of crop yield loss.

7.2 Disease Management

Everts (2002) reported that the cover crops decrease populations of bacterial and fungal pathogens by breaking their life cycles. The soil inoculum of bacterial blight (*Ralstonia solanacearum*) in banana was reduced by growing cover crops like kudzu (*Pueraria phaseoloides*) and sorghum.

The onset of early blight in tomatoes can be delayed by using cover crops such as cereal rye and flowering rapeseed as mulches, which reduces soil splash onto leaves. Similarly, vegetable crop diseases caused by *Rhizoctonia* spp. can also be reduced by growing oats as cover crop (Sustainable Agriculture Network 1998).

Abawi and Widmer (2000) reported that the root rot disease complex (caused by several pathogenic fungi [*Fusarium solani* f. sp. *phaseoli*, *R. solani*, *Pythium ultimum*, and *T. basicola*] and the plant-parasitic nematodes [*Pratylenchus* spp.] individually or in any possible combination) in beans were suppressed by growing rapeseed, wheat, and rye cover crops. Similarly, the take-all in wheat, *Sclerotinia* (white mold) in lettuce, and Verticillium wilt in cauliflower can be managed by brassicas as cover crops (Hartz et al. 2005). Likewise, the biotic factors (fungal and nematode pathogens) in strawberry replant problem were suppressed by utilizing Indian grass (bunch grass) (*Sorghastrum avenaceum*) and brown mustard (*Brassica juncea*) as cover crops, which led to 32% and 28% higher strawberry yields, respectively, compared to yields from strawberries in fumigated soil (Seigies and Pritts 2006).

In the Salinas Valley, the lettuce drop disease, caused by *Sclerotinia minor*, was managed in large areas by rotating lettuce with mustard cover crops (Hao et al. 2003). Similarly, the Verticillium wilt on tomato was suppressed by mustard cv. Caliente 119 and Sudan grass strips of cover crops known to have "biofumigant" properties. Rotation of tomatoes with mustard and Sudan grass yielded twice as much as tomatoes grown after the buckwheat cover crop control (Subbarao et al. 1999). Some of the other diseases controlled by mustard cover crops (*Brassica and Sinapis* spp.) include *Sclerotinia sclerotiorum* (Smolinska and Horbowicz 1999) and *Verticillium dahliae* (Olivier et al. 1999).

The soil-borne diseases which cause 10–15% losses in vegetable crops can be managed by disease-suppressive cover crop rotations with Sudan grass, Brassica, millet cover crops resulting in significant increases in yield. The other examples of green manure cover crops being effective against vegetable diseases include lucerne hay/residues against *Sclerotinia sclerotiorum* in lettuce (Asirifi et al. 1994) and common root rot of pea (*Aphanomyces eutieches*) (Williams-Woodward et al. 1997), and buckwheat against common scab (*Streptomyces scabies*) and Verticillium wilt of potatoes (Wiggins and Kinkel 2005).

7.3 Insect Pest Management

The habitat, food, and shelter needed for insect pest natural enemies during the winter are provided by cover crops such as crimson clover, cereal rye, vetch, or some other cover crops. The overall number of beneficial insects is increased by growing cover crops. The natural enemies can move from dying winter cover crops to spring-planted crops to provide some pest suppression. Each cover crop provides different resources and habitats that may encourage some species of natural enemies.

The beneficials have time to find other habitat, if a cover crop is allowed to die naturally. The beneficial populations shall have less effect by carefully mowing a cover crop than disking or plowing. Bugg and Waddington (1994) reported that the use of cover crops augment biological control of pests through habitat manipulation for natural enemies.

The seasonal population of predatory mite *Euseius tularensis* can be enhanced to reduce pest populations of citrus thrips by planting various leguminous cover crops such as bell bean, woolly pod vetch, New Zealand white clover, and Austrian winter pea which provide sufficient pollen as a feeding source (Grafton-Cardwell et al. 1999).

Growing of a green manure cover crop can significantly decrease infestations of cabbage root fly (*Delia radicum*) (O'Donnell and Coaker 1975; Finch and Edmonds 1993), which is a serious pest with the potential to cause widespread economic damage to Brassica crops (Coaker and Finch 1971). This is because the presence of a green manure cover crop belonging to nonhost plant species reduces pest colonization (Finch and Collier 2000). The egg-laying by the cabbage root fly was reduced by 36–82% when cauliflowers were planted among 24 other nonhost plant species (Finch et al. 2003).

The leaf hopper pests in grape vineyards can be managed by planting clover and other legume ground covers that attract beneficial wasps and spiders and provide them with habitat and food source.

The multiple benefits provided by cover crops such as cereal rye and flowering rapeseed are as follows:

- Increased beneficial insect populations.
- Minimized aphid pressure on many crops.
- Reduced pest damage (cucumber beetle in pumpkins).
- Reduced pest populations (Colorado potato beetles in tomatoes).

7.3.1 Pollen and Nectar Source for Predators

Pollen and nectar plants play considerable role in increasing the effectiveness of biological control agents in fruit orchards. Commonly used flowering green manure cover crops such as buckwheat (Bowie et al. 1995), crimson clover (Tillman et al. 2004), and Phacelia (Hickman and Wratten 1996; Denys and Tscharntke 2002) have all been reported to act as pollen and nectar sources for predatory insects such as hoverflies, lacewings, ladybirds, and parasitic wasps when grown in conjunction with other crops.

7.3.2 Overwintering Habitats for Generalist Predators

Several researchers have reported that the grass cover crops like Tussocky grasses (cocksfoot or tall oat grass) act as most effective habitats for the overwintering of generalist predators specifically carabid and staphalinid beetles (Andersen 1997; Collins et al. 2003; Kajak and Lukasiewicz 1994). Kajak and Lukasiewicz (1994) reported that these predators move from grass clover leys into nearby crops for biological control of pests (for further details on habitat management, see Chap. 11).

7.3.3 Understory Cover Crops in Orchards

The biological control of orchard arthropod pests is enhanced by the manipulation of ground-cover vegetation (Prokopy 1994). A significantly lower incidence of insect pests was observed in orchards with rich floral undergrowth, mainly because of an increased abundance and efficiency of predators and parasitoids, than in clean-cultivated orchards (Smith et al. 1996). The codling moth (*Cydia pomonella*) attack was less severe in uncultivated orchards as compared to continuously cultivated orchards (Peterson 1926). Similarly, orchards with weeds showed greater percentage of fruit moth larval parasitism than in clean-cultivated orchards (Peppers and Driggers 1934).

The presence of goldenrod (*Solidago* sp.), lamb's-quarter (*Chenopodium album*), ragweed (*Ambrosia* sp.), and smartweed (*Polygonum* sp.), which provided alternate hosts for the parasite *Macrocentrus ancylivorus*, helped in effective management of the oriental fruit moth in peach orchards (Bobb 1939). Likewise, the parasitism of tent caterpillar eggs and pupae in apple orchards increased fourfold and eighteenfold, respectively, while parasitism of codling moth larvae increased fivefold by the presence of wild flowers over nonweedy orchards (Leius 1967).

Sowing of the honey plants *Phacelia* and *Eryngium* in forest plantations attracted the parasitoid *Scolie dejeani* to its grub hosts (Telenga 1958). Similarly, aphids in apple orchards were managed by sowing of the honey plants *Phacelia* and *Eryngium* which increased the abundance of the wasp *Aphelinus mali* and improved the activity of *Trichogramma* spp. wasps. Likewise, three successive plantings of a cover crop *Phacelia tanacetifolia* in apple orchards increased parasitization of the San Jose scale (*Quadraspidiotus perniciosus*) from 5% in clean-cultivated plots to 75% in the *Phacelia* plots (Churnakova 1960).

Leston (1973) reported that the light shade provided by coconut to cocoa supported high populations of *Oecophylla longinoda* and kept the cocoa crop free from cocoa capsids in Ghana. Likewise, the use of a cover crop was recommended to improve the biological control of coreid pests by the ant *Oecophylla smaragdina subnitida* in coconut groves in the Solomon Islands (O'Connor 1950). Similarly, economic control of the rhinoceros beetle (*Oryctes rhinoceros*) in Malaysian oil palm (*Elaeis guineensis*) plantations was possible by simply encouraging heavy ground cover, irrespective of type including the growth of weeds between the trees, due to flight obstruction of the adult beetles or restriction of their movement on the ground (Wood 1971).

The presence of weeds in walnut orchards served as a temporary food source for the most important aphid predator, *Hippodamia convergens*, in California. Chopping or disking of the ground cover under the trees in late April or early May force the beetles onto the walnut trees for the management of walnut aphids (*Chromaphis juglandicola*) (Sluss 1967). Similarly, establishment of various small grain and crucifer cover crops in pear orchards supported several species of general predators by aphids and *Lygus* bugs harbored by the cover crops in Yakima Valley (Fye 1983). Likewise, Croft (1975) recommended allowing of ground plants to grow in the apple orchards to encourage the phytophagous mites which served as an early-season food source for the predatory mite *Amblyseius fallacis,* which later moves up into the trees and regulates the spider mites *Panonychus ulmi* and *Tetranychus urticae*.

Under-story cover crops such as *Ageratum conyzoides*, *Erigeron annuus*, *Aster tataricus* planted or conserved in 135,000 ha of citrus orchards in China encouraged natural enemies, especially *Amblyseius* spp., which gave excellent results against the citrus red mite (*Panonychus citri*) (Liang and Huang 1994). Similarly, the natural enemy populations were substantially enhanced in apple orchards by the cover crop system consisting of *Lagopsis supina* (Labiatae) than Chinese rape (*Brassica campestris*) and/or alfalfa (Yan et al. 1997). Likewise, the ground cover of orchard grass (unsuitable host for leaf hoppers) in peach orchards attracted relatively few adult leaf hoppers, *Scaphytopius acutus* (vectors of x-disease) (McClure 1982).

The weed ground-cover plots in grape vineyards increased the abundance of generalist predators, especially spiders, which may help to reduce the leaf hopper populations (Settle et al. 1986). Likewise, habitat modification by managing a ground cover of Johnson grass (*Sorghum halepense*) or Sudan grass resulted in enhanced activity of predatory mite (*Metaseiulus occidentalis*) against phytophagous mites such as the Willamette mite (*Eutetranychus willamette*) (Fig. 7.2) (Flaherty 1969).

7.4 Nematode Management

The warm season legume cover crops are effective in reducing populations of certain plant-parasitic nematodes by breaking their life cycles (Potter et al. 1998; Vargas-Ayala et al. 2000). The populations of sting (*Belonolaimus longicaudatus*) and root-knot (*Meloidogyne incognita*) nematodes were effectively reduced in cash crops by hairy indigo and joint vetch cover crops combined with mulching of cowpea clippings (Rhoades and Forbes 1986). Likewise, the population densities of several root-knot nematode species were lowered (present simultaneously) by the cover crop velvet bean in greenhouse and field tests (Rodriguez-Kabana et al. 1992).

A step-wise procedure of cover cropping strategy that combines mowing, mulching, and green manuring of sun hemp for nematode control is as follows (Fig. 7.3) (Hooks et al. 2006):

- Plant sun hemp (sow seed at 40–60 lb./acre): allow it to grow to early flowering stage and mow.
- Till strips into the mowed field.
- After a week, plant the cash crop into the tilled strips.

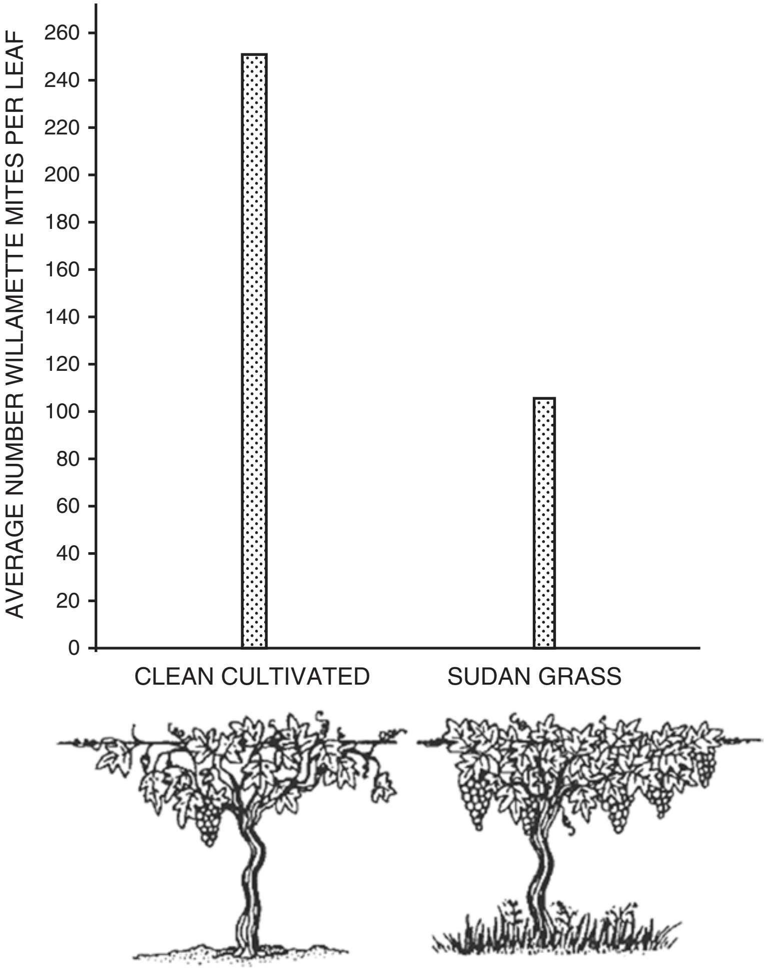

Fig. 7.2 Effect of ground cover with Sudan grass on Willamette mite populations in a California vineyard (After Flaherty 1969)

The root-knot nematode damage in snap bean crop was reduced by rotation with certain cover/green manure crops like crotalaria, hairy indigo, joint vetch, pigeon pea, and velvet bean. Similarly, Loos (1961) reported that the burrowing nematode *Radopholus similis* on banana can be eliminated by planting of sugarcane or cover crops such as Pongola grass (*Digitaria decumbens*), *Panicum maximum* var. *trichoglume*, and *Phaseolus atropurpureus* following the destruction of bananas. Likewise, the root-knot nematode (*M. incognita*) population on black pepper was reduced by growing of nonhost cover crop like Siratro (*Macroptilium atropurpureus*) in the interspaces (Ichniohe 1975).

Some cover crops which act as trap crops can be utilized for the management of certain nematodes. The trap crop *Solanum sisymbriifolium* stimulated hatching of

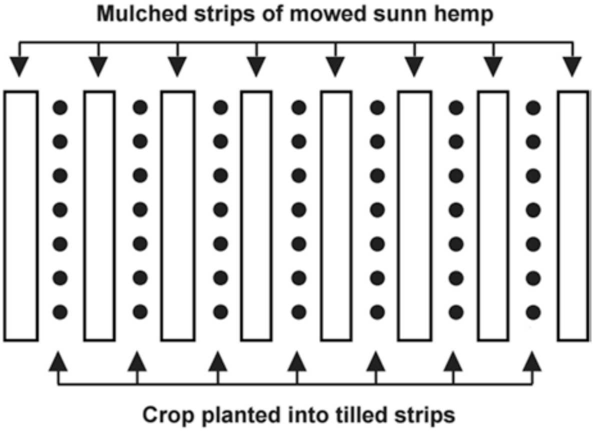

Fig. 7.3 A cover cropping strategy that combines mowing, mulching, and green manuring of sun hemp for nematode control

potato cyst nematodes (*Globodera* spp.) but was completely resistant, since no progeny cysts were formed (Scholte 2000a, b; Scholte and Vos 2000; Timmermans et al. 2005). The sustainable production of sugar beet in fields infested with the sugar beet cyst nematode (*Heterodera schactii*) was achieved by using Brassicaceous green manure cover crops which act as trap crops for nematodes (Thorup-Kristensen et al. 2003; Schlathoelter 2004; Matthiessen and Kirkegaard 2006). Similarly, growing green manure cover crops like fodder radish (*Raphanus sativus*) and white mustard (*Sinapis alba*) preceding sugar beet crops also gave effective management of the sugar beet cyst nematode crops (Caubel and Chaubet 1985; Lelivelt and Hoogendoorn 1993). Even though the larvae of *H. schactii* enter the roots of sugar beet and develop, their sexual differentiation is disrupted, resulting in very low numbers of females in the following generation, causing a significant decline in the population and reducing infestation of subsequent sugar beet crops.

7.5 Weed Management

The weed suppression by cover/green manure crops results in saving labor used for hoeing and reducing the use of herbicides, lowering production costs. Three basic ways by which cover crops and surface crop residues control or inhibit weeds in subsequent cash crops include:

- Shading and smothering of weeds by preventing adequate air and light for seed germination.
- Crops out-compete weeds for nutrients.
- Decomposition of cover crops producing allelopathic toxic effect on weed seed germination and seedling growth.

Teasdale and Daughtry (1993) reported that the vigorous cover crop stand is primarily responsible for suppression of weed seed germination and growth by

Table 7.1 Effect of cover crops on the allelopathic effects on weeds

Cover crop	Weeds suppressed	References
Cereal rye	Lambs quarters, redroot pigweed, common ragweed	Barnes and Putnam (1986) and Masiunas et al. (1995)
Crimson clover	Pitted morning glory, wild mustard, Italian ryegrass	Teasdale and Daughtry (1993) and White et al. (1989)
Hairy vetch	Lambs quarters, yellow foxtail, yellow nut sedge, pitted morning glory	Teasdale and Daughtry (1993) and White et al. (1989)
Sorghum-Sudan grass	Annual ryegrass	Forney and Foy (1985)
Velvet bean	Yellow nutsedge, chickweed	Hepperly et al. (1992) and Fujii et al. (1992)
Wheat	Morning glory, prickly sida	Liebl and Worsham (1983)

simply out-competing weed seeds for light and nutrients. The thick residues that remain on the surface after the cover crop is killed prevent weed growth by physically modifying the amount of natural light, soil temperature, and soil moisture that are necessary for weed seed germination.

The weed suppression effect due to smothering is reduced as cover crop residues decompose, which depends on several variables such as temperatures, rainfall, field tillage, and C:N ratio. The decomposition rate can be speeded up by warm temperatures, rainfall, and field tillage. Cover crop residue decomposition has indirect correlation with C:N ratio. The mature small grain cover crops like rye and grasses have a high C:N ratio (around 50) and a much slower decomposition rate, while legumes like hairy vetch which have a low C:N ratio (around 12) have a much faster decomposition rate.

The legumes that are used as green manures such as lucerne (Chung and Miller 1995), crimson clover (Dyck and Liebman 1994), vetch (Kamo et al. 2003), subterranean clover (Nagabhushana et al. 2001), and red clover (Fisk et al. 2001) have been found to have allelopathic effects on certain weeds (Table 7.1). Teasdale and Daughtry (1993) reported that the allelopathic effects were more apparent if cover crops (particularly crimson clover and hairy vetch) are incorporated rather than left on the surface in no-till management.

The level of weed control of common lambsquarters (*Chenopodium album*) and redroot pigweed (*Amaranthus retroflexus*) nearly equal to that of a standard herbicide treatment was obtained in lettuce by incorporation of rapeseed cover crop foliage into the soil treatment (Boydston and Hang 1995). Krishnan et al. (1998) reported that green manure cover crop incorporation in soil gave more modest control (i.e. 30–40%) of redroot pigweed and velvet leaf (*Abutilon theophrasti*) in soybeans.

The most common annual broadleaf and grassy weeds were suppressed for 4 to 8 weeks in tomatoes by cereal rye cover crop residues on the soil surface, thus eliminating the need for a soil-applied herbicide at transplanting without depressing yield (Smeda and Weller 1996). The level of weed control in several crops depends on different cover/green manure species (Table 7.2).

Table 7.2 Effect of some important cover/green manure species on level of weed control

Common name	Scientific name	Level of weed control[a]
Velvet bean	*Mucuna* spp.	4
Jack bean	*Canavalia ensiformis*	3
Cowpea	*Vigna unguiculata*	3
Pigeon pea	*Cajanus cajun*	2
Tephrosia	*Tephrosia vogeli* or *T. candida*	2

[a] 4-Extremely good, 3-Good, 2-Fair, 1-Poor

Table 7.3 Effect of summer cover/green manure crops (CGMC) on weed infestation in cotton (60 days after sowing)

	Weeds		Species (%)	
Treatments	Plants/m^2	Relative %	Narrow-leaved[a]	Broad-leaved[b]
Without CGMC	2676	100	19	81
Cowpea var. Tupí	782	29	1	99
Lab-lab (White seed)	675	25	20	80
Pigeon pea	518	19	15	85
Calopo	425	16	4	96
Jack bean	382	14	3	97
Black-seeded mucuna	300	11	7	93
Sun hemp	191	7	9	91
Gray-seeded mucuna	130	5	9	91

Choré Experimental Station (Florentín 1997)

[a] Predominant weeds: sandbur (*Cenchrus echinatus*), sour grass (*Digitaria insularis*)

[b] Predominant weeds: dayflower (*Commelina* sp.), painted spurge (*Euphorbia heterophylla*), hispid starburr (*Acanthospermum hispidum*)

Florentín (1997) reported that the green manure/cover crops like gray-seeded mucuna and sun hemp gave the best weed suppression of 95 and 93% in cotton, respectively, over control without CGMCs (Table 7.3). Besides weed suppression, the use of green manure/cover crops favor the cotton crop by reducing competition for water, light, and nutrients, resulting in saving the labor (hoeing) for weed control.

The incidence of weeds in maize crop is also reduced by prior growing winter green manure/cover crops (Table 7.4) (Florentín 1997).

The incidence of difficult-to-control weeds such as nut grass (*Cyperus rotundus*) and Jamaican crabgrass (*Digitaria horizontalis*) was reduced by sowing pigeon pea at high densities. Similarly, the infestation of sandbur (*Cenchrus equinatus*) was reduced on several farms by gray-seeded mucuna cover crop.

Indian and white mustard cover crops were equally effective in reducing weed emergence of shepherd’s purse and burning nettle in lettuce-treated pots. Cover/fodder crops such as Desmodium (*Desmodium* spp.), Mucuna (*Mucuna* sp.,

Table 7.4 Effect of flattening winter cover/green manure crops (CGMC) with a knife-roller on weed infestation before sowing maize

Cover/Green manure crop	No. of weeds/m^2				Dry matter of weeds	
	Narrow-leaved[a]	Broad-leaved[b]	Total	Relative %	g/m^2	Relative %
Winter fallow	15	85	296	100	144	100
Sweet white lupine	15	85	264	89	119	83
Peas var. Arvejón	21	79	196	66	105	73
Triticale	18	82	159	54	58	40
Bitter white lupine	23	77	146	49	57	40
Sunflower	6	94	142	48	34	24
Black oats	29	71	99	33	8	6
Oilseed radish	9	91	46	16	8	6
Black oats + Hairy vetch	0	100	30	10	4	3
Hairy vetch	0	0	0	0	0	0

Choré Experimental Station (Florentín 1997)

[a] The predominant wide-leaved weed was Brazilian pusley (*Richardia brasiliensis*)

[b] The predominant narrow-leaved species was Jamaican crabgrass (*Digitaria horizontalis*)

Stizolobium atterrinum), and Stylosanthes (*Stylosanthes guianensis*) stimulated 70% more Striga seed germination than maize without being parasitized (Ndung'u et al. 2000; Khan et al. 2008).

Growing of gray-seeded mucuna as cover for the first year, and of dwarf mucuna the second year, reduced the number of hoeings per year to one as compared to three per year in the conventional system, under cultivation of no-till sugarcane. The use of gray-seeded mucuna as cover for the cultivation of watermelon also gave similar results.

The efficiency of weed suppression can be increased by growing mixtures of cover/green manure crops (CGMCs) from different families than sowing the same species alone. For example, the attack of anthracnose on cover crop white lupine was considerably reduced when associated with black oats cover crop. In addition, the efficiency of weed suppression of Dayflower (*Commelina* sp.) increased in a mixture of white lupine and black oats than white lupine alone.

The classic example of mixed cropping is that of the American "three sisters"—maize, beans, and cucurbits (squash and pumpkins). All three seeds are planted in the same hole. The maize provides a stalk for the beans to climb on, the beans are nutrient-rich to offset that taken out by the maize, and the squash grows low to the ground to keep weeds down and water from evaporating from the soil in the heat.

Even though cover crops in rotation suppress weeds, care should be exercised that they do not serve to increase weed infestation by becoming weeds themselves, since Phacelia has the ability to self seed prolifically and may become a weed in subsequent crops.

7.6 Mechanism of Pest Suppression

7.6.1 Disease and Nematode Management

The two ways by which the green manure cover crops suppress diseases and nematodes include:

- Green manures provide organic substrates for sustenance of microbial communities (bacteria, nonpathogenic Fusarium species, Streptomyces and other Actinomycetes) which in turn suppress pathogens through competition, antibiosis, parasitism, or by inducing systemic resistance in plants (Hoitink and Boehm 1999).
- Green manures may have a direct toxic effect on the pathogen (glucosinolates produced during biofumigation) (Larkin and Griffin 2007).

The mechanisms by which soilborne diseases, such as apple replant disease, Fusarium wilt, Verticillium wilt, and plant-parasitic nematodes were managed by using cover crops include (Stone 2012):

7.6.1.1 Extending the Length of a Crop Rotation

Many pests and pathogens cannot survive long without their hosts. Hence, the build-up of pathogens and pests can be reduced by increasing the time between susceptible crops through cover crops in rotation.

7.6.1.2 Improving Soil Structure

The poor soil conditions as a result of inadequate drainage, poor soil structure, low organic matter, low soil fertility, and high soil compaction encourage the damage from soil-borne diseases (Abawi and Widmer 2000). Cover crops such as Sorghum-Sudan grass, sweet clover, and oilseed radish which are specifically good at loosening compacted soil and improving soil structure can be utilized to manage soil-borne diseases.

7.6.1.3 Providing a Physical Barrier

The amount of soil (and pathogens) splashed onto plants can be reduced by a living or dead mulch of a cover crop. In addition, the mulch can also keep fruits of squash or tomatoes off the ground to prevent infection from soil-borne pathogens.

7.6.1.4 Enhancing Suppressive Effects of Soil Life

The microbial activity of soil is increased by cover crops. Davis et al. (2010) reported that the green manure cover crops such as peas, Sudan grass, rapeseed, oats, or rye were found to reduce Verticillium wilt in subsequent potato crops by enhancing the root colonization with more nonharmful fungi which may displace pathogens. Similarly, the apple replant disease was managed using wheat as cover crop which may provide habitat for bacteria that suppress the pathogens (Mazzola and Mullinix 2005). Likewise, Brassicas such as Indian and brown mustard

(*B. juncea*), Forge and Cutlass mustard cultivars and oilseed radish releases glucosinolates during their decomposition (Abawi and Widmer 2000) which have a strong effect on potato scab and black scurf, and other soil-borne pathogens (Larkin and Griffin 2007).

7.6.2 Weed Management

The different mechanisms by which green manure cover crops suppress weeds include the following (Liebman and Davis 2000):

- The green manure cover crops are effective in suppressing weed populations by breaking their life cycles. By planting and cultivation of similar crop types continuously, weeds often become adapted to a particular niche cycle (Blackshaw 1994). This niche cycle is disrupted by growing green manure cover crops in rotation.
- The green manure cover crops reduce weed competition by competing for light, water, and nutrients. McLenaghen et al. (1996) reported that the weed suppression was directly correlated with the ground cover of the green manure. For example, mustard, which grows rapidly and covers the ground, is the most effective crop for weed suppression.
- The management practices such as mowing (Norris and Ayres 1991) and grazing (Dowling and Wong 1993) associated with growing a green manure cover crop will suppress weeds.
- The reduced germination of weed seeds occurs due to lack of soil disturbance during the long growing period of a ley (Roberts and Feast 1973).

7.7 Conclusions

A significant contribution has been made to sustainable agriculture by cover/green manure crops. Besides pest management, the favorable outcomes due to cover/green manure crops include enhancing agro-biodiversity, high flexibility, low input costs, increasing soil organic carbon, managing soil erosion, and reduced risk. These benefits from cover/green manure crops make agriculture eco-friendly and economically viable system for many end users. The scope of cover/green manure crops for pest management can be expanded by integrating them with cropping systems research.

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Intercropping

8

Abstract

Intercropping (cultivating two or more crops at the same time in the same field) brings about increased diversity in an agro-ecosystem. Besides reducing the damage by pests, diseases, and weeds, intercropping increases higher growth rate, helps in better utilization of resources, maintains ecological balance, increases soil conservation through greater ground cover, provides better lodging resistance for crops susceptible to lodging, increases soil fertility by using legumes as intercrops, provides insurance against crop failure, improves the quality and quantity of products, and offers greater financial stability. Intercropping minimizes environmental impacts of agriculture through reduced pesticide requirements.

Keywords

Agro-biodiversity • Intercropping • Insect pests • Disease pathogens • Weeds • Crop mixtures

8.1 Introduction

Conventional monocropping system is responsible for depletion of the natural resources and causes environmental pollution. In view of these and other problems with monoculture farming become more apparent, “sustainability” is the need of the hour, and interest in intercropping is gaining importance as part of the solution. Intercropping can be defined as simultaneous growing of two or more different crops (e.g. grain + legume – nitrogen-fixing crops) at the same time in the same field or in alternate rows. Increasing the productivity per unit area is the objective of intercropping (Harwood 1974). Intercropping systems increase diversity in an agricultural ecosystem, ecological balance, better use of soil nutrients (Igzoburkie 1971); improve the quantity and quality of products, soil structure, weed control,

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microclimate manipulation (e.g. growing a tall crop to provide a wind barrier); provide habitat for natural enemies and even act as a trap crop; and reduce damage by pests, diseases, and weeds. In addition, Anil et al. (1998) reported that intercropping was found to improve nutrients by increasing nitrogen from legumes or increasing the uptake of phosphorus and potassium.

In developing countries, intercropping is a common practice in the agriculture system. In intercropping, the subsidiary crops are grown in between two widely spaced rows of main crops. The most common intercropping includes cereals and legumes, both for forage and for grain. The cereal-legume intercropping provides nitrogen to the system by the fixation of atmospheric nitrogen by the legume. Examples of intercropping schedule include green gram/red gram-cotton, sugarcane-soybean, and green gram/black gram-maize.

The most desirable traits to be considered in selection of crops for intercropping systems include the following (Francis et al. 1976):

- Efficient in fertilizer use
- Erect and non-lodging types
- Good population response
- Insect pest, disease, and nematode resistance
- Insensitivity to photoperiod
- Potential for high yield
- Suppression of weeds
- Uniform and early maturity

There are many spatial combinations possible for intercropping:

- Mixed intercropping: Different crops are planted in the same row or without regard to distinct row or strip arrangements.
- Relay intercropping: Planting in succession, where a second crop is planted into a standing crop at the reproductive stage before harvesting.
- Row intercropping: Growing two or more crops together at the same time in alternating rows or at least one crop planted in rows.
- Strip intercropping: Growing two or more crops together in strips wide enough to permit separate crop production using machines but close enough for the crops to interact.

A review of 209 published field studies in which 287 herbivore species were studied showed that 52% of the pest species (149 species) were less abundant in the intercrop. The population of natural enemies of the pests was also higher in 53% of the studies in the intercrop (Fig. 8.1) (Andow 1991).

The different crops interplanted are not likely to share the same insect pests and disease-causing pathogens, which is the rationale behind intercropping. In view of intercropping other crops (belonging to different family group) in between, the distance between plants of the same species is increased. The reduction in insect pest populations under intercropping might be due to higher numbers of natural insect

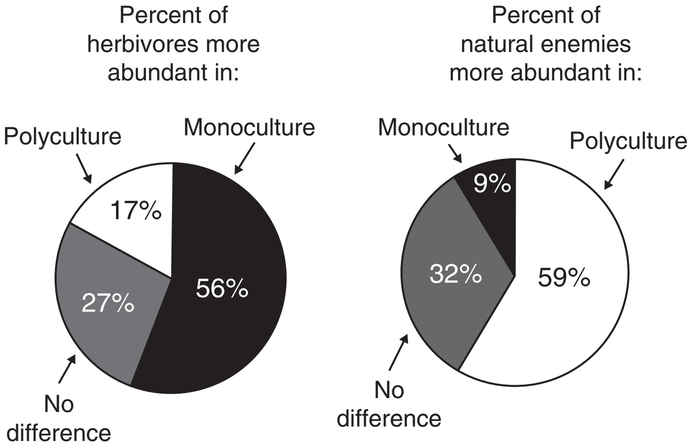

Fig. 8.1 Effect of intercrops on insect pests and their natural enemies (Andow 1991)

enemies in the intercrop and/or reduced herbivore colonization and tenure time of the intercrop. The herbivore movement patterns are often more important in accounting for reduced pest abundance in an intercrop, rather than the natural enemies. The population reduction of insect pests, diseases, nematodes, and weeds can be managed by proper designing of intercropping through shading by complex canopies or allelopathy (Gliessman and Amador 1979), better use of soil nutrients (Igzoburkie 1971), and improved productivity per unit of land (Harwood 1974).

8.2 Insect Pest Management

Intercropping can be employed to manage insect and mite pests by disrupting the ability of the pest to find its host (Andow 1991) or the intercrop does not host key pests on the main crop or insects are actually repelled by the odor of non-host plants. The movement and host-finding ability of insect pests are affected by a mixture of leaf shapes or by simply alternating rows or strips of different crops. Tahvanainen and Root (1972) reported that the search for hosts by insects is affected by the odors released by non-host intercrops, making mixtures of dissimilar crops less attractive than monocultures. For example, the odors released by plants in the cabbage family attract Crucifer flea beetles (*Phyllotreta cruciferae*), but the random movement of flea beetles within that area is obstructed by intercropping, resulting in reduction of flea beetle numbers. Some of the natural enemies use plant odors or visual cues to locate their hosts by first finding the plants on which the hosts are located. In contrast, intercropping has no effect on cabbageworm butterflies (*Pieris rapae*) population, since they are good at finding their host plants in a mixture of other plants. The Colorado potato beetles' movement is disrupted by planting strips of rye–hairy vetch cover crop between widely spaced rows of potatoes, since the newly emerged beetles find their hosts primarily by walking. Later, mowing of the cover strips and mulching the soil interferes with beetle movement and provides habitat for beetle predators.

Laster and Furr (1972) reported that the tobacco budworms and bollworms (*Heliothis* spp.) population were much larger in intercropped sesame (4 rows) than on the main crop of cotton (24 rows), indicating sesame's attractiveness to *Heliothis* and its ability to harbor high numbers of beneficial insects, which made it useful in a cotton pest management program. Similarly, undersowing of clover to deter cabbage root fly (Finch and Edmonds 1994) and *Medicago litoralis* to deter carrot root fly (Ramert 1993; Rämert and Ekbom 1996) effectively prevented the pests. Likewise, *Lygus* spp. in a lettuce agro-ecosystem were managed by using various green manure crops which act as good trap crops (Rämert et al. 2001). Intercropping of pigeon pea with sorghum resulted in reduction of *Helicoverpa armigera* damage to pigeon pea and an increase in the combined yield (Bhatnagar et al. 1982).

8.2.1 Floral and Nectar Resources from Intercrops

The activity of predators and parasitoids can be enhanced by providing them with habitat and food sources such as nectar, pollen, and alternate hosts or prey through intercropping with insectary plants (also called companion plants). For many beneficial arthropods, including pollinators, pollen is an important source of nutrients and protein, and nectar is an important energy and nutrient source. The availability of nectar from flowering plants *Spermacoce verticillata* and *Chamaecrista fasciculata* enhances the parasitism of mole crickets in Florida by the introduced wasp *Larra bicolor* (Portman et al. 2010). Patt et al. (1997) reported that the predation of Colorado potato beetle (*Leptinotarsa decemlineata*) egg masses in eggplant is enhanced by strip-intercropping with dill (*Anethum graveolens*).

Organic growers enhance the population of beneficial insects, including predators such as lacewings, lady beetles, minute pirate bugs, and hover flies, as well as parasitoids and pollinators by planting of buckwheat, alyssum, and other flowering plants as sources of nectar and pollen, and maize and other grasses as sources of large quantities of pollen. Since the flowers of insectary plantings attract both the pests and beneficials, evaluation of the beneficial/pest ratio becomes critical (Luna and Jepson 2002). Similarly, Bugg et al. (2008) reported that the aphid infestation in lettuce can be managed by intercropping with sweet alyssum (*Lobularia maritima*) to enhance the predatory activity of syrphid flies which feed on nectar and pollen as adults and feed on aphids as larvae. Likewise, the pest populations on crop plants are managed by intercropping with good bug blends (mixtures of seeds that flower at different times) that offer nectar and pollen at different times of the growing season for natural enemies.

On the contrary, the availability of floral resources can also benefit certain pest species, such as thrips, leafminers, Lygus bugs, and certain moths. For example, Zhao et al. (1992) reported that the population of cabbage worm and diamondback moth were higher on broccoli interplanted with certain flowers than broccoli planted alone. Hence, it is important to keep in mind that insectary plants must not serve as a significant host for other insect pests and diseases, and they should integrate easily into the farmer's production system (for further details on intercropping, see Chap. 8).

8.2.2 Shelter and Overwintering Sites

Besides pollen and nectar, the provision of important resources such as alternate prey, shelter, or overwintering sites is essential for the intercrop to increase the numbers of beneficial insects to prevent chance colonization of the field from turning into a major pest outbreak. There is a need for steady food resources and undisturbed vegetation nearby for certain generalist predators like spiders, ground beetles, and rove beetles to colonize the field when pests arrive; since they typically have only one or two generations per year and are not highly mobile. The overwintering sites for ground beetles can be provided by grass strips between fields, which help the beetles to colonize adjacent fields during the growing season (for further details on habitat management, see Chap. 11).

The factors involved in intercropping systems that prevent the buildup of insect pests in different crops are presented in Table 8.1.

8.3 Disease Management

Intercropping systems have the potential to act as effective disease management tools, especially in cereal crops (Anil et al. 1998). For example, the fungal leaf diseases were reduced under the mixtures of spring-barley/oats and winter-rye/winter wheat (Vilich-Meller 1992), while the mixture of wheat and *Medicago lupulina* reduced the incidence of take-all disease of wheat (Lennartsson 1988). The increase in number of genotypes and the randomness of the mix helps to enhance the disease control effect. Garrett and Mundt (1999) suggested that the reduced chance of fungal spores encountering a susceptible plant in a mix might be responsible for this effect.

Intercropping reduced the incidence of diseases in 53% of cases, while in 18% instances it increased them due to reduced cultivation and increased shading, favoring some pathogens; associate species serving as alternative hosts; and crop residues serving as a source of pathogen inoculums (Francis 1989).

The bacterial wilt (*Ralstonia solanacearum*) incidence in potato was most effectively reduced by intercropping with maize and cowpea. Similarly, the bacterial wilt (*R. solanacearum*) in tomato was decreased and crop stand increased by intercropping with garlic, maize, marigold onion, and sorghum. Likewise, Fininsa and Yuen (2002) found that the four types of cropping systems (sole cropping, row, mixed, and broadcast intercropping) delayed the onset of epidemic, lowered bacterial blight (*Xanthomonas campestris* pv. *phaseoli*) incidence and severity, and reduced the disease progress rate.

Table 8.1 Factor(s) involved in intercropping systems that prevent insect pests

Intercropping system	Pest(s) regulated	Factor(s) involved
Beans grown in relay intercropping with winter wheat	*Empoasca fabae* and *Aphis fabae*	Impairment of visual searching behavior of dispersing aphids
Brassica crops and beans	*Brevicoryne brassicae* and *Delia brassicae*	Higher predation and disruption of oviposition behavior
Brussels sprouts intercropped with fava beans and/or mustard	Flea beetle, *Phyllotreta cruciferae*, and cabbage aphid, *Brevicoryne brassicae*	Reduced plant apparency, trap cropping, enhanced biological control
Cabbage intercropped with white and red clover	*Erioischia brassicae*, cabbage aphids, and imported cabbage butterfly, *Pieris rapae*	Interference with colonization and increase of ground beetles
Intercropping of pigeon pea with red, black, and green gram	Pod borers, jassids, and membracids	Delayed colonization of herbivores
Cassava intercropped with cowpeas	Whiteflies *Aleurotrachelus socialis* and *Trialeurodes variabilis*	Changes in plant vigor and increased abundance of natural enemies
Cauliflower strip cropped with rape and/or marigold	Blossom beetle, *Meligethes aeneus*	Trap cropping
Corn intercropped with beans	Leafhoppers, *Empoasca kraemeri*; leaf beetle, *Diabrotica balteata*; and fall armyworm, *Spodoptera frugiperda*	Increase in beneficial insects and interference with colonization
Corn intercropped with fava beans and squash	Aphids, *Tetranychus urticae* and *Macrodactylus* sp.	Enhanced abundance of predators
Corn intercropped with clover	European corn borer, *Ostrinia nubilalis*	Unknown
Corn intercropped with soybean	European corn borer, *Ostrinia nubilalis*	Differences in corn varietal resistance
Corn intercropped with sweet potatoes	Leaf beetles, *Diabrotica* spp., and leafhoppers, *Agallia lingula*	Increase in parasitic wasps
Intercropping corn and beans	*Dalbulus maidis*	Interference with leafhopper movement
Cotton intercropped with forage cowpea	Boll weevil, *Anthonomus grandis*	Population increase of parasitic wasps, *Eurytoma* spp.
Intercropping cotton with sorghum or maize	Corn earworm, *Heliothis zea*	Increased abundance of predators
Cotton intercropped with okra	*Podagrica* sp.	Trap cropping
Strip cropping of cotton and alfalfa	Plant bugs, *Lygus hesperus* and *L. elisus*	Prevention of emigration and synchrony in the relationship between pests and natural enemies

(continued)

Table 8.1 (continued)

Intercropping system	Pest(s) regulated	Factor(s) involved
Strip cropping of cotton and alfalfa on one side and maize and soybean on the other	Corn earworm, *Heliothis zea*, and cabbage looper, *Trichoplusia ni*	Increased abundance of predators
Intercropping cowpea and sorghum	Leaf beetle, *Oetheca benningseni*	Interference of air currents
Cucumbers intercropped with maize and broccoli	*Acalymma vittata*	Interference with movement and tenure time on host plants
Groundnuts intercropped with field beans	*Aphis craccivora*	Aphids trapped on epidermal hairs of beans
Maize intercropped with canavalia	*Prorachia daria* and fall armyworm, *Spodoptera frugiperda*	Unknown
Maize-bean intercropping	*Spodoptera frugiperda* and *Diatraea lineolata*	Lower oviposition rates, trap cropping
Strip cropping of muskmelons with wheat	*Myzus persicae*	Interference with aphid dispersal
Oats intercropped with field beans	*Rhopalosiphum* sp.	Interference with aphid dispersal
Peaches intercropped with strawberries	Strawberry leafroller, *Ancylis comptana*, and oriental fruit moth, *Grapholita molesta*	Population increase of parasites, *Macrocentrus ancyclivorus*, *Microbracon gelechise*, and *Lixophaga variabilis*
Groundnut intercropped with maize	Corn borer, *Ostrinia furnacalis*	Abundance of spiders, *Lycosa* sp.
Sesame intercropped with corn or sorghum	Webworms, *Antigostra* sp.	Shading by the taller companion crop
Sesame intercropped with cotton	*Heliothis* spp.	Increase of beneficial insects and trap cropping
Soybean strip cropped with snap beans	*Epilachna varivestis*	Trap cropping
Squash intercropped with maize	*Acalymma thiemei, Diabrotica balteata*	Increased dispersion due to avoidance of host plants shaded by maize and interference with flight movements by maize stalks
Tomato and tobacco intercropped with cabbage	Flea beetles, *Phyllotreta cruciferae*	Feeding inhibition by odors from non-host plants
Tomato intercropped with cabbage	Diamondback moth, *Plutella xylostella*	Chemical repellency or masking

Source: Based on Altieri (1987), Altieri and Letourneau (1982), and Andow (1991)

Intercropping of tomato with French bean and brinjal reduced the incidence of tomato leaf curl virus (TLCV) as the intercrops act as trap crops for the whiteflies which transmit the TLCV virus.

8.4 Nematode Management

Intercropping systems can also be used for nematode management. Banana nematodes were effectively managed by using the intercrop *Crotalaria juncea*, recording the maximum banana bunch weight (16.7 kg as compared to 11.03 kg in control) (51% more than control) followed by *Tagetes erecta* (16.2 kg), *Sesamum indica* (15.87 kg), *Acorus calamus* (15.67 kg), and carbofuran (15.23 kg) (Charles and Venkitesan 1993). Shanthi (2003) reported that intercropping banana with sun hemp (plowing the green manure 45 days after sowing) reduced the population of *Radopholus similis*, *Pratylenchus coffeae*, and *Helicotylenchus multicinctus* by 38.4%, while marigold and cowpea intercrops recorded 29.0 and 22.3% reduction, respectively. Intercropping of banana with *Tagetes* spp. gave significant increase in fruit yield (12 kg/plant as compared to 7 kg in control) and reduced the population of *Pratylenchus* sp. by 85% (Sundararaju et al. 2002).

The rate of multiplication of the citrus nematode, *Tylenchulus semipenetrans*, was considerably reduced by the intercrops such as marigold and mustard to 10.03 and 8.59%, respectively (Mani 1988). α-Terthienyl is the active principle in *Tagetes* spp. which is toxic to these nematodes.

Siddiqi and Saxena (1987b) reported that the rate of multiplication of *Tylenchorhynchus brassicae* was reduced by neem seedlings intercropped with tomato, brinjal, cabbage, and cauliflower by 59, 48, 50, and 68%, respectively, compared to control. Intercropping of tomato with marigold at 1:4 and 1:6 ratios and mustard at 1:2 ratios was found to be effective in reducing root galls, egg masses, and nematode population at harvest and gave a cost:benefit ratio of 1:8.36, 1:7.88, and 1:3.31, respectively (Rangaswamy et al. 1999).

Intercropping of tomato with *Zinnia elegans* reduced the nematode reproduction factor of *M. incognita* and *R. reniformis* to 0.88 and 0.80, respectively, compared to 3.86 and 2.43 in control, respectively. In addition, the intercrop reduced the root-knot index to 1.08 compared to 3.75 in control (Tiyagi et al. 1986).

Shivaprasad et al. (2001) reported that the final nematode population of *M. incognita* on brinjal was reduced (14.41%) by intercropping with sweet potato cv. Sree Bhadra. The above treatment also significantly lowered the number of galls, egg masses, and root-knot index, and enhanced brinjal fruit yield.

Intercropping of lettuce with *Tagetes erecta* reduced root galling by 56 and 72% and root-knot nematode population by 73 and 94%, respectively (Perwez et al. 1988).

Planting the intercrop marigold in tea plantations reduced the lesion nematode *Pratylenchus loosi* population and increased leaf yield by 7%. Medhane et al. (1985) reported that intercropping of betel vine with *Tagetes erecta* was effective in reducing the population of *M. incognita* by 41.4% and root galling by 54%.

In summary, the management of nematodes in several crops using different intercropping systems is presented in Table 8.2.

Table 8.2 Management of nematode diseases using intercropping

Crop	Nematode pest	Intercrop(s)	Reference(s)
Banana	Nematodes	*Tagetes erecta*, *Crotalaria juncea*, *Coriandrum sativum*, *Sesamum indica*, *Acorus calamus*	Charles and Venkitesan (1993)
		Sun hemp, coriander, marigold, radish, lucerne	Vadivelu et al. (1987)
	Radopholus similis, *Pratylenchus coffeae*, *Helicotylenchus multicinctus*	Sun hemp	Shanthi (2003)
	R. similis	*Crotalaria*	Charles et al. (1985)
		Papaya, marigold	Lakshmana Murthy (1983)
		Tagetes, *Crotalaria*, radish	Subramanian and Selvaraj (1988)
	Pratylenchus sp.	*Tagetes erecta*	Sundararaju et al. (2002)
Citrus (acid lime)	*Tylenchulus semipenetrans*	Marigold, mustard	Mani (1988)
Citrus		Onion, garlic, marigold, *Crotalaria*	–
Mulberry	*Meloidogyne incognita*	Marigold	Govindaiah et al. (1990)
Potato	*Meloidogyne* spp.	Onion, maize, *Tagetes patula*	–
Tomato, brinjal	*M. incognita,*	Neem and Persian lilac seedlings	Siddiqi and Saxena (1987a)
	Rotylenchulus reniformis		
Tomato	*M. incognita*	Marigold, mustard	Rangaswamy et al. (1999)
	M. javanica	Onion	Ram and Gupta (2001)
	M. incognita, R. reniformis	*Zinnia elegans*	Tiyagi et al. (1986)
	Root-knot	Marigold, onion, garlic	Jain et al. (1990)
		Castor	Hackney and Dickerson (1975)
Brinjal	*M. incognita*	Sweet potato cv. Sree Bhadra	Shivaprasad et al. (2001)
	Root-knot	Marigold, margosa, Persian lilac	Choudhury (1981)
		Knol-khol	Ayyar (1926)
Chilli	Root-knot	Marigold, neem, Persian lilac	–

(continued)

Table 8.2 (continued)

Crop	Nematode pest	Intercrop(s)	Reference(s)
Okra	*M. incognita*	Sesame	Atwal and Mangar (1969) Tanda and Atwal (1988)
	Root-knot	Marigold, margosa, Persian lilac	–
Pea	*Meloidogyne* spp.	Marigold, mustard	–
French bean	*M. incognita* Race 2	Finger millet, chili, groundnut	Ramappa (1988)
Cabbage, cauliflower	*Tylenchorhynchus brassicae*	Neem seedlings	Siddiqi and Saxena (1987a, b)
Lettuce	Root-knot	*Tagetes erecta*	Pervez et al. (1988)
Rose	*Pratylenchus penetrans*	African marigold	–
Gladiolus	*Meloidogyne* spp.	Marigold	–
Crossandra	*Longidorus africanus*	Pea, carrot, squash, spearmint, onion, radish, cauliflower, cabbage	–
	Meloidogyne spp., *Pratylenchus delattrei*	Marigold	Khan and Parvatha Reddy (1994)
Coconut	*Radopholus similis*	Cocoa	–
Tea	*Pratylenchus loosi*	Marigold	–
Betel vine	*M. incognita*	*Tagetes erecta*	Medhana et al. (1985)
Black pepper	*R. similis*	Coffee	Venkitesan (1976)
Ginger	*Meloidogyne* spp.	Maize, capsicum	–

8.5 Weed Management

Intercropping systems are considerably effective in suppression of the weed population density and biomass production. The low-growing "smother intercrop" species are sown between rows of main crop species for suppression of weeds. A review of several studies revealed that the weed biomass in the smother intercrop species was lower in 47 cases and higher in 4 cases than in the main crop grown alone (as a sole crop); a variable response was observed in 3 cases. The weed biomass in the intercrop was lower than in all of the component sole crops in 12 cases, intermediate between component sole crops in 10 cases, and higher than all sole crops in 2 cases; when intercrops were composed of two or more main crops. Forage grass and legume species have been extensively used for successful management of weeds in a number of temperate zone cropping systems (Table 8.3). There are strong economic incentives for intercropping, particularly where the cost of herbicides is relatively high.

Table 8.3 Comparison of weed control levels with intercrops

Green manure cover crop	Weed control
Cowpea/black bean (*Vigna unguiculata*)	Good
Rice bean (*Vigna umbellata*)	Good
Jack bean (*Canavalia ensiformis*)	Good
Lablab bean (*Lablab purpureum*)	Good
Peanut/groundnut (*Arachis hypogaea*)	Fair

In both legume (e.g. Bambarra groundnut, *Voandzeia subterranea*; bean, *Phaseolus vulgaris*; cowpea, *Vigna unguiculata*; groundnut, *Arachis hypogea*; lablab bean, *Dolichos lablab*; pea, *P. sativum*; pigeon pea, *Cajanus cajan*; rattlebox/sun hemp, *Crotalaria* spp.; soybean, *Glycine max*) and non-legume (e.g. castor bean, *Ricinus communis*; cotton, *Gossypium hirsutum*; lin seed, *Linum usitatissimum*; sesame, *Sesamum indicum*; and sunflower, *Helianthus annuus*) intercrop species, the root exudates stimulate the suicidal early germination of *Striga* spp. seeds in a rotational strategy and effectively reduce soil seed banks (Vail et al. 1990; Kayeke et al. 2007; Husson et al. 2008).

Intercropping of maize/cassava with cowpea (*Vigna unguiculata*) and egusi melon (*Citrullus anatus*) gave adequate weed suppression during the critical period of 4–8 weeks after planting without affecting the maize/cassava yield as compared to reduction in cassava yield by 49% and maize yield by 53% in control (uncontrolled weeds) (Unamma et al. 1986). The above treatment also gave better economic returns than smother crops and herbicides. Similarly, the intercrop egusi melon was found as an effective labor-saving method for weed control in plantain [Musa (AAB Group)] (Obiefuna 1989), yam (*Dioscorea* spp.) (Akobundu 1980a), and yam/maize/cassava intercrop (Akobundu 1980a) production systems.

The weed growth was effectively suppressed in rice by intercropping black gram (*Vigna mungo*) 21 days after planting rice, which eliminated one-hand weeding and increased the total crop yield and income, as compared to sole-cropped rice (Sengupta et al. 1985). Ali (1988) reported that intercropping of pigeon pea with green gram suppressed weed growth by 22–38% without affecting seed yields. Similarly, the green gram intercrop effectively suppressed weeds in maize and enhanced gross returns by 15–37% without herbicides as compared to sole-cropped maize or green gram treated with herbicides (Bantilan et al. 1974).

In contrast, Kurtz et al. (1952) reported that intercropping of low-growing smother crops, such as forage legume or grass sods, can greatly reduce the yields of the main crop species (maize) if competition for water or nutrients is strong. The reduction in main crop yields can be partially compensated with added nitrogen and water, use of growth retardants (Akobundu 1980b), low doses of herbicides (Vrabel et al.1982), use of less aggressive intercrop species or cultivars, variations in planting dates (Vrabel et al. 1980), and mowing or surface tillage of intercrops (Grubinger and Minotti 1990).

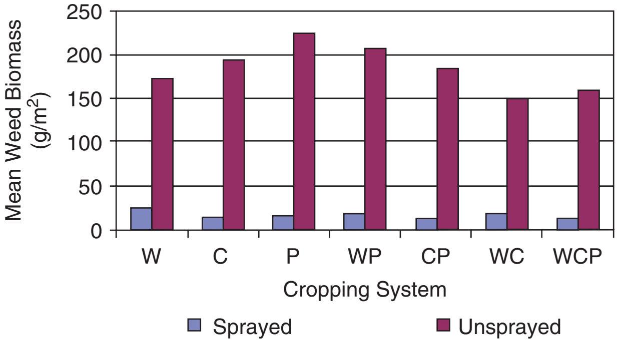

Fig. 8.2 Effect of intercropping on weed biomass (*W* - wheat, *C* - canola, *P* - peas)

Relay intercropping with cover/green manure crops could improve the effect of natural weed control by keeping the soil surface covered. The adoption and long-term usage of relay intercropping with cover/green manure crops among the farmers control weeds over a period of 4–8 months.

The intercropping systems suppressed weeds better than monocrops (Anon 2004). The number of crops in the intercropping and the weed biomass are indirectly correlated. As the number of crops increased in the mix, the weed biomass decreased, indicating that intercrops suppressed weeds better than monocrops. Weed suppression was maximum in wheat-canola and minimum in wheat-peas (which had weeds and lodging problems) when herbicides were not used (Fig. 8.2).

8.5.1 Intercrop Yield and Weed Suppression

Abraham and Singh (1984) reported a negative correlation between weed growth and intercrop yield advantage. The intercrops such as cowpea, green gram, groundnut, or soybean suppressed weed growth and increased sorghum yields and total crop production above levels obtained from sole-cropped sorghum. Likewise, the intercrops cowpea, black gram, green gram, soybean, or sorghum suppressed weeds and enhanced total seed yields as compared to pigeon pea sole crops (Ali 1988). Similarly, Shetty and Rao (1981) found that increases in sorghum/pigeon pea intercrops density resulted in decreased weed growth, higher crop yields, and higher LER values. The fact that intercrops suppress weeds and increase yields suggests the ability of intercrops to capture a greater share of available resources than sole crops and usurp these resources from weeds.

The intercrops such as maize, bean, and cassava suppressed weed biomass by capturing a greater share of available resources under the low soil fertility regime than sole crops, and the increases in LER values were coupled with increased usurpation of resources from associated weeds (Soria et al. 1975). Tripathi and Singh (1983) reported that the total crop seed yield and weed growth were both increased by fertilizer application, but intercropping of maize with soybean resulted in higher total seed yield and lower weed growth at each fertilizer level as intercrops consistently captured greater share of available resources than did maize sole crops.

The complex interactive effects of soil fertility, intercrop density, and intercrop species composition may affect the relationships between intercrop yield advantages and weed suppression. For example, intercropping of high maize densities with soybean gave lower amounts of weed growth, higher LER values, and higher total crop seed yields, than did intercrops with low maize densities at high soil fertility levels. On the contrary, at low soil fertility levels, intercropping of low maize densities with soybean gave higher LER values but had no consistent effect on total crop seed yield or weed growth (Weil and McFadden 1991).

8.5.2 Allelopathy

Intercropping of maize/cowpea with squash (*Cucurbita pepo*) suppressed weeds, not only because of the shade cast by the squash leaves but also because of selective allelochemical inhibition (Chacon and Gliessman 1982). The non-crop species have potential to offer possibilities for selective allelochemical weed control in intercropping systems as contemplated by Gliessman (1983). The selectivity in the effects of allelochemicals (toxins) released by the crops in suppression of weeds is very important for effective allelopathy (for further details on allelopathy, see Chap. 18).

In conclusion, the weed suppression using intercropping systems in different crops are presented in Table 8.4.

8.6 Mechanism of Action

8.6.1 Insect Pests

The various hypotheses proposed for suppression of insect pests (4–8 months in a year) due to intercropping are as follows:

- Disruptive crop hypothesis: The subsidiary crop species interferes with host-finding ability of insect pests through volatiles, visual, etc., and disrupt the pest's ability to attack the host crop species effectively.
- Natural-enemy hypothesis: Intercrops attract more number of natural enemies (predators and parasitoids), provides refuge and food resources (pollen and nectar) (van Emden 1965) for natural enemies, and provides perches for birds which prey on insect pests. For example, the weedy intercrop white dill (Queen Anne Lace) attracts several natural enemies; sunflower intercropped with bell pepper encourage biological control by attracting minute pirate bug (*Orius* spp.) and other beneficials.
- Trap crop hypothesis: Since the trap intercrop is more attractive to insect pests than the main crop, pests are diverted away from the main crop and are attracted by the trap intercrop. For example, the flea beetles from collard are attracted to

Table 8.4 Management of weeds using intercropping

Crop	Weeds	Intercrop(s)	Reference(s)
Maize	Weeds	Green gram	Bantilan et al. (1974)
Maize	Weeds	Bean	Fleck et al. (1984)
Maize	Weeds	Soybean	Tripathi and Singh (1983)
Maize	Weeds	Cowpea/quash (*Cucurbita pepo*)	Chacon and Gliessman (1982)
Maize	Weeds	Subterranean clover (*Trifolium subterraneum*)	Enache and Ilnicki (1990)
Maize/cassava	Weeds	Cowpea, egusi melon (*Citrullus anatus*)	Unamma et al. (1986)
Maize/cassava	Weeds	Bean	Soria et al. (1975)
Maize/cassava/yam	Weeds	Egusi melon	Akobundu (1980a)
Yam	Weeds	Egusi melon	Akobundu (1980a)
Plantain [Musa (AAB Group)]	Weeds	Egusi melon	Obiefuna (1989)
Rice	Weeds	Black gram	Sengupta et al. (1985)
Pigeon pea	Weeds	Green gram, cowpea, black gram, soybean, sorghum	Ali (1988)
Barley, faba beans	Grass weed (*Agropyron repens*)	Italian ryegrass, red clover	Dyke and Barnard (1976) and Williams (1972)
Subterranean or leaf clover (*T. vesiculosum*)	Weeds	Bermuda grass (*Cynodon dactylon*) or bahia grass (*Paspalum notatum*)	Evers (1983)
Wheat	Weeds	Canola	Anon (2004)
Sorghum	Weeds	Cowpea, green gram, groundnut, soybean	Abraham and Singh (1984)
Sorghum	Weeds	Pigeon pea	Shetty and Rao (1981)
–	*Striga asiatica, S. hermonthica*	Cotton	Vail et al. (1990)
–	*Striga* spp.	Bean, castor, cotton, cowpea, groundnut, lablab bean, linseed, pea, pigeon pea, sesame, soybean, sunflower, sun hemp	Kayeke et al. (2007) and Husson et al. (2008)

cruciferous intercrops with strong chemical attractants; stem borers from maize and sorghum to molasses grass which produces volatiles that attract parasitic wasps in Kenya (Khan et al. 1997); and the strip intercrop alfalfa attracts Lygus bugs away from cotton in California (Altieri 1994).
- Resource concentration hypothesis: Insect pests with a narrow host range are more likely to find and remain on hosts grown in pure stands and will attain higher relative densities in simple environments, which in turn attract more natural enemies (Root 1973).
- Associational resistance hypothesis: The taxonomic and microclimatic complexity of diverse systems will reduce herbivore outbreaks (Tahvanainen and Root 1972).
- Physical barrier hypothesis: Since the host plants are usually more dispersed in intercropped systems, it might be more difficult for insect pests to find the individual host plants. The time spent by the herbivore searching and probing diversionary intercrops may reduce the time and energy invested in damaging main crops and may increase mortality among potential pests before they affect the main crop (Trenbath 1977).
- Repellent effect hypothesis: Certain intercrops might repel herbivores due to a repellent effect (Aiyer 1949; Vandermeer 1989).

Hasse and Litsinger (1981) and Litsinger et al. (1991) summarized several factors that supposedly explain pest reduction in intercropping systems mainly due to resource concentration and natural-enemy hypothesis (Table 8.5).

In summary, several mechanisms involved in preventing several insect pests under different intercropping systems are presented in Table 8.6.

8.6.2 Diseases

There four mechanisms involved in lowering the population growth rate of the attacking pathogen in an intercropping system are as follows:

- The intercrops are non-hosts or poor hosts to the pathogens.
- The intercrops interfere directly with the attacking pathogens.
- The intercrops encourage antagonistic organisms which infect pathogens.
- The non-host or resistant intercrops acts as physical barriers to the pathogen inoculum.

8.6.3 Weeds

The intercrop combinations may suppress the growth of weeds more effectively and increase yields than sole crops through capturing of greater pre-emptive use of available additional resources from weeds (Hart 1980).

Table 8.5 Possible factors involved in intercropping systems that prevent insect pests

Factor	Explanation	Example
Interference with host-seeking behavior		
Camouflage	A host plant may be protected from insect pests by the physical presence of other overlapping plants	Camouflage of bean seedlings by standing rice stubble for bean fly
Crop background	Certain pests prefer a crop background of a particular color and/or texture	Aphids, flea beetles, and *Pieris rapae* are more attracted to cole crops with a background of bare soil than to ones with a weedy background
Masking or dilution of attractant stimuli	Presence of non-host plants can mask or dilute the attractant stimuli of host plants, leading to a breakdown of orientation, feeding, and reproduction processes	*Phyllotreta cruciferae* in collards
Repellent chemical stimuli	Aromatic odors of certain plants can disrupt host-finding behavior	Grass borders repel leafhoppers in beans; populations of *Plutella xylostella* are repelled from cabbage-tomato intercrops
Interference with population development and survival		
Mechanical barriers	All companion crops may block the dispersal of herbivores across the polyculture. Restricted dispersal may also result from mixing resistant and susceptible cultivars of one crop by settling on non-host components.	
Lack of arrestant stimuli	The presence of different host and non-host plants in a field may affect colonization of herbivores. If herbivore descends on a non-host, it may leave the plot more quickly than if it descends on a host plant	
Microclimatic influences	In an intercropping system, favorable aspects of microclimatic conditions are highly fractioned; therefore, insects may experience difficulty in locating and remaining in suitable microhabitats. Shade derived from denser canopies may affect feeding of certain insects and/or increase relative humidity which may favor entomophagous fungi	
Biotic influences	Crop mixtures may enhance natural-enemy complexes	

Table 8.6 Mechanisms involved in intercropping systems that prevent insect pests

Crop	Intercrop	Pest(s) reduced	Mechanisms
Apple	*Phacelia* sp., *Eryngium* sp.	San Jose scale, aphid	Parasitic wasps
	Weedy ground cover	Tent caterpillar, codling moth	Parasitic wasps
Barley	Alfalfa, red clover	Aphid	Predators
Bean	Goose grass, red spangle top	Leafhopper	Chemical repellent
Brassicas	Candy tuft, shepherd's purse, wormseed mustard	Flea beetle	Chemical repellent
	Similar-sized crops	Root fly, cabbage butterfly and moth	Chemical repellent, predators

(continued)

Table 8.6 (continued)

Crop	Intercrop	Pest(s) reduced	Mechanisms
Brussels sprouts	Weedy ground cover	Imported cabbage butterfly	Predators
	French beans, grasses	Aphid	Physical interference
	White clover	Cabbage root fly, aphid, white cabbage butterfly	Visual masking
	Clover	Aphid	Physical interference
Cabbage	Tomato	Diamondback moth	Uncertain
	Hawthorn	Diamondback moth	Attract pest to alternative plant
	Red and white clover	Cabbage aphid, imported cabbage butterfly	Physical interference, predators
	Clover	Cabbage root fly	Predators
	Green ground cover	Imported cabbage butterfly	Visual masking
Carrots	Onion	Carrot fly	Chemical repellent
Cauliflower	Corn spurry	Cabbage looper, flea beetle, aphid	Predators
	Lambs quarters	Imported cabbage butterfly	Predators
	White or red clover	Cabbage aphid, imported cabbage butterfly	Physical interference, predators
Collards	Tomato, ragweed	Flea beetle	Chemical repellent
	Pigweed, lambs quarters	Green peach aphid	Predators
	Weedy ground cover	Cabbage aphid	Parasitic wasps
	Weedy ground cover with wild mustards	Flea beetle	Predators
	Tomato, tobacco	Flea beetle	Chemical repellent
	Weedy ground cover	Flea beetle, cabbage butterfly	Uncertain
	Weedy ground cover	Flea beetle	Visual masking

(continued)

Table 8.6 (continued)

Crop	Intercrop	Pest(s) reduced	Mechanisms
Corn	Wild parsnip, wild mustard, chickweed, shepherd's purse, and lady's thumb smartweed	Black cutworm	Parasitic wasps
	Pigweed	Fall armyworm	Uncertain
	Giant ragweed	European corn borer	Parasitic wasps
	Sweet potato	Leaf beetle	Attract pest to alternative plant
	Beans	Leafhoppers, leaf beetle, fall armyworm	Physical interference, Predators
	Beans, weeds	Fall armyworm	Predators
	Pigweed, Mexican tea, goldenrod, beggertick	Fall armyworm	Predators
	Soybean	Corn earworm	Predators
	Peanut	Corn borer	Visual masking
	Clover	Corn borer	Physical interference
Cowpea	Sorghum	Leaf beetle	Chemical repellent
Cucumber	Corn, broccoli	Striped cucumber beetle	Physical interference
Crucifers	Wild mustard	Cabbage worm	Parasitic wasps
Fruit trees	Rye, wheat, sorghum used as mulch	European red mite	Predators
	Alder, bramble	Red spider mite	Predators
Grapes	Wild blackberry	Grape leafhopper	Parasitic wasps
	Johnson grass	Pacific mite	Predators
	Sudan grass, Johnson grass	Willamette mite	Predators
	Kale, closely planted	Aphid	Visual masking
Kale	Weedy ground cover	Bean fly	Physical interference
Green gram	New Zealand white clover	Fruit fly	Physical interference
Oats	Carrots	Thrips	Visual masking
Onions	Ragweed	Oriental fruit moth	Parasitic wasps
Peach	Strawberry	Oriental fruit moth	Predators
	Ragweed, smartweed, lambs quarters, golden rod	Oriental fruit moth	Uncertain
Radish	Broccoli	Green peach aphid	Parasitic wasps

(continued)

Table 8.6 (continued)

Crop	Intercrop	Pest(s) reduced	Mechanisms
Soybean	Corn, weed cover	Corn earworm	Parasitic wasps
	Sickle pod	Velvet bean caterpillar, green stink bug	Uncertain
	Desmodium sp., *Croton* sp., *Cassia* sp.	Corn earworm	Parasitic wasps
	Barley, wheat	Monitored only predators of soybean pests	Predators
	Rye	Seed corn maggot	Physical interference
Squash	Corn	Cucumber beetle	Physical interference
	Corn, cowpea	Western flower thrips	Predators
Sugar beet	Manure	Pests preyed upon by predatory ground beetles	Predators
	Broccoli	Green peach aphid	Parasitic wasps
Sweet potato	Morning glory	Argus tortoise beetle	Parasitic wasps
Tomato	Cabbage	Flea beetle	Chemical repellent
	Cabbage	Diamondback moth	Chemical repellent
Turnip	Dutch white clover	Cabbage root maggot	Chemical repellent
Vegetables	Wild carrot	Japanese beetle	Parasitic wasps
Walnut	Weedy ground cover	Walnut aphid	Parasitic wasps

8.7 Conclusions

In organic farming systems, intercropping could be an important potential tool for weed suppression. There is considerable evidence of the utility of intercropping on suppression of weeds for farmers who wish to maintain or increase crop yields while minimizing the use of herbicides. This may be due to increased allelopathic suppression of weeds by intercrops or increased resource preemption by the intercrop, resulting in greater quantities of resources captured by crops and smaller quantities captured by weeds. Alternatively, intercropping may enhance yields even when they fail to suppress weed growth below levels obtained from component sole crops, suggesting that intercrops may use resources not exploitable by weeds, increased resource conversion efficiency by crops, or shifts in crop biomass allocation.

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Trap Cropping

9

Abstract

Trap crops are plants grown before or with the main crop in a smaller area (the trap crop). They are the more preferred hosts when grown with the main crop. Trap crops can increase the efficiency of control by concentrating the pests in one location and by applying a chemical treatment without spraying the main crop, or by destroying the trap crops and associated pests through tillage or burning. It is also possible to release biological control agents into the trap crops, using it as a nursery for beneficial organisms that will then spread into the main crop. The trap crops are effectively employed for the control of several herbivores, nematodes, and weeds in several agroecosystems. Trap cropping is economical to adopt, saves on input use, and is effective against pests, resulting in increased productivity.

Keywords

Antagonist crops • Insect pests • Weeds • Nematodes • Pest management

9.1 Introduction

There is a growing interest in utilizing plant biodiversity for the control of herbivores with some cultural approaches, including trap cropping. This was one of the most common herbivore management practices adopted by farmers from ancient times before the use of chemical pesticides after the Second World War (Thurston 1991; Talekar and Shelton 1993). There is a need to revert to trap cropping in view of negative externalities of chemical control. It can be combined with other methods to enhance pest management.

Trap crops, which are more attractive than main crops, are grown in a smaller area in order to trap the pests before or with the main crop in many cases. Before the

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trap crop matures, it is uprooted and destroyed so that main crop is protected from pests (Hokkanen 1991; Shelton and Badenes-Perez 2006).

Efficiency of pest management can be enhanced by concentrating the pests in one location and destroying them by applying a chemical treatment without spraying the main crop or by destroying the trap crops and associated pests through tillage or burning. The biological control agents can also be released into the trap crops, using it as a nursery for beneficial organisms that will then spread into the main crop. Kuepper and Thomas (2002) reported that the organic farmers can employ this technology for pest management without the use of chemical pesticides. For example, Zalom et al. (2001) recommended this system for the management of Lygus bugs, *Lygus lineolaris*, in organic strawberry production.

The devastating pests which are widely distributed can be managed by using trap cropping strategy. This system is most suitable for herbivores that are fairly sedentary as compared to highly mobile ones and which are carried away by wind. Trap crops, which require a limited space relative to the main crop, are easily planted and maintained and are most economical to use in this system. The life cycle of concentrated pests on trap crops are controlled by using available management practices such as cultural approaches, biological control agents, or chemical pesticides.

9.2 Selection of Trap Crops

It is a knowledge-intensive practice which needs a clear understanding of pest's biology, host range, development and multiplication, spread and survival strategies to device management strategies. The following aspects should be kept in mind while selecting trap crops for pest management:

- They should simply become far more attractive than the main crop for feeding and oviposition.
- Trap crops should attract and contain the pests, preventing their spread to the main crop.
- The pattern of pest movement decides their planting. For example, planting trap crops around the borders of field may prevent the spread of the disease pathogen *Leptinotarsa decemlineata* in potato, while trap crops within the cash crop (maize) arrest the movement of the pathogen *Ostrinia nubilalis.*
- For economically feasible and effective pest management, the trap crops should occupy very limited area (about 10–15%) in the field (ESA 2003).
- Planting of "dead-end trap crop" such as bitter cress (*Barbarea vulgaris*) is preferable for egg-laying by diamondback moth (*Plutella xylostella*) (24–66-fold more than cabbage) and prevents pest movement to cabbage vegetable crop (Shelton and Nault 2004).

9.3 Types of Trap Cropping

9.3.1 Traditional Trap Cropping

The trap crop is normally highly receptive than the main crop with respect to feeding and egg-laying and blocks the entry of pests to the cash crop. The pests are aggregated on the trap crop, which can be easily controlled using cultural, biological, and chemical methods. For example, Godfrey and Leigh (1994) reported that the Lygus bugs (*Lygus lineolaris*) on cotton can be managed by using alfalfa in central valley, California. Similarly, Pair (1997) reported that the conventional trap crop such as squash is being used commercially to control pests such as *Anasa tristis* and *Acalymma vittatum* in cucurbits.

Srinivasan and Krishna Moorthy (1991) have developed a trap cropping strategy by using *Brassica juncea* for the management of diamondback moth (*Plutella xylostella*) and other pests of cabbage and cauliflower and to increase crop productivity. This technology was demonstrated in several farmers' fields which gave effective control of cabbage and cauliflower pests and increased the yields significantly (Table 9.1) (Khaderkhan et al. 1998; Krishna Moorthy et al. 2003).

Sesame is also being employed for attracting the herbivore *Plutella xylostella* on cruciferous crops. Similarly, cauliflower intercropped with noncrucifer host plants like sunflower, tomato, and marigold was highly effective in reducing the aphid incidence and enhancing the number of natural enemies, resulting in higher yields. Likewise, intercropping of gerbera with field bean (*Lablab purpureus*) as a trap crop is effective for the management of leaf miner.

Srinivasan et al. (1994) have developed trap cropping technology for the management of tomato fruit borer, *Helicoverpa armigera*, by using African marigold, *Tagetes erecta*, as a trap crop. The pests concentrated on marigold are managed by using a biological control agent (*Ha* NPV at 250 LE/ha) or neem products (4% NSKE or 4% pulverized NSPE, 28 and 45 DAP). The effectiveness of this technology in managing the pest and increasing the fruit yields was demonstrated in farmers' fields across three states in India (Table 9.2) (Amerika Singh et al. 2004).

Shivaramu (1999) has developed a trap cropping technology for the management of chili fruit borer *H. armigera* using marigold as a trap crop (Fig. 9.1). This strategy was found very effective in suppressing the chili fruit borer and increasing the fruit yields significantly. Similarly, trap cropping strategy has been utilized for the management of *Liriomyza trifolii* in *Lablab purpureus*, *Meloidogyne* spp. on

Table 9.1 Management of cabbage pests using Indian mustard as a trap crop

Practice	% yield increase	% increase in net returns	Cost:benefit ratio
Indian mustard trap cropping	57	591	1:2.42
Traditional method (cabbage sole crop)	–	–	1:0.83

Source: Krishna Moorthy et al. (2003)

Table 9.2 Management of tomato fruit borer using African marigold as trap crop

Location	Practice	Tomato fruit yield (tons/ha)	Net returns (Rs.)	Cost:Benefit ratio
Bangalore, Karnataka	African marigold trap cropping	74.03	249,721	1:4.82
	Sole tomato	45.05	69,704	1:0.61
Varanasi, Uttar Pradesh	African marigold trap cropping	14.25	39,917	13.30
	Sole tomato	13.00	38,167	1:2.02
Ranchi, Jharkhand	African marigold trap cropping	22.29	56,705	1:1.87
	Sole tomato	18.77	41,776	1:1.32

Source: Amerika Singh et al. (2004)

Fig. 9.1 Management of chili fruit borer using marigold as a trap crop

Solanum tuberosum, *Pomacea canaliculata* and *Pomacea maculata* on *Oryza sativa*, *Busseola fusca* on *Zea mays*, *Spilosoma obliqua* on *Vigna unguiculata*, and *Lygus hesperus* on *Gossypium* spp. and *Fragaria* × *ananassa* using *Chrysanthemum indicum, Tagetes erecta, T. patula, Sorghum vulgare, Sesamum indicum,* and *Medicago sativa* as trap crops, respectively (UC IPM 2011).

9.3.2 Dead-End Trap Cropping

The dead-end trap crops are highly receptive to crop pests which cannot survive on these crops and prevent their entry into cash crops (Shelton and Nault 2004; Badenes-Perez et al. 2005). For example, bitter cress and sun hemp act as dead-end traps against Lepidopterous pests of crucifers and French bean main crops (Shelton and Nault 2004; Lu et al. 2004; Jackai and Singh 1983). Generally, dead-end trap crops are located at crop edges and are highly receptive for egg-laying by pests belonging to Order Lepidoptera (Thompson and Pellmyr 1991).

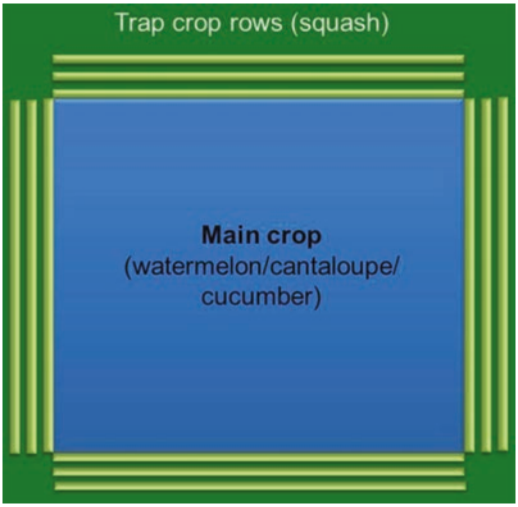

Fig. 9.2 Perimeter trap cropping for pest management

9.3.3 Genetically Engineered Trap Cropping

The deliberate gene manipulation through the use of biotechnology (genetic engineering) is the main basis on which the future trap crops are being developed for pest management. For example, Hoy (1999) reported that planting of Bt (*Bacillus thuringiensis*) potatoes early in the season acts as dead-end trap crops to attract immigrating ten-lined potato beetles to the main non-Bt potatoes planted later. Likewise, Cao et al. (2005) reported that crop pests belonging to Lepidoptera were controlled by using Bt collard green as a dead-end trap crop.

Genetically engineered trap crops can also be used to manage insect vector spread stylet-borne viruses, as they remove the virus rapidly from the insect's stylet (Fereres 2000). For example, the papaya ring spot virus (PRSV) is managed by both commercially growing PRSV-resistant papaya or by using it as a trap crop (Gonsalves 1998; Gonsalves and Ferreira 2003), since PRSV is difficult to manage with insecticides.

9.3.4 Perimeter Trap Cropping

Incorporation of spatial orientation of attractive crops (to attract insect pests from the main crop), natural population regulators, and plant attributes; to redesign the system of crop production to improve pest management is called perimeter trap cropping (PTC) (Fig. 9.2) (Boucher et al. 2003). The perimeter trap crops attract pests from the main crop, which can be managed by using cultural, biological, or chemical methods. The pests that are likely to attack the crop at border area are managed effectively by this technology. The efficacy of trap cropping has been dramatically increased on a variety of crops in recent years.

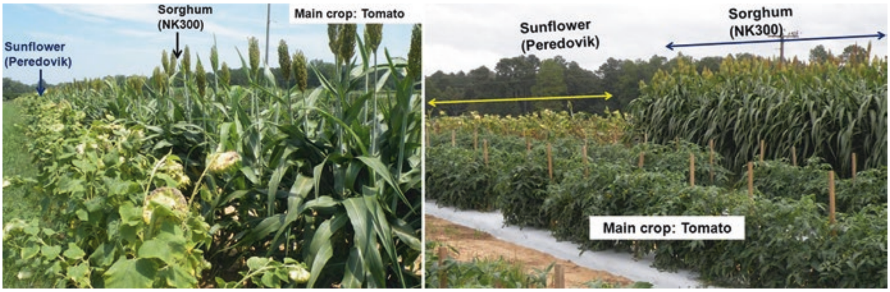

Fig. 9.3 *Left* – Perimeter trap crop design with sunflowers planted behind sorghum NK300. *Right* – Tomatoes were planted on the other side of sorghum (Majumdar et al. 2012)

Hoy et al. (2000) reported that early planting of potato plants in the perimeter was highly receptive to *Leptinotarsa decemlineata*, which can be controlled by cultural, biological, or chemical methods to prevent their entry into the main potato crop. Similarly, Bt potatoes can also be used to control *L. decemlineata* on main potato crop (Hoy 1999). Likewise, Aluja et al. (1997) suggested planting of perimeter papaya trees to reduce fruit fly, *Toxotrypana curvicauda*, damage.

Planting of early-maturing sunflowers around oilseed sunflowers gave effective and economic control of the red sunflower seed weevil, *Smicronyx fulvus* (Brewer and Schmidt 1995). This strategy can be used to control *Acalymma vittatum* and *Melittia cucurbitae* on *Cucurbita pepo* using *Cucurbita pepo* cv. Blue Hubbard on field border, which also prevented the incidence of bacterial wilt spread by *A. vittatum* (Boucher and Durgy 2003). The trap crop *Capsicum annuum* cv. Hot Cherry Pepper gave protection against *Zonosemata electa* on Capsicum, and increased the net profits by $382 per ha as compared to 15% of the fruit infested in control (Boucher et al. 2003). Commercial farmers using PTC harvested 99.99% clean capsicum fruit.

Input requirements on insecticides have been dramatically reduced by using perimeter trap cropping. Mitchell et al. (2000) reported that the diamondback moth (DBM) infestations on cruciferous vegetable crops in Florida were effectively managed by perimeter trap cropping with *Brassica oleracea*. The DBM population on the collards (*Brassica oleracea*) was reduced by a naturally occurring parasitic wasp *Diadegma insulare* and prevented its spread into cabbage crop. Pesticide cost was saved to the extent of $118 to $158 per ha in view of 56% fewer insecticide sprays to manage DBM than in conventional fields.

Western flower thrips in pepper fields were managed by planting sunflower on the perimeter, which encouraged the buildup of predatory minute pirate bugs (*Orius* spp.) in Florida (Funderburk et al. 2011).

Perimeter trap cropping system incorporating sorghum (NK 300) and Peredovik sunflower provided significant reduction of leaf-footed bugs in tomato, resulting in significant reduction in pesticide usage (Fig. 9.3). Treatment of sorghum at peak leaf-footed bug activity with insecticide gave 78–100% control of the pest without the need for treating the main crop (Majumdar et al. 2012).

Fig. 9.4 Stimulo-deterrent diversion trap crop strategy for pest management

9.3.5 Sequential Trap Cropping

In this system, the attractive crop is grown before or after the cash crop. The sequential trap cropping has been utilized for the management of the herbivores such as *Leptinotarsa decemlineata* on *Solanum tuberosum*, *Plutella xylostella* on *Brassica oleracea* var. *capitata* and *Agriotes obscures* on *Fragaria* × *ananassa* by early planting with trap cops like *Solanum tuberosum*, *Brassica oleracea* and *Triticum vulgare*, respectively (Hoy et al. 2000; Pawar and Lawande 1999; Vernon et al. 2000).

9.3.6 Multiple Trap Cropping

In this system, various trap crops are grown simultaneously to improve the management of multiple crop pests. For example, Hokkanen (1989) reported that simultaneous planting of trap crops such as *Brassica rapa*, sub spp. *Pekinensis* and *chinensis*, *Tagetes erecta*, *Brassica napus*, and *Helianthus annuus* for the management of beetles feeding on pollen of *Brassica oleracea.* Similarly, the groundnut leaf miner, *Aproarema medicella*, can be managed by planting several attractive trap crops such as *Ricinus communis*, *Pennisetum glaucum*, and *Glycine max* (Muthiah 2003). Likewise, Seal et al. (1992) found that wireworms in sweet potato fields can be managed by simultaneously growing of *Solanum tuberosum* and *Zea mays* as attractive crops.

9.3.7 Push-Pull Trap Cropping

The "stimulo-deterrent diversion trap crop strategy" can be employed to manage stem borers and *Striga* weed on maize and sorghum. In this strategy, repellent intercrops are used for driving stem borers away ('push'), and attractive trap crops are used in the crop border to attract female moths ('pull') to lay eggs (Fig. 9.4). Besides controlling stem borers, Molasses grass enhances natural enemy population (*Cotesia* sp.), when intercropped with maize (Khan et al. 1997). The intercrop *Pennisetum* *purpureum* secretes gummy substance which restricts larval development, causing few to survive (Khan et al. 2006).

Push-pull trap crop strategy can also be adopted to control Old World (African) bollworm of cotton (Duraimurugan and Regupathy 2005), pea leaf weevil, *Sitona lineatus* in beans (winter peas as trap crop) (Smart et al. 1994), *Leptinotarsa decemlineata* on *Solanum tuberosum* (Martel et al. 2005), beetle that feeds on field mustard (Potting et al. 2005), maggot, *Delia antigua* on onions (onion culls as trap crop) (Miller and Cowles 1990), and thrips, *Frankliniella occidentalis* on chrysanthemums (chrysanthemum cv. Springtime as trap plants that are most attractive) (Bennison et al. 2001) (for further details on push-pull strategy, see Chap. 12).

9.3.8 Biological Control-Assisted Trap Cropping

In this strategy, attractive crops increase population of biological control agents to manage crop pests. Virk et al. (2004) found that the rates of parasitism of cotton bollworm, *Helicoverpa armigera* by *Trichogramma chilonis* increased when the sorghum was used as a trap crop. Besides controlling stem borers, the trap crop Molasses grass enhance the population of biocontrol agent *Cotesia* sp. when intercropped with maize (Khan and Pickett 2004).

Planting of cowpea as a bund crop attracts *Cheilomenes* spp.; maize as intercrop is known to encourage *Chrysoperla carnea*; growing cowpea as trap crop increases the parasitization of *H. armigera* larvae and predation of eggs by coccinellids; growing *Tagetes* spp. as border crop attracts heavy egg-laying by *H. armigera* which in turn attracts parasitization by *Trichogramma* spp.

Cowpea varieties CO-2 and CO-4 harbored the highest population of legume aphid, *Aphis craccivora*, and whiteflies which are attracted by predatory ladybird beetles in large numbers. Similarly, cowpea cultivars CO-2, CO-4, and C-152 harbored aphids and leafhopper *Empoasca kerri*, which are attracted by ladybird and spider predators which fed on aphids and nymphs of leafhoppers.

9.3.9 Semiochemically Assisted Trap Cropping

The attraction of insect pests to the trap crop involves the production of pheromones by the trap crops to enhance their effectiveness. For example, Borden and Greenwood (2000) employed baiting of trees with semiochemical traps to manage the spruce and bark beetles (*Dendroctonus rufipennis* and *Dryocoetes confusus*). The fruit flies in papaya orchards can be managed by baiting trees in the border with semiochemical traps (Aluja et al. 1997). Vernon et al. (2000) found that the effectiveness of traps can be enhanced by treating border winter pea plants with the aggregation pheromone to enhance the concentration of pea leaf weevils (Smart et al. 1994). *Leptinotarsa decemlineata* on *Solanum tuberosum* is managed by using semiochemicals that can enhance attraction (Dickens et al. 2002).

9.4 Advantages and Benefits

9.4.1 Advantages

The advantages of perimeter trap cropping are as follows:

- Complement current pest management program.
- Difficult to control pest's damage but can be restricted to border plants.
- Savings in pesticide costs and improvement in crop quality.
  - Development of pesticide resistance is delayed.
  - Less environmental and safety concerns.
  - Lower pesticide costs and reduce pesticide residues.
- Negative externalities of chemical pesticides can be reduced.
- Biological control agents are encouraged.

9.4.2 Benefits

Trap cropping offers several benefits in pest management systems, which include the following:

- Pests of cash crops are reduced.
- Cash crops need not be sprayed with chemical pesticides.
- Cost of maintaining trap crops is compensated by economizing on input costs.
- Increase in marketable yield.
- Naturally occurring biocontrol is enhanced by increased concentration of insect pests on trap crops which may attract natural enemies.
- Synergistic effects due to integration of multiple trap crops (Martel et al. 2005).
- Semiochemicals are effectively utilized to enhance concentration of insect pests on trap crops (Raffa and Frazier 1988).
- Chances of pests developing resistance to pesticides is limited, since noninsecticidal components/reduced amounts of pesticides are used (Foster et al. 2005).

In summary, use of trap crops for the management of various insect pests on several crop plants is presented in Table 9.3.

9.5 Nematode Management

Vigna unguiculata and *Crotalaria* species act as trap crops for the management of root-knot nematodes (*Meloidogyne* species). Planting of *V. unguiculata* early in the season helps to trap the root-knot nematodes in their root system, which are destroyed earlier to nematode reproduction, before taking up the main crop. Similarly, early-season planting of *Crotalaria* species attracts the root-knot

Table 9.3 Effect of trap crops for the management of various insect pests on several crops

Main crop/s	Trap crop/s	Insects managed
Cotton	Lucerne	*Lygus hesperus*
	Castor, Bengal gram, corn, tobacco, cowpea, sunflower	*Helicoverpa* spp.
	Okra	Flower weevil
	Cotton	Cotton boll weevil, *Anthonomus grandis*
Garlic	Basil, marigold	Thrips
Vegetables, ornamentals	Chervil	Slugs
Cabbage	Collards	Diamondback moth
	Brassica rapa sub sp. *chinensis, Brassica juncea, Raphanus raphanistrum* sub sp. *sativus*	*Hellula undalis, Halticus tibialis, Lipaphis erysimi*
Corn	*Phaseolus vulgaris*	*Liriomyza trifolii*, *Cerotoma trifurcata*, *Ophiomyia phaseoli*, *Spodoptera frugiperda*
	Sudan grass	Stem borer
	Glycine max	*Helicoverpa* spp.
	Vetiver	Corn stalk borer
Corn, cowpea, millet, sorghum	Desmodium	*Chilo partellus*
Tomato	*Anethum graveolens, Levisticum officinale*	*Manduca quinquemaculata*
Potato	Tansy, horse radish	Colorado potato beetle
	Potato	*Leptinotarsa decemlineata*
Bell pepper	Hot cherry pepper	*Zonosemata electa*
Vegetables (Solanaceae, Brassicaceae, Leguminosae, Cucurbitaceae)	Marigold (French & African)	*Meloidogyne* spp.
Carrot	Medick	*Chamaepsila rosae*
	Onion, garlic	*Chamaepsila rosae, Thrips tabaci*
Brassica oleracea	Nasturtium	Aphids, *Phyllotreta cruciferae*, cucumber beetle, squash vine borer
	Brassica juncea	*Crocidolomia binotalis*
	Tomato	*Plutella xylostella*
Brassicaceae (Cruciferae)	Radish	*Phyllotreta cruciferae*, *Delia radicum*

(continued)

Table 9.3 (continued)

Main crop/s	Trap crop/s	Insects managed
Soybean	*Secale cereale*	*Delia platura*
	Sesbania bispinosa	*Acrosternum hilare*
	Senna obtusifolia	*Anticarsia gemmatalis*, *Acrosternum hilare*
	Green beans	Mexican bean beetle
	Snap bean	Stink bugs, Mexican bean beetle, bean leaf beetle
Rape	Rape, marigold, cauliflower	Blossom beetle, *Meligethes aeneus*
Pine trees	Pine logs	Pine shoot beetle, *Tomicus piniperda*
Spruce	Spruce tree logs	Spruce bark beetle, *Ips typographus*

nematode larvae to infect the roots, but the nematode is not able to complete the life cycle (Cook and Baker 1983).

Mohandas (2001) reported that planting of sweet potato cv. Shree Bhadra acts as a dead-end trap crop which allows the root-knot nematode larvae to enter the roots but does not allow the nematode development and reproduction, resulting in drastic reduction of *Meloidogyne* population in soil. Subsequently, crops like okra, tomato, coleus, and African yam which are susceptible to root-knot nematodes can be taken up profitably.

Growing of French marigold, *Tagetes patula* trap crop in alternate rows with potato was found effective in reducing larval population in soil, root galling and tuber infestation while the yields increased up to 123% over control.

Solanum sisymbriifolium, which is highly susceptible to cyst nematodes, acts as a trap crop for the control of *Globodera rostochiensis* and *G. pallida* on potato.

Tomato nursery beds previously planted with trap crop (marigold) effectively controlled root-knot nematodes and also increased the germination of tomato seeds and production of healthier (nematode-free) seedlings (Rangaswamy et al. 1999).

Root-knot nematodes on brinjal were managed by early planting of knol-khol as a trap crop, which was destroyed before taking up the main crop (Ayyar 1926).

9.6 Enhancing Effectiveness of Trap Crops

The efficacy of trap cropping is enhanced by integrating with other components like baiting with pheromone traps, use of sequential cropping with nonhosts, releasing natural enemies, and spraying chemical pesticides. Plant breeding can be employed in developing trap crop cultivars with glossy wax characters on leaves, or more attractiveness to natural enemies (Poppy and Sutherland 2004; Eigenbrode et al. 1991; Badenes-Perez et al. 2005).

Hokkanen (1991) recommended that in general, a small area can be utilized for planting the trap crop. About 5–13% of the crop area was employed for the management of *Plutella xylostella* on Cole crops (Badenes-Perez et al. 2005; Srinivasan and Krishna Moorthy 1991).

According to Root (1973), the specialist insect herbivores are contained within the field and prefer larger plants, higher planting densities, and enough moisture as per resource concentration hypothesis (Badenes-Perez et al. 2005; Maguire 1983; Showler and Moran 2003).

9.7 Conclusions and Recommendations

The successful implementation of trap cropping systems has provided the long-term and sustainable management of pests which are difficult to control both in developing (e.g., use of stimulo-deterrent diversion trap crop strategy to manage *Chilo partellus* in maize) and in developed countries (e.g., *Lygus hesperus* on *Gossypium* species). Genetic engineering has provided additional avenues in this strategy in case of PRSV-resistant papaya and Colorado-beetle-resistant Bt potatoes. The more traditional trap cropping systems can be implemented commercially in case of capsicum against *Zonosemata electa* (Boucher et al. 2003) and the use of *Brassica juncea* to manage *Acrosternum hilare* in maize (Rea et al. 2002).

In recent times, the interest in trap cropping strategy to manage crop pests is enhanced as indicated by the publication of more than 150 publications on the subject during the last two decades. The increased interest in trap cropping has been especially shown by organic growers, nongovernmental agencies, and State Agricultural Universities/Indian Council of Agricultural Research Institutes, particularly in underdeveloped regions. The concepts of this strategy to include the diverse modalities can be increasingly expanded by the interaction between the farmers, scientists, and extension educators.

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Companion Planting

10

Abstract

Companion planting is a knowledge-based strategy which involves growing of several crops (crop diversity) to achieve economizing on space, balanced nutrition, habitat management to enhance natural enemies, and increase productivity, besides the management of biotic stresses, such as insect pests, disease pathogens, nematodes, and weeds. These benefits could include providing cover for shade-loving plants, repelling harmful insects, attracting beneficial insects, or providing necessary soil requirements for other plants. Companion plants repel pests, camouflage their odor, enrich the soil by fixing nitrogen, disorient the adult pests, attract beneficials, suppress weeds, deter and kill root nematodes, protect soil moisture, and act as trap plants, and their root exudates prevent soil-borne pathogens. Management of various pests infesting several crop plants using companion planting technology is discussed in this chapter.

Keywords

Biodiverse planting • Companion plants • Pest repulsion • Natural enemy attraction

10.1 Introduction

Companion planting is a form of biodiverse cropping which involves growing of several crop plants to derive benefits like the management of biotic stresses from insect and mite pests, disease pathogens (fungi, bacteria, viruses), nematodes, and weeds; proper utilization of field; balanced nutrition; pollination; enhanced growth and flavor; providing habitat for beneficials; or increase in crop productivity (Frank 1983; McClure 1994). It involves interplanting of companion plants along with main/cash crops in order to achieve advantages in the form of deterring pests through camouflaging their odor, disorienting the adult pests, acting as trap plants,

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Fig. 10.1 Companion planting

and preventing soil-borne pathogens by secreting toxic chemicals from roots (Cunningham 1998; Finch and Collier 2000). Certain flowering companion plants attract beneficial parasitoids (wasps) seeking the flowers' nectar, which oviposit eggs in juvenile pests. Companion planting is a form of polyculture that enhances the biodiversity of agro-ecosystems (Cunningham 1998) (Fig. 10.1).

Companion plants facilitate insect pest management directly by deterring pests away from the main crops, providing habitat for biological control agents, and encouraging biological processes. Besides protecting the target crop, the ideal companion plant should provide economic return to the farmer at harvest (Vandermeer 1989) or enhance economic benefit by way of increased yield (Hokkanen 1991; Altieri 1999). The beneficials encouraged by companion planting include predators and parasitoids which reduce both pest damage and pesticide use. Companion planting is recommended for chemical pesticide-free agriculture and organic sustainability.

10.2 Benefits

The various benefits of companion planting are as follows:

- Acts as a nurse crop to provide shade, windbreak, and weed suppression.
- Acts as a trap crop which is more attractive to the pest than the main crop (growing *Brassica oleracea* to attract diamondback moth from cruciferous vegetables).
- Avoids risk through crop diversification.
- Combines beauty and purpose, giving an enjoyable and healthy environment.
- Conserves water through living mulch and shading.
- Efficient use of space by using quick-growing companion plants (broccoli).
- Enhances the population of natural enemies (predators, parasitoids, and pathogens) of pests.

Fig. 10.2 Companion planting of maize or corn (*right*) and sorghum to attract natural enemies of cotton pests (Photo: Rex Dufour, NCAT)

- Has allelopathic effect, which influences the growth, survival, and reproduction of pest organisms.
- Improves soil tilth, reduces soil erosion, enhances organic biomass and the moisture-retaining ability of soil (Hartwig and Ammon 2002; Folorunso et al. 1992).
- Improves soil fertility (legume plants such as beans, peas, clover, alfalfa, and vetch enhance biological N-fixation).
- Leads to increased yield.
- Has less reliance on pesticides.
- Provides habitats such as food (nectar and pollen) and oviposition sites for beneficials (predators and parasitoids) (Fig. 10.2).
- Provides physical protection or support of one plant by another.
- Repels pests by releasing sex pheromones (marigold repels aphids).
- Suppresses insect and mite pests, disease pathogens, nematodes, and weeds.

10.3 How Does Companion Planting Work?

Certain companion plants deter herbivores away from the main/cash crops, perform the function as trap crops, and enhance natural enemies which reduce the population of crop pests. The deterring of pests by the companion plants may be due to masking of plants (e.g., thyme, lavender, and scented geranium) and production of natural toxins or poisons (e.g., *Matricaria chamomilla, Thymus vulgaris, Lavandula angustifolia*, and *Pelargonium graveolens*).

Fig. 10.3 Effect of companion crop (Pacific Gold mustard) for the management of insect pests on main broccoli crop [(++) is more attractive than (+)]

10.3.1 Disrupts Host Location by Pests

10.3.1.1 Deterring of Pests

Companion plants attract insect pests away from the target crop, and the concentrated pests can be managed by using pesticides or other cultural or biological control methods (Fig. 10.3) (Hokkanen 1991; Shelton and Badenes-Perez 2006).

Japanese beetles can be driven away from main crops like *Phaseolus vulgaris* or *Rosa indica* by growing companion trap crops like scented geraniums (*Pelargonium graveolens*) and four o'clock plants (*Mirabilis jalapa*) nearby, which are toxic to adult beetles.

Nasturtiums attract large numbers of black aphids from main crops, which can be managed by regular handpicking or periodical treatment with an organic insecticidal soap. If the infestation is very heavy, nasturtiums can be uprooted and destroyed.

Interplanting low-growing herbs (companion trap plants) with *Lycopersicon esculentum* and *Solanum tuberosum* deters pests away from main crops.

This strategy can also be employed for the management of cruciferous pests by using companion plants like marigolds and mint (Finch et al. 2003; Atkins 1980; Zohren 1968).

10.3.1.2 Repelling Pests

The most obvious way by which companion plants manage pests is by repelling them. Cook et al. (2007) utilized this strategy for the management of insect pests and weed suppression in crop species.

Many flying insect pests are put off or confused by the smell of volatiles released by companion plants like *Allium cepa*, *A. sativum*, *Tagetes erecta*, and *T. patula*. Hence, companion planting of these crops randomly in the whole field facilitates the management of insect pests (Fig. 10.4). Similarly, growing of aromatic companion plants also helps in the management of crop pests (Uvah and Coaker 1984; Lu et al. 2007).

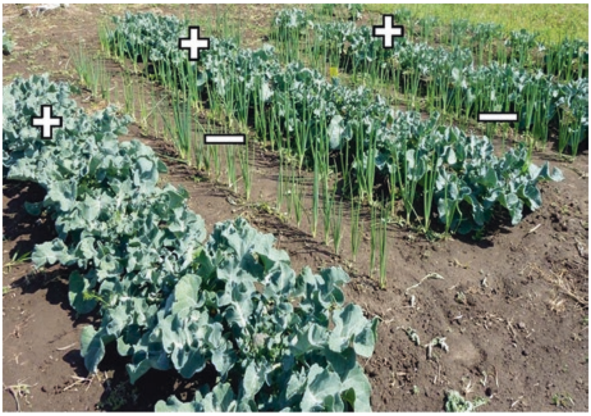

Fig. 10.4 Effect of intercropping of companion plant (spring onions) for the management of insect pests in main crop (broccoli) [attractive (+), repellent (−)]

Fig. 10.5 Effect of intercropping of companion plants (marigolds) for the management of pests in main crop (broccoli)

10.3.1.3 Masking of Host Plant Odors

Volatiles released from companion plants interfere with host plant location by masking the host plant odors (Fig. 10.5) (Tahvanainen and Root 1972; Buranday and Raros 1975; Perrin and Phillips 1978).

10.3.1.4 Camouflage or Physically Block

The location of host plants by the pests can be obstructed visually or physically (Fig. 10.6), making host plants less apparent by companion plants (Feeny 1976). For example, the companion planting of maize with squash or pumpkins (resulting in diverse canopy) is preventing from *Melittia cucurbitae* damage. Similarly, damage from raccoons to sweet corn can be prevented by companion planting with prickly squash vines. Likewise, Amoako-Atta (1983) found that companion planting with *Sorghum vulgare* managed *Alcidodes leucogrammus* on *Vigna unguiculata*.

Fig. 10.6 Effect of companion plant (dill) for the management of pests in the main crop (broccoli)

Table 10.1 Effect of companion trap cropping for the management of pests in crop plants

Main crop	Companion plant	Pests managed
Spinacia oleracea, *Beta vulgaris* subsp. *vulgaris*	*Brassica juncea*	*Disonycha xanthomelas*
Brassica oleracea subsp. *capitata*, *Spinacia oleracea*, *Beta vulgaris* subsp. *vulgaris*	*Raphanus sativus*	*Pegomya hyoscyami*
Brassica oleracea subsp. *capitata*	*Brassica oleracea*	*Plutella xylostella*

10.3.1.5 Attraction of Natural Enemies

Provision of habitats such as food (nectar and pollen) and oviposition sites attract the beneficials such as predators and parasitoids. The natural enemies like ladybugs and other beneficials that prey on insect pests are attracted to *Aster* spp., *Cosmos bipinnatus*, and *Rudbeckia hirta* from Asteraceae family.

The companion plants such as carrots, dill, parsley, and cilantro attract natural enemies like praying mantis, ladybugs, and spiders by providing shelter for them and other beneficial or parasitic insects. These beneficial insects are the natural protectors of the garden, seeking out harmful insects and feeding on them.

10.3.1.6 Acting as Trap Plants

Some companion trap plants are more attractive to insect pests than the target crops. Hence, the pest insects are attracted and concentrated on the trap plants, which can be managed by pesticides or other cultural/biological methods. Companion trap cropping can be employed to manage various pests in several crops (Table 10.1).

10.3.1.7 Integration of Companion Planting Techniques

The integration of multiple companion plants synergistically improves pest control in the target crop. For example, Cook et al. (2007) reported that in Kenya, the "push-pull" system using repellent companion plants (molasses grass, *Melinis minutiflora*) interplanted with border trap plants (Sudan grass, *Sorghum vulgare sudanense*) gave effective management of stem borer in corn.

Fig. 10.7 Conservation of biological control agents by growing flowering plants

10.3.2 Enhance Conservation Biological Control

The native population of biological control agents has to be conserved and enhanced to manage pest populations by means of habitat management (growing flowering flora within the crop field or at margins) (Fig. 10.7) (Van den Bosch and Telford 1964).

10.4 Pest Management

10.4.1 Insect Pests

Growing of companion plant like desmodium (forage legume) in maize crop is capable of suppressing parasitic weed (*Striga hermonthica*) by releasing chemicals from its roots, enriching soil with nitrates, supplying fodder to livestock, and increasing the productivity of maize (Midega et al. 2014).

10.4.1.1 Aphids

Aphids are a major problem often feeding on young cabbage heads or even on sweet corn tassels. Predators such as *Chrysoperla rufilabris* and *Coccinella septempunctata* feed on aphids. Companion flowering plants such as *Coriandrum sativum,* dill (*Anethum graveolens*), fennel (*Foeniculum vulgare*), *Daucus carota*, and yarrow (*Achillea millefolium*) enhance the population of green lacewings and ladybugs.

10.4.1.2 Caterpillars

Different types of caterpillars cause major damage to cruciferous and leafy vegetable crops. These pests can be managed by using predatory wasps. Companion plants such as catnip, chamomile, lemon balm, and peppermint, and other plants which also attract aphids can be employed to manage caterpillars.

10.4.1.3 Leafhoppers

Leafhoppers are a major problem causing significant damage on eggplant, tomatoes, potatoes, and beans. Besides causing direct damage by feeding, they also act as vectors of several virus/mycoplasma diseases. The predatory wasps can be used to manage leafhoppers. Companion plants like English lavender, buckwheat, statice, and sweet alyssum, and other plants which also attract aphids and caterpillars can be used to manage leafhoppers.

10.4.2 Weeds

Dense planting of target crops helps to suppress weeds by simply covering all available space and shading out competitors. Weeds can also be suppressed by using crop rotation or mixed cropping with companion plants.

10.4.3 Diseases

Growing companion crops along with target crops ensures crop diversity and reduces the risk of crop failure. Practicing of companion planting discourages disease pathogens. For example, Schoeny et al. (2008) found that Ascochyta blight severity was significantly reduced in a pea when grain crop was used as a companion crop. The canopy microclimate is modified by the grain companion intercrop, making it less humid. The grain intercrop also reduced the raindrop splash effect, which reduced the spread of the disease by preventing spore dispersal.

Some selected target crops and preferable/nonpreferable companion plants are presented in Table 10.2.

10.5 Mechanism of Action

Pimpinella anisum: It attracts natural enemies and drives away aphids and other pests from crucifers.

Barley: Dover (1986) found that intercropping of *Hordeum vulgare* with *Brassica oleracea* reduced the population of *Plutella xylostella*.

Basil: It deters aphids from their host plants. Planting basil near tomatoes reduces the pressure from hornworms.

Phaseolus vulgaris: Interplanting *Phaseolus vulgaris* and *Solanum tuberosum* in alternate rows controls *Leptinotarsa decemlineata* on *S. tuberosum*. Similarly, intercropping of *Cucurbita* spp. with *Phaseolus vulgaris* manages *Melittia cucurbitae* on cucurbits.

Borage: It repels *Manduca quinquemaculata* and *Trichoplusia ni* on *Lycopersicon esculentum* and crucifers, respectively. Borage also is responsible for managing several pests on various crops.

Table 10.2 Preferable and nonpreferable companion plants for different target crops

Crop	Preferable companion plants	Nonpreferable companion plants
Amaranthus spp.	*Zea mays, Allium cepa, Solanum tuberosum*	Cruciferous vegetables
Cynara cardunculus, *Cynara cardunculus* var. *scolymus*	*Brassica oleracea*, *Cucumis sativus*, *Cucurbita* spp.	*Solanum tuberosum*
Asparagus officinalis	*Lycopersicon esculentum, Petroselinum crispum*, *Ocimum* spp.	*Allium cepa, A. sativum*, *Solanum tuberosum*
Ocimum spp.	*Lycopersicon esculentum,* pepper, marigold	*Ruta graveolens*
Phaseolus vulgaris	*Daucus carota*, *Brassica oleracea* var. *capitata*, *Brassica oleracea*, *Zea mays*, *Cucumis sativus*, *Rosmarinus officinalis*, *Solanum tuberosum, Fragaria* × *ananassa*, *Apium graveolens, Satureja hortensis, Raphanus sativus*	Leek, onion, garlic, shallots, chives, *Beta vulgaris*, *Brassica oleracea, Dianthus annus*
Beet	*Brassica oleracea capitata*, onions, kohlrabi	*Phaseolus vulgaris*, field mustard
Rubus spp.	*Vitis vinifera*, *Tanacetum vulgare*	*Rubus occidentalis*
Vaccinium corymbosum	*Trifolium* spp.*, Fragaria* × *ananassa,* *Achillea millefolium*	*Lycopersicon esculentum*
Borago officinalis	*Cucurbita pepo*, *Fragaria* × *ananassa*, *Lycopersicon esculentum*	–
Brassica oleracea	Aromatic plants, celery, *Beta vulgaris*, *Allium* spp., *Matricaria chamomilla,* *Spinacia oleracea,Beta vulgaris* subsp. *vulgaris*	*Anethum graveolens*, *Fragaria* × *ananassa*, *Phaseolus vulgaris*, *Lycopersicon esculentum*
Daucus carota	*Pisum sativum*, *Lactuca sativa*, *Allium cepa*, *Rosmarinus officinalis*, *Lycopersicon esculentum*	*Anethum graveolens*, *Pastinaca sativa*, *Raphanus sativus*
Catnip	Eggplant	–
Apium graveolens	*Allium* spp., *Brassica* spp., *Lycopersicon esculentum*, *Phaseolus vulgaris*, *Tropaeolum* spp.	Parsnip, potato
Chamomile	Cabbage, onion	–
Chervil	Radish	–
Chives	Carrot	–
Zea mays	*Solanum tuberosum*, *Phaseolus vulgaris*, *Pisum sativum*, *Cucurbita pepo*, *Cucumis sativus*	*Lycopersicon esculentum*
Vigna unguiculata	*Phaseolus vulgaris, Daucus carota, Zea mays, Cucumis sativus, Raphanus sativus, Brassica rapa* subsp. *rapa*	*Allium cepa, A. sativum*, *Solanum tuberosum*
Cucumis sativus	*Phaseolus vulgaris*, *Zea mays*, *Pisum sativum*, *Raphanus sativus*	Irish potato, aromatic plants

(continued)

Table 10.2 (continued)

Crop	Preferable companion plants	Nonpreferable companion plants
Dead nettle	Potato	–
Dill	Cabbage	Caraway, carrots
Eggplant	Beans, marigold	–
Feverfew	Roses	–
Flax	Carrots, potatoes	–
Garlic	Roses, raspberries	–
Zingiber officinale	*Ocimum* spp., *Lycopersicon esculentum*	–
Cucurbita spp.	*Zea mays*, *Dianthus annus*	–
Vitis vinifera	*Ocimum* spp., *Phaseolus vulgaris*, *Allium schoenoprasum, Trifolium* sp., *Brassica nigra*, *Origanum vulgare*, *Pisum sativum*	*Brassica oleracea* subsp. *capitata*
Armoracia rusticana	Potatoes	–
Hyssop	Grapes, cabbage	–
Lavender	Rosemary, southernwood, wormwood	–
Lactuca sativa	*Daucus carota*, *Raphanus sativus*, *Fragaria* × *ananassa*, cucumber	–
Cucurbitaceae	*Amaranthus* spp., *Phaseolus vulgaris*, *Matricaria chamomilla*, *Zea mays*	*Brassica oleracea*
Mint	Cabbage, tomatoes	–
Nasturtium	Radishes, cabbage, cucurbits, fruit trees	–
Abelmoschus esculentus	*Capsicum annum*, *Cucurbita pepo*, *Ipomoea batatas*	*Phaseolus vulgaris*, *Pisum sativum*
Allium spp.	*Beta vulgaris*, *Daucus carota*, *Lactuca sativa*, *Brassica oleracea*, *Satureja hortensis*	*Phaseolus vulgaris*, *Pisum sativum*
Petroselinum crispum	*Lycopersicon esculentum*, *Asparagus officinalis*	–
Pisum sativum	*Daucus carota*, *Raphanus sativus*, *Brassica rapa* subsp. *rapa*, *Cucumis sativus*, *Zea mays*, *Phaseolus vulgaris*	*Allium* spp., *Gladiolus* spp., *Solanum tuberosum*
Arachis hypogea	*Solanum melongena*, *Cucumis melo* var. *cantalupo*, *Cucurbita pepo*, *Helianthus annuus*	*Allium* spp., *Gladiolus* spp., *Solanum tuberosum*
Pennyroyal	Roses	—
Capsicum annum	*Ocimum* spp., *Trifolium* sp., *Origanum majorana*, *Lycopersicon esculentum*	*Brassica* spp.
Petunia	Beans	–
Solanum tuberosum	*Phaseolus vulgaris*, corn, cabbage family, *Tagetes* spp., horseradish	*Cucurbita pepo*, squash, *Lycopersicon esculentum*, *Cucumis sativus*, *Helianthus annuus*
Cucurbita pepo	*Zea mays*, *Tagetes* spp.	*Solanum tuberosum*

(continued)

Table 10.2 (continued)

Crop	Preferable companion plants	Nonpreferable companion plants
Portulaca oleracea	*Ocimum* spp., *Beta vulgaris*, *Brassica oleracea* var. *capitata*, *Daucus carota*, *Zea mays*, *Lactuca sativa*, *Brassica rapa* subsp. *rapa*, *Raphanus sativus*	*Phaseolus vulgaris*, *Pisum sativum*
Raphanus sativus	*Pisum sativum*, nasturtium, *Lactuca sativa*, cucumber	Hyssop
Rosmarinus officinalis	*Brassica oleracea* var. *capitata*, *Phaseolus vulgaris*, *Daucus carota*, *Salvia officinalis*	–
Spinacia oleracea	*Fragaria* × *ananassa*, *Vicia faba*	–
Cucurbita pepo	*Tropaeolum* spp., *Zea mays*, *Tagetes* spp.	Irish potato
Fragaria × *ananassa*	*Borago officinalis*, *Phaseolus vulgaris*, *Lactuca sativa*, *Tanacetum* spp., *Carum carvi*	*Solanum tuberosum*
Saccharum officinarum	*Pisum sativum*, *Vigna unguiculata*	*Sorghum vulgare*, Johnson grass
Helianthus annuus	*Phaseolus vulgaris*, *Zea mays*, *Cucumis sativus*, *Cucumis melo* var. *cantalupo*, *Arachis hypogea*	*Solanum tuberosum*
Ipomea batatas	Okra, peppers, *Helianthus annuus*	*Sorghum vulgare*, *Sorghum halepense*
Ruta graveolens	*Rosa* spp., *Rubus* spp.	*Ocimum basilicum*
Salvia officinalis	Rosemary, *Brassica oleracea* var. *capitata*, *Daucus carota*	*Cucumis sativus*
Southernwood	Cabbages	–
Sonchus spp.	*Lycopersicon esculentum*, *Zea mays*, *Allium cepa*	–
Satureja hortensis	*Phaseolus vulgaris*	–
Tanacetum vulgare	Fruit trees, *Rosa* spp., *Rubus occidentalis*	–
Thyme	Cabbage	–
Lycopersicon esculentum	*Allium* spp., *Tropaeolum* sp., *Tagetes* spp., *Asparagus officinalis*, *Daucus carota*, *Petroselinum crispum*, *Cucumis sativus*	*Solanum tuberosum*, *Foeniculum vulgare*, *Brassica* spp.
Brassica rapa subsp. *rapa*	*Pisum sativum*	*Solanum tuberosum*
Watermelon	Nasturtium, marigold	Irish potato, mustard
Yarrow	Aromatic herbs	–

Fig. 10.8 Effect of Buckwheat (*left*) in managing pests of crucifers (*right*) and controlling unwanted plants

Buckwheat: It is receptive to natural enemies of crop pests and controls pests attacking crucifers. Buckwheat also controls unwanted plants in crops (Fig. 10.8).

Calendula: It turns off tomato hornworms and asparagus beetles.

Carrots and Leeks: Intercropping of *Daucus carota* and *Allium ampeloprasum* is responsible for repelling pests on both crops.

Castor Beans: Perimeter companion planting of *Ricinus communis* deters away *Gryllotalpa brachyptera* pests on vegetable crops.

Nepeta cataria: Interplanting of *Nepeta cataria* deters away *Epitrix fuscula* and *Anasa tristis* on *Cucumis sativus* and *Solanum melongena*, and *Leptinotarsa decemlineata* on *Solanum tuberosum*.

Chamomile: It attracts natural enemies such as syrphid flies and predatory wasps.

Chervil: It repels *Nasonovia ribisnigri* from *Lactuca sativa*.

Chinese cabbage: Gao et al. (2004) reported that Chinese cabbage reduced the population of *Phyllotreta striolata* on onions.

Chives: It repels *Popillia japonica* and protects *Malus pumila* trees from *Venturia inaequalis*. It deters *Macrosiphoniella sanborni* from chrysanthemums and *Helianthus annus*. Interplanting of chives protects *Rosa* spp. from the disease pathogen *Diplocarpon rosae.*

Chrysanthemum: It deters and kills root nematodes.

Trifolium repens: Intercropping of *Trifolium repens* with *Brassica oleracea* enhances predatory mite population, resulting in pest control (Hooks et al. 2007).

Collard: Mutiga et al. (2010) reported that interplanting of collard with crucifers reduced *Brevicoryne brassicae* population.

Comfrey: It acts as trap crop for *Limax* spp.

Coriandrum sativum: It drives away *Leptinotarsa decemlineata*, *Macrosiphum euphorbiae*, and *Tetranychus urticae* on *Solanum tuberosum*.

Corn: Intercropping of *Zea mays* with *Brassica oleracea* controls *Melittia cucurbitae* on Cucurbitaceous crops.

Cucurbits: Simultaneous cropping of maize and *Cucurbita pepo* drives away rodents damaging maize crop. Similarly, companion plant wild cucurbits with spines protects maize and *Phaseolus vulgaris* from rodent damage.

Daffodils: Repel mice with a border of daffodils.

Dahlias: Repel nematodes.

Dead Nettle: It repels potato bugs.

Dill: It drives away pests like *Anasa tristis*, *Myzus persicae*, and *Tetranychus urticae* from *Lactuca sativa, allium cepa*, and *Cucumis sativus*. Dill also attracts predatory syrphid flies which manage crop pests.

Elderberry: Application of leaf decoction (the extraction by boiling water-soluble substances down) of elderberry controls aphids and *Diabrotica undecimpunctata* on *Cucumis sativus*. It also attracts syrphid flies which predate on crop pests.

Fennel: Fennel is receptive to predatory syrphid flies which facilitate biological control of crop pests.

Feverfew: It acts as a trap crop for aphids preventing damage to the main crops.

Linum usitatissimum: It repels *Solenopsis* ants (which spread the crop pests) from *Solanum tuberosum.*

Allium sativum: Interplanting of *Allium sativum* with *Lycopersicon esculentum*, *Solanum melongena*, *Brassica oleracea* var. *capitata*, *and Rosa* spp. deters *Macrosiphum* spp., *Popillia japonica*, and other crop pests. It also repels *Cydia pomonella* on *Malus pumi*, *Synanthedon exitiosa* on *Prunus persica*, and *Trichoplusia ni* on *Brassica oleracea* var. *capitata.*

***Geranium* spp.**: It drives away *Pieris rapae* on *Brassica oleracea* var. *capitata*, *Helicoverpa zea,* and *Cicadulina mbila* on *Zea mays*.

Henbit: It repels insect pests.

Horseradish: It repels potato bug.

Hyssop: It drives away *Pieris rapae* on crucifers like *Brassica oleracea* (cultivar group *Italica*), *Brassica oleracea* var. *capitata*, and *Brassica oleracea* (cultivar group *Gemmifera*).

Lavender: It repels whiteflies and moths from crop plants.

Leek: It deters *Chamaepsila rosae* from *Daucus carota* and *Delia antiqua* from *Allium cepa*. It also prevents oviposition.

Melissa officinalis: It repels *Anasa tristis* from crop plants.

Lettuce: Companion planting of *Lactuca sativa* with *Brassica oleracea* (Gongylodes Group) or *Raphanus sativus* deters earth flies.

Lovage: It encourages beneficial predatory ground beetles.

Marigolds: Both African and French marigolds produce biochemicals (thiophene) from their roots that are toxic to root-knot nematodes (Marotti et al. 2010). Marigolds will repel beetles, nematodes, and even some animal pests. They drive away *Delia radicum* on cabbage and *Epilachna varivestis* on beans. Marigolds also attract predatory syrphid flies which attack greenfly. They trap *Tetranychus urticae* and *Limax* spp.

***Mentha* spp.**: They repel *Mamestra brassicae* on crucifers by luring predatory syrphid flies.

Nasturtiums: Nasturtium (*Tropaeolum majus*) acts as a barrier trap crop for insect pests such as *Macrosiphum* spp., *Bemisia* spp., *Anasa tristi*s, and *Acalymma vittatum*, and protects crops like *Lycopersicon esculentum*, *Raphanus sativus*, *Brassica oleracea* var. *capitata*, and *Cucumis sativus*. The insect pests concentrated on nasturtium can be managed by spraying insecticides.

Onion: Intercropping of onion with *Daucus carota*, *Beta Vulgaris*, *Lactuca sativa*, *Brassica oleracea*, and *Fragaria* × *ananassa* drives away *Myzus persicae* due to strong odors released by onion (Amarawardana et al. 2007). It also deters *Oryctolagus cuniculus* from crops like *Pisum sativum*, *Phaseolus vulgaris*, *Lactuca sativa*, and *Brassica oleracea* var. *capitata.*

Pennyroyal: It repels flea beetles.

Peppermint: Peppermint helps to keep cabbage butterflies away. It is receptive to natural enemies of crop pests.

Capsicum annum: It controls soil-borne pathogens such as vascular wilts and *Rhizoctonia* spp. on eggplant, *Lycopersicon esculentum*, *Beta vulgaris* subsp. v*ulgaris*, *Cucurbita* spp., and *Cucumis sativus* through rhizosphere secretions.

Potato: Interplanting of potatoes with *Phaseolus vulgaris* controls *Epilachna varivestis*.

Pyrethrums: They repel insect pests.

Rosmarinus officinalis: It controls *Mamestra brassicae*, *Trichoplusia ni*, *Callosobruchus maculatus*, and *Chamaepsila rosae* on *Brassica oleracea* var. *capitata*, *Phaseolus vulgaris*, *Daucus carota*, and *Salvia officinalis.*

Rue: It repels Japanese beetles.

Sage: It reduces the population of *Plutella xylostella* on *Brassica oleracea* (Gemmifera Group) (Dover 1986). It also repels carrot fly, flea beetles, and slugs.

Savory: It controls *Cerotoma trifurcata* on *Phaseolus vulgaris*.

Southernwood: It repels *Mamestra brassicae* on *Phaseolus vulgaris*.

Satureja hortensis: It repels *Cerotoma trifurcata* on *Phaseolus vulgaris*.

Tanacetum vulgare: It repels *Popillia japonica*, *Acalymma vittatum*, and *Anasa tristis* from crop plants.

Thymus vulgaris: Thyme is thought to ward off cabbage worms. It also reduces the population of *Plutella xylostella* on Brassica oleracea (Gemmifera Group) (Dover 1986).

Wormwood: It is good at keeping away white cabbage moth around vegetable crops through strong odors.

Yarrow: It attracts beneficials.

10.6 Conclusions

The use of several companion plants to reduce different pests has been demonstrated in various crops. Mode of action of companion plants in managing crop pests is not properly worked out (Bomford 2009). The chemical properties in the plant may be responsible for repelling insect pests as suggested by many studies (Cook et al. 2007), while Finch et al. (2003) consider that the chemicals may not be involved in pest management.

Companion planting by diversifying the cropping schemes is an in-field approach for the management of crop pests by the growers. Hence, additional information has to be gathered to devise specific cropping systems against particular pests. This strategy to enhance pest management can be achieved by plant species diversity conservation and reduction in pesticide use. Even though companion planting may help in reducing pest populations, there is still a need for balanced IPM program using cultural, mechanical, biological, and chemical methods for maintaining a healthy crop.

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Habitat Management

11

Abstract

Habitat management is an innovative strategy to enhance the population of biological control agents such as predators, parasitoids, and pathogens in order to manage insect pests, disease pathogens (fungi, bacteria, and viruses), nematodes, and weeds. This is achieved by maintaining vegetational diversity through polycultures (intercropping, cover crops, and crop rotation), provision of supplementary food resources (pollen and nectar), managing vegetation in field margins (beetle banks, hedgerows, strip highways for habitat), shelters, and artificial nesting structures.

Keywords

Encouraging beneficials • Vegetational diversity • Supplemental foods • Polycultures • Beetle banks • Hedgerows • Cover/green manure crops • Crop rotation

11.1 Introduction

The natural enemies such as predators are important for managing pests of crop plants. They contribute an estimated sum of US$ 400 billion per year globally to the economic value of the ecosystem services (Van Lenteren 2006). In spite of this, the field of biological control has been neglected since the past five decades, giving more importance and resources to chemical pesticides, which are responsible for decreased biodiversity, acute human toxicity, pollution of groundwater, and reduced resilience. Hence, there is a public outcry demanding alternative pest management strategies for the effective and ecofriendly pest management. The research on pests should include their host range and habitats that are very important for their management.

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In view of the recent progress in our knowledge of conservation biology, there is a need to change over from the traditional biological control to the conservation biological control by conserving the habitats for increasing the population buildup of natural enemies (Letourneau 1998; Pickett and Bugg 1998). The use of strategies that increase the effectiveness of natural enemies by manipulation of their habitat and behavioral functions is called the conservation biological control. This strategy can be applied to both indigenous (native) and introduced biological control agents that are present within the country or imported from their country of origin (Barbosa 1998).

The ways by which the habitat is managed to enhance biological control in agroecosystems and to improve crop protection will be discussed in this chapter.

11.2 Habitat Management

The habitat management for enhancing the biological control agents is beginning to receive attention in crop protection. The agroecological conservation of natural enemies (predators, parasitoids, and pathogens) which are already present in nature and increasing their numbers through provision of diet (nectar and pollen), overwintering sites, hedgerows, and crop diversity (polycultures) are generally believed to manage crop pests and thereby increase crop productivity (Kruess and Tscharntke 2000; Altieri and Letourneau 1982). The pest suppression by natural enemies is referred to as "top-down" control ("natural enemies hypothesis"), while suppression of herbivores with vegetational diversity tactics (intercropping, crop rotation) provides "bottom-up" control ("resource concentration hypothesis") (Root 1973). The conservation and performance of natural enemies can be achieved through high diversity of habitats and vegetation and reduced disturbance.

The availability of overwintering sites and the ability of an insect to locate suitable habitats and food resources during its lifetime are determined by the composition of agricultural landscape (Perrin 1980). The cultural approaches that favor increase in aerial and soil biological control agents should be encouraged in agroecosystems (Figs. 11.1 and 11.2).

Some of the methods that are employed to retain and increase population of biological control agents include:

- Intercropping (polycultures)
  - Push-pull strategy
  - Perimeter trap cropping
- Cover crops
  - Understory cover crops
- Crop rotation
- Supplementary food resources
  - Flowering plants
  - Pollen and nectar
  - Artificial food supplements
  - Alternate prey and preferred host

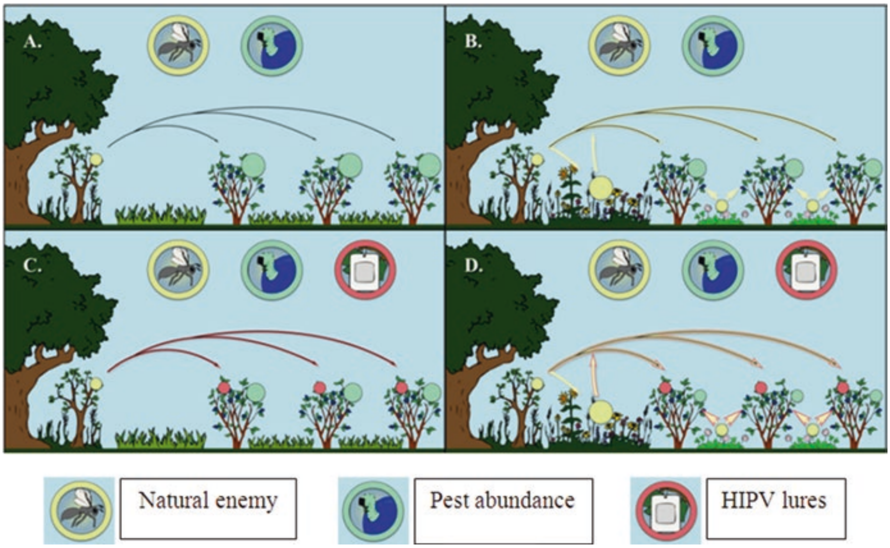

Fig. 11.1 Habitat management for increasing the biological control agents in agroecosystems for effective pest management. (**a**) Traditional practice (no habitat management, less biological control agents, more pest population); (**b**) Habitat management (polycultures, provision of diet – nectar and pollen, more biological control agents, less pest population); (**c**) Inclusion of pheromones (cues like HIPVs – herbivore-induced plant volatiles attract biological control agents); (**d**) Integration of habitat management and inclusion of pheromones (enhance biological control agents in main crop)

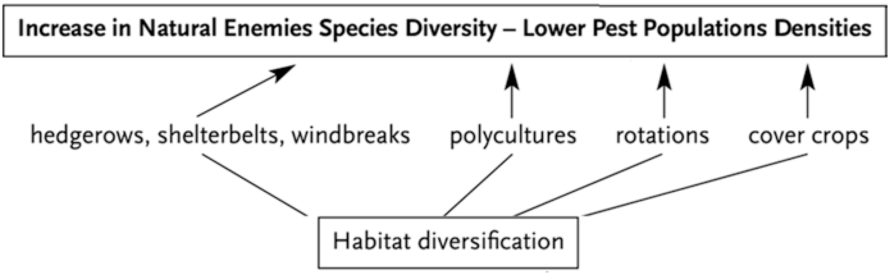

Fig. 11.2 Effect of habitat diversification through agricultural practices on natural enemy population

- Managing vegetation in field margins
  - Beetle banks
  - Hedgerows
  - Strip highways
  - Shelters
  - Artificial nesting structures

11.3 Intercropping and Polycultures

Intercropping systems increase diversity in an agricultural ecosystem, enhance ecological balance and better utilization of soil nutrients (Igzoburkie 1971), improve the quantity and quality of products, provide overwintering sites for biological control agents, and reduce damage by pests, diseases, and weeds. Among 209 field experiments conducted on 287 insect pests, polycultures reduced the population of 149 (52%) insect pests, while the biological control agents were increased in 53% cases (Andow 1991).

The abundance and diversity of beneficial insects in the agroecosystems can be increased by intercropping with clover, which flowers profusely, providing nectar and pollen (Theunissen 1994). Vegetational diversity enhances agroecosystem stability by suppressing pests and diseases (Altieri and Nicholls 2004). Beizhou et al. (2011) found that decrease in herbivores and enhancement of ratio between biological control agents and herbivores was noticed when pear orchard was intercropped with aromatic plants.

Intercropping can be employed to manage insect and mite pests by disrupting their ability to find their hosts (Andow 1991) or by repelling major herbivores through the release of strong volatiles. The odors released by plants in the cabbage family attract crucifer flea beetles (*Phyllotreta cruciferae*), but the random movement of flea beetles within that area is obstructed by intercropping, resulting in the reduction of flea beetle numbers. The Colorado potato beetles' movement is disrupted by planting bands of *Secale cereale –Vicia villosa* green mulch crops among rows of *Solanum tuberosum*, since newly emerged pests find their hosts primarily by walking. Later, mowing of the cover strips and mulching the soil give hiding sites for natural enemies. Undersowing of clover repels *Delia radicum* (Finch and Edmonds 1994) and medick repels *Chamaepsila rosae* (Rämert and Ekbom 1996) effectively (for further details on intercropping, see Chap. 8).

11.3.1 Push-Pull Strategy

A strategy called "stimulo-deterrent diversion" has been developed for the management of stem borers and parasitic weed on corn (Fig. 11.3) by using green leaf Desmodium (*Desmodium intortum*) for driving the stem borers away ("push") and Sudan grass (*Sorghum vulgare sudanense*) in the crop edge which lure female moths ("pull") to lay eggs. When the eggs hatch, 80% die as the grass also secretes gummy exudates that trap the larvae and kill them (Khan et al. 2006). Besides controlling stem borers, Sudan grass also enhances biological control agent (*Cotesia* sp.), when intercropped with corn (Khan et al. 1997).

"Push-pull" strategies have also been developed for the management of boll worms, *Helicoverpa armigera* in cotton (Duraimurugan and Regupathy 2005); pea leaf weevil, *Sitona lineatus* in beans (Smart et al. 1994); Colorado potato beetle, *Leptinotarsa decemlineata* in potatoes (Martel et al. 2005); maggot, *Delia antiqua* on onions (Miller and Cowles 1990); and thrips, *Frankliniella occidentalis* on

Fig. 11.3 Management of corn stem borer using *Desmodium intortum* to push the pest and *Sorghum vulgare sudanense* to pull the pest to the crop edge

chrysanthemums (Bennison et al. 2001) (for further details on stimulo-deterrent diversion strategy, see Chap. 12).

11.3.2 Perimeter Trap Cropping

Planting of a trap crop completely encircling the main crop specifically to attract target pests is called perimeter trap cropping. This type of planting system repels pests away from the main crop, significantly reduces pesticide applications, and preserves the beneficials in the main crop. It functions by aggregating the pests in the border area, which helps in the multiplication of natural enemies, killing the pests.

Planting of trap crops such as cowpeas and snap beans repels Mexican bean beetles and stink bugs away from soybeans. The unsprayed trap crop attracts 92% of pepper maggot population, resulting in effective protection (98–100%) of sweet bell peppers inside. The pepper maggot on the trap crop can be managed by spraying pesticides. Similarly, the damage of flea beetles was controlled by planting mustard surrounding cruciferous crops.

The diamondback moth (DBM) on cabbage can be managed by planting two rows of collards trap crop around the cabbage that attracts and concentrates the pest (Fig. 11.4). The DBM on collards is controlled by the naturally occurring parasitic wasp, *Diadegma insulare*. This system reduced the pesticide use by 56% and increased net savings by $117–$156/ha (for further details on trap cropping, see Chap. 9).

Fig. 11.4 Perimeter trap cropping of cabbage with collards

Fig. 11.5 *Left* – The cover crop crimson clover (Photo: KJ Graham). *Right* – The predator *Geocoris punctipes* (Photo: H Pilcher)

11.4 Cover Crops

Cover cropping (growing of a single or multiple crops of legumes and cereals) is responsible for improving soil structure and water infiltration, enhancing soil fertility, preventing soil erosion, modifying the microclimate, and suppressing pests including insects, disease pathogens, nematodes, and weeds.

Cover crops make available hiding and overwintering sites for biological control agents. Vegetational diversity is the simplest tactics to manage insect pests. They attract beneficial insects for pest control and improve pollination. By providing food and habitat, the cover crops encourage the beneficials. The flowering cover crops (clovers, legumes, buckwheat) are particularly helpful for attracting the beneficial animals and insects. They are also useful to attract pollinators, which shall enhance pollination rates of crops in the field.

Cover cropping of non-Bt cotton with crimson clover (Fig. 11.5) encouraged natural enemies of bollworm (*Helicoverpa armigera*), which reduced the pesticide inputs. Populations of the predator (*Geocoris punctipes*) (Fig. 11.5) built up on crimson clover in the early spring and moved onto cotton and subsequently preyed on bollworm pests in early season cotton (Fig. 11.6). The crimson clover also provided nectar to predators, honeybees, and other insect pollinators.

Fig. 11.6 The effect of cover crop crimson clover on predator population

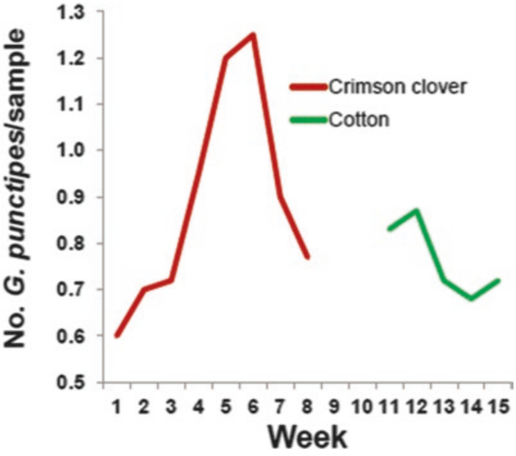

Fig. 11.7 The wheat cover crop in cotton for control of thrips

Conservation tillage in rye cover crop promoted natural enemies of *Helicoverpa armigera* in non-Bt cotton and in addition minimized insecticide inputs. Conservation tillage in rye provided the habitat for fire ants and thus enhanced the predation of *Helicoverpa* pests on cotton. Fire ants are predators of eggs and larvae of *Helicoverpa* pest insects in cotton. The wheat cover crop in cotton reduced the thrips population (Figs. 11.7 and 11.8).

The cover crop can be used in rotations for controlling soil-borne pathogens. Incorporation of green manure Brassica cover crop in soil acts as biofumigant in managing the soil-borne pathogens of *Pisum sativum*, *Daucus carota*, and *Phaseolus vulgaris*; *Verticillium* wilt of potato; and damping-off in lettuce (Sanders 2005).

The weeds in crop plants can also be managed by cover crops that release allelopathic compounds that inhibit the germination or growth of weeds, and by competing for light and nutrients. Some of the cover crops which can suppress weeds include cereal grains and grasses (suppress fall and winter weeds), buckwheat, spring cereals, Japanese millet, sorghum-Sudan grass hybrids, annual ryegrass, and fall rye (smother crops). Some cover crops such as legumes, cereals, and Brassica

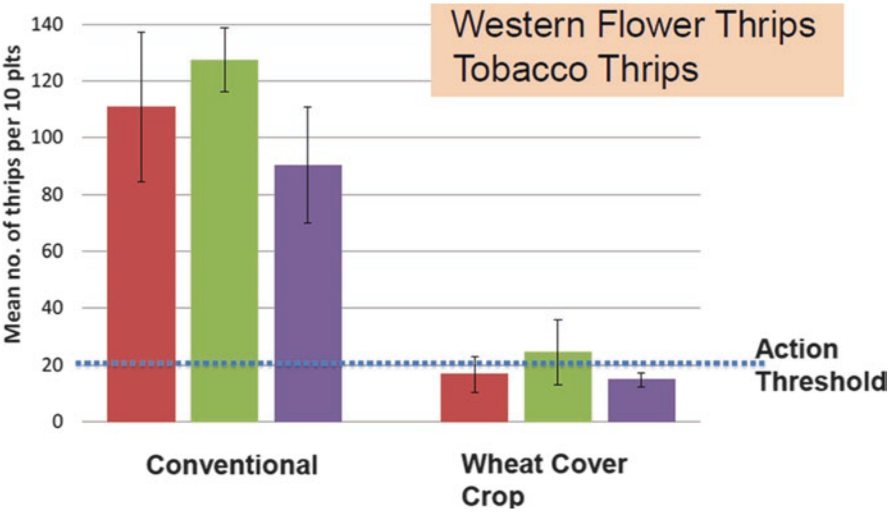

Fig. 11.8 Effect of wheat cover crop on thrips population (per ten plants) in three management zones

can reduce weed populations by releasing allelopathic compounds. The spread of cover crop residues on soil surface suppresses weed seed germination by physically modifying the amount of natural light, soil temperature, and soil moisture. Mulching of soil surface with rye residues suppresses weeds like lamb's-quarter and pigweed by releasing allelochemicals (for further details on cover crops, see Chap. 7).

11.4.1 Understory Cover Cropping

A reduction in herbivore population in fruit crops with rich floral undergrowth is due to the enhancement of natural enemies, as compared to clean cultivated orchards (Smith et al. 1996). The presence of goldenrod (*Solidago* sp.), lamb's-quarter (*Chenopodium album*), ragweed (*Ambrosia* sp.), and smartweed (*Polygonum* sp.) provided as other susceptible insect pest hosts for the wasp parasitoid multiplication, which helped in the effective management of the oriental fruit moth in peach orchards (Bobb 1939). Likewise, the biological control of eggs and pupae of *Malacosoma californicum* in apple orchards increased 4-fold and 18-fold, respectively, while that of *Cydia pomonella* was enhanced five times by understory cover cropping (Leius 1967).

The enhanced biological control of leafhoppers (*Erythroneura elegantula*) (Fig. 11.9) and thrips (*Frankliniella occidentalis*) in grape vineyards can be achieved by understory cover cropping (the vegetation of summer cover crops) by encouraging the population of parasitoids (*Anagrus epos*) and predators, including spiders (Nicholls et al. 2001).

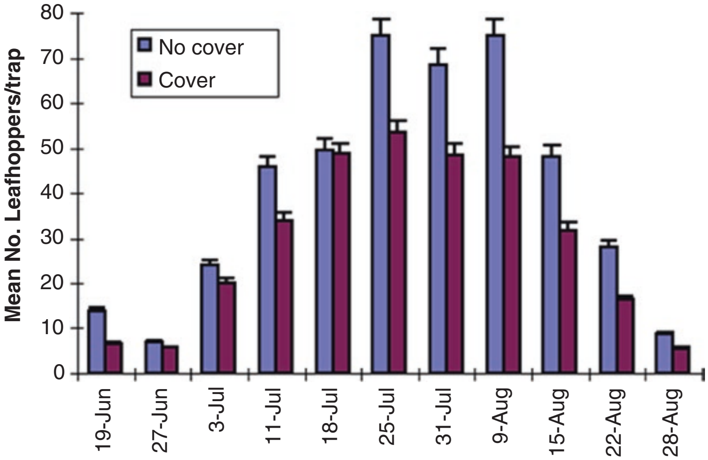

Fig. 11.9 Effect of summer cover crops on population densities of adult leafhoppers, *Erythroneura elegantula*, in grape vineyards in Hopland, California

Fig. 11.10 Effect of undersowing of cover crop for the management of grape leaf roller

Liang and Huang (1994) reported that the understory billygoat weed in citrus fruit crops gave complete biological protection from *Panonychus citri* by predatory mites.

Understory cover cropping with *Fagopyrum esculentum* in grape orchards was found effective for management of the leaf roller *Platynota stultana* (Fig. 11.10).

11.5 Crop Rotation

Sequential cropping is an effective tool for the management of insect and mite pests, diseases, nematodes, and weeds. The inclusion of crops that do not support growth and reproduction of the pathogen in rotation reduces the amount of soil-borne inoculum. Crops from different families should be used in crop rotation. At least 2 years should lapse between the crops from same families.

Some common characteristics of herbivores which are managed by sequential cropping (Flint and Roberts 1988) include:

- Fairly narrow host range of herbivore.
- Restriction of pest within limited area.
- Herbivore's incapability to survive long periods without a crop.
- Herbivore needs to be sedentary in nature.

In order to optimize pest regulation and soil fertility, the simplest forms of biodiversification include the legume-cereal crop rotations. The yield increases in crop rotations are mainly due to interference in pest biology and increasing the biological control agents in soil, including endomycorrhizal fungi, which facilitate proper use of nutrition and moisture. The soil-borne diseases which are difficult to control can be managed by following a 2–8-year sequential cropping with nonhosts to the pathogen.

The root rot and damping-off disease pathogens on onion were markedly reduced and yield increased when planted after *Daucus carota*. Club root of cabbage, *Plasmodiophora brassicae*, was effectively controlled by growing tomato, cucumber, snap bean, and buckwheat in rotation. Sequential cropping of *Brassica oleracea* prior to *Brassica oleracea* (Botrytis Group) decreased the incidence of vascular wilt due to biofumigation action. Similarly, scab and vascular wilt diseases on *Solanum tuberosum* were managed by growing maize or *Medicago sativa* prior to *S. tuberosum*. Likewise, vascular wilt incidence on *S. tuberosum* was also reduced by growing *Fagopyrum esculentum* prior to *S. tuberosum*. Rotation of *Brassica oleracea* with *Lactuca sativa* reduced the incidence of *Sclerotinia minor*. Crop rotation with cereals (sorghum, maize) reduced the incidence of field bean pod borer (*Adisura atkinsoni*). Similarly, crop rotation (paddy – sweet potato – cowpea) can minimize sweet potato weevil (*Cylas* spp.) damage.

Planting of sugarcane or pangola grass (*Digitaria decumbens*) following the destruction of banana infected with *R. similis* eliminates the nematode after 10 weeks. Khan et al. (1975) reported that the incidence of *Meloidogyne* sp. was reduced in chilies and sponge gourd when rotated with spinach and bottle gourd. Likewise, the stunt nematode (*Tylenchorhynchus brassicae*) population in cruciferous vegetable crops was reduced when rotated with *Triticum vulgare* (Siddiqui et al. 1973).

Rotation of *Vigna mungo* or *Glycine max* with cash crops markedly suppressed weeds. Similarly, rotation of spring *Lactuca sativa* with Japanese millet, cowpea, or soybean reduced weed population. Likewise, the growth of notorious weed

Parthenium hysterophorus in crop area is significantly suppressed by rotation with sickle pod (for further details on crop rotation, see Chap. 15).

11.6 Supplementary Food Resources

11.6.1 Flowering Plants

The plants belonging to the family Compositae are very effective in attracting natural enemies. Among the composites, by far the highest numbers of insects (including beneficials) are attracted to tansy, a vigorous spreading perennial. The access to flowering resources is required for the natural enemies for their growth and development (Wäckers et al. 2005). The efficacy of biological control of insect pests is dependent on the availability of flowering resources essential for natural enemies (van Rijn and Sabelis 2005). Some of the flowering plants like *Trifolium alexandrinum*, *T. incarnatum*, *T. repens*, *Vigna unguiculata*, *Fagopyrum esculentum*, and *Vicia villosa* provide habitat for beneficial insects and spiders.

Other flowering plants which attract beneficials are presented in Table 11.1.

Table 11.1 The flowering crops which enhance natural enemies

Flowering crop	Beneficial insects attracted
Trifolium alexandrinum	*Geocoris* spp.
Robinia pseudoacacia	Coccinellids
Ceanothus spp.	Syrphidflies
Carum carvi	Chrysopids, syrphidflies, *Orius insidiosus*, mites, Hymenopteran wasps
Polygonum arenastrum	*Geocoris* spp., syrphidflies, Hymenopteran wasps, Melyrid beetles
Vigna unguiculata	Hymenopteran wasps
Trifolium incarnatum	Anthocorids, *Geocoris* spp., Coccinellids
Fagopyrum esculentum	Syrphidflies, Anthocorids, *Vespa velutina*, Dipteran flies, chrysopids, Coccinellids
Vicia villosa	Coccinellids, Anthocorids, *Vespa velutina*
Daucus carota	Chrysopids, *Vespa velutina*, Anthocorids, Dipteran flies
Quillaja saponaria	Syrphidflies, chrysopids
Mentha spicata	*Vespa velutina*
Alyssum maritimum	Dipteran flies, syrphidflies, chalcids
Trifolium subterraneum	*Geocoris* spp.
Foeniculum vulgare	Hymenopteran wasps, *Vespa velutina*
Ammi visnaga	Syrphidflies, Anthocorids, Melyrid beetles, Dipteran flies
Tanacetum vulgare	Hymenopteran wasps, Coccinellids, *Orius insidiosus*, chrysopids
Melilotus albus	Dipteran flies, *Apis* spp., *Vespa velutina*
Achillea millefolium	Coccinellids, Hymenopteran wasps, *Apis* spp.

Fig. 11.11 Nectar-bearing plants with small attractive flowers – wild carrot, dill, and goldenrod

11.6.2 Pollen and Nectar Resources

Commonly used flowering green manure cover crops such as buckwheat (Bowie et al. 1995), *Trifolium incarnatum* (Tillman et al. 2004), and *Phacelia tanacetifolia* (Hickman and Wratten 1996) have all been reported to supply food supplements for natural enemies like syrphidflies, *Chrysoperla carnea*, ladybirds, and *Neoneurus vesculus*, when grown in conjunction with other crops.

The food supplements are required by most of the natural enemies as part of their diet. Significant increase in several functions of natural enemies is dependent on food supplements like pollen and nectar resources (Wäckers et al. 2008; Hogg et al. 2011). The best nectar sources suitable for small parasitoids and also larger predators include plants having very small flowers (Fig. 11.11). Adult hoverflies, which are aphid predators, need pollen for eggs to mature and produce their young ones. In order to attract and nourish natural enemies, readymade seed mixes of flowering plants are available.

There is a need to select plants which provide nonprey food to the beneficials but not to crop herbivores (Baggen et al. 1999). Understory flowering cover crops in grape vineyards enhance natural enemy population which control light brown apple moth (*Epiphyas postvittana*) (Begum et al. 2006). The integration of nonprey food and predators and parasitoids has the potential for enhancing biological control synergy (Simpson et al. 2011a, b).

11.6.3 Artificial Food Supplements

In order to attract or aggregate lady beetles, syrphidflies, and adult lacewings, artificial food supplements containing yeast, whey proteins (casein hydrolyzate), and sugars may be required for egg production in the absence of abundant prey. Some of the artificial foods available from suppliers of natural enemies include Wheast, BugPro, and Bug Chow.

11.6.4 Alternative Prey and Preferred Hosts

The survival and reproduction of natural enemies can be increased by maintaining considerable amount of alternate preferred hosts below economic injury thresholds. This can be achieved by planting the hosts for alternative prey around crop border or in bands in cropped area. To augment populations of natural enemies and their longtime survival on ornamental and food crops, the banker plant systems to provide alternative food or hosts can be used (Van Driesche et al. 2008; Frank 2010). The efficiency of natural enemies that predate on *Plutella xylostella* depends on the relative abundance of aphids on cabbage. Likewise, when the preferred prey, western flower thrips, is scarce in field, anthocorid bugs benefit from alternative prey.

Another tactic that can be employed to augment the population of natural enemies is to provide their preferred host. The two parasitic wasps, *Trichogramma evanescens* and *Apanteles rubecula*, prefer cabbage butterflies as their preferred host. The population of cabbage butterflies can be increased to tenfold in spring by continual releases of fertile females, which helps to build up the population of these two parasitic wasps all along the season at effective levels.

11.7 Managing Vegetation in Field Margins

The field margins can be manipulated into habitats for natural enemy reservoirs by providing overwintering sites and with pollen, nectar, and additional food resources. Bianchi et al. (2006) reviewed 24 research studies and reported that enhancing vegetational diversity by including flowering plants in the field border increased the biological control agents in 74% of cases, while the pest population decreased in 45% of cases. The predators and parasitoids move from field corridors into crops and provide effective biological control of crop pests, more so in field borders as compared to inside the field in the following cases:

- *Ostrinia nubilalis* in maize due to parasitic wasp.
- *Meligethes aeneus* in *Brassica napus* (parasitism decreased to 20% at the center as compared to 50% in the field border) (Thies and Tscharntke 1999).
- By planting *Prunus domestica* by the side of *Vitis vinifera*, egg parasitic wasp, *Anagrus epos*, reduces *Erythroneura elegantula* due to the provision of alternative prey to the parasitoid.
- Planting supplementary food-supplying flowering plants in the crop border of *Saccharum officinarum* encourages the parasitoid (*Lixophaga sphenophori*) of *Rhabdoscelus obscurus*.

Some practices that can be used to increase the natural enemies by managing field margins are as follows:

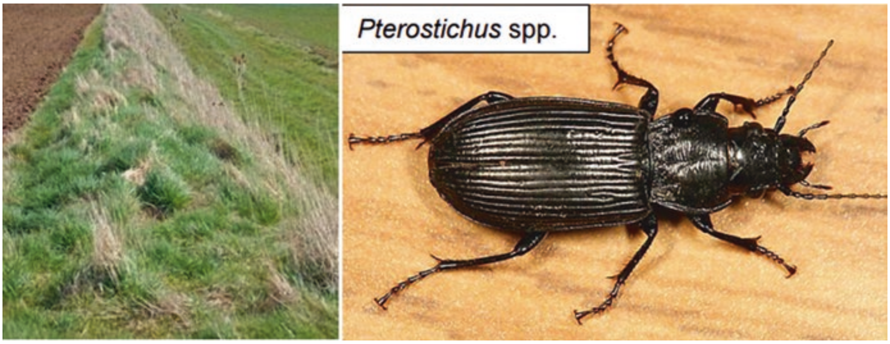

Fig. 11.12 The beetle bank

11.7.1 Beetle Banks

In order to provide overwintering sites for natural enemies, the raised beds are normally provided in margins or inside the larger fields so that beneficials (predaceous ground beetles, *Demetrias atricapillus* and *Tachyporus hypnorum*) can reach the center of the field more quickly (Thomas et al. 1992) (Fig. 11.12). The installation of beetle banks can be ideally located in less productive land to negate the loss of productive land.

The grasses such as *Lolium, Dactylis*, *Agrostis*, and *Holcus* can be sown on raised beetle banks. The pollen- and nectar-bearing flowering plants can also be grown on these banks to attract beneficials belonging to Hymenoptera and Syrphidae. The polyphagous herbivore predators can reach populations to the extent of 1500/ m^2 (Thomas et al. 1992).

The beetle banks provide not only natural enemies to the grower, but also increased income due to less cost on pesticides, effective pest management, and enhanced production. For example, Thomas et al. (1991) reported that through installation of beetle banks, farmer can save a sum of £300 per year in labor and insecticide costs, and prevent damage from crop pests.

11.7.2 Hedgerows

The hedgerows provide habitats for overwintering natural enemies which can give more effective biological control of crop pests. For example, maize crop embedded in hedgerows provided better biological pest control of armyworm, *Pseudaletia unipuncta* as compared to corn without hedgerows. Similarly, the parasitoid *Eriborus terebrans* gave better control of European corn borer in edges of maize fields with hedgerows than without them (Marino and Landis 1996).

The "mini hedgerows" are raised narrow strips at field margins planted with suitable vegetation (grasses or flowering plants as adult food resources for beneficials). The suitable grasses for planting on mini hedgerows include *Holcus lanatus* and

Fig. 11.13 Creating refuge strips of anise flowering plants amid soybean crop is receptive to natural enemies

Dactylis glomerata to increase predators and parasitoids in whole field (Thomas 1990). These grasses were found to provide overwintering habitats for cereal aphid predators such as caradids, *Bembidion lampros*; rove beetles, *Tachyporus* spp.; and several species of linyphiid spiders; and increased their population densities (Chiverton 1989). Similarly, provision of hedgerows of *Rosa woodsii* (provide alternate overwintering site to major parasitoid) to *Malus pumila* plantations helped in the biological control of *Archips* spp.

11.7.3 Strip Highways for Habitat

The highways of habitat to predators and parasitoids can be provided by planting flower strips in the crop field at a regular interval of 50–100 m. The natural enemies use this habitat for multiplication and dispersal into field centers. The bean aphids (*Brevicoryne brassicae*) on wheat, sugar beets, and cabbage can be managed by planting tansy to enhance the population of syrphid predators. Likewise, the cabbage aphids (*Brevicoryne brassicae*) can be controlled by planting strips of tansy leaf and buckwheat in Swiss cabbage fields, which enhanced small parasitic wasp populations (White et al. 1995). Similarly, the aphids on lettuce and cruciferous crop fields can be managed by planting strips of Alyssum every 50–100 m in order to attract syrphid flies. Creating refuge strips of flowering anise plants amid soybean crop is receptive to natural enemies (Fig. 11.13).

11.7.4 Shelters (Refugee Sites)

The provision of appropriate shelters is required to promote natural enemies' survival (foraging, resting, overwintering, or nesting) and protection from environmental hazards. The shelters that can provide protection to beneficials from windy areas include hedgerows, windbreaks, or shelter belts. Many natural enemies use flowers' pollen and nectar from windbreaks and hedgerows as their food (Beane and Bugg 1998). The herbaceous and woody plants in crop fields often serve as overwintering and resting shelters for various natural enemies (Beane and Bugg 1998).

11.7.5 Artificial Nesting Structures

The predation of cotton leaf worms and tobacco hornworms from the red wasp (*Polistes annularis*) increased by erecting artificial nesting structures. The natural enemies in cropped area can be enhanced by building artificial houses to lacewings (McEwen and Sengonca 2001). Some predatory mites which feed on pest mites use domatia (naturally occurring shelters from certain plants) as shelters. The population of predatory mites is higher in plant leaves with greater domatia structures (Loughner et al. 2008). The lower population of spiders and powdery mildew in certain grape cultivars is due to the presence of leaf domatia (English-Loeb et al. 2005).

11.8 Conclusions

In order to implement the crop diversification strategy more rapidly, it is necessary to enhance natural enemies within cropped area and in field borders by providing food and shelter for their survival and multiplication (Gurr et al. 1998). If within the crop contribution to the overall natural enemy population in subsequent years is minor, then providing additional food supplements is to be given more importance. In order to specifically attract more biological control agents from other areas, vegetational diversity has to be created to ensure supply of resources such as alternative prey and preferred hosts for the natural enemy population.

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Stimulo-Deterrent Diversion Strategy

12

Abstract

A strategy called "stimulo-deterrent diversion" has been developed for the management of stem borers and parasitic weeds on corn by using green leaf Desmodium (*Desmodium intortum*) for driving the stem borers away ("push") and Sudan grass (*Sorghum vulgare sudanense*) in the crop edge which lure female moths ("pull") to lay eggs. When the eggs hatch, 80% die as the grass also exudes a sugary secretion that traps the larvae and kills them. Besides controlling stem borers, Sudan grass also enhances biological control agent (*Cotesia* sp.), when intercropped with corn.

"Push-pull" strategies have also been developed for the management of lepidopteron pests in cabbage and cauliflower; fruit borer, *Helicoverpa armigera* in tomato; *H. armigera* in Gossypium spp.; *Sitona lineatus* in *Phaseolus vulgaris*; *Leptinotarsa decemlineata* in *Solanum tuberosum*; *Delia antiqua* on *Allium cepa*; and *Frankliniella occidentalis* on *Chrysanthemum indicum*.

Keywords

Push component • Pull component • Pheromones • Insect pests • Border crop • Main crop • Cash crop

12.1 Introduction

The novel "stimulo-deterrent diversion strategy" (also commonly called as "push-pull strategy") uses "push" intercrop and "pull" border crop, deployed in tandem, to manage crop pests by enhancing biological control agents. By using a repellent intercrop, the herbivores are pushed away from the main crop and pulled simultaneously by border plants to adjacent/border areas where they are collected and controlled. The feature of this strategy is that both the trap and the repellent plants are of economic importance.

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Fig. 12.1 Stem borer damage on maize

Pyke et al. (1987) from Australia first conceived this "push-pull" strategy to reduce reliance on insecticides for the management of bollworm *Helicoverpa* spp. in cotton to which the moths were becoming resistant. Miller and Cowles (1990) called this as "stimulo-deterrent diversion strategy" and utilized it for the management of maggot on *Allium cepa*.

"Push-pull" strategy is being widely adopted by economically backward growers for the successful management of stem borers on cereal crops and to increase crop production and productivity. As part of integrated pest management (IPM) strategies for the future, this strategy is likely to address the adverse effects of pesticides on the agroecosystem This technology is suitable for smallholder farmers for effectively solving the major pest problems of crop plants.

12.2 Management of Insect Pests

The "stimulo-deterrent diversion strategy" is adopted for the management of several insect pests in subsistence farming (*Chilo partellus* on *Zea mays* and *Sorghum vulgare*), in intensive arable agriculture (*Helicoverpa armigera* on *Gossypium* spp., *Sitona lineatus* on *Phaseolus vulgaris*, *Leptinotarsa decemlineata* in *Solanum tuberosum*, and *Meligethes aeneus* on *Brassica napus*), and in horticulture (lepidopteron pests of cabbage and cauliflower, fruit borer on tomato, *Delia antiqua* on *Allium cepa*, and *Frankliniella occidentalis* on *Chrysanthemum indicum*).

12.2.1 *Chilo partellus* on *Zea mays* and *Sorghum vulgare*

Chilo partellus (Fig. 12.1) is an important limiting factor in the production of maize and sorghum and cause 30–40% reduction in yield (Khan and Pickett 2004). This

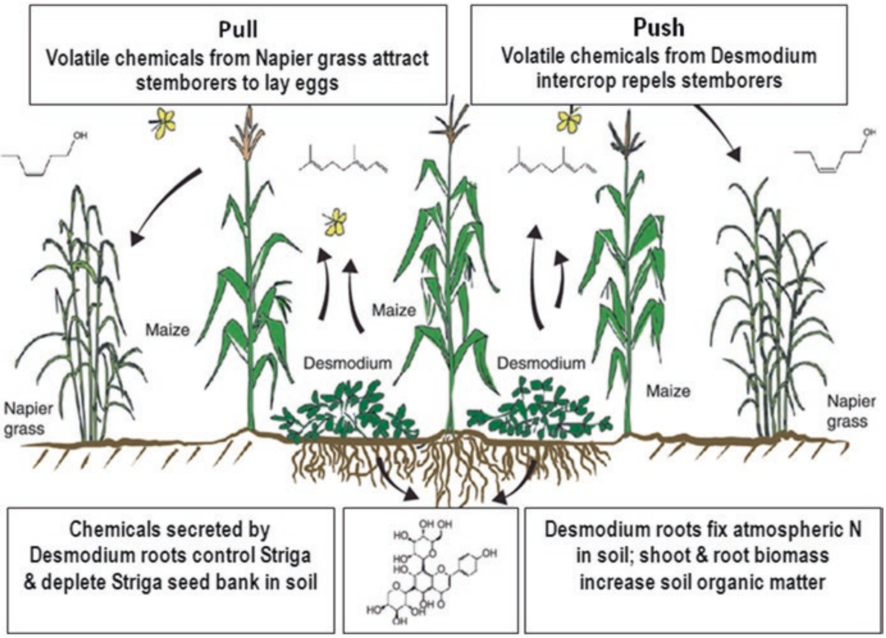


Fig. 12.2 Stimulo-deterrent diversion strategy for the management of stem borers

pest is difficult to control as the immature stages of the pest are present inside the stem of host crops. The chemical control of stem borers is not economical, since maize and sorghum are low-value crops cultivated by resource-poor, smallholder farmers. Hence, alternative pest management strategies involving low inputs have to be developed.

The "stimulo-deterrent diversion strategy" has been developed for the management of stem borers and parasitic weeds on corn and sorghum, using repellent intercrops (molasses grass, *Melinis minutiflora*; leguminous silver leaf Desmodium, *Desmodium uncinatum*; and green leaf Desmodium, *Desmodium intortum*) for driving the stem borers away ("push") and attractive trap crops (Napier grass, *Pennisetum purpureum*, and Sudan grass, *Sorghum vulgare sudanense*) in the crop border to attract female moths ("pull") to lay eggs (Figs. 12.2 and 12.3). The trap crop *Pennisetum purpureum* secretes gummy substance which restricts larval development, causing few to survive (Fig. 12.4) (Khan et al. 2006b). Besides controlling stem borers, molasses grass also increased stem borer parasitoid, *Cotesia sesamiae* (Fig. 12.5) (Khan et al. 1997).

12.2.1.1 Components of Stimulo-Deterrent Diversion Strategy

The components of stimulo-deterrent diversion strategy have been presented in Fig. 12.6. The volatile chemicals produced by molasses grass (push) and Napier grass (pull) are depicted in Fig. 12.7 (Khan et al. 2000, 2006a; Kimani et al. 2000).

Fig. 12.3 Molasses grass (*Melinis minutiflora*) intercropped with maize at 1:1 ratio and surrounded by trap crop Sudan grass (*Sorghum vulgare sudanense*) in push-pull strategy at Suba district (Kenya)

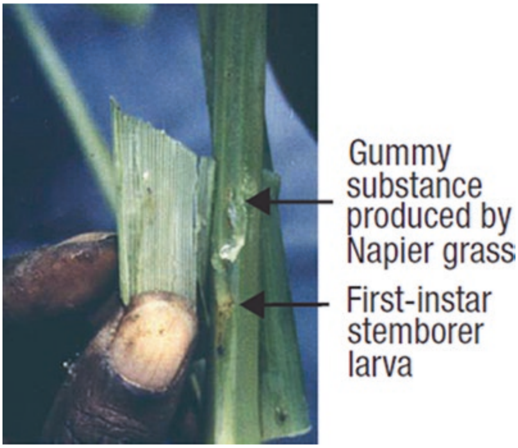


Fig. 12.4 Productions of gummy secretion by *Pennisetum purpureum*, which restricts larval development, causing few to survive

Leguminous Desmodium maintains and improves soil nutrition by the addition of organic biomass and fixing atmospheric nitrogen. All the three crops (main, inter, and border crops) are revenue earning and provide forage to farm animals. This technology increased maize and sorghum yield by threefold (Khan et al. 2011) and increased benefit: cost ratio (Khan et al. 1997).

12.2.2 Pests of Cabbage and Cauliflower

The major pest of cabbage and cauliflower are presented in Fig. 12.8.

Srinivasan and Krishna Moorthy (1991) developed the stimulo-deterrent diversion strategy by repelling lepidopteron pests from cabbage and cauliflower and concentrated them on Indian mustard border trap crop. In this technology, two rows of Indian mustard were planted at regular intervals (25 rows of crucifers) (Fig. 12.9). Neem products (neem seed kernel extract [NSKE]/neem seed extract/pulverized

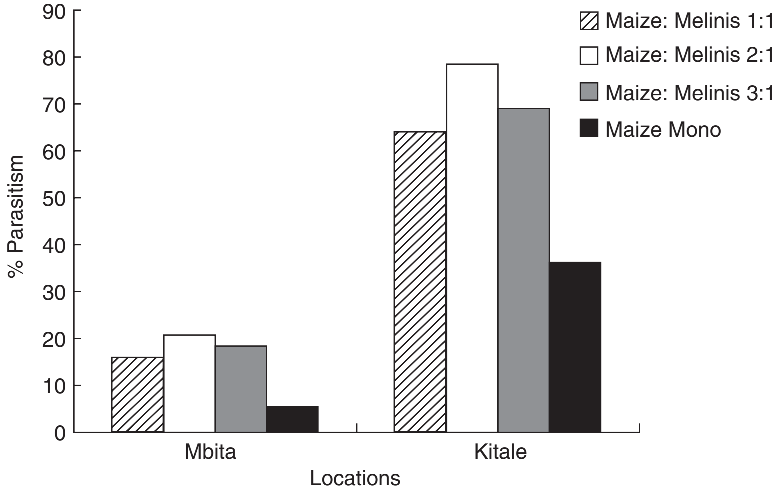
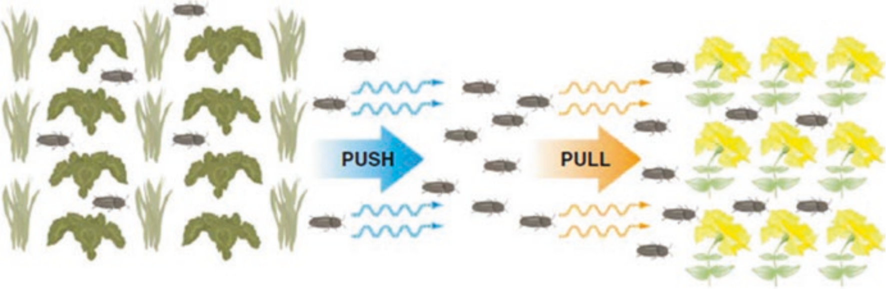


Fig. 12.5 Biological control of stem borer with parasitoid *Cotesia sesamiae* when corn is interplanted with molasses grass (*Melinis*)



- Visual distractions
- Non-host volatiles
- Anti-aggregation pheromones
- Alarm pheromones
- Oviposition deterrents
- Antifeedants

- Visual stimulants
- Host volatiles
- Aggregation pheromones
- Sex pheromones
- Oviposition stimulants
- Gustatory stimulants

Fig. 12.6 Components of stimulo-deterrent diversion strategy

neem seed extract) were sprayed at primordial formation to “push” colonizing lepidopteron pests away from cabbage/cauliflower and to concentrate these pests on Indian mustard border trap crop. The border trap crop mustard was sprayed with 0.1% dichlorvos to control lepidopteron insect pests that colonized it. This technology enhanced cabbage yields from 60 to 152% (Khaderkhan et al. 1998).

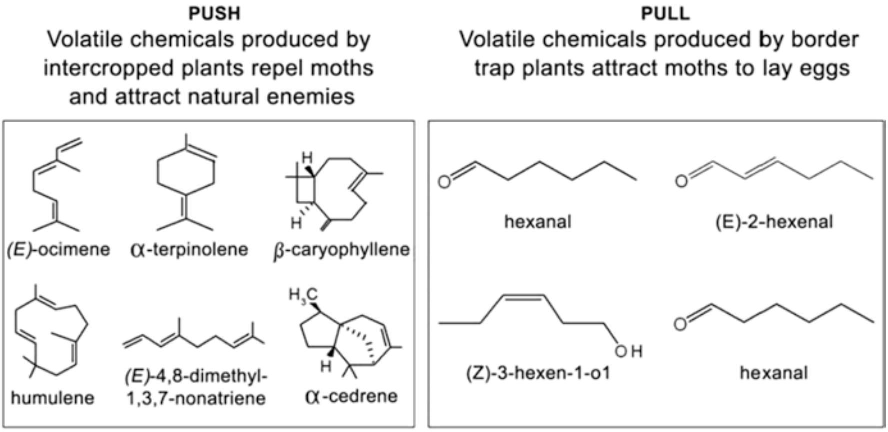


Fig. 12.7 Volatile chemicals produced by molasses grass (push) and Napier grass (pull)

Fig. 12.8 Cabbage and cauliflower pests (*Clock-wise*: diamondback moth, leaf webber, head borer, and aphids)

Fig. 12.9 Management of cabbage (*left*) and cauliflower (*right*) pests using push-pull strategy

Fig. 12.10 Fruit borer damage on tomato

Fig. 12.11 *Left* – Control of *Helicoverpa armigera* by push-pull strategy. *Center* – Fruit borer egg laid on the tight bud of marigold, *Right* – Tomato fruit borer trapped in marigold flower

12.2.3 Fruit Borer on Tomato

Fruit borer, *Helicoverpa armigera*, is a major problem on tomato (Fig. 12.10) and hard to control, since the larvae are present inside the fruit. It is responsible for 25–60% yield loss in different states like Karnataka, Punjab, and Tamil Nadu (Tewari and Krishna Murthy 1984; Singh and Singh 1975; Srinivasan 1958).

Srinivasan et al. (1994) developed the "stimulo-deterrent diversion strategy" using neem formulations to drive away fruit borer from tomato and to concentrate the pests on African marigold trap crop, which can be managed by spraying the insect pathogen *Ha*NPV. In this technology, marigold seedlings (45-day-old) are

Fig. 12.12 The bollworm damage on cotton leaves and boll

planted in a single row at regular intervals (after 16 rows of tomato) (Fig. 12.11) and 4% NSKE is applied to "push" colonizing fruit borers away from tomato and to concentrate the pests on African marigold trap border crop. The fruit borer lays eggs on the tight buds of marigold, and hatched larvae are trapped in marigold flowers (Fig. 12.11). Two sprays of *Ha*NPV on marigold managed *H. armigera* and significantly reduced damage to tomato fruits and enhanced production.

12.2.4 Cotton Boll Worms

The cotton bollworm *Helicoverpa armigera* (also called as tomato fruit borer, gram pod borer, and American bollworm) (Fig. 12.12) is one of the most important pests of cotton responsible for considerable losses. The pest has become resistant to chemical pesticides normally used for its management (Kranthi et al. 2004). Hence, there is a need to develop a novel and effective strategy using cultural methods, botanicals, and biological control agents.

Duraimurugan and Regupathy (2005) developed the "stimulo-deterrent diversion strategy" using neem formulations to drive away bollworms from *Gossypium* spp. to concentrate the pests on trap crops such as okra and pigeon pea, which can be managed by using biological control agent (*Ha*NPV). The cotton bollworm preferred to feed on okra and pigeon pea than on cotton. Spraying of cotton plants with 5% neem seed kernel extract (NSKE) repelled bollworms to pigeon pea. Application of HaNPV on okra and pigeon pea gave effective control of bollworms. This technology reduced bollworm damage by 61–72% and increased the kapas yield by 85–119% over control (Table 12.1).

Table 12.1 Stimulo-deterrent diversion strategy for the management of cotton bollworm at two locations

Treatments		Vaigaidam (summer 2003)		Bhavanisagar (summer 2003)	
Main crop (cotton)	Trap crop	% Boll damage (open boll basis)*	Kapas yield (t/ha)	% Boll damage (open boll basis)*	Kapas yield (t/ha)
NSKE	Okra – NPV	11.2 (19.5)^{a}	1.83^{a}	14.8 (22.5)^{a}	1.60^{a}
NSKE	Okra – Untreated	14.1 (22.0)^{b}	1.76^{a,b}	21.5 (27.5)^{c}	1.45^{a,b,c}
Untreated	Okra – NPV	29.1 (32.6)^{e,f}	1.43^{d,e,f}	28.0 (31.9)^{e}	1.23^{c,d,e}
Untreated	Okra – Untreated	29.7 (33.0)^{e,f}	1.38^{e,f}	33.1 (35.1)^{f}	1.10^{e}
NSKE	Pigeon pea – NPV	23.1 (28.7)^{c}	1.72^{a,b,c}	17.2 (24.4)^{b}	1.55^{a,b}
NSKE	Pigeon pea – untreated	24.4 (29.5)^{d,e}	1.58$^{b–e}$	22.1 (28.0)^{c,d}	1.50^{a,b}
Untreated	Pigeon pea – NPV	28.4 (32.2)^{d,e}	1.35^{f}	28.3 (32.1)^{e}	1.25^{c,d,e}
Untreated	Pigeon pea – untreated	30.9 (33.7)^{f}	1.28^{f,g}	29.1 (32.6)^{e}	1.20^{d,e}
NSKE + NPV	–	23.9 (9.2)^{c}	1.61$^{a–d}$	22.2 (28.1)^{c,d}	1.36$^{a–d}$
NSKE	–	26.9 (31.2)^{d}	1.56^{c,d,e}	23.7 (29.1)^{d}	1.35^{b,c}
NPV	–	36.9 (37.4)^{g}	1.12^{g,h}	35.2 (36.3)^{g}	0.90^{f}
Sole crop – untreated	–	40.0 (39.19)^{f}	0.99^{h}	38.0 (38.0)^{g}	0.73^{g}

Means in a column followed by the same letter(s) are not significantly different ($P = 0.05$) by DMRT

*Figures in parentheses are arcsine transformed values

12.2.5 Pea Leaf Weevil in Beans

Sitona lineatus is a major pest of peas and beans. The adults feed on the terminal (clam) leaf of seedlings (reduces leaf area), which can reduce plant stand density, and the juveniles feed on *Rhizobium* nodules (Fig. 12.13).

The "stimulo-deterrent diversion strategy" was developed to control pea leaf weevils using neem antifeedant (push) to repel the pest and border planting of winter peas as trap crops (pull) to attract the pest (Smart et al. 1994). The application of neem antifeedant was also found effective against the pest. Border trap crop (winter peas) can be treated with the aggregation pheromone to enhance the concentration of pest insects (semiochemically assisted trap crop). Instead of winter pea, clover can also be used as a trap crop against pea leaf weevils (Cook et al. 2007).

Fig. 12.13 Feeding damage of pea leaf weevils on leaves and nodules

Fig. 12.14 Colorado potato beetle damage on leaves

12.2.6 *Leptinotarsa decemlineata* on *Solanum tuberosum*

Leptinotarsa decemlineata (Fig. 12.14) is a major pest of potato. The "stimulo-deterrent diversion strategy" was developed to control Colorado potato beetle using neem-based antifeedant (push) to repel the pest and early perimeter planting of potato as trap crop (pull) to attract the pest as well as natural enemies (Martel et al. 2005b). Potato crop was planted early in the season and chemical attractant was sprayed at weekly intervals, which significantly attracted more adult beetles as well as natural enemies (Martel et al. 2005a; Dickens 1999; Dickens et al. 2002) where they can be treated with insecticides.

12.2.7 Pollen Beetle on Oilseed Rape

The pollen beetle (*Meligethes aeneus*) (Fig. 12.15) is a major pest of oilseed rape (*Brassica napus*). The "stimulo-deterrent diversion strategy" has been developed to manage the pest using turnip rape (*B. rapa*) as an attractive border trap crop (Fig. 12.16) (Potting et al. 2005). Turnip rape is a much preferred host to the pollen

Fig. 12.15 Feeding damage of *Meligethes aeneus* on *Brassica napus*

Fig. 12.16 Management of *Meligethes aeneus* on *Brassica napus* using turnip rape as perimeter trap crop

beetle than oilseed rape that considerably reduced pollen beetle on oilseed rape under field conditions. The factors responsible for the effectiveness of turnip rape to attract pollen beetle include growth stage-related olfactory and visual stimuli (high proportions of alkenyl glucosinolates) (Cook et al. 2006). The insecticides, parasitoids, or pathogens (*Metarhizium anisopliae*) are utilized to manage concentrated pests on turnip rape.

12.2.8 Onion Maggots

The onion maggot, *Delia antiqua* (Fig. 12.17), is an important pest of onion. A “stimulo-deterrent diversion strategy” has been formulated by spraying 50% cinnamaldehyde formulated in activated charcoal to repel the pest (push) and simultaneously providing deeply planted discarded onion bait traps to attract the pest for oviposition (pull) (Miller and Cowles 1990). Both the components were effective in reducing the oviposition considerably.

Fig. 12.17 Onion maggot damage on bulb

Fig. 12.18 Thrips damage on leaves and flower of chrysanthemum

12.2.9 Chrysanthemum Thrips

The production of greenhouse-grown chrysanthemums is severely affected by western flower thrips (*Frankliniella occidentalis*) that cause direct damage by feeding (Fig. 12.18) and indirect damage by the transmission of viruses and unacceptability of flowers in the market due to their presence.

A "stimulo-deterrent diversion strategy" has been developed to repel *Frankliniella occidentalis* from chrysanthemums by spraying the antifeedant botanical obtained from Dorrigo pepper on the main crop and concentrating them onto trap plants (chrysanthemum cultivar “Springtime” that is most attractive) (Bennison et al. 2001a). The concentrated pests are controlled by using biological control agents. The attractiveness of chrysanthemum cv. “Springtime” was increased by baiting with susceptible host volatiles like (E)-β-farnesene (Bennison et al. 2001a, b).

12.3 Benefits and Limitations

12.3.1 Benefits

Some of the common benefits of push-pull strategies are as follows (Fig. 12.19):

- Synergic effects due to integration of two or more push and pull components (Martel et al. 2005b).
- Antifeedants and oviposition deterrents are effectively utilized by adding pull stimuli (Raffa and Frazier 1988).
- Population reducing components’ efficiency is enhanced (Martel et al. 2005b).
- Chances of pests developing resistance to pesticides are reduced, since noninsecticidal components/reduced amounts of pesticides are used (Foster et al. 2005).

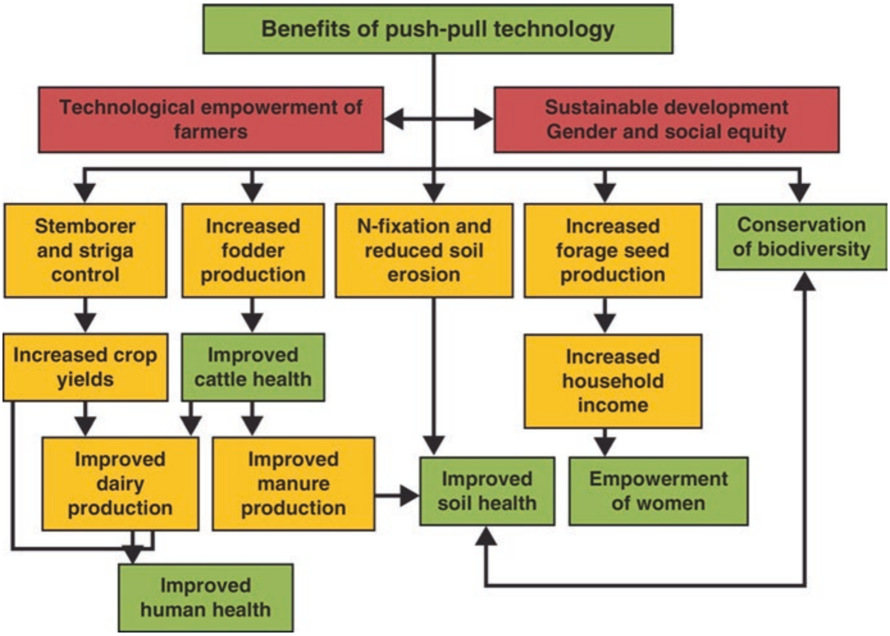


Fig. 12.19 Benefits of push-pull technology

- Overriding of the pest by deterrents and concomitantly avoiding severe deprival of pest to its host.
- Integrating the effects of “push” and “pull” multiplicatively.
- Pests are concentrated on trap crops which can be managed by releasing biocontrol agents.

12.3.2 Limitations

- Considerable research effort is required to develop the technology.
- Cost of semiochemical registration is very high.
- The adoption of push-pull strategies is very much limited.

12.4 Integration with Other Management Strategies

Since the components used in push-pull technology involve ecofriendly and benign alternatives, they can be directly incorporated into IPM strategies. Several eco-friendly components such as biopesticides, Bt toxin, and transgenic crops can be employed in developing more effective push-pull technologies. The dead-end trap crops, which attract pests but are unable to survive and multiply, can also be used in this strategy. In addition, the pest predators and parasitoids which are available commercially can be utilized in improving the push-pull technologies. In order to pull parasitoids from the surrounding areas into the crop field where they are required, HIPVs including (*Z*)-jasmone, sex pheromone component nepetalactone, and the lady beetle pheromones (tricosane and pentacosane) can be used, which attract the aphid parasitoids.

12.5 Conclusions

The “stimulo-deterrent diversion strategy” to control insect pests of limited crops has been developed using deterrent (push) and stimulant (pull) components. These methods should be integrated with sustainable and environmentally sensitive components to decrease insecticide inputs, which have negative externalities. Broad-spectrum insecticides should be replaced with innovative technologies, especially with semiochemicals. Improvement in input accessibility and effective transfer of technology are some of the crucial aspects for further upscaling of this technology. There is a need for developing improved “stimulo-deterrent diversion strategies” for the management of damaging herbivores affecting various crops which can be used more widely in the future.

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Cultural Approaches

13

Abstract

Cultural approaches have to be followed in order to get good crops and also for effective pest management. Adoption of these methods is the first and foremost step in organic farming for pest control. Commonly used cultural operations can be very effectively utilized to manage many crop pests. Many of these methods are general in nature and some are very specific for a particular pest. They generally target the weak points in the biology of pests and are also the cheapest among all control methods. Crop rotation (which is an important cultural approach) needs to be practiced invariably with legumes (like cowpea) and green manure crops (dhaincha, *Sesbania aculeata*, or sun hemp, *Crotalaria juncea*). Crop rotation improves soil health and reduces soil-borne disease pathogens and plant nematodes. Application of organic amendments to the soil also has to be done to get proper growth of plants and to enhance beneficial biological processes in the soil. Cultural approaches help in the sustainability of crop production as well as crop protection.

Keywords

Nutrient management • Cultural practices • Spacing and density • Water management • Habitat manipulation/diversity

13.1 Introduction

Pests (insects, mites, and nematodes) are the important limiting factors in crop production. They are responsible for significant crop losses to the extent of 26–40% of the attainable yield every year in major food and cash crops (Oerke 2006). The present modern agricultural systems are reliant on agrochemical inputs for pest management. There is a consumer demand for pesticide-free food products and a social concern for minimal use of harmful pesticides for pest management.

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Over-reliance on pesticides disrupts parasitoid and predator populations, causes outbreaks of secondary pests, exposes farmers to serious health risks, has negative consequences for the environment, causes development of pesticide resistance, leaves pesticide residues in food products, decreases effectiveness of many pesticides, adds to increased costs, and pollutes the air, soil, and water (Pimentel and Levitan 1986). Hence, there is an immediate need for alternative pest management strategies to overcome the above limitations, and to provide sustainable and eco-friendly production system. In this respect, several beneficial cultural practices can be utilized for pest management and to minimize the use of toxic chemicals.

13.2 Cultural Methods

In order to avoid pest injury to crops and to reduce pest populations, the deliberate alteration of either the cropping system itself or specific crop production practices can be adopted in the agro-ecosystem. They reduce pest establishment, growth and reproduction, dispersal, and survival by making the environment less attractive. Cultural practices are the modifications of standard horticultural and agricultural practices that changes pests' habitat or environment. These practices are also called as ecological pest management strategies. The main advantages of cultural control practices include low cost and being simple to adopt by the farmers. Prevention is better than cure is the ideology of the cultural practices. The main objective of cultural practices is to bring the pest populations below economic threshold levels.

Although cultural practices reduce pest damage to a considerable extent, they alone may not be able to provide effective pest control. Hence, they are good candidates that can be used as components in the integrated pest management.

13.2.1 Strategies

The strategies on which cultural control is based are as follows:

- Enhance biological control agents and alter the host, thereby reducing pest survival on the crop.
- Interfere with egg laying, making habitat unacceptable to pests.
- Manipulate environment to increase the population of natural enemies.
- Prevent multiplication of pests on crops.
- Reduce pest populations by creating adverse biotic conditions and modifying the crop environment.
- Utilize the weaknesses in pest biology so that the crop is not made available to the pest in space and time.

13.2.2 Benefits and Constraints

13.2.2.1 Benefits

- Compatibility with other pest management practices
- Cost-effectiveness
- Delayed development of resistance as compared to chemical control
- Do not need extra labor
- Less impact on the environment
- Makes the environment less favorable for pests
- Modifications of normal farming practices
- No detrimental side effects
- Preventive strategy rather than curative
- Suitable for low-value crops

13.2.2.2 Constraints

- Certain cultural control practices may cause soil erosion problems.
- Community-wide adoption is required.
- Partial pest control.
- Not effective on all pests.
- Long-term planning is required.
- May increase some pests, while suppressing others.
- Need careful timing.
- Slow acting and not useful for controlling pest outbreaks.

13.3 Cultural Management Practices

The key cultural practices used for pest management are as follows:

- Cropping systems
  - More spacing between the plants and rows
  - Inter cropping
  - Adjusting sowing and planting times
  - Sequential cropping
  - Cover cropping
  - Trap cropping
  - Nursery crops
  - Habitat management
- Maintenance of site
  - Reduced tillage
  - Nutrient management
  - Pruning, defoliation, and topping
  - Water management
  - Sanitation
  - Crop residue mulching

- Harvesting procedures
  - Timing of harvesting
  - Strip harvesting

13.3.1 Selection of Site

Selection of a proper site suitable for the crop and the habitat for biological control agents, but unsuitable for the pest is important to prevent pest infestation. Aspect, climate, elevation, microclimate, slope, soil conditions, weed species, etc. are some of the factors that should be considered while selecting a site. Stress on the crop should be avoided at any cost, since the stressed plants are susceptible to pest attack.

13.3.2 Cropping Systems

13.3.2.1 Crop Isolation

The likelihood of crops being affected by pests depends on their location. The probability of pest attack can be reduced by crop isolation. When climatic conditions are particularly not ideal, crop isolation is most appropriate for growing annual crops. For example, the carrot fly can be managed by crop isolation.

13.3.2.2 Planting Density and Spacing

Planting density and spacing affect pest population. The primary objective of the cultural method is to maximize production by effective pest management. Increased planting densities may be used to neutralize yield reduction due to pest damage. The pest population as well as damage can also be reduced by this method.

It is based on the following observations:

- High crop density also increases some pest populations.
- Low planting density attracts some insect pests (more aphids are attracted at low planting densities).
- Promotion of plant growth can be achieved by using proper plant spacing (maize stalk borer can be managed by this method).
- Early crop maturity is encouraged by plant spacing, resulting in the management of cotton boll weevils and pink bollworms.
- Crop receptivity to *Helicoverpa zea* is reduced by using narrow row spacing, which results in quicker closing of the plant canopy over the soil.
- The effectiveness of natural enemies for the pest management is enhanced with close spacing.

The crop density and disease development are directly correlated. In general, as the crop density increases, the disease incidence also increases. For example, the practice of crowding of seedlings in the nursery encourages soil-borne disease pathogens like *Cylindrocladium* and *Pythium* due to the following reasons:

- Splash dispersal of inoculum is easier due to closer physical contact of neighboring seedlings.
- Increase in relative humidity due to crowding of seedlings which encourages pathogen multiplication.
- The distance to travel by pathogens or their vectors from one host to the next is reduced.
- When the seedlings are close together, the transfer of inoculum from one plant to another is easy.
- Seedlings are prone to injury while carrying out cultural practices.

All these conditions favor the development of disease.

The corn earworm infestations can be reduced by using narrow row spacing, which helps in covering the exposed soil easily through crop canopy.

On the other hand, reduced disease incidence and increased yields result from dense stands. For example, the groundnut rosette virus is reduced by dense stands because the aphid vector is inhibited from landing. Hence, the disease incidence increases with weeding in this case.

Planting densities can be manipulated by varying sowing or planting rates and fertilization of crops. The increased planting densities may be used to neutralize yield loss due to disease pathogens.

13.3.2.3 Intercropping

For details on intercropping for pest management, see Chap. 8.

13.3.2.4 Timing of Seeding and Planting

The simple cultural practice of altering the time for planting can be utilized to manage pests. Susceptibility period of pest attack can be reduced by allowing the crop to mature before a pest becomes abundant.

French beans come up very well during June–January when the temperature is not high and the incidence of stem fly is very low. In summer, tomato leaf curl virus is very serious and fruit set is also very low due to high temperature. Hence, it will be better to avoid planting tomato in summer or it can be planted in such a way that fruiting should start before the temperature reaches more than 35 °C. Diamondback moth is a serious pest of cabbage and cauliflower during summer months. Hence, it is good practice to avoid these during summer months.

The Hessian fly (*Mayetiola destructor*) in the Midwest can be managed by delayed planting. Many times, early sown crops escape pest attack. Gherkin crop raised in January suffers less damage from fruit fly incidence. Vegetables grown during winter months do not have leaf miner and nematode damage. Fruit fly (melon fly) (*Bactrocera* spp.) infestation is very high during the rainy season. Hence, growing cucurbits like bitter gourd during the rainy season should be avoided as far as possible.

Early planting of potato during the third or fourth week of March in Shimla Hills would reduce the damage due to *M. incognita*. The lowest tuber infestation and lowest larval population in the soil at harvest gave maximum yields.

Crops may be planted in winter when soil temperatures are still low for the activation of nematodes. Both early potatoes and sugar beets grow in soils too cold for cyst nematode activity. By the time the soil warms sufficiently for the nematodes to become active, the plants are advanced in growth and eventually produce crop.

Shallow sowing of *Brassica rapa* at a depth of 1.5 cm enhanced rapid and higher germination of seedlings and reduced soil-borne disease pathogens like *Pythium aphanidermatum* and *Rhizoctonia solani* as compared to sowing at a depth of 3.0 cm (Nuttall 1982).

Due to their inherent characteristics, some early maturing crop varieties escape the onslaught of pathogens and resist their attack (e.g., early maturing varieties of pea and wheat escape damage due to powdery mildew, *Erysiphe polygoni*, and black stem rust, *Puccinia graminis tritici*, respectively).

By altering the time for planting and using early maturing crop varieties, the seedlings emerge from soil early and the crop matures faster than the time period when disease pressure is greatest due to the environment. Similarly, the cotton crop escapes from root rot by early planting in spring.

The wheat plants escape from streak mosaic virus by delayed planting. Likewise, the cotton plants escape from damping-off caused by *Pythium* spp. by late planting.

Time of planting is used largely to avoid oviposition period of particular pests, invasion by migrants, and/or disease transmission by insect vectors.

13.3.2.5 Crop Rotation

See Chap. 15.

13.3.2.6 Destruction of Volunteer Plants

Volunteer plants act as source of infection, since they are very attractive to many pests. They should be destroyed in order to prevent perpetuation of a pest to the next crop.

13.3.2.7 Management of Alternate Hosts

The weeds act as alternate hosts on which many insect pests such as aphids, beet leaf hopper, and raspberry cane borer reproduce during the absence of main host crops. Hence, the brambles should be destroyed to facilitate the management of insect pests. However, the nursery sites for the natural enemies of crop pests should not be destroyed as they encourage natural enemies.

13.3.2.8 Cover Crops

See Chap. 7.

13.3.2.9 Trap Crops

See Chap. 9.

13.3.2.10 Barrier Crops

Barrier crops have been used as a management practice since the 1950s for reducing the spread of nonpersistently transmitted aphid-borne viruses (Fereres 2000). The height of the barrier crop is important to camouflage the main crop and thus reduce the risk of virus transmission. But the competition between the barrier and the protected crop should be minimal. Barrier crop of maize can be used to reduce the incidence of insect pests like brinjal shoot and fruit borer if grown around the crop properly to suppress the visibility of the main crop.

13.3.2.11 Companion Plants

Growing friendly plant species (companion plants) together with the main crop enhances growth and flavor and protects the plants from pests. Companion plants assist in the growth by attracting beneficial insects, repelling pests, or providing nutrients, shade, or support to beneficials. For example, growing marigold reduces nematodes in many crops like banana, tomato, melons, etc. (Natarajan et al. 2006). Planting Borage (*Borago officinalis*) with squash*,* strawberry, or tomato reduces horn worm (*Manduca quinquemaculata*).

13.3.2.12 Management of Nursery Crops

Nursery crops are more attractive to the pests than the main cash crops. But they also help in the buildup of natural enemy population, which later disperse to the main commercial crop and provide effective biological pest control.

13.3.2.13 Habitat Management

See Chap. 11.

13.3.3 Maintenance of Site

13.3.3.1 Reduced Tillage

See Chap. 2.

13.3.3.2 Nutrient Management

See Chap. 5.

13.3.3.3 Pruning, Defoliation, and Topping

Overwintering stages of pest populations such as aphids and spiders, and their spread during the next year can be reduced considerably by destroying affected plant parts. For example, aphid infestations on apples and other fruit tree orchards can be managed by removing affected plant parts. However, excessive pruning may result in population increase of some pests such as aphids, leaf hoppers, and mites.

13.3.3.4 Water Management

The plants can be kept healthy, vigorous, and resistant to pest injury by proper irrigation. The infestations of two spotted spider mites (*Tetranychus urticae*) in tree fruits can be considerably reduced by overhead irrigation. Rice pests such as stem borers, gall midge, hispa, black bugs, and plant hoppers can be suppressed by alternate draining and flooding. Other rice pests like whorl maggots, root-feeding midges, water weevils, and caseworms can be controlled by draining the field for 1–2 days.

In order to retard the disease development and to reduce the level of inoculums, irrigation can be adopted. The incidence of apple scab is reduced by overhead sprinkler irrigation of dormant fruit trees by reducing or inactivating air-borne pathogen spores. The ascospores of scab pathogen which are short-lived cannot survive until sprouting of new growth. The germination of powdery mildew spores is encouraged by short daily watering, but penetration of the spores is prevented since plant surface dries quickly.

Rate of water application through drip or trickle irrigation in rhizosphere region is not sufficient to disperse plant pathogens. In addition, the drip irrigation provides islands of soil wetting areas rather than uniform wetting, which prevents the dispersal of soil-borne disease propagules.

On the other hand, the severity of Phytophthora root rot of *Carthamus tinctorius* (Dunniway 1977) and root rot of cotton (Ghaffar and Erwin 1969) is increased under water stress conditions, and the disease incidence is reduced by an adequate irrigation regime.

The soil-borne fungal pathogens causing southern blight and some wilt diseases are prevented by planting on raised beds, which improves soil drainage. This practice of planting on raised beds is also helpful in the management of soil-borne pathogens in vegetable crops and leguminous crops such as peanuts, soybeans, and cluster beans when grown in compact and poorly drained soils. Soil drainage can also be improved by the incorporation of organic matter (cover crop, compost, etc.) into the soil.

13.3.3.5 Crop Sanitation

The two main goals of crop sanitation include reduction and elimination of disease propagules (Palti 1981). Sanitation includes an array of cultural approaches such as destruction of infested plants and plant parts, staking of plants, destruction of alternate/collateral hosts, and field sanitation. Staking exposes the leaves to more sunshine and aeration, resulting in reduced incidence of insect pests like cucurbit borer, *Diaphania indica*. Destruction of infested plants and plant parts is a very important and most effective plant protection method for the control of leaf miner, *Liriomyza trifolii* in tomato, beans, and cucurbits. Periodical removal and destruction of infested fruits controls tomato fruit borer, *Helicoverpa armigera*; brinjal shoot and fruit borer, *Lucinodes ortbonalis*; and dolichos pod borer, *Adisura atkinsoni*.

The spread of destructive diseases such as bacterial wilt of cucurbits and viral diseases of stone fruits can be managed by the removal (rogueing) of diseased plants as they appear. Pruning of water sprouts, sucker growth, or foliage (during the dormant phase of the orchards) helps to manage aphids on apples.

Many pests are seed borne and found on the exterior or interior of seed. The seed-borne pests may be managed by using pest-free or certified seeds if possible.

Fig. 13.1 Staking of tomato plants to prevent leaves and fruits touching the soil to control Phytophthora fruit rot

Exterior seed-borne pathogens can be removed with disinfectants (bleach, hydrogen peroxide, and ethanol).

The selection of disease-free planting material forms a very important control measure, since many plants are vegetatively propagated. Some diseases such as black scurf of potato and red rot of sugarcane can be controlled by planting healthy planting stock in disease-free fields.

Some of the other sanitation practices followed for the pest management include:

- Destruction of cull piles in production fields
- Keeping leaves as dry as possible
- Planting on raised beds
- Preventing leaves and fruits from touching soil by staking (Fig. 13.1)
- Preventing water splashing
- Provision of good air circulation
- Removal or destruction of plant pathogens from farm equipment and tools
- Removing infected plant parts
- Use of clean stakes for trellising (wash soil and debris from stakes and disinfect with a 10% bleach solution)

13.3.3.6 Destruction of Crop Residues

Crop residues provide hiding habitats for herbivores, which are often prevented by clean cultivation. Apple and plum pests are reduced by collecting and destroying dropped fruits from beneath apple and prune trees, respectively.

13.3.3.7 Crop Residue Mulching

See Chap. 3.

13.3.4 Harvesting Procedures

13.3.4.1 Timing of Harvesting

Disrupting the survival of the pest in its habitat can be achieved by early harvesting or clipping the foliage. Bark beetle (Scolytidae) infestations in pine plantations can be managed by early harvesting of the timber stands.

13.3.4.2 Strip Harvesting

Strip harvesting system can be employed to manage Lygus bugs in alfalfa. As the older strips are harvested, the pest moves into the younger hay strips. There shall be no increase in the Lygus bug population, since the biological control agents of Lygus bugs shift from older strips to newer strips. The adult Lygus bugs deposit eggs when they move to the new half-grown hay strip, which is cut short to destroy eggs and released juveniles.

13.4 Conclusions

There is an increasing interest in cultural practices for pest management in order to reduce dependence on the use of pesticides. These practices improve the soil health and reduce pest incidence in a sustainable manner. Each and every cultural practice should be reevaluated and modified if necessary as a potential tool for pest management. These practices which are simple and less costly should also be used as components in Integrated Pest Management (IPM).

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Weed Manipulation

14

Abstract

Weeds are responsible for reduction in crop yields by exerting a direct biotic stress on crops by competing for sunlight, moisture, and some nutrients. Price et al. (Ann Rev Ecol 11:41–60, 1980) suggested that weeds have positive and/or negative effects on insect pests and also on their natural enemies, thereby affecting crop plants indirectly. The ecology of insect herbivores and associated natural enemies is affected by the manipulation of a specific weed species, through a particular weed control practice, or a cropping system (Norris RR, Interactions between weeds and other pests in the agroecosystem. In: Hatfield JL, Thomason IJ (eds) Biometeorology in integrated pest management. Academic, New York, pp 343–406, 1982; Andow D, Effect of agricultural diversity on insect populations. In: Lockeretz W (ed) Environmentally sound agriculture. Praeger, New York, pp 91–115, 1983). In addition, the weeds also have some positive effects such as providing habitat for beneficial organisms, recycling nutrients, or providing a means of induced resistance to pests, pathogens, and other weeds. A reasonable degree of weed management rather than total control is helpful in better exploitation of likely benefits. The dynamics of insect populations and crop health are affected by the multiple interactions among crops, weeds, herbivores, and natural enemies, and in particular, weed ecology and management.

Keywords

Weed management • Insect pests • Habitat management • Natural enemies • Crop health

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14.1 Introduction

Weed management is important before they compete with the crop for water, light, and nutrients and seriously affect crop yields. Weeds also act as alternate hosts for pests and diseases that attack the crop.

Certain weeds positively affect biology and dynamics of natural enemies of crop pests, since weeds are important components of agro-ecosystems. The positive effects of weeds include provision of alternative prey/hosts, pollen, or nectar, as well as microhabitats which are important requisites for natural enemies that are not available in weed-free monocultures (Van Emden 1965). They also provide resources (alternate host or pollen/nectar) to predators and parasitoids of insect pests of annual crops.

The damage due to weeds can be considerably reduced by delaying weed emergence relative to crop emergence during the growing season, as weeds that emerge earlier in the growing season (the first one-third of their life cycle) are more damaging to crop yields than the populations that emerge later. Hence, weed management is important, as opposed to weed control.

14.2 Weeds as Sources of Insect Pests in Agro-Ecosystems

Weeds are the most important biological factors which pose a major threat to sustainable agricultural systems and reduce crop yields due to their consumption of resources that would otherwise be available to the crop (Gallandt and Weiner 2007). They also act as alternate hosts to more than 70 families of insect pests and pathogens in agro-ecosystems (Bendixen and Horn 1981). Locally abundant weeds belonging to the same family as the affected crop plants are responsible for many pest outbreaks. The weeds unrelated to the crop may also be reservoirs of polyphagous pests, as *Aphis gossypii* feeds on over 20 unrelated weed species in and around cotton fields. Thresh (1981) reviewed the role of weeds in the epidemiology of insect pests and plant diseases, especially the virus diseases (beet curly top) transmitted from weeds to adjacent crop plants by insect vectors (leaf hopper, *Circulifer tenellus*).

Pest outbreaks occur when weeds are present near the crops. The most important factor determining high levels of carrot fly larval damage to carrots is due to the presence of the weed *Urtica dioica* surrounding carrot fields (Wainhouse and Coaker 1981). McClure (1982) found that adult leaf hoppers from edge vegetation invade peach orchards and subsequently colonize preferred wild hosts under tree groundcover. The rosy apple aphid *Dysaphis plantaginea* which gets alternative food from the weed plantains (*Plantago* spp.) survives most of the summer on plantains, returning to apples in late summer. Similarly, Altieri and Letourneau (1982) reported that the dock sawfly (*Ametrastegia glabrata*) normally feeds on weeds such as docks (*Rumex* spp.) and knotgrass (*Polygonum* spp.), and the last generation larvae move on to adjacent apple trees and bore into fruits or shoot tips.

Certain grasses such as *Bromus* spp., *Festuca* spp., and *Lolium multiflorum* (*italicum*) act as hosts for insect pests like *Sitobium avenae* and *Rhopalosiphum padi* which transmit the barley yellow dwarf virus (BYDV). Similarly, *Agropyron repens* and various *Festuca* and *Poa* spp. (also acting as hosts for wheat bulk fly) which are highly susceptible to fruit fly favor the buildup of saddle gall midge on *Lolium multiflorum* (Burn 1987). Likewise, the grass weeds in corn fields increase the attractiveness to the second flight of the European corn borer (*Ostrinia nubilalis*). Hence, these grass species should be excluded from under sowings of crops.

The agro-ecological approaches such as exploitation of crops' competitive ability, or high levels of adaptation to cultivation timing/methods, herbicide use, and crop life cycles should be explored to suppress weeds. Jordan (1993) suggested that a combination of weed suppression (to reduce weed numbers) and weed tolerance (to maintain yield stability in environments where weed competition is unavoidable) is the most effective strategy for weed control. Some other opportunities to manage weed communities include intercropping, making use of under sowings, rotation design (including alternating spring and winter sown crops), and varying cultivation practices and techniques.

14.3 Role of Weeds in Ecology of Natural Enemies

The biology and dynamics of natural enemies of crop pests is positively affected by certain weeds which are important components of agro-ecosystems. Van Emden (1965) reported that weeds provide alternative prey/hosts, pollen, or nectar, as well as microhabitats which are important requisites for natural enemies that are not available in weed-free monocultures. The predators and parasitoids of insect pests of annual crops survive on resources (alternate host or pollen/nectar) which are usually provided by weeds.

Weeds are habitats for about 65% of the phytophagous insect species, and the composition of the remaining arthropods varies greatly among predators and parasitoids (Nentwig 1998). Most parasitoids belong to Hymenoptera families such as Aphidiidae, Braconidae, and Ichneumonidae, and also Proctotrupidae and Chalcidoidea, which survive on Asteraceae and Brassicaceae weeds reaching population levels of 5–30 individuals per square meter of vegetation. The dominant predators include Empididae flies, Coleoptera (Cocinellidae, Carabidae, Staphilinidae, and Cantharidae), and chrysopid green lacewings survive on borage, blue knapweed, and *Papaver rhoeas* reaching population levels of up to 70 predators/m^2 (Zandstra and Motooka 1978).

There is a need to select plants which provide nonprey food to the beneficials without providing resources to pest insects. For example, lacy phacelia (*Phacelia tanacetifolia*) and Nasturtium (*Tropaeolum majus*) provide resources for natural enemies without enhancing moth pests (Baggen et al.1999).

The common knotweed attracts natural enemies such as big-eyed bugs, hoverflies, parasitic wasps, and soft-winged flower beetles.

14.3.1 Importance of Flowering Weeds

In order to ensure effective reproduction and longevity, the adult hymenopteran parasitoids require food in the form of pollen and nectar. The nectar requirement of female Ichneumonid parasitoids (*Diadegma insulare*) of the diamondback moth is provided by the wildflowers such as *Brassica kaber*, *Barbarea vulgaris*, and *Daucus carota* (Idris and Grafius 1995). Wildflower corolla's opening diameter and flower shading provided to the parasitoid by the plant facilitate enhanced fecundity and longevity of the wasp. *Phacelia tanacetifolia* has been used as a pollen source to enhance syrphid fly populations in cereal fields in the United Kingdom because of its long flowering period over the summer (Wratten and Van Emden 1995).

Some Ichneumonid parasitoids, such as *Mesochorus* spp., should feed on nectar for egg maturation (Van Emden 1965), while three Ichneumonid species require carbohydrates from the nectar of certain Unbelliferae for normal fecundity and longevity (Leius 1967). The wasp parasitoids *Exeristes comstockii* and *Hyssopus thymus* of the European pine shoot moth, *Rhyacionia buoliana,* significantly increased in the presence of several flowering weeds (Syme 1975). *Euphorbia hirta* was reported as an important nectar source for the sugarcane weevil parasitoid, *Lixophaga sphenophori,* in Hawaii (Topham and Beardsley 1975). The alfalfa caterpillar *(Colias eurytheme)* parasitic wasp, *Apanteles medicaginis*, lived longer and exhibited a higher fecundity by feeding on several weeds species (*Convolvulus, Helianthus,* and *Polygonum*) in San Joaquin Valley, California. Likewise, Zandstra and Motooka (1978) found that the European pine shoot moth parasitoid, *Orgilus obscurator*, and the mole cricket parasitoid, *Larra americana*, were dependent on wildflowers for feeding.

The annual crops and orchards with rich undergrowths of wildflowers showed significant increase in parasitism of insect pests. Apple orchards with floral undergrowths showed 18 times greater parasitism of tent caterpillar eggs and larvae and codling moth larvae as compared to orchards with sparse floral undergrowth (Leius 1967). Telenga (1958) reported that the effectiveness of the San Jose scale *(Quadraspidiotus perniciosus)* parasitoid, *Aphytis proclia,* improved to 75% as a result of three successive planting of *Phacelia* sp. cover crop (nectar producing) as compared to 5% in clean cultivated orchards in Russia. The cabbageworm (*Pieris* spp.) parasitoid, *Apanteles glomeratus*, feeding on nectar from wild mustard flowers lived longer and laid more eggs and increased parasitization from 10 to 60% (Telenga 1958).

The rates of parasitization of *Heliothis zea* eggs by *Trichogramma* sp. were greater due to the emission of kairomones, when the eggs were placed on soybean next to corn (58.0% parasitization) and the weeds *Desmodium* sp. (71.0% parasitization), *Cassia* sp. (60.4%), and *Croton* sp. (66.6%) than on soybean grown alone (30.4%) (Altieri et al. 1981).

Van Emden (1965) found that the insect predators also depend on weed flowers for their food sources. Pollen is reported to be a significant food source for many predaceous Coccinellidae, since pollen appears to be instrumental in egg production in many syrphid flies. The sugar requirement of lacewings is fulfilled by several flowers from Compositae family which supply nectar (Hagen 1986).

14.4 Insect Dynamics in Weed-Diversified Crop Systems

The diversity of weeds is likely to prevent outbreaks of certain types of crop pests as compared to weed-free fields, in view of increased mortality of pests imposed by natural enemies (Root 1973; Altieri et al. 1977). More numbers of predators were observed in crop fields with a dense weed cover and high diversity than weed-free fields (Root 1973; Perrin 1975; Speight and Lawton 1976). The presence of weeds that provided nectar for the adult female wasps is essential for the successful establishment of several parasitoids. Altieri and Letourneau (1982) have presented the relevant examples of cropping systems in which the presence of specific weeds has enhanced the biological control of particular pests in Table 14.1. Weedy crops rather than weed-free crops reduced the population densities of 27 insect species (Baliddawa 1985). The population densities of mite *Eotetranychus willamette* were found to be relatively lower in grape vines with weeds than in weed-free orchards (Flaherty 1969).

The main factors responsible for regulating pest population in the weed-diversified crops include parasitoids and predators, camouflage and masking, and reduced colonization. Pest regulation by natural enemies (parasitoids and predators) alone accounted for 56% of the cases. The mechanisms by which significant reduction in pest population brought about by the weedy component in agricultural systems include:

- Plant dispersion and diversity which alter herbivore movement or searching behavior, thereby affecting herbivore density (Risch 1981; Kareiva 1983).
- Presence of alternative resources and microhabitats in weedy crops that reach greater abundance and diversity levels to support natural enemies which impose greater mortality on pests (Root 1973; Letourneau and Altieri 1983).

Grass weeds such as *Eleusine indica* and *Leptochloa filiformis* in bean plots significantly reduced leaf hopper, *Empoasca kraemeri* and *Diabrotica balteata* (fell by 14%) populations. The populations of adults and nymphs of *E. kraemeri* fell drastically when 1-m-wide grass weed borders surrounded bean monocultures (Fig. 14.1). The reduction in leaf hopper population was significantly more with pure stands of *L. filiformis* than with those of *E. indica* (Schoonhoven et al. 1981).

Corn plots containing natural weed complexes or selected weed associations had consistently lower incidence of fall armyworm, *Spodoptera frugiperda* than in weed-free plantings. Similarly, Puvuk and Stinner (1992) reported that parasitism of second generation *Ostrinia nubilalis* larvae by the Ichneumonid parasitoid; *Eriborus terebrans* was greater in treatments with weeds than in weed-free plantings. Likewise, the aphid population in winter barley plots with grassy weeds was lower,

Table 14.1 Effect of weed–crop diversity on pest management in different agro-ecosystems

Agro-ecosystem	Pest	Factor (suggested or proved)	Reference
Apple trees grown with *Phacelia* sp. and *Eryngium* sp.	San Jose scale, *Quadraspidiotus perniciosus* and various species of aphids	Greater abundance and activity of the parasitoids, *Aphelinus mali* and *Aphytis proclia*	Telenga (1958) quoted by Altieri and Letourneau (1982)
Apple plants with weeds	Tent caterpillar, *Malacasoma americanum,* and codling moth, *Cydia pomonella*	Increased activity and abundance of parasitic wasps, *Aphelinus mali* and *Aphytis proclia*	Lewis (1965)
Citrus with *Hedera helix*	*Lachnosterna* spp.	Enhancement of *Aphytis lingnanensis*	–
Citrus with natural weed complex	Mites, *Eotetranychus* sp., *Panonychus citri, Metatetranychus citri,* Diaspidid scales	Unknown	–
Grape vines with Johnson grass, *Sorghum halepense*	Pacific mite, *Eotetranychus williamettei*	Buildup of predaceous mites, *Metaseiulus occidentalis*	Flaherty (1969)
Vineyards with wild blackberry, *Rubus* sp.	Grape leaf hopper, *Erythroneura elegantula*	More alternate hosts for the parasitic wasp, *Anagrus epos*	Doutt and Nakata (1973)
Peach and ragweed, *Ambrosia* sp.; smart weed, *Polygonum* sp. and lambs quarter, *Chenopodium album*; golden rod, *Solidago* sp.	Oriental fruit moth, *Grapholitha molesta*	Provision of alternate hosts for the parasitoid, *Macrocentrus ancylivorus*	Bobb (1939)
Peach and ragweed	Oriental fruit moth	Provision of alternate hosts for the parasitoid, *Macrocentrus ancyclivorus*	–
Peach and rosaceous weeds and *Dactylis glomerata*	Leaf hoppers, *Paraphelepsius* sp., and *Scaphytopius actus*	Unknown	–
Vegetables grown among wild carrot (*Dacus carota*)	Japanese beetle, *Popillia japonica*	Greater activity of the parasitic wasp, *Tiphia popilliavora*	King and Holloway quoted by Altieri and Letourneau (1982)

(continued)

Table 14.1 (continued)

Agro-ecosystem	Pest	Factor (suggested or proved)	Reference
Collards, *Brassica oleracea*, and other brassicas grown among weeds	*Pyllotreta striolata, Myzus persiscae, Brevicoryne brassicae, Pieris rapae*	Camouflage	Pimentel (1961)
Collards and ragweed, *Ambrosia artemislifolia*	Flea beetle, *Phyllotreta cruciferae*	Chemical repellency and masking	Tahvanainen and Root (1972)
Collards grown among weeds, mainly *Amaranthus retroflexus, Chenopodium album,* and *Xanthium stramonium*	Green peach aphid, *Myzus persicae*	Greater abundance of predators, *Chrysoperla carnea*	Horn (1981)
Cruciferous crops with quick flowering mustards	Cabbage worm, *Pieris* sp.	Increased activity of the parasitoid, *Apanteles glomeratus*	National Academy of Sciences (1969)
Cabbage with white and red clover	*Erioischia brassicae, B. brassicae*	Less colonization and greater predator population of *Harpalus rufipes, Phalangium* sp.	Dempster and Coaker (1974)
Cabbage with *Crataegus* sp.	Diamondback moth, *Plutella maculipennis*	Provision of alternate hosts for parasitic wasps, *Horogenes* sp.	–
Broccoli with wild mustard	*Phyllotreta cruciferae*	Trap cropping	–
Brussels sprouts with weeds (hoed or cut back to 15 cm)	*Myzus persicae, Brevicoryne brassicae, Aleyrodes brassicae, Pieris rapae*	Camouflage	Smith (1976)
Brussels sprouts grown among natural weeds complex	*P. rapae, B. brassicae*	Camouflage and more predation	Smith (1976)
Brussels sprouts grown with *Spergula arvensis* weeds	*M. brassicae, E. forficalis, B. brassicae*	Lower colonization and greater predator population	Theunissen and den Ouden (1980)
Brussels sprouts under sown with white clover	*E. brassicae, B. brassicae, P. rapae*	Camouflage and greater predation	Dempster and Coaker (1974)
Beans with goose grass, *Eleusine indica* and red spragletop, *Leptochloa filiformis*	Leaf hopper, *Empoasca kraemeri*	Chemical repellency or masking	Tahvanainen and Root (1972)

(continued)

Table 14.1 (continued)

Agro-ecosystem	Pest	Factor (suggested or proved)	Reference
Beans growing among weeds or surrounded by weedy borders	*E. kraemeri, Diabrotica balteata*	Unknown	Altieri et al. (1977)
Coffee with natural weed complex	Pentatomid, *Antestiopsis intricata*	Unknown	–
Oil palm with *Pueraria* sp., *Flemingia* sp., ferns, grasses, and creepers	Scarab beetles, *Oryctes rhinoceros* and *Chalcosoma atlas*	Unknown	–
Sorghum with *Helianthus* spp.	*Schizaphis graminum*	Enhancement of parasitoids, *Aphelinus* spp.	–
Sweet potatoes with morning glory, *Ipomoea asarifolia*	Argus tortoise beetle, *Chelymorpha cassidea*	Provision of alternate hosts for the parasitoid, *Emersonella* sp.	–
Green gram grown among natural weed complex	Bean fly, *O. phaseoli*	Less colonization	Litsinger and Moody (1976)
Green gram grown among weeds	Bean fly, *O. phaseoli*	Camouflage	Altieri and Whitcomb (1979b)
Soybean grown with *Cassia obtusifolia*	The green stinkbug *N. viridula*, and velvet bean caterpillar *Anticarsia gemmatalis*	Greater abundance of predators	–
Soybean with broadleaf weeds and grasses	*Epilachana varivestis*	Enhancement of predators	–
Soybean with *Crotalaria usaramoensis*	*Nezara viridula*	Enhancement of tachnid, *Trichopoda* sp.	–
Corn grown with giant ragweed	European corn borer, *Ostrinia nubilalis*	Alternate hosts for the tachinid parasite, *Lydella grisesens*	Syme (1975)
Corn grown with natural weed complex	*Heliothis zea*, *Spodoptera frugiperda*	Enhancement of predators	–
Corn grown with *Setaria viridis* and *S. faberi*	*Diabrotica virgifera* and *D. barberi*	Unknown	–
Cotton and cowpea strip planted with weeds	Boll weevil, *Anthonomus grandis*	Greater parasitic wasp, *Eurytoma* sp. population	Pierce (1912) quoted in Marcovitch (1935)
Cotton grown with ragweed, *Ambrosia* sp.	Boll weevil, *Anthonomus grandis*	Provision of alternate hosts for the parasitoid, *Eurytoma tylodermis*	van den Bosch and Telford (1964)

(continued)

Table 14.1 (continued)

Agro-ecosystem	Pest	Factor (suggested or proved)	Reference
Cotton and ragweed plus *Rumex crispus*	Boll worm, *Heliothis* sp.	Greater predator population	Smith and Reynolds (1972)
Cotton and *Salvia coccinea*	*Lygus vosseleri*	Unknown	–
Sugarcane with *Borreria verticillata* and *Hyptis atrorubens*	Cricket, *Scapteriscus vicinus*	Provision of nectar and pollen source for the parasite, *Larra americana*	Wolcott (1942) quoted by Altieri and Letourneau (1982)
Sugarcane with *Euphorbia* spp. weeds	Sugarcane weevil, *Rhabdoscelus obscurus*	Provision of nectar and pollen for the parasitoid, *Lixophaga sphenophori*	Topham and Beardsley (1975)
Sugarcane with grassy weeds	Aphid, *Rhopalosiphum maidis*	Destruction of alternate host plants	–
Sugarcane with *Borreria verticillata* and *Hyptis atrorubens*	Cricket, *Scapteriscus vicinus*	Provision of nectar for the parasitoid, *Larra americana*	–
Alfalfa with natural blooming weed complex	Alfalfa caterpillar, *Colias eurytheme*	Increased activity of *Apenteles medicaginis*	van den Bosch and Telford (1964)

Baliddawa (1985), Altieri and Letourneau (1982) and Andow (1991)

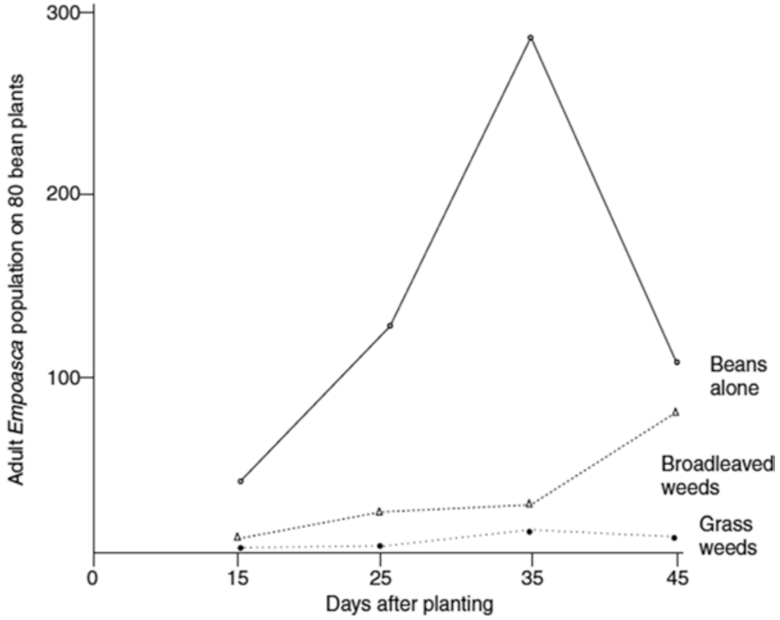

Fig. 14.1 Effect of grass weed borders around 16 square meter bean plots on the population of adult *Empoasca kraemeri* (After Altieri et al. 1977)

while the number of predatory staphylinid beetles was ten times higher than the plots without weeds (Burn 1987).

Barney et al. (1984) observed greater foliage–predator complex (carabid, *Harpalus pennsylvanicus* and foliage predators, i.e., *Orius insidiosus* and Nabidae) in spring-planted alfalfa plots infested with weeds than in weed-free plots (Barney et al. 1984). Likewise, the natural enemy action against aphids was enhanced by the presence of weeds in Brussels sprouts due to the provision of oviposition sites for predators (Smith 1969). Similarly, Theunissen and den Ouden (1980) reported that the pest populations of *Mamestra brassicae, Evergestis forficalis,* cabbage root fly, and *Brevicoryne brassicae* were drastically reduced in Brussels sprouts plots by selectively allowing a cover of *Spergula arvensis*.

The weed species which are not related to crop species can provide effective means of reducing insect herbivores by preventing the plant competition. The specialist herbivore population (cabbage worm, *Pieris rapae*, and diamondback larvae, *Plutella xylostella*) was lower in collards with non-Brassicaceae weed polyculture due to the presence of carabid and staphylinid predators than in collards with the Brassicaceae weed polyculture and in collard monoculture (Schellhorn and Sork 1997).

14.5 Manipulation of Crop–Weed Management

Even though there is a clear evidence that encouragement of specific weeds in crop fields may improve the regulation of certain insect herbivores (Altieri and Whitcomb 1979a), weed competition with crops and interference with certain cultural practices need to be prevented by careful manipulation strategies. Further, Bantilan et al. (1974) suggested that the factors affecting crop–weed balance within a crop season, as well as economic thresholds of weed populations, should be defined.

Insect herbivore regulation without economically affecting crop yields can be achieved by shifting the crop–weed balance, carefully using herbicides, or selecting cultural practices that favor the crop cover over weeds. This can be achieved by the following practices:

- Designing competitive crop mixtures
- Following close row spacing
- Keeping the crop weed-free during the first one-third of their growth cycle
- Managing soil fertility
- Planting cover crops
- Practicing cultivation regimes
- Providing mulches
- Allowing weed growth only in alternate rows or in field margins

Besides reducing competitive weed interference, it is desirable to change in the species composition of weed communities to ensure the presence of plants that attract natural enemies of insect herbivores. Changing levels of key chemical constituents in the soil, direct sowing of weed seeds, and use of herbicides that suppress certain weeds while encouraging others are some of the means by which the manipulation of weed species can be achieved (Altieri and Whitcomb 1979b; Altieri and Letourneau 1982).

14.5.1 Soil Management Practices

Manipulation of soil fertility in fields can indirectly affect the local weed complex. The weeds such as buckhorn plantain *(Plantago lanceolata)* and curly dock *(Rumex crispus)* predominate in soils with low soil potassium, while showy crotalaria *(Crotalaria spectabilis),* morning glory *(Ipomoea purpurea),* sicklepod *(Cassia obtusifolia), Geranium carolinianum,* and coffee senna *(Cassia occidentalis)* dominate in soils with low soil phosphorus (Hoveland et al. 1976).

Growth of certain weeds can be influenced by soil pH. For instance, alkaline soil encourages weeds of the genus *Cressa*; acidic soil enhances *Pteridium* sp., and saline soil favors weeds belonging to other species (many Compositae and Polygonaceae) (National Academy of Sciences 1969). The soil processes related to soil–weed dynamics such as tillage, crop rotation, and use of cover crops and green manures are some of the other major soil management practices that affect weeds. These practices combined in a cropping system are responsible for:

- Abundance of safe sites and decrease in the filling of available sites
- Lessened crop yield loss per individual weed (Liebman and Gallandt 1997)
- Persistence of weed seeds in the soil reduced

14.5.2 Herbicides

Some herbicides kill certain weeds while encouraging the growth of other weeds. For example, jimson weed *(Datura stramonium),* prickly sida *(Sida spinosa),* velvetleaf *(Abutilon theophrasti),* and venice mallow *(Hibiscus trionum)* can be grown among cotton and soybean without the presence of other unwanted weed species, when trifluralin is applied at 0.6 kg/ha before sowing (Buchanan 1977). In order to achieve early increases of natural enemy populations, similar methods can be developed to favor particular beneficial weeds.

14.5.3 Direct Sowing

The colonization and reproductive efficiency of the leaf hopper *Empoasca kraemeri* decreased by direct sowing of the grasses *Eleusine indica* and *Leptochloa filiformis* to form a one-meter border around bean fields in Colombia (Altieri and Whitcomb 1979a). The habitats for natural enemies can be created by using flowering weed–seed mixtures in the market that are recommended for planting in and around crop fields.

14.5.4 Spatial Patterns of Weeds

In order to promote weeds to occur in clumps within fields rather than being uniformly distributed, weed spatial distributions can be encouraged. Liebman and Gallandt (1997) found that the crop loss caused by clumped weeds are likely to be less damaging to crop yield than that caused by evenly or randomly distributed weeds. Even though the clumped weeds may reduce yields in a field spot, they also provide a source of natural enemies that colonize the rest of the fields from the clump.

14.5.5 Manipulation of Weed's Critical Competition Period

By delaying weed emergence relative to crop emergence during the growing season, the damage due to weeds can be considerably reduced; since weeds that emerge earlier in the growing season (the first one-third of their life cycle) are more damaging to crop yields than the populations that emerge later (Liebman and Gallandt 1997). Zimdahl (1980) has compiled data on the duration of weed competition data for certain crops, and identified the critical weed-free maintenance periods for various crop–weed associations.

Lower flea beetle *(Phyllotreta cruciferae)* densities were observed in the weedy monocultures than in the weed-free monocultures by allowing weed growth during selected periods of the collard crop cycle (2 or 4 weeks weed-free or weedy all season). Weedy-all-season systems resulted in the occurrence of the lowest weed densities. The reduction in flea beetle feeding and damage can be achieved by growing collards under various levels of weed *Brassica campestris*. *Brassica campestris* (the dominant plant of the weed community) which germinated quickly and flowered early that supported the flea beetle densities at least five times greater on a per-plant basis than on collards (Altieri and Gliessman 1983). Kloen and Altieri (1990) reported that sowing of wild mustard 1 week after broccoli transplanting showed reduced aphid numbers while increasing effective predation by syrphid larvae without reducing the yield.

14.5.6 Under Sowing of Weeds

A significantly lower incidence of insect pests was observed in orchards with rich floral weed undergrowth, mainly because of an increased abundance and efficiency of predators and parasitoids, than in clean cultivated orchards (Smith et al. 1996). The presence of goldenrod (*Solidago* sp.), lamb's quarter (*Chenopodium album*), ragweed (*Ambrosia* sp.), and smartweed (*Polygonum* sp.), which provided alternate hosts for the parasitoid, *Macrocentrus ancylivorus*, provided effective management of the oriental fruit moth in peach orchards (Bobb 1939). Likewise, the parasitism of tent caterpillar eggs and pupae in apple orchards increased four-fold and 18-fold, respectively, while parasitism of codling moth larvae increased five-fold by the presence of wild flowers over nonweedy orchards (Leius 1967).

Table 14.2 Composition of the seed mixture for wildflower strips

Annual species	Biennial species	Perennial species
Agrostemma githago	*Cichorium intybus*	*Achillea millefolium*
Anchusa arvensis	*Daucus carota*	*Anthemis tinctoria*
Buglossoides arvense	*Dipsacus fullonum*	*Centaurea jacea*
Camelina sativa	*Echium vulgare*	*Leucanthemum vulgare*
	Malva sylvestris	*Hypericum perforatum*
Centaurea cyanus	*Melilotus albus*	*Malva moschata*
Consolida regalis	*Pastinaca sativa*	*Onobrychis viciifolia*
	Reseda lutea	*Origanum vulgare*
Fagopyrum esculentum	*Silene alba*	*Tanacetum vulgare*
Legousia speculum-veneris	*Tragogpogon orientalis*	
	Verbascum densiflorum	
Misopates orontium	*Verbascum lychnitis*	
Nigella arvensis		
Papaver dubium		
Papaver rhoeas		
Silene noctiflora		
Stachys annua		
Vaccaria hispanica		
Valerianella rimosa		

14.5.7 Weed Strip Highways for Habitat

The biological pest control can be enhanced by planting wildflower strips with a mixture of different annual, biennial, and perennial plant species by providing various environmental requisites for natural enemies: supplementary foods (alternate host or prey, or in some cases pollen); complementary foods (nectar, pollen, honeydew); modified microclimate (after agricultural practices); and shelter (wintering or nesting habitat) (Table 14.2).

The highways of habitat to predators and parasitoids can be provided by planting diverse flowering weed plants into strips that cut across crop fields every 50–100 m. The natural enemies use this habitat for multiplication and dispersal into field centers. The bean aphids (*Brevicoryne brassicae*) on wheat, sugar beets, and cabbage can be managed by planting tansy leaf (*Phacelia tanacetifolia*) every 20–30 rows to enhance the population of syrphid predators. Similarly, the aphids on lettuce and cruciferous crop fields can be managed by planting strips of Alyssum every 50–100 m in order to attract syrphid flies. Likewise, creating refuge strips of flowering anise plants amid soybean crop attracts beneficial insects that prey on insect pests.

14.6 Conclusions

Even though weeds stress crop plants unquestionably through interference processes, the diversity of weeds prevents outbreaks of certain types of crop pests due to increased mortality imposed by natural enemies, as compared to weed-free fields. A significant compromise between weed science and entomology includes defining periods of weed-free maintenance in crops so that numbers of pests do not surpass tolerable levels. The presence of weeds in crop fields cannot be automatically judged as damaging and in need of immediate control. Depending on the plant species involved, environmental factors, and management practices, crop–weed interactions vary and are overwhelmingly site specific. The weeds are important components in many agro-ecosystems, adding to the complexity of interacting trophic levels mediating a number of crop– insect interactions with major influence on final yields. Without understanding the role of weed-diversified systems, we cannot understand plant–herbivore interactions, the effects of plant diversity on natural enemies, and predator–prey and parasite– host interactions.

Increased emphasis needs to be placed on understanding the ecological relationships on weed management, as opposed to weed control. The herbicides may be considered as merely a component of the total weed management system. The season-long, weed-free monocultures are not always assumed to be the best crop production strategies (Aldrich 1984).

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Crop Rotation

15

Abstract

Crop rotation, also called as sequential cropping, improves soil health and reduces insect and mite pests, soil-borne disease pathogens, nematodes, and weeds. This practice has to be invariably followed with legume crops (e.g., cowpea) or green manure crops (e.g., dhaincha, *Sesbania aculeata*; sun hemp, *Crotalaria juncea*). Pest populations can be kept to a level at which crop damage is reduced to a minimum by using an effective and most widely used land management practice known as crop rotation. The numbers of pests are reduced by growing nonhost crops, the number of years for this to occur depending on the initial population and the rate of population decrease. While choosing crops for rotation, one must be careful that they not only provide economically useful crops but also do not promote a new set of pests in place of the ones to be controlled. Some of the other benefits of crop rotation include biodiversity enhancement, improving soil structure, increased profit margins, prevention of soil erosion, supply of nutrients, and timeliness of planting operations.

Keywords

Pests • Diseases • Nematodes • Weeds • Crop rotation • Pest management

15.1 Introduction

Since ancient times, farmers have learnt that monocropping leads to crop losses, and by growing a sequence of crops over several years, the productivity of the land can be increased significantly. The crop rotations enhanced soil organic matter, soil fertility, soil tilth, and pest management.

Irish potato famine is linked to one crucial farming mistake, that is, growing the same crop in the same piece of land year after year. The land is depleted of nutrients, and the soil is eroded. The pathogen responsible for late blight of potato

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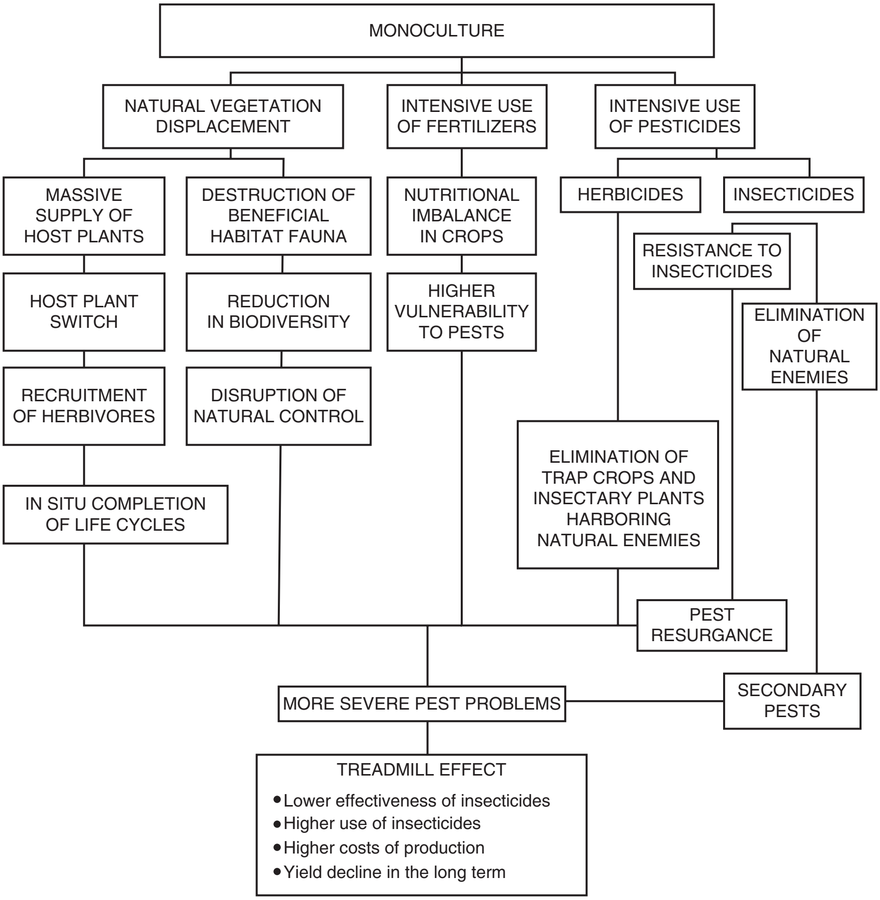

Fig. 15.1 The pest problems associated with monoculture

(*Phytophthora infestans*) remained in the soil and multiplied. The famine could have been prevented by following the simple cultural practice of crop rotation to divert the spread of late blight disease.

The pest and other problems associated with monoculture are presented in Fig. 15.1.

15.2 Crop Rotation

Sequential growing of crops belonging to different families in the same land is called crop rotation. Pest populations (insects, mites, disease pathogens, nematodes, and weeds) can be kept to a level at which crop damage is reduced to a minimum by using an effective and most widely used land management practice known as crop rotation. The numbers of pests are reduced by growing nonhost crops, the number of years for this to occur depending on the initial population and the rate of population decrease. While choosing crops for rotation, one must be careful that they not only provide economically useful crops, but also do not promote a new set of pests in place of the ones to be controlled.

The crops belonging to the same family should not be grown continuously in the same field. The crops belonging to different families should be grown in succession. A crop of one plant family is followed by another from a different family that is a nonhost crop of the pest to be managed. Grasses, legumes, and root crops are most commonly rotated with each other. Pests which are suitable for management by crop rotation include the ones that cannot survive for more than one or two seasons without suitable host crops, with restricted mobility, life cycle of one or two years, and soil-inhabiting species with a limited host-plant range. Devastating soil pests can be managed to a greater extent by following balanced crop rotations. Some of the rotational crops that reduce pest population densities include *Avena sativa*, *Secale cereale*, *Tagetes* spp., *Vigna unguiculata*, sun hemp, velvet bean, sorghum, and sorghum-Sudan grass.

The reduction of pest population present in the soil (commonly in the form of sclerotia, spores, or hyphae) is the goal of crop rotation. The pest populations can potentially build up due to continuous growing of the same crop; hence, it becomes difficult to grow that crop further without significant yield losses. Soil population levels of the pathogen can be lowered by growing a crop that is a nonhost plant for that pathogen for 2–3 years. The breeding cycle of the pest species is broken and its population reduced by rotating a nonhost crop after a host crop.

15.3 Benefits and Limitations

15.3.1 Benefits

Crop rotation has several agronomic, socioeconomic, and environmental benefits compared to monoculture (Cook and Ellis 1987).

15.3.1.1 Agronomic Benefits

1. *Breaking Pests' Life Cycle:* The breeding cycle of the pest species is broken and its population reduced.
2. *Improving Soil Structure:* Crop rotation with shallow- and deep-rooted crops helps to explore different soil profiles for water and nutrients (that contributes to enhancement of yield) and thereby improve physical properties of the soil such as tilth and bulk density.
3. *Supply of Nutrients:* A long period crop rotation was found responsible for increasing soil organic carbon (2%), total soil nitrogen (22%), soluble phosphorus, exchangeable potassium, and soil pH (Clark et al. 1998).
4. *Soil Erosion Reduction:* The use of cover crops (legumes and grasses) in crop rotation can reduce soil erosion by water and runoff.

5. *Timeliness of Planting Operations:* The workload during planting season of a good crop mix is spread over for several weeks, which help in timely planting to obtain higher crop yields.

15.3.1.2 Environmental Benefits

1. *Biodiversity Enhancement:* The increased crop rotational diversity basically alters the microbial community structure and activity, with positive interactions on aggregate formation and soil organic matter accrual.
2. *Reduced Greenhouse Gas Emissions:* The legume-based crop rotations can decrease nitrogen fertilizer use, thereby significantly reducing related greenhouse gas emissions of nitrous oxide.
3. *Reduced Water Pollution:* The diversified crop rotations used for the management of nutrition and crop pests reduce the dependence on fertilizers and pesticides, thereby reducing ground water pollution.

15.3.1.3 Socioeconomic Benefits

1. *Work Load Distribution:* The workload is evenly distributed throughout the year for planting and harvesting operations under crop rotation systems.
2. *Increased Margins:* Crops when grown in rotation need lesser inputs, and there is an increase in crop yields (10–25%) through improvement in soil properties and a decrease in weed and insect population.
3. *Economic Security:* By foreseeing the behavior of markets and using crops with increasing prices in crop rotations, the farmers can increase their farm income.

15.3.2 Limitations

- Increased management skills are required.
- Uncertainty about markets and income potential.
- Limited markets for alternative crops.
- Rotational plants produced need extra equipment and storage.
- Rising of livestock for utilization of forages produced.

15.4 Pest Management

Crop rotation plays a crucial role in reducing the pest (insect and pests, disease pathogens, nematodes, and weeds) damage by including nonhost plants in rotation that interrupts their life cycle. The crops from the same family should not be planted in sequence because they share the same pests (e.g., wheat and barley, tomato and eggplant). Hence, there is a need to rotate crops belonging to different families in sequence. At least a two-year rotation should be followed to manage foliar diseases, while a four-year rotation for the management of soil-borne disease pathogens (Fig. 15.2). *Phytophthora capsici* infection in Solanaceous and Cucurbit crops can be controlled with three- to five- year crop rotation with Fabaceae (Leguminosae),

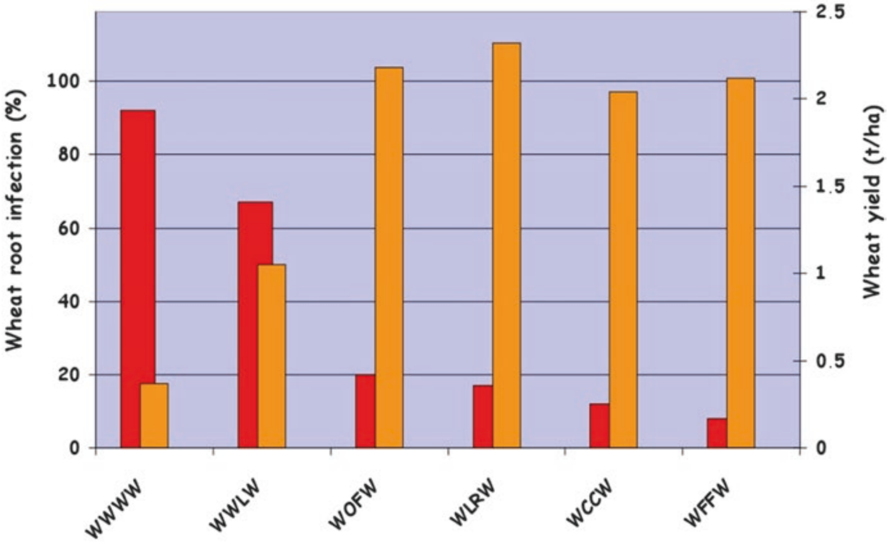

Fig. 15.2 Effect of crop rotation on fungal root diseases in wheat (*W* wheat, *L* lupines, *O* oats, *F* fallow) (Reis 1983)

Brassicaceae (Cruciferae), Apiaceae (Umbelliferae), Alliaceae (Amaryllidaceae), Asteraceae (Compositae), Chenopodiaceae, and Poaceae (Gramineae).

Crop rotations can also be used to manage insect pests with less mobility, limited host range, and source of infestation within the field itself (Flint and Roberts 1988).

The plant parasitic nematodes can be controlled by using crop rotation. Inclusion of crops such as rapeseed, mustard, velvet bean, sorghum-Sudan grass, and sun hemp (antagonistic crops) in rotation gives effective control of nematodes.

Crop rotations can also be used to suppress weeds in crop plants. Rotation of spring lettuce with *Glycine max*, *Vigna unguiculata*, and *Echinochloa esculenta* (fast and vigorous growing), and *Brassica oleracea* will have less weed competition to subsequent lettuce crops due to little or no weed seed spill.

Summer cover crops, such as soybean or cowpea and Japanese millet (vigorous and fast growing), and then fall broccoli will have less weed competition to subsequent lettuce crops due to little or no weed seed spill.

The cover crops such as Sudan grass, sorghum, rye, barley, wheat, and oats can be used in rotation with crop plants to suppress weeds through allelopathy, shading, and competition. The leachates and residues of hairy vetch, crimson clover, and other legumes can also suppress weeds when used in rotation with main crops.

Some of the insect pests, disease pathogens, and nematodes controlled (partially or entirely) by crop rotation are presented in Table 15.1.

Table 15.1 Insect pests, diseases, and nematodes that can be managed by crop rotation

Insect pests/crops	Diseases/crops	Root-knot nematodes/crops
Hypera postica (lucerne)	Bacterial blight (wheat, barley)	*Meloidogyne incognita* (velvet bean, rapeseed, common vetch, castor bean, French marigold)
Diabrotica virgifera (maize)	Bacterial wilt (alfalfa)	*M. javanica* (velvet bean, rapeseed, sesame, common vetch, French marigold)
Leptinotarsa decemlineata (potato, tomato)	Granville (bacterial) wilt (tobacco, potato, eggplant)	*M. arenaria* (velvet bean, sesame, common vetch, castor bean, French marigold)
Meromyza saltatrix (*Triticum* spp.)	Black Shank (tobacco)	*M. hapla* (French marigold)
Zonosemata electa (pepper)	Black Dot (potato) *Exserohilum turcicum* (maize)	
Anasa tristis (*Cucurbita* spp.)	*Ustilago maydis* (maize) *Sclerotium rolfsii* (peanuts)	
Mayetiola destructor (*Triticum* spp.)	*Verticillium dahliae* (*Solanum tuberosum, Dianthus annus*)	
	Sclerotinia sclerotiorum (*Arachis hypogea, Solanum tuberosum, Glycine max*)	

15.4.1 Insect Pests

The life cycle of the target insect is an important consideration. Some of the common crop pest characteristics that are amenable for control by crop rotations include the following (Flint and Roberts 1988):

- Pests that cannot survive for more than one or two seasons without suitable host crops
- Pests with restricted mobility
- Pest life cycle of one or two years
- Soil-inhabiting pest species with a limited host-plant range
- Pest source should be within the field

A single-year rotation with nonhosts such as small grains or sorghum should be adequate for the management of *Diabrotica virgifera* and *D. barberi* on maize. Similarly, Colorado potato beetle can be managed by crop rotation with grain crops.

Bugg and Waddington (1994) found that planting of cover crops such as vetches and clovers in rotation enhanced the populations of *Geocoris* spp., Coccinellids, and other natural enemies of crop pests. For example, planting eggplant into strip-tilled crimson clover destroyed Colorado potato beetles feeding on eggplant.

A major option for management of carrot fly (*Chamaepsila rosae*) includes implementing crop rotation to ensure separation of carrot fields from year to year (Hermann et al. 2010).

The incidence of field bean pod borer (*Adisura atkinsoni*) can be reduced by crop rotation with cereals (sorghum, maize). In the same way, the weevil (*Cylas* spp.) damage on sweet potato can be minimized by crop rotation (Rice – sweet potato – cowpea).

15.4.2 Diseases

Knowing the biology of disease pathogens is a prerequisite for successful management of diseases by crop rotation. Technique of sequential cropping with hosts and nonhosts to starve disease pathogens is employed in crop rotation. In order to manage diseases through crop rotation, we need to know the following aspects:

- Duration of pathogen's survival in the soil
- Host range (including weeds and cover crops) on which the pathogen can survive
- Other ways of survival between susceptible crops
- Reintroduction and spread of pathogen

Some pathogens cannot be successfully managed by rotation if their spores are spread by wind to faraway places. The required rotation period might be shorter in an organic field where biological control operates to decrease disease propagules, as compared to a conventional field.

15.4.2.1 Duration of Crop Rotation

The target pathogens which cannot survive for long can be effectively suppressed by crop rotation. The most suitable fungal and bacterial pathogens which can be managed by crop rotation are those that survive only on crop debris in soil, since they die after decomposition of organic matter.

Some fungal and bacterial soil-borne disease pathogens which can survive on crop residues for long in soil are difficult to manage by crop rotation.

The pathogen populations of certain species of *Pythium* causing seed decay and damping-off of tender seedlings of *Cucurbita* spp. and wire stem of *Brassica oleracea* cannot be completely controlled, but can be reduced by rotation with small grains.

Certain fungal pathogens produce specialized structures like oospores, sclerotia, chlamydospores, and cleistothecia that survive for several years in soil. For example, sclerotia produced by *Colletotrchum coccodes* (anthracnose in tomato), *Sclerotinia sclerotiorum* (white mold of lettuce) and *Verticillium dahliae* (Verticillium wilt of potato) survive for at least 8, 10, and 13 years, respectively. In such cases, long rotations with nonhosts should be followed (Table 15.2).

Rotation of crucifers with legumes suppresses disease pathogens by encouraging biological control agents (myxobacteria and *Streptomyces*) and by secreting glucosinolates from roots which are toxic in nature. Cruciferous plants like white mustard, brown mustard, rapeseed, broccoli, and IdaGold have especially high

Table 15.2 Duration of crop rotation for soil-borne disease pathogens

Duration of crop rotation	Crop(s)	Pathogen(s)
5–8 years	*Asparagus officinalis*	*Fusarium* oxysporum f. sp. *asparagi*
	Brassica oleracea var. *capitata, Raphanus sativus*	*Plasmodiophora brassicae*
	Pisum sativum	*Fusarium oxysporum* f. sp. *pisi*
	Cucumis melo	*Fusarium solani* f. sp. *cucurbitae*
2–4 years	*Brassica oleracea* var. *capitata*	*Phoma lingam, Xanthomonas campestris* pv. *campestris*
	Pastinaca sativa	*Itersonilia pastinaceaea*
	Pisum sativum	*Aphanomyces euteiches*
	Cucurbita pepo	*Didymella bryoniae*

concentrations of glucosinolates which can be utilized for the management of soil-borne disease pathogens of crop plants.

Leguminous plants like clover *Trifolium repens*, *Pisum sativum*, *Phaseolus vulgaris*, *Vicia villosa*, and *Lupinus polyphyllus* enhance antagonistic microorganisms which control disease pathogens when included in crop rotations. For example, the Fusarium wilt in watermelon can be managed by incorporation of hairy vetch residue into soil.

15.4.2.2 Controlling Soil-Borne Diseases

Soil-borne diseases can be managed by following the long rotations with nonhost crops. For example, the populations of Granville wilt or southern bacterial wilt decline by using short rotation with nonhosts like *Glycine max, Festuca* spp., *Zea mays, Gossypium* spp., and *Sorghum vulgare*. Similarly, carrot root dieback (*Pythium* spp. and *Rhizoctonia solani*) is controlled by rotation with onion. Likewise, crop rotation with *Satureja hortensis, Mentha piperita,* or *Thymus vulgaris* controls club root of crucifers.

Growing corn or alfalfa before potato reduced both Verticillium wilt and scab of potato. Likewise, rotation of lettuce with broccoli reduced white mold (*Sclerotinia minor*) and lettuce drop (*Sclerotinia sclerotiorum*) diseases. Similarly, rotation with *Phaseolus vulgaris*, *Zea mays*, and *Sorghum vulgare* helped in effective management of bacterial wilt, anthracnose, spring black stem, and *Stagonospora* disease pathogens on alfalfa.

Bacterial wilt incidence in potato can be reduced to the extent of 94% by crop rotation with maize, wheat, barley, oat, sun hemp, finger millet, and vegetables like cabbage, onion, and garlic. A 2-year rotation with potato-finger millet-finger millet-potato reduced wilt incidence by 81%. Fusarium wilt in a variety of crops can be managed by rotation with *Cyamopsis tetragonoloba – Cuminum sativum, Cyamopsis tetragonoloba – Triticum vulgare, Cyamopsis tetragonoloba – Brassica nigra*.

Effectiveness of crop rotation is enhanced by the presence of more active beneficial organisms that affect the pathogen and can reduce the duration of rotation.

Management of crop diseases using crop rotation is presented in Table 15.3.

Table 15.3 Effect of crop rotation on disease control

Crop	Pathogen	Rotational crop(s) recommended
Musa spp.	Fusarium wilt	Rice or sugarcane
Potato	Common scab, *Streptomyces scabies*	Wheat, peas, oat, barley, lupin, soybean, sorghum, bajra
	Bacterial wilt, *Ralstonia solanacearum*	Maize, wheat, barley, oat, sun hemp, finger millet, cabbage, onion, garlic
Tomato, brinjal	Bacterial wilt, *Ralstonia solanacearum*	Cowpea-maize-cabbage, okra-cowpea-maize, maize-cowpea-maize, finger millet-brinjal (Pusa Purple Cluster)-French bean
Crucifers	Black rot, *Xanthomonas campestris* pv. *campestris*	Rice
Cucumber	Powdery mildew, *Sphaerotheca fuliginea, Erysiphe cichoracearum*	Rice in low lands

15.4.3 Nematode Pests

In general, rotation separates susceptible and nonsusceptible crops to a particular nematode. For example, the root-knot nematode can be managed by crop rotation with mustard, marigold, pigeon pea, sorghum, small grains (bajra), sugarcane, sesame, chrysanthemum, cosmos, sun hemp, dhaincha, dahlia, marigold, balsam, lentil, radish, spinach, fenugreek, zinnia, and grasses. Similarly, Khan and Khan (1973) found that a number of crops and other plants like sugarcane, *Coffea robusta*, jack bean (*Canavalia ensiformis*), velvet bean (*Stizolobium deeringianum*), chilies, maize, sorghum, *Leucaena glauca*, finger millet (*Eleusine coracana*), *Crotalaria, Capsicum fruitescens*, carrot, *Anethum graveolus*, coriander, *Foenicutum vulgare*, *Spinacea oleracea, Beta vulgaris,* onion, garlic, mustard, cauliflower, pigeon pea, chrysanthemum, coriander, cosmos, sun hemp, dhaincha, cluster bean, dahlia, marigold, horse gram, balsam, linseed, radish, sesame, zinnia, and *Raphanus sativus* are reported resistant to the reniform nematode. These crops can be utilized in rotation to manage the above nematodes. The susceptible crops can be replanted when nematode populations become lower than the thresholds.

Some plants antagonistic to nematodes reduce populations to a greater extent than nonhosts. For example, planting of *Crotalaria spectabilis* and *C. striata* (whose root systems have a toxic effect on root-knot nematodes) in advance of a crop may reduce subsequent damage by nematodes (Ochse and Brewton 1954). Similarly, Meijneke and Oostenbrink (1958) reported that the populations of *Pratylenchus*, *Tylenchorhynchus*, *Paratylenchus*, and *Rotylenchus robustus* were reduced by crop rotation with *Tagetes* spp. Likewise, *M. hapla* can be managed by rotation with corn or cotton, since these crops are nonhost to this species.

McSorley and Dickson (1995) showed that the cover crop velvet bean effectively suppressed root-knot, stubby-root, and sting nematodes simultaneously. Likewise, *Mucuna pruriens* successfully reduced populations of root-knot nematodes and lesion nematodes (*Pratylenchus zeae*) (Arim et al. 2006).

Germani et al. (1983) reported that leguminous green manure crops reduced the population of rice root nematode and enhanced rice production.

Management of plant parasitic nematodes using crop rotation is presented in Table 15.4.

Table 15.4 Management of plant parasitic nematodes using crop rotation

Crop	Nematode(s)	Effective rotation crop(s)	References
Banana	*Radopholus similis, Pratylenchus coffeae, Helicotylenchus multicinctus*	Rice, green gram	Rajendran et al. (1979)
Pineapple	*M. incognita, Criconemoides* spp., *Helicotylenchus* spp., *Rotylenchulus reniformis*	Pangola grass	Ayala et al. (1967)
Grapevine	*Xiphinema index*	Cereals, alfalfa (7 years)	Lamberti (1981)
Potato	Root-knot	French beans, leafy vegetables, maize, wheat, barley	Raj and Nirula (1969)
Tomato	Root-knot	Tomato resistant cv. Hisar Lalit, onion, okra, garlic, cluster bean, coriander	Khan et al. (1975)
		Sesamum, niger	Sahoo et al. (2004)
	M. incognita, M. javanica	Peanut	Taylor and Sasser (1978)
	M. incognita	Peanut, mustard	Sharma et al. (1980)
	M. javanica	Cotton, wheat	Hashmi and Hashmi (1990)
		Carrot, capsicum, onion	Kanwar and Bhatti (1992)
Brinjal	Root-knot	Sweet potato (cv. Sree Bhadra)	Sheela et al. (2002)
		Sorghum, wheat, chili, mustard, marigold, garlic, cauliflower, *Panicum maximum*	Netscher (1983) and Singh (1991)
Chili	*M. incognita*	Marigold, spinach, bottle gourd	Khan et al. (1975)
	Root-knot	Marigold, onion, garlic, asparagus	Trivedi and Tiagi (1984)

(continued)

Table 15.4 (continued)

Crop	Nematode(s)	Effective rotation crop(s)	References
Onion	Parasitic nematodes	Cowpea	Vetrivelkalai and Subramanian (2006)
Okra	Root-knot	Marigold, spinach, bottle gourd	Khan et al. (1975)
		Onion, tomato resistant cv. Hisar Lalit	Kanwar (1990)
		garlic-cluster bean, coriander	Anon (1993)
		Sweet potato (cv. Sree Bhadra)	Sheela et al. (2002)
		Cabbage, marigold, wheat, cereals, kochia	Alam et al. (1977)
Cabbage, cauliflower	*Tylenchorhynchus brassicae*	Wheat	Siddiqi et al. (1973)
		Mustard, radish, sesame	Haque and Gaur (1985)
French bean	Root-knot	Chili or groundnut, finger millet	Ramappa (1988)
Carrot	*M. incognita*	Spinach, marigold, radish	Hasan and Jain (1998)
Crossandra	Parasitic nematodes	Cauliflower, cabbage, pea, radish, carrot, spearmint, squash, onion	Kolodge et al. (1987)

15.4.4 Weeds

The greatest challenge to organic field and vegetable crop production is weed management. When the crop is a poor competitor, weeds occur naturally. Rotation still stands one of the best, cost-effective, and widely practiced methods of weed suppression. The germination of weed seeds is adversely influenced and altered by crop rotations. Rotation of wheat with pea and gram is effective for the management of weed *Avena fatua*, while rotation of lucerne with grain crop suppressed *Cuscuta* weed. Inclusion of lowland rice in crop rotation reduced obnoxious weeds like *Cyperus rotundus*, while the growth of *Parthenium* is suppressed by planting *Cassia tora* or marigold (*Tagetes* spp.). *Desmodium* sp. in rotation with sorghum or maize is responsible for germination of *Striga* seeds but without formation of haustoria. Effective smothering of weeds without causing main crop yield reduction occurs by crop rotation with *Vigna radiata* and *Glycine max*.

Crop rotations should be designed to reduce weed reproduction. Some cover crops can suppress weeds.

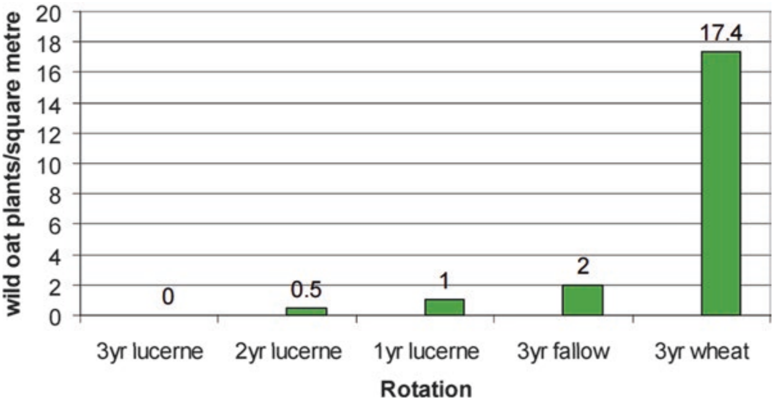

Fig. 15.3 Effect of lucerne on wild oat density in wheat rotation

Three years of well-managed lucerne pasture completely controlled wild oats in the following wheat crop, while even one year of lucerne reduced wild oats to just one plant per square meter. The wild oat population was reduced to two per square meter by adopting 3 years of bare fallow. But continuous growing of three crops of wheat increased the wild oat population to 17 plants per square meter in the third crop (Fig. 15.3).

15.5 Conclusions

Even though the crop rotations play a major role in most successful crop production enterprises, they are particularly essential for agroecological pest management. The best approach for sustainable pest management is to disrupt its biology. Another strategy is to design cropping systems to encourage biological control agents which can manage crop pests. It is essential to evaluate which rotations can be practiced successfully in the agroecosystem to maximize yield and pest management. The multiyear, multicrop rotations manage pests and weeds with less reliance on chemical pesticides, produce high yields for each crop in rotation, and enhance soil fertility with less need for synthetic fertilizers.

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Plant Breeding

16

Abstract

The most effective, practical, and cheapest method of managing pests and diseases is probably by the use of resistant cultivars. Breakdown of plant resistance due to evolution of new races of pathogen/pest is one of the most important drawbacks. In widespread and protracted agriculture, there are many examples of resistant varieties which have continued to give a good control of pests and diseases. Breeding for a very high level of resistance is always not desirable, since partial resistance has often given adequate degree of management under field conditions, especially when such resistance has been integrated with other management approaches. Crops with transgenic resistance to herbivores, diseases, and tolerance to weeds have been developed in commercial crops like *Zea mays*, *Gossypium* spp., *Glycine max*, and *Solanum tuberosum* which are being cultivated in large areas throughout the world.

Keywords

Breeding • Organic farming • Pest resistance • Transgenic crops • Insect pests • Diseases • Nematodes • Weeds

16.1 Introduction

Plant breeding is a simple and cost-effective practice of developing cultivars resistant to biotic stresses. It is estimated that development of improved high-yielding varieties/hybrids through conventional breeding which responds to high inputs accounts for more than 95% of agriculture production. Such cultivars cannot be afforded by marginal farmers, which do not respond to low inputs as well as organic farming systems (Murphy et al. 2007; Wolfe et al. 2008). Further, introduction of semidwarf genes to solve lodging problems in grain crops showed susceptibility to leaf spot disease.

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Traits demanded by consumers like higher productivity and resistance/tolerance to pests are some of the objectives of breeding goals for both the low-input sector and conventional breeding. Resistance to seed-borne diseases and increased competitiveness against weeds are some of the other traits desired by farmers. Breeding programs to develop resistant varieties against pests, diseases, and weeds in low-input agriculture are the needs of the hour.

Resistance to biotic stresses and tolerance to weeds can be achieved through conventional breeding. However, the durable resistance is the need of the hour. The long-term theory and genetics for improved durable resistance is through molecular biology and genetic engineering. Genetically modified (GM) crops (transgenics) can be developed by introducing one (or a few) foreign "good" gene(s) into the best accepted cultivars.

Plant breeding is responsible for strengthening numerous plant defenses against pests. The plant defenses may be either structural (tough leathery leaves, leaf hairs, and spines) or toxic plant chemicals that deter feeding (allelopathic chemicals that deter weed growth, and leaf waxes that form barriers for pests and diseases).

The selection for a single resistant gene (monogenic or oligogenic in vertical resistance) is being generally followed in conventional plant breeding. The development of new races of the pest can easily break down the resistance, since single gene is responsible for resistance. The initial amount of inoculum is reduced in vertical resistance which can delay the epidemic. The horizontal resistance (also called polygenic resistance) is effective against many races of the pathogen. It slows down the rate at which disease increases in the field. The durable resistance is preferred. Our knowledge is steadily expanding on the role of plants in their own defense (Agrios 2005).

16.2 Benefits and Drawbacks

16.2.1 Benefits

The benefits of resistant cultivars are as follows:

- Strong line of defense
- Preventative measure
- Practical method of pest control
- Affordable by farmers

16.2.2 Drawbacks

The drawbacks of resistant cultivars include the following:

- Resistance may be overcome by pathogens
- Genetic resistance is not always available
- Desirable traits may be found in susceptible varieties

16.3 Disease Resistance

In developing countries, importance is being given in developing improved cultivars with resistance to biotic stresses in staples like cassava, chickpea, cowpea, peanuts, potato, rice, and wheat. Resource-poor farmers prefer this method of disease management since it is environment-friendly and does not require additional cost.

Disease-resistant varieties of rice to bacterial blight, blast, brown spot, and tungro are widely adopted. The durability of resistance can be properly managed through crop diversity and multilines. Leung et al. (2003) reported success in breeding disease-resistant rice varieties.

Groundnut cultivars like ICGV 89104 and ICGV 91114 have been developed which are resistant to major diseases. Pande et al. (2001) reported that these cultivars significantly reduced the severity of both diseases and gave 55–60% higher yield than the local cultivar. Likewise, groundnut cultivars have also been developed for resistance against major virus diseases (Reddy 1998).

The potential to reduce disease incidence in a number of crops has been observed through systemically acquired resistance (SAR). Various substances such as chitosan, monopotassium phosphate, and salicylic acid triggered this SAR phenomenon in a plant. SAR phenomenon was also triggered by the application of nonpathogenic isolates of *Fusarium oxysporum* and plant-growth-promoting rhizobacteria (*Bacillus*, *Pseudomonas*). The commercial product sold under the trade name Messenger contains a bacterial protein (harpin), which offers some protection against plant pathogens in food commodities, ornamentals, trees, and turf grasses.

In okra, yellow vein mosaic disease is a serious disease. It is transmitted by a whitefly vector *Bemicia tabaci*. Many tolerant/resistant varieties and hybrids are commercially available. Similarly, for tomato leaf curl disease, another virus disease transmitted by the same whitefly, many resistant varieties and hybrids are available. Bacterial wilt is another major pest problem in tomato and brinjal. Many tolerant varieties/hybrids are commercially available and these should be chosen for organic farming. A list of varieties tolerant to pests of horticultural crops is given by Parvatha Reddy (2008). Such specifically bred tolerant varieties or hybrids can also be planted as they give better yield if the soil fertility is high. In tomato and many other vegetables, multiple-disease-tolerant varieties/hybrids are available. Growing these will help in reducing the pest incidence. An organic farmer has to decide on the crops and varieties based on all the above factors.

16.3.1 Disease Suppression by Rhizosphere Competence

Maintaining disease-suppressive biological control agents and endomycorrhizae in the rhizosphere provide resistance to seed- and soil-borne diseases (Wissuwa et al. 2009; Roberti et al. 2008). Soil antagonists have been shown to contribute to disease suppressiveness through a range of different mechanisms like crop plant resistance and vying for site and nutrients (Sari et al. 2008).

16.3.2 Resistance to Major Seed-Borne Diseases

Resistance to seed-borne diseases is an important issue in organic seed production. Hence, it is economical to adopt cultivars resistant/tolerant to seed-borne disease pathogens (Blazkova and Bartos 2002; Wächter et al. 2007; Ciuca and Saulescu 2008; Fofana et al. 2008).

There is a need for developing tomato varieties resistant to bacterial seed-borne diseases and viral pathogens for organic systems, since the source of resistance is already available in commercially used tomato germplasm for organic systems (Hall 1980). Tomato cultivars have also been developed against the predominant strain of tomato mosaic virus (ToMV) by transferring another resistance gene (*Tm-1*) from *S. habrochaites* without the use of embryo culture (Pelham 1966). Broccoli cultivars resistant to seed-borne bacterial black rot disease are being developed (Tonguç and Griffiths 2004).

16.3.3 Resistance to Other Fungal and Bacterial Diseases

There is a need to develop *Triticum vulgare* cultivars with resistance against *Septoria tritici*, *Puccinia graminis tritici*, and *Blumeria graminis* f. sp. *tritici*. Qualitative as well as quantitative resistance sources are available for late blight (*Phytophthora infestans*) of tomato which confers resistance to specific races.

Tolerance to black spot and other diseases that infect roses is available in antique roses, which are generally more tolerant than most of the more recently developed hybrids. Similarly, "Natchez" cultivar of crape myrtle is resistant to powdery mildew and is commonly used in Florida.

16.4 Nematode Resistance

The vegetable crops such as broccoli, Brussels sprouts, chives, cress, garlic, ground cherry, leek, mustard, and rutabaga are reasonably reported as resistant to root-knot nematodes (Donald 1998), while asparagus, Globe artichokes, horseradish, Jerusalem artichoke, onion, rhubarb, and sweet corn exhibited tolerant reaction. *Vigna unguiculata* varieties such as California Blackeye #5, Mississippi Silver, Tennessee Brown, and Iron Clay inhibited root galling more effectively than the cultivar Purple Knuckle (intermediate) planted into the sandy soils of Florida (Hagan et al. 1998; McSorley 1999).

Different varieties reported to be resistant/moderately resistant/tolerant to several nematodes are presented in Table 16.1.

Table 16.1 Crop varieties resistant to root-knot nematodes

Crop	Pest/disease	Resistant varieties
Passion fruit	*Meloidogyne incognita*	Yellow, Kaveri
Carrot	Root-knot nematode	Arka Suraj
China aster	*M. incognita*	Shashank, Poornima (MR)
Tuberose	*M. incognita*	Sringar, Suvasini (T)
Mentha	*M. incognita*	Kukrail, Arka Neera
Black pepper	*M. incognita*	IISR Pournami (T)
Ginger	Root-knot nematodes	IISR Mahima

MR moderately resistant, *T* tolerant

Table 16.2 Resistant varieties of crop plants against insect pests

Crops	Insect pests	Resistant varieties
Chili	Thrips	NP 46 (T)[a]
Okra	Fruit borer	Pusa A-4
Pumpkin	Fruit fly	Arka Suryamukhi

[a] *T* tolerant

16.5 Resistance to Insect Pests

The key strategy for development of herbivore resistant varieties is simple, economical, effective, and environment friendly for insect pest management. Very few resistant varieties against insect pests have been developed (Table 16.2).

The presence of epicuticular wax on resistant varieties may affect insect pests positively or negatively. Reduced tissue damage from lepidopteron pests, thrips (Eigenbrode and Espelie 1995), and fewer eggs laid by cabbage maggots and root fly was observed in cabbage white heads specifically with glossy (waxless) variants (Eigenbrode and Espelie 1995; Voorrips et al. 2008).

Host-plant resistance against insect pests is based on morphological features and makes the plant less attractive visually. The tearing actions of chewing mouth parts are resisted by thick cell walls and plant tissue of resistant plant.

Plants with a thick cuticular wax layer are protected against desiccation and physically inhibit insect feeding. Some raspberry varieties with wax on leaf surface contain chemicals that negatively affect certain insects. Cabbage varieties with glossy or waxy leaves reduce *Plutella xylostella* population, thereby making them more susceptible to predators.

The impact on insect pests by the presence of trichomes or hair-like structures depends on trichome density, erectness, length, and shape. The presence of trichomes may obstruct the insect feeding and ingesting of tissue. Herbivores like *Aphis fabae* and *Empoasca fabae* on *Phaseolus vulgaris*, *Tetranychus urticae* on *Fragaria x ananassa*, and *Bemisia tabaci* on *Lycopersicon esculentum*, *Capsicum annum*, and *Solanum tuberosum* are partially managed by the occurrence of pubescence on crop plants.

Table 16.3 Insect pests which can be managed using nonpreference mechanisms of resistance in different crops

Crop plants	Herbivores managed by nonpreference mechanism
Triticum vulgare	*Cephus cinctus*
Oryza sativa	*Sciropophaga incertulas*
	Nilaparvata lugens
Zea mays	*Helicoverpa zea*
	Rhopalosiphum maidis
	Helicoverpa armigera
	Sitophilus zeamais
	Zyginidia manaliensis
Glycine max	*Empoasca fabae*
Pisum sativum	*Acyrthosiphon pisum*
Brassica oleracea var. *capitata*	*Brevicoryne brassicae*
Beta vulgaris	*Pemphigus betae*
Brassica oleracea	*Brevicoryne brassicae*
Melilotus officinalis	*Sytonia cylindricollis*

16.5.1 Resistance Mechanisms to Insect Pests

The four mechanisms of insect resistance in crop plants include nonpreference, antibiotics, tolerance, and avoidance or escape.

16.5.1.1 Nonpreference

Various characteristics of the host plant (morphological and chemical features) prevent herbivore feeding, development, and multiplication, which are known as nonpreference, nonacceptance, and antixenosis. In this type of insect resistance, insect pests will not accept a resistant host plant. Color, hairiness, leaf angle, light penetration, odor, and taste are some of the plant features which are associated with nonpreference. For example, fregobract, long pedicel, nectarilessness, okra leaf, open canopy, red plant body, and smooth leaves are some of the plant characters responsible for nonpreference to cotton bollworms.

Several insect pests which can be managed using nonpreference mechanisms of resistance in different crops are presented in Table 16.3.

16.5.1.2 Antibiosis

Resistant plants produce antibiotics in response to feeding by insect pests that prevent development and multiplication of herbivores. For example, high level of gossypol, heliocides, silica, and tannin contents are responsible for insect resistance in cotton.

Table 16.4 Mechanisms of insect resistance in crop plants due to production of antibiotics

Crop plants	Herbivores managed due to production of antibiotics
Triticum vulgare	*Mayetiola destructor, Cephus cinctus, Schizaphis graminum*
Hordium vulgare	*Oulema melanopus, Schizaphis graminum*
Oryza sativa	*Sciropophaga incertulas*
Zea mays	*Ostrinia nubilalis, Chilo paretllus*
Gossypium spp.	*Helicoverpa* spp.
Beta vulgaris	*Pemphigus betae*
Medicago sativa	*Therioaphis maculate, Acyrthosiphon pisum*
Brassica oleracea var. *capitata*	*Brevicoryne brassicae*
Solanum tuberosum	*Macrosiphum euphorbiae*
Nicotiana tabacum	*Tetranychus evansi*
Medicago sativa	*Hypera postica*

16.5.1.3 Tolerance

Despite insect attack, tolerant cultivars give a certain quantity of the produce which is higher than the susceptible cultivars. Flowering compensation potential, greater recovery of damaged parts, healthy leaf growth, rejuvenation potential, and superior plant vigor are responsible for tolerance.

Several insect pests which can be managed by the production of antibiotics in different crops are presented in Table 16.4.

16.5.1.4 Avoidance or Escape

Early maturing crop cultivars escape from insect pest attack. Early maturing *Gossypium* varieties escape from *Pectinophora gossypiella* attack at later stages of crop growth.

16.6 Tolerance to Weeds

16.6.1 Weed Competition

Weed management tends to be less problematic in some crop plants with potentially important weed suppression trait like allelopathy (Wu et al. 1999). Hence, there is a need to identify varieties with high allelopathic activity, in order to transfer allelopathic feature in crop cultivars (Wu et al. 2000).

Glucosinolate breakdown products in the Brassicaceae have weed-suppressive effects. The enzyme myrosinase catalyzes the conversion of glucosinolates into isothiocyanates during plant tissue maceration (Vaughn and Boydston 1997). Hence, there is a need to breed crop varieties with increased glucosinolate levels in vegetative tissues for suppression of weeds.

16.6.2 Tolerance to Cultural Operations

There is a need to develop crop cultivars which can resist plant damage caused during cultural operations to remove weeds in row crops (especially in wheat) under reduced or minimum tillage systems (Krauss et al. 2010; Hakizimana et al. 2000; Faustini and Paolini 2005; Murphy et al. 2008). One of the vital aspects to weed suppression is early ground cover (Bond and Grundy 2001).

16.7 Genetic Engineering (Recombinant DNA Technology)

In order to fulfill the objective of food security, some scientists believe that genetically modified crops developed through biotechnological approaches fit into the gambit of sustainable intensification (Birch et al. 2011). Biotechnology is receiving major emphasis, since it is an innovative means to provide a wave of new, safe, and effective products through molecular biology and genetic engineering to resolve pest management problems. These biorational products and materials are developed by introducing one (or a few) foreign "good" gene(s) into the best accepted cultivars.

Genetic engineering alters the genetic makeup of cells by deliberate and artificial means to transfer or replace genes to create recombinant DNA. This process involves the following steps:

- Cutting DNA molecules at specific sites to get fragments containing useful and desirable genes from one type of cell.
- Inserting these genes into a suitable vector or carrier.
- Putting the recombinant DNA into completely different plant cell or bacterial cell.

By this process, the modified plant cells acquire useful characters, such as tolerance to weeds, and resistance to pathogens, nematodes, and insect pests. The recombinant DNA molecules can be cloned and amplified to an unlimited extent.

16.7.1 Opportunities

Transgenic resistance to insect pests, disease pathogens, nematodes, and tolerance to weeds is a recent and controversial technique. In order to protect crops against insect attacks, Bt genes have been inserted in crop plants. Some success has also been achieved in developing disease-resistant (especially in papaya to ring-spot virus, plum to plum pox virus, French beans to golden mosaic virus, and potato to late blight fungus), insect pest-resistant (particularly in brinjal to shoot and fruit borer, soybean to lepidopteron pests, and rice to yellow stem borer and leaf folder), and weed-tolerant (glyphosate tolerant corn) varieties. Growing of genetically modified pest-resistant crops such as canola, corn, cotton, and soybean has considerably

Fig. 16.1 *Left* – Brinjal fruits damaged by fruit and shoot borer. *Right* – Bt brinjal resistant to the pest

cut down the cost on insecticides, which adversely affect the environment and biodiversity (Phipps and Park 2002; Barbosa 1998). Once the social, legal, and economic obstacles are overcome, development of GM crops for pest management in staple food crops like *Triticum vulgare*, *Oryza sativa*, *Zea mays*, and *Glycine max* would significantly increase by leaps and bounds in the next two decades.

16.7.2 Transgenic Insect-Resistant Crop Varieties

16.7.2.1 Maize

Bt maize resistant to the European maize borer (*Ostrinia nubilalis*), corn ear worm (*Helicoverpa zea*), and root worm (*Diabrotica* spp.) have been developed.

16.7.2.2 Cotton

Bt cotton resistant to bollworms have been developed.

16.7.2.3 Potato

Transgenic potato cultivars with resistance to Colorado potato beetle (*Leptinotarsa decemlineata*), potato tuber moth (*Phthorimaea operculella*), and European corn borer (*Ostrinia nubilalis*) have been developed (Naimov et al. 2003).

16.7.2.4 Brinjal

Bt brinjal varieties resistant to shoot and fruit borer (*Leucinodes orbonalis*) have been developed (Fig. 16.1).

16.7.2.5 Soybean

Bt Soybean (*Glycine max*) resistant to Lepidopteron pests have been developed (Fig. 16.2).

Fig. 16.2 *Left* – Transgenic Bt soybean resistant to velvet bean caterpillar. *Right* – Nontransgenic soybean (showing extensive defoliation due to the pest

Fig. 16.3 *Left* – Bt rice variety showing resistance to *Sciropophaga incertulas*. *Right* – Non-Bt rice showing damage by the pest (*T* transgenic, *C* control)

16.7.2.6 Rice

Bt rice varieties resistant to Lepidopteron pests have been developed (Pathak and Khan 1994) (Figs. 16.3 and 16.4).

16.7.3 Transgenic Disease-Resistant Crop Varieties

16.7.3.1 Papaya

Transgenic papaya varieties resistant to the ring-spot virus (cvs. Rainbow and SunUp) have been developed (Fig. 16.5).

Fig. 16.4 *Foreground* – Non-Bt rice showing *Cnaphalocrocis medinalis* damage. *Background* – Bt rice variety showing resistance to the pest (*T* transgenic, *C* control)

Fig. 16.5 *Left* – Nontransgenic papaya damaged by ring-spot virus. *Right* – Transgenic papaya showing resistance to the virus

16.7.3.2 Plum

Genetically modified plum variety (cv. Honey Sweet) resistant to plum pox virus has been developed (Fig. 16.6) (Hily et al. 2004).

16.7.3.3 Sweet Potato

Transgenic sweet potato varieties resistant to *feathery mottle virus* have been developed.

16.7.3.4 Cassava

Genetically modified cassava cultivars resistant to cassava mosaic disease have been developed (Yadav et al. 2011).

16.7.3.5 Summer Squash

Transgenic summer squash varieties (CZW-3) resistant to cucumber mosaic virus (CMV), zucchini yellow mosaic virus (ZYMV), and watermelon mosaic virus 2 (WMV) have been developed (Fuchs et al. 1998).

Fig. 16.6 *Left* – Transgenic plum plum fruits resistant to *plum pox virus*. *Right* – Nontransgenic plum fruits showing symptoms of the virus

Fig. 16.7 *Left* – Transgenic potato resistant to late blight. *Right* – Nontransgenic potato damaged by the disease

16.7.3.6 Potato

Genetically modified potato varieties resistant to the late blight fungus have been developed (Fig. 16.7).

16.7.3.7 Pinto Bean

Transgenic bean cultivars resistant to the golden mosaic virus have been developed (Fig. 16.8).

16.7.3.8 Sweet Pepper

Genetically modified sweet pepper varieties resistant to cucumber mosaic virus (CMV) have been developed.

Fig. 16.8 *Foreground* – Nontransgenic bean plants susceptible to golden mosaic virus. *Background* – Transgenic bean plants resistant to the virus

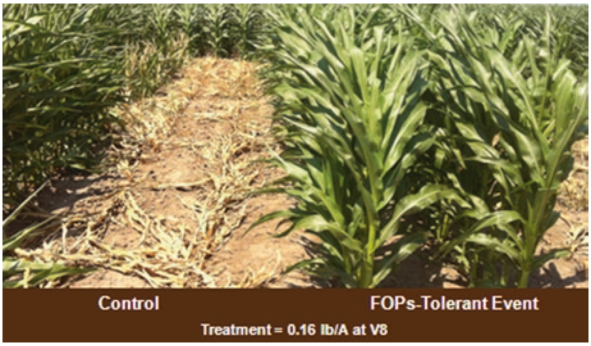

Fig. 16.9 *Left* – Nontransgenic herbicide-susceptible maize. *Right* – Transgenic herbicide-tolerant maize

16.7.3.9 Rice

Transgenic rice varieties resistant to sheath blight (*Rhizoctonia solani*) and blast (*Magnaporthe oryzae*) have been developed.

16.7.4 Transgenic Herbicide-Tolerant Crop Varieties

Genetically modified herbicide-tolerant cultivars of soybean, cotton, maize (Fig. 16.9), and alfalfa have been developed.

16.7.5 Transgenic Crop Varieties with Combined Resistance

Transgenic potato cultivars with combined resistance to Colorado potato beetle and potato virus Y, Colorado potato beetle and potato leaf roll virus, and maize varieties with combined resistance to *Striacosta albicosta, Ostrinia nubilalis*, *Agrotis ipsilon, Spodoptera frugiperda*, and herbicide tolerance have been developed (Castle et al. 2006).

16.8 Conclusions

Locally available traditional varieties are generally more tolerant to pests and diseases. However, the yield may be low compared to commercial varieties which perform well under high fertilizer and pesticide umbrella. Growing pest-resistant varieties or hybrids (wherever available) drastically reduces the risk of crop failure. In recent times, more emphasis is given by research workers and seed companies to develop pest-resistant varieties/hybrids coupled with high yields as compared to only high yield (Singh and Malhotra 2013). However, insect-tolerant varieties or hybrids are very rare in any crop. Hence for strengthening IPM, there is a need to breed insect-resistant varieties or hybrids. Biotechnological approaches should receive major emphasis, since they are innovative means to provide a wave of new, safe, and effective products through molecular biology and genetic engineering to resolve pest management problems.

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Cultivar Mixtures/Multiline Cultivars

17

Abstract

Use of multiline crop cultivars enhances guaranteed production, besides managing disease pathogens. However, the exact mode of action on disease pathogens is not well understood. Management of air-borne disease pathogens (*Septoria* spp., *Helminthosporium* spp., *Rhynchosporium* spp., and *Pseudocercosporella herpotrichoides*), soil-borne disease pathogens (*Helminthosporium victoria*, *Rhizoctonia solani*, *Pseudocercosporella herpotrichoides*, *Phytophthora sojae*, and *Cephalosporium gramineum*), viral diseases (oat yellow dwarf, wheat mosaic), and multiple diseases by using multiline crop cultivars have been discussed in this chapter. Management of insect pests (corn leafhopper, oat aphids, and leafhoppers on potato, cabbage, and lima bean) and weeds are also discussed.

Keywords

Crop pests • Rusts • Powdery mildews • Compensation • Facilitation • Variety mixtures • Multiline cultivars

17.1 Introduction

The monocropping practice is responsible for eroding genetic diversity of domesticated plants (FAO 2001) and prone to severe attack by disease pathogens (Altieri 1987). Some of the negative consequences of genetic uniformity include increased genetic vulnerability to pests (caused by microbial pathogens, insect pests, and weeds), prevention of crop yield stability, and increase in input costs on inorganic fertilizers and chemical pesticides which increase cost of cultivation.

One of the several alternatives to the monocropping practice is to utilize multiline crop cultivars with different genetic background to overcome diseases, insect pests, and weeds, besides guaranteed crop production (Lannou and Mundt 1996; Finckh

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and Wolfe 1998; Zhu et al. 2000). This technology has been primarily employed to manage crop disease pathogens like *Magnaporthe grisea* on *Oryza sativa* (Zhu et al. 2000), *Rhynchosporium secalis* on *Hordeum vulgare* (Newton et al. 1997), and *Puccinia striiformis* f. sp. *tritici* on *Triticum vulgare* (Sapoukhina et al. 2013). Some of the mechanisms by which multiline crop cultivars reduce the disease incidence include obstructing spore dispersal by resistant/tolerant plants, so that susceptible plants escape the disease (Chin and Wolfe 1984; Zhu et al. 2000).

This approach relies on crop diversity (Wolfe 1985) to adjust to unfavorable climatic factors, cut down the cost on inorganic fertilizers, and pest management (Finckh and Wolfe 1998; Yachi and Loreau 1999). Varietal mixtures can increase productivity by complementation between crop plants (Callaway 1995), resource partitioning, and niche differentiation (Loreau 2000; Mulder et al. 2001; Tilman 1996, 2004; Creissen et al. 2016).

Plant breeders developed crop varieties resistant to diseases and insect pests, which did not last long due to the development of new strains of the pathogen after their release into agricultural production. One of the potential low-cost methods of suppressing pests is enhancing the genetic diversity of the crop by mixing the seed of cultivars (genetic diversification) that vary in their susceptibility to specific pests (Wolfe 1988).

In order to produce good pest control and yield stability, multiline crop cultivars should be grown profitably with less input costs. The delay in breakdown of resistance can be achieved by changing the composition of mixtures. Crop varieties that possess different resistance genes (multiline varieties) and uniform for good quality can be developed by breeders that can be used in variety mixtures.

17.2 What Is a Cultivar Mixture?

Cultivar mixtures are quicker and cheaper to formulate and modify, enhance guaranteed economic returns, decrease in input costs on chemical pesticides without causing major changes to the agricultural production system. Multiline crop cultivars are phenotypically similar (height, grain type) but genetically different against insect pests and diseases (Browning and Frey 1981; Wolfe 1985). For example, barley multiline cultivars in Sub-Saharan countries used for the management of *Blumeria graminis* f. sp. *hordei* have similar agronomic characters. However, *Sorghum vulgare* multiline cultivars are visually different in color (Fig. 17.1).

In modern intensive agriculture, the balance between hosts and pests in artificial ecosystems is not balanced and disease flare-ups occur which are frequently managed using highly effective pesticides and by employing new cultivars with different resistance genes. In traditional ecologically based agriculture, disease flare-ups are rare in agroecosystems due to equilibrium obtained from the coevolution of crops and pathogens.

Fig. 17.1 Multiline cultivars of *Sorghum vulgare* with different grain colors

17.3 Cultivar and Species Mixtures in Practice

Worldwide, multiline cultivars are used in small as well as in very large areas. The area under varietal mixtures is substantial to the extent of 7000 ha of wheat in Pacific Northwest, USA, 14,000 ha of barley in Poland and Denmark, and 20,000 ha of coffee in Colombia.

17.3.1 Reasons for Growing Mixtures

The reasons for growing varietal mixtures are as follows:

- To attain better quality (Switzerland, coffee in Colombia).
- To avoid damage due to freezing in temperate countries.
- For management of diseases, insect pests, and weeds.
- To obtain higher yield stability.

17.3.2 Uses of Growing Mixtures

The uses of growing cultivar mixtures include animal feed, bread and beer production, and quality products. In order to avoid the dreaded pathogen *Hemileia vastatrix* on *Coffea* spp., almost all coffee in Colombia is produced through cultivar mixtures to get the highest quality coffee.

The resilience to biotic stresses can be enhanced by the cultivar mixtures due to their differences in reaction to key pests and productivity (Hughes et al. 2008; Tooker and Frank 2012).

17.4 Disease Management

The spread and intensity of disease can be moderated by intraspecific diversity within populations (Keesing et al. 2010; Wolfe 1985), which is responsible for large-scale employment of this technology (Mundt 2002; Zhu et al. 2000).

17.4.1 Air-Borne Pathogens

The air-borne dispersal phase of diseases such as rusts, mildews, *Septoria* spp., *Helminthosporium* spp., *Rhynchosporium* spp., and even *Pseudocercosporella herpotrichoides* can be reduced by adopting variety mixtures or multilines. Multiline crop cultivars offer guaranteed economic returns because of interactions among the components. The inoculums of air-borne pathogens can be reduced by using multiline crop cultivars which obstructs dispersal of propagules to susceptible lines, modifying the crop microclimate, or inducing resistance in certain varieties (Finckh et al. 2000; Mundt 2002). In addition to reducing the inoculums of pathogens, the durability of resistance genes is also enhanced by varietal mixtures (Mundt 2002; McDowell and Woffenden 2003).

Finckh and Mundt (1992) showed that the diseases were responsible for wheat yield loss between 52 and 58% in monocropping, which can be significantly reduced by adopting multiline crop cultivars. Similarly, varietal mixtures reduced level of wheat powdery mildew infection by 35% (Day 1984).

By increasing the number of cultivars in multilines in a mixture, the disease management efficiency can also be enhanced. However, even two cultivars in multilines mixture can efficiently manage *Puccinia triticina* on *Triticum vulagre* (Cox et al. 2004).

The random mixtures were effective in reducing crown rust in oats. Bean rust disease can be managed by reducing genotype unit areas (GUA) (Mundt and Leonard 1986). Likewise, by reducing genotype unit areas, disease pathogens such as *Puccinia striiformis* f. sp. *tritici* and *Puccinia triticina* on *Triticum vulagre* can also be managed (Brophy and Mundt 1991).

Newton and Begg (2008) showed that planting of multiline crop cultivars in patches can be utilized to manage scald disease in *Hordeum vulgare*. In addition to management of scald disease, patchy sowing was also found to enhance barley crop productivity (Newton and Guy 2009).

Using resistant and susceptible cultivars in mixtures is beneficial for the management of diseases. In Yunnan Province, Zhu et al. (2000) reported that by planting resistant and susceptible cultivar mixtures, the incidence of *Magnaporthe grisea* on *Oryza sativa* can be significantly reduced, resulting in higher productivity

(Wolfe 2000). Similarly, the incidence of late blight of potato (*Phytophthora infestans*) was reduced by 36–37% in mixtures as compared to monocropping (Garrett and Mundt 1999).

The powdery mildew disease on *Hordeum vulgare* declined from over 50% to less than 10% in multiline crop cultivars, thus reducing the fungicide requirement substantially (Wolfe 1997). Moreno Ruiz and Castillo Zapata (1990) reported that by growing multiline cultivars of *Coffea* spp., the incidence of rust disease in Latin-American countries was considerably reduced.

17.4.2 Soil-Borne Pathogens

The soil-borne pathogens can be managed by using variety mixtures through interactions between plant genotypes in mixtures. Hariri et al. (2001) reported that the soil-borne mosaic viral disease of wheat vectored by *Polymyxa graminis* zoospores can be managed by using cultivar mixtures. The reduction in soil infested foci of *Avena sativa* blight disease is obtained by multiline cultivars (resistant and susceptible) (Ayanru and Browning 1977). Sugar beet (*Beta vulgaris*) mixtures containing about 17–33% resistant plants can manage crown/root rot disease caused by *Rhizoctonia solani* (Halloin and Johnson 2000). Mundt et al. (1995) showed that eyespot of wheat, caused by *Pseudocercosporella herpotrichoides*, can be managed by mixing one or more cultivars of resistant wheat.

17.4.3 Viral Diseases

Studies on the effects of varietal mixtures on viral diseases are very much limited. Mixtures of resistant:susceptible oat (*Avena sativa*) cultivars in 1:1 ratio decreased *yellow dwarf virus* (Power 1991). The higher disturbance of aphids in varietal mixtures might be responsible for reduced virus transmission rates, since aphids have to feed for long periods to transmit the virus (Power 1991).

Mixtures of resistant:susceptible wheat cultivars in 1:1 and 3:1 ratio reduced soil-borne mosaic disease in *Triticum vulgare*. Inclusion of lines with resistance to virus in multiline cultivars affected the spread of disease to susceptible lines, because the soil-borne vector, *Polymyxa graminis*, did not produce viruliferous zoospores under field conditions (Hariri et al. 2001).

17.4.4 Management of Multiple Diseases

Varietal mixtures can be utilized to manage multiple diseases under field conditions by using more than one resistant line. For example, by including two cultivars (one resistant to *Pyrenophora tritici-repentis* and another to *Puccinia triticina*) in varietal mixtures of wheat, both disease pathogens can be managed (Cox et al. 2004).

Table 17.1 Use of multiline cultivars for the management of *Puccinia striiformis* f. sp. *tritici* on *Triticum vulagre*

Components	Mixtures	Mean reduction in disease severity
2	10	31
3	10	42
4	5	49
5	1	48

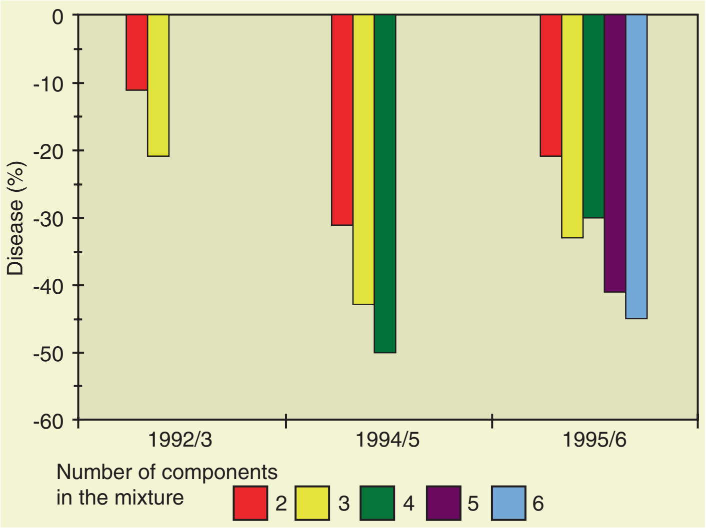


Fig. 17.2 Effect of number of component cultivars on severity of scald in mixtures of *Hordeum vulgare*

17.4.5 Cultivar Numbers in Good Mixture?

Disease control benefit achieved is influenced by the number of cultivars in multilines. The number can go as high as 5 (3–4 is ideal) to decrease the incidence of *Puccinia striiformis* f. sp. *tritici* on *Triticum vulagre* (Table 17.1) (Mundt 1994). Similarly, the number can be increased up to 5 to decrease the severity of scald on winter barley (Fig. 17.2) (Newton et al. 1997).

Management of several crop diseases using various multiline cultivars is presented in Table 17.2.

17.4.6 Mechanisms of Action

Cultivar mixtures only decrease the pathogen propagules spread in each life cycle to decrease the disease incidence. Spores are deposited on resistant plants, and thereby eliminated from the epidemic. Further, presence of avirulent pathogens on

Table 17.2 Effect of cultivar mixtures on the degree of disease suppression in different crops

Crop	Disease	Character	Decrease in incidence (%)	References
Zea mays	*Puccinia sorghi*	Pustules/plant	50	Mundt and Leonard (1986)
Phaseolus vulgaris	*Uromyces appendiculatus*	AUDPC	30–60	Mundt and Leonard (1986)
Triticum vulgare	*Puccinia striiformis* f. sp. *tritici*	Severity	14–64	Mundt (1994)
	Leaf rust	Severity	45	Mundt (1994)
Barley	Scald	Severity	12	Mundt et al. (1994)
	Scald	Severity	11–50	Newton et al. (1997)
	Powdery mildew	Severity	0–20	Newton et al. (1997)

specific host genotypes induces defense responses in susceptible plants, which slows down the infection process, leading to reduction in the disease incidence.

Modes of action of multiline crop cultivars includes the following:

- Barrier action
- Induced resistance
- Microclimate modification

17.4.6.1 Dilution and Barrier Effect

The reduction/slowdown in rate of plant to plant disease spread can be achieved by increasing the distance between susceptible plants. Obstruction of pathogen spread and interruption is provided by presence of resistant plants in the canopy. The strength of the barrier effect is influenced by the physics of spore dispersal and the proportion of plants that resist the pathogens.

Disease development is slowed down by decreasing the density of susceptible plants. The disease pathogen *Blumeria graminis* f. sp. *hordei* on *Hordeum vulgare* can be managed by following the ideal spatial arrangement of host genotypes in multiline crop cultivars (Chin and Wolfe 1984).

Similarly, the obstruction of disease pathogen inoculum also causes the barrier effect. The effectiveness of the cultivar mixture is influenced by the size of the host plant in both dilution and barrier effect mechanisms. Garrett and Mundt (1999) reported that by increasing the proportion of susceptible cultivars, the disease management efficiency of mixture decreases.

17.4.6.2 Induced Resistance

Inoculation with spores of an avirulent strain or race triggers biochemical host defense response such as induced resistance, which slows down the development of

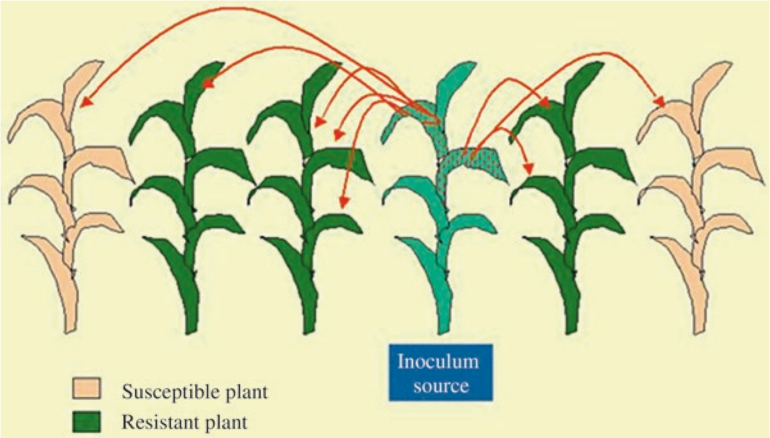
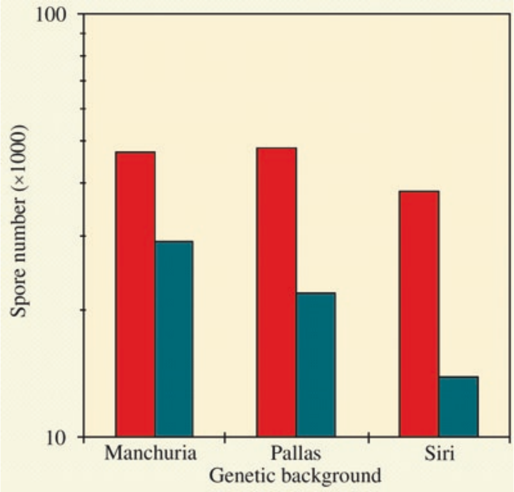


Fig. 17.3 Induced resistance

Fig. 17.4 Effect of cultivar mixtures on powdery mildew spore production on *Hordeum vulgare* (*red*-virulent; *blue*-avirulent, and then *virulent*) (Martinelli et al. 1993)



new races of the pathogen (Fig. 17.3) (Lannou et al. 1995). This results in reduction of either the number of new spores produced or the infection efficacy as a result of powdery mildew on barley (Fig. 17.4) (Martinelli et al. 1993). Lannou et al. (1995) reported that a significant disease reduction at the epidemic level was observed even in induced resistance at local level by nonpathogenic propagules. Induced resistance plays a major role in the management of wheat stripe rust and barley powdery mildew by using multiline crop cultivars (Calonnec et al. 1996; Chin and Wolfe 1984).

Table 17.3 Effect of genotypic diversity on herbivore management and enhancement of productivity

Crop	Ecological variable	Pests managed	Effect on crop productivity	References
Corn	Insect density	*Cicadulina mbila*	Positive	Power (1988)
Oat, *Avena sativa*	Insect density and behavior	*Rhopalosiphum padi*	Positive	Power (1991)
Potato, cabbage, lima bean	Insect density	*Empoasca fabae*	Mixed	Cantelo and Sanford (1984)

17.4.6.3 Microclimate Modification

The microclimate conditions are modified by the crop cultivar characteristics of component cultivars which are more favorable for suppression of the disease (Wolfe 1985). The microclimate conditions, especially the humidity, play an important role in the management of rice blast using multiline crop cultivars (Zhu et al. 2005).

17.5 Insect Pest Management

Increasing genotypic diversity by multiline crop cultivars reduces herbivore populations and enhances crop productivity (Table 17.3) (Teetes et al. 1994). Figure 17.5 presents the mode of action of multiline crop cultivars for insect management and enhancement of yield (Tooker and Frank 2012; Underwood 2009).

Varietal mixtures with intraspecific diversity have enhanced insect pest management in agroecosystems (Cantelo and Sanford 1984; Power 1991). Power (1991) found that mixtures of five corn and two oat varieties harbor fewer leafhoppers and aphids, respectively, when pest populations were large. Likewise, mixing of susceptible and more resistant varieties of potato reduced the leafhopper population (Cantelo and Sanford 1984).

Reduction in aphid (*Rhopalosiphum padi*) populations can be achieved by increasing the diversity of mixtures of wheat genotypes (*Triticum aestivum*) as compared to monocultures. The genotypic mixtures were more productive than monocultures in the absence of aphids, due to the release of greater amounts of volatile organic compounds by noninfested genotypic mixtures.

17.5.1 Challenges

The challenges of multiline crop cultivars in pest management are as follows:

- Even though species diversity can improve pest suppression, the effectiveness appears context dependent and inconsistent (Andow 1991; Baggen and Gurr 1998).

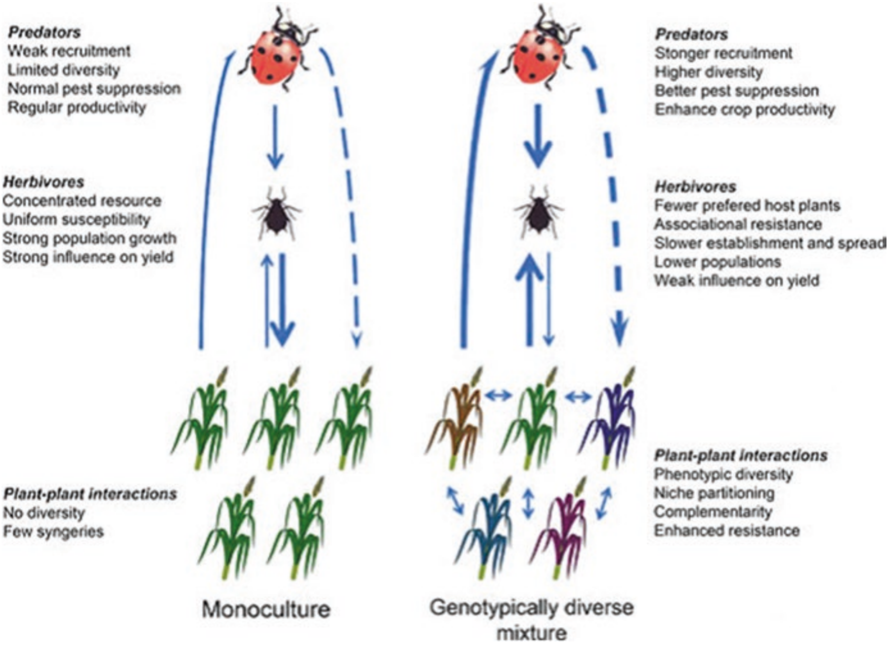


Fig. 17.5 The mode of action of multiline crop cultivars for insect pest management and enhancement of yield

- The farmer has to face considerable logistical and/or economic challenges to increase plant species diversity in agroecosystems. With modern agricultural equipment, it is not compatible to grow multiple crops. Besides, the land available for production is reduced by diversification via noncrop areas.

Hence, strategies to increase plant diversity for better pest control are rarely implemented by farmers, in view of questionable economic benefits and considerable challenges (Letourneau et al. 2011; Lin 2011).

17.6 Weed Management

The competing weed seedlings can be prevented from establishing using multiline crop cultivars (Crutsinger et al. 2006). Enhanced weed suppression can be obtained by proper variety selection (Kiaer et al. 2006; Rodríguez 2006). Varietal mixtures enhanced the competitive ability of rainfed, low-input, lowland rice, reduced weed biomass production and rice biomass losses, and enhanced grain yield (Binang et al. 2011).

17.7 Conclusions

Reduction in disease, decrease in insect pest abundance, and increase in crop yield occur by enhancing the diversity of genotypes within crop fields. Planting of varietal mixtures for pest management is highly beneficial to the farmers. In order to effectively manage pathogens of rice, wheat, and other crops, the popular way is to use diverse varietal mixtures. Further, intraspecific crop diversity strongly influences the insect herbivore populations. Enhancing genotypic diversity is an ecologically sound pest management strategy that decreases pest problems.

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Allelopathy

18

Abstract

Allelopathy, a naturally occurring ecological phenomenon of interference among organisms, is emerging as a pragmatic approach for resolving multiple issues, including pest management, stress mitigation, and growth enhancement in crop production in modern agriculture. It is employed for managing weeds, insect pests, diseases, and nematodes in crop plants through multiple approaches, including crop rotations, cover crops, intercropping, mulching, incorporation of crop residues, and application of water extracts. Application of mixtures of allelopathic plant extracts is more effective than application of single-plant extract. The dose of herbicide can be reduced by one-half by combining it with the application of allelopathic plant extracts which give as much weed control as the standard herbicide dose in several crops. The development of herbicide resistance in weed ecotypes may be reduced by using lower doses of herbicides. Hence, this phenomenon is quite effective and an environment-friendly alternative to pesticides in managing agricultural pests and improving the productivity of agricultural systems. In this chapter, potential application of the allelopathic phenomenon for natural pest management in crop plants is discussed.

Keywords

Allelochemicals • Environment • Weeds • Insect pests • Diseases • Nematodes • Crop rotation • Mulching • Cover crops • Crop protection • Secondary metabolite

18.1 Introduction

The most widely adopted method for managing pests (weeds, insect pests, diseases, and nematodes) for successful crop production is the use of chemical pesticides. Indiscriminate use of pesticides has led to contamination of surface and ground water (Snelder et al. 2008), residues of pesticides from plants entering the soil or

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food chain, that prove hazardous to both humans and animals (McKinlay et al. 2008). The food security, a challenge for scientists and farming community, is due to ever-increasing human population that is expected to reach nine million by 2050. Pests which are responsible for 26–40% crop losses are one of the major constraints in crop production (Oerke 2006). The phenomenon of allelopathy may be wisely exploited in cropping systems to substitute for heavy use of pesticides for an effective, economical, natural, and alternative method of sustainable pest management.

18.2 Allelopathy

Allelopathy is a natural ecological phenomenon whereby secondary metabolites synthesized by plants, fungi, viruses, and microorganisms affect the functioning of other organisms in their vicinity, negatively (inhibitory) or positively (stimulatory) (Farooq et al. 2011). According to Rice (1984), allelopathy is the influence of one plant on the growth of another one, including microorganisms, by the release of chemical compounds into the environment. These chemicals released (allelochemicals) are mostly secondary metabolites produced as by-products during different physiological processes in plants (Farooq et al. 2011; Bhadoria 2011). The allelochemicals can be synthesized in any plant parts, i.e., leaves, stems, roots, bark, seeds, which are identified as alkaloids, amino acids, brassinosteroids, carbohydrates, flavonoids, glucosinolates, hydroxamic acids, jasmonates, momilactone, phenolics, salicylates, and terpenoids (Kruse et al. 2000; Jabran and Farooq 2012). Allelochemicals are released into the environment under favorable environmental conditions through the processes of decomposition, leaching, root exudation, and/or volatilization, affecting the growth of adjacent plants (Rice 1984; Bonanomi et al. 2006). Vital physiological processes like activity of many enzymes, cell division and elongation, membrane fluidity, photosynthesis, protein biosynthesis, respiration, and tissue water status are influenced by allelochemicals (Field et al. 2006). They can be used as natural pesticides at high concentration for the management of crop pests (Farooq et al. 2009).

Allelochemicals can be utilized to solve problems such as resistance development in pest biotypes, pest management, and soil and environmental pollution caused by the nonjudicious use of synthetic pesticides (Dayan et al. 2009; Zhu and Li 2002; Roeleveld and Bretveld 2008). The biotic stresses such as weed infestation, insect pests, disease pathogens, and nematodes can be managed by using allelopathic crops as cover crops, intercrops or green manures, mulch, smother crops, or grown in rotational sequences. Besides pest management, allelopathic crops may additionally build up fertility and organic matter status of the soil, thereby reducing soil erosion and improving farm yields (Jabran et al. 2007; Khanh et al. 2005). The effect of allelochemicals on pest management may be enhanced by combining extracts of several plants (Jamil et al. 2009). Hence, allelopathy can be utilized as a natural alternative to chemical and mechanical options for pest management, crop growth, and enhancement of productivity.

18.3 Weed Management

Allelopathic species suppress weeds when employed in the field following crop rotation (Wu et al. 1999), cover or smother crops (Khanh et al. 2005; Bhowmik and Inderjit 2003), intercropping, crop residue incorporation (Khanh et al. 2005; Bhowmik and Inderjit 2003; Singh et al. 2003; Wu et al. 1999), mulching (Khanh et al. 2005; Singh et al. 2003), and allelopathic crop water extracts (Jabran et al. 2007, 2008, 2010a, b; Rastogi and Sinha 2009).

The inhibitory potential of different allelochemicals in crops and trees is attributed to the blockage or cessation of important physiological and metabolic processes of a plant that has been used directly and indirectly for weed management (Cheema et al. 2004; Iqbal et al. 2007; Jamil et al. 2009; Farooq et al. 2011b). The use of allelochemicals for weed suppression is a pragmatic substitute for synthetic herbicides that do not have any residual or toxic effects (Bhadoria 2011).

Birkett et al. (2001) reported the following pragmatic options for weed suppression using allelopathy:

- Exploration of traditional approaches like intercropping with plants such as *Mentha* spp., *Satureja montana*, and cultivated members of the genus *Ocimum* to suppress weeds (Shlevin 2000). Soil application of the essential oils from these plants can replace commonly used methyl bromide for soil fumigation to manage soil-borne pathogens. Intercropping with aggressive competitors like sweet potato (*Ipomoea batatas*) can be utilized for successful management of noxious weeds and parasitic plants such as strigas (*Striga hermonthica* and *S. riga asiatica*) (Oswald et al. 1998).
- Intercropping of maize with two leguminous plants such as greenleaf Desmodium (*Desmodium intortum*) and silverleaf Desmodium (*D. uncinatum*) is employed for effective management of *S. hermonthica* and stem borer infestations (Khan et al. 2000). The *C*-glycosylflavonoid called isoschaftoside released from silverleaf Desmodium is responsible for allelopathic suppression of *Striga* in maize–silverleaf Desmodium intercropping (Hooper et al. 2009), since the *Desmodium* spp. are known for their insect-repelling properties (Khan et al. 2000).

Hence, allelopathy may be exploited profitably in various weed management strategies as detailed below.

18.3.1 Crop Rotation

Allelochemicals from smothering or allelopathic crops which are released during the decomposition of the preceding crop residues are responsible for the suppression of weeds (Mamolos and Kalburtji 2001; Narwal 2000; Voll et al. 2004). An increase in crop yields to the extent of 20% can be obtained by a properly designed crop rotation (Sauerborn et al. 2000). The potential autotoxic effects associated with allelochemicals are also neutralized during crop rotation. The allelochemicals added to soil by the sorghum (*Sorghum bicolor*) crop are responsible for the suppression of weeds in the following crops (Einhellig and Rasmussen 1989).

In the rice–wheat cropping system, integration of smothering allelopathic crops, such as maize, pearl millet (*Pennisetum glaucum*), and sorghum grown after harvesting wheat (*Triticum aestivum*) and before rice transplantation, offers effective weed suppression for the upcoming rice crop for at least 45 days. Rotation of wheat fields (heavily infested with weeds) with fodder crops such as Egyptian clover (*Trifolium alexandrinum*) or oats (*Avena sativa*) gave natural weed control for at least one season (Peters et al. 2003). Wheat stimulates parasitic seed germination without attachment, and thus acts as a trap crop (false host) for suppression of the parasitic weed infestation (Lins et al. 2006).

In contrast, some crop rotations with allelopathic crops may also have damaging consequences. For example, allelochemicals exuded from sorghum affected the development of the subsequent wheat crop in a sorghum–wheat rotation (Roth et al. 2000). Hence, there is a need for investigation of rotational sequences with allelopathic effects to control weeds and screening and development of crop varieties with allelopathic effects against pests (for further details on crop rotation, see Chap. 15).

18.3.2 Cover Crops

Besides controlling weeds (Hiltbrunner et al. 2007; Hartwig and Ammon 2002; Gallandt and Haramoto 2004), cover crops conserve soil, suppress insects, nematodes, and other disease pathogens, enhance nutrient recycling, and supply fodder. Soil incorporation of green manure cover crops provides allelopathic effects by the release of chemicals that inhibit the germination of weed seeds. Dabney et al. (1996) suggested that drilling of direct sown crops should be delayed as the germination suppressive effect can last several weeks, while transplants can be introduced directly into the system with a reduction in weed germination. The crops with large seeds are less sensitive to the allelopathic effects of green manure residues than small-seeded weeds (Putnam and DeFrank 1983).

Several green manure cover crops such as crimson clover (Dyck and Liebman 1994), lucerne (Chung and Miller 1995), red clover (Fisk et al. 2001), subterranean clover (Nagabhushana et al. 2001), vetch (Kamo et al. 2003), sun hemp (*Crotalaria juncea*), yellow sweet clover (*Melilotus officinalis*), cowpea, alfalfa (*Medicago sativa*), and velvet bean have been found to have allelopathic effects on weeds. Similarly, some cereal crops like sorghum and ryegrass (*Lolium perenne*) (rye being the most effective) (Nagabhushana et al. 2001), and high glucosinolate varieties of Brassicas (Vaughn and Boydston 1997) can also contribute to weed control.

Some cover/fodder crops such as Desmodium (*Desmodium* spp.), Mucuna (*Mucuna* sp.), and Stylosanthes (*Stylosanthes guianensis*) can stimulate 70% more *Striga* germination than maize without being parasitized (Ndung'u et al. 2000; Khan et al. 2008). The mechanism involved in allelopathic suppression effect on *S. hermonthica* by Desmodium includes both chemical stimulation of germination and

Table 18.1 Allelopathic effects of cover crops on weeds

Cover crop	Weeds suppressed	References
Hairy vetch	Lamb's-quarters, yellow foxtail, yellow nutsedge, pitted morning glory	Teasdale and Daughtry (1993) and White et al. (1989)
Crimson clover	Pitted morning glory, wild mustard, Italian ryegrass	Teasdale and Daughtry (1993) and White et al. (1989)
Cereal rye	Lamb's-quarters, redroot pigweed, common ragweed	Barnes and Putnam (1986) and Masiunas et al. (1995)
Wheat	Morning glory, prickly sida	Liebl and Worsham (1983)
Velvet bean	Yellow nutsedge, chickweed	Hepperly et al. (1992) and Fujii et al. (1992)
Sorghum Sudan grass	Annual ryegrass	Forney and Foy (1985)

inhibition of the development of *S. hermonthica* hyphae by at least two different isoflavanones released from Desmodium roots.

The barnyard grass (*Echinochloa crus-galli*) population was substantially reduced in maize by the use of legume cover crops such as jack bean (*Canavalia ensiformis*), jumbie bean (*Leucaena leucocephala*), velvet bean, and wild tamarind (*Lysiloma latisiliquum*). Caamal-Maldonado et al. (2001) reported that velvet bean was the most effective cover crop for the suppression of weeds in maize. Similarly, soybean weeds such as crab grass (*Digitaria ciliaris*) and barnyard grass were effectively suppressed by barley (*Hordeum vulgare*) grown as a cover crop (Kobayashi et al. 2004). Likewise, Kobayashi et al. (2003) reported that the mission grass (*Pennisetum polystachion*), a troublesome weed in rubber plantations, was managed by the smothering effects of cover crops such as velvet bean, jack bean, and hyacinth bean (*Lablab purpureus*). Use of spider lily (*Lycoris radiata*) as a ground cover crop or its incorporation into the soil as mulch inhibits emergence and reduces root and shoot growth and root dry weight of rice weeds by the release of allelochemical lycorine (0.08%) (Iqbal et al. 2006).

Teasdale and Daughtry (1993) reported that in no-till management, the allelopathic effects of crimson clover and hairy vetch are more apparent if the cover crop is incorporated rather than left on the surface. Some of the cover crops which exhibit allelopathic effects on certain weeds are presented in Table 18.1 (for further details on cover crops, see Chap. 7).

18.3.3 Mulching

Allelopathy can play an effective role in suppressing weeds by soil surface mulching with crop residues (Cheema et al. 2003a, b, c, d; Khaliq et al. 2010). Spreading of mulch over the soil surface suppresses weeds by obstructing seed germination and inhibiting weed seedling growth through the release of allelochemicals (Teasdale and Mohler 2000; Bilalis et al. 2003). Besides weed suppression, soil surface mulching of allelopathic crop residues enhances agricultural sustainability by adding organic matter to the soil, enhancing biological activities in the soil, controlling soil erosion, conserving soil moisture, improving water infiltration into the soil, regulating/modifying the soil temperature, and decreasing the impact of raindrops on the soil (Doring et al. 2005).

The use of mow-killed grain rye as a mulch prevents weed germination (Creamer et al. 1996) by leaching of allelochemicals from rye residue which do not harm transplanted tomatoes, broccoli, and many other vegetable crops. Ciaccia et al. (2015) found that by flattening rye cover crop with a roller-crimper, melons can be transplanted into the residue to lower the weed pressure, protect soil from both desiccation and erosion, and enhance yield. Rye is considered as one of the best crops for weed seed suppression, since it contains 16 different allelopathic chemicals (Jabran et al. 2015). Putnam (1988) reported that the chemicals produced by actinomycetes, algae, fungi, or other microbes, associated with particular plant root systems in the upper soil layers, can enhance the specific allelopathic effects of certain plants.

The noxious paddy weeds such as barnyard grass, flat sedge (*Cyperus difformis*), jungle rice (*Echinochloa colonum*), and purple nutsedge (*Cyperus rotundus*) can be suppressed by more than 70% and paddy yield can be increased by 20% by the application of allelopathic plant mulches to rice fields at 1–2 t ha^{-1} (Xuan et al. 2005). Sunflower (*Helianthus annuus*), wheat and maize weed species like annual meadow grass (*Poa annua*), common chickweed (*Stellaria media*), German chamomile (*Matricaria chamomilla*), henbit dead-nettle (*Lamium amplexicaule*), and shepherd's purse (*Capsella bursa-pastoris*) can be managed by soil amendment with olive wastes (10 cm deep) (Boz et al. 2003). The suppression of weed population of barnyard grass and monochoria (*Monochoria vaginalis*) and enhancement of rice yields by 35% can be achieved by the application of surface mulch of purple passion fruit (*Passiflora edulis*) at 2 t ha^{-1}, and rice hull and bran at 1 t ha^{-1} (Xuan et al. 2003) through the release of ten allelochemicals from coumarins, long-chain fatty acids, and lactones (Khanh et al. 2006).

Soil amendment with mint marigold (*Tagetes minuta*) (medicinal plant) at 1–2 t ha^{-1} suppressed problematic rice weeds such as barnyard grass and purple nutsedge, while little seed canary grass (*Phalaris minor*) weed in wheat fields is managed, and plant height, tillering, dry matter, and grain yield are increased by mulching with leaf and root powder of Indian catmint (*Anisomeles indica*) (Batish et al. 2007b).

Weed management through allelopathic mulches, incorporation of crop residues, cover crops, and intercropping is presented in Table 18.2.

18.3.4 Allelopathic Plant Extracts

Substantial suppression of the weed density and biomass reduction is achieved by the use of allelopathic plant extracts at high concentrations. One of the most widely used water extract of plants as a natural herbicide is sorghum, which suppresses weed biomass (49%) and density (44%) of *C. album*, *Fumaria indica*, *P. minor,* and *Rumex dentatus* in wheat crop, with a simultaneous increase in grain yield (21%)

Table 18.2 Weed control through allelopathic mulches, crop residues incorporation, cover crops, and intercropping

Allelopathic source	Application mode	Crop	Weed species	Weeds % dry weight reduction	Yield increase (%)	References
Sorghum	Soil incorporation	Wheat	*Platanthera minor*, *Chenopodium album*	48.0–56.0	16.0–17.0	Cheema and Khaliq (2000)
	Surface mulch	Cotton	*Trianthema portulacastrum*, *Convolvulus arvensis*, *Cynodon dactylon*, *C. rotundus*	5.0–96.6	69.2–119.3	Cheema et al. (2000)
Sunflower + Rice + Brassica	Soil incorporation	Maize	*T. portulacastrum*	60.1	41.0	Khaliq et al. (2010)
Cotton + Sorghum	Intercropping	–	*C. arvensis*, *T. portulacastrum*	92.0	23.7	Iqbal et al. (2007)
Mexican marigold (*T. minuta*)	Dried leaf powder mulch	Rice	*Echinochloa crus-galli*, *C. rotundus*	41.2	33.8	Batish et al. (2007a)
Rye	Cover crop	Rice	*Sida spinosa*, *Xanthium strumarium*, *Ipomoea* spp., *Cassia obtusifolia*, *Portulaca oleracea*, *Amaranthus* spp.	80–90	–	Nagabhushana et al. (2001)

(Cheema and Khaliq 2000). Further, they reported that sorghum water extract provided 15–47% and 19–49% reduction in weeds density and dry weight, respectively. Similarly, biomass and population of wheat weeds like lamb's-quarters (*C. album*), lesser swine-cress (*Coronopus didymus*), toothed dock (*R. dentatus*), and Indian fumitory (*Fumaria parviflora*) were significantly suppressed to the extent of 53% and 36%, respectively. Wheat yield was increased by 14% when sorghum water extract at 10% concentration was applied 60 days after sowing (DAS). Likewise, considerable suppression of wheat weeds like lamb's-quarters, little seed canary grass, wild oat (*Avena fatua*), field bindweed (*C. arvensis*), and toothed dock density by 22–39% was reported by the application of sorghum water extract (Cheema et al. 2002a, b).

Weeds of cotton, sunflower, and green gram have also been successfully suppressed using sorghum water extract, resulting in increased yield of these crops by 3–59% depending upon the type of crop, frequency of application, and time of application (Cheema et al. 2012). Similarly, the sole application of sorghum water extract suppressed weeds to the extent of 35.4–49.0%, 29.0–40.1%, 23.7–59.6%, and 40.4% in wheat (Cheema and Khaliq 2000), cotton (*Gossypium hirsutum*) (Cheema et al. 2002a, b), green gram (*Vigna radiata*) (Cheema et al. 2001), and rice (Wazir et al. 2011), respectively.

Cheema et al. (2003a, b, c, d) reported that the integration of plant extracts of sorghum with Brassica, eucalyptus, rice, and sunflower was found more effective for weed management than the sole application of either water extract (Cheema et al. 1997). There is a synergistic effect of allelochemicals due to the interactions between different plant extracts (Duke and Lydon 1993). Jamil et al. (2009) obtained 36–55% and 42–62% suppression of weeds like little seed canary grass and wild oat biomass, respectively, and increased wheat grain yield by 89% in the first year and by 35% in the second year of experimentation over weedy check, by combined application of sorghum and sunflower extracts at 6 L ha^{-1} each.

The water-soluble secondary metabolites or allelochemicals present in the plant tissues are responsible for growth suppression of weeds due to the interference with the cell division, hormone biosynthesis, and mineral uptake and transport (Rizvi et al. 1992); membrane permeability (Harper and Balke 1981); plant–water relations (Rice 1984); respiration and protein metabolism (Kruse et al. 2000); and stomatal oscillations and photosynthesis (Einhellig and Rasmussen 1979).

Suppression of several weeds by the use of different plant extracts is presented in Table 18.3.

18.3.5 Combined Effect of Allelopathic Water Extracts and Herbicides

The dose of chemical herbicides can be reduced by the integration of plant extracts with potential herbicides (Cheema et al. 2012). Integration of plant extracts of Brassica, rice, and sesame (Rehman et al. 2010), and eucalyptus, sorghum, and sunflower (Cheema et al. 2003a, b, c, d) effectively suppressed weeds and reduced

Table 18.3 Effect of allelopathic plant extracts on weed suppression

Allelopathic plant extract	Crop	Weeds controlled	Weed control		% Yield increase over control	References
			Reduction in density (%)	Reduction in dry weight (%)		
Sorghum	Wheat	*F. indica*, *P. minor*, *R. dentatus*, *C. album*	21.6–44.2	35.4–49.0	11.0–20.0	Cheema and Khaliq (2000)
	Cotton	*T. portulacastrum*, *C. dactylon*, *C. rotundus*	47.0	29.0–40.1	17.7–59.0	Cheema et al. (2002a, b)
	Green gram	*C. rotundus*, *C. album*, *C. arvensis*	17.5–31.6	23.7–59.6	4.0–17.7	Cheema et al. (2001)
	Rice	*Echinocloa colonum*, *C. rotundus*, *Cyperus iria*	–	40.4	12.5	Wazir et al. (2011)
Sunflower	Wheat	*A. fatua*, *M. officinalis*, *P. minor*, *Rumex obtusifolius*	10.6–33.6	2.2–16.5	1.6–10.7	Cheema et al. (2003a, b, c, d) and Naseem et al. (2010)
Sorghum	Sunflower	*A. fatua*, *P. minor*	–	10.0–62.0	18.55–62.0	Jamil et al. (2009)
	Brassica					
	Tobacco					
	Sesame					

herbicide dose up to one-half of the recommended one. Thus, crop growth and yield can be enhanced by allelopathic weed suppression by reducing weed–crop competition (Table 18.4).

Integration of sorghum allelopathic plant extract (12 L ha^{-1}) along with 50–60% reduced rate of isoproturon application suppressed weeds in wheat fields (Cheema et al. 2003a, b, c, d). Similarly, weeds in cotton and maize were suppressed by combined application of sorghum allelopathic plant extract (12 L ha^{-1}) with a half-dose of atrazine (150 g ha^{-1}) (Cheema et al. 2003a, b, c, d; Iqbal et al. 2009). Further, integration of one-third of the standard dose of pendimethalin along with sorghum plant extract (12 L ha^{-1}) produced more seed cotton yield than the full dose (Iqbal et al. 2009). Likewise, weeds in a canola field were suppressed by the application of sorghum plant extract along with 60% reduced rate of isoproturon (400 g ha^{-1}) (Cheema et al. 2003a, b, c, d).

There is a substantial scope for decreasing the dose of herbicides by the integration of mixtures of plant extracts from different plants. For example, combined application of a mixture of plant extracts from Brassica, rice, sorghum, and

Table 18.4 Effect of integration of allelopathic plant extracts and reduced doses of herbicides on weed management

Allelopathic plant extract + herbicide (1/2 dose)	Crop	Weeds controlled	Weed control		% Yield increase over control	References
			Reduction in density (%)	Reduction in dry weight (%)		
(Sorghum) + Isoproturon	Wheat	*P. minor*, *Melilotus parviflora*	94.2	64.8	32.2	Cheema et al. (2002a, b)
(Sorghum + sunflower) + Pendimethalin	Sunflower	*C. album*, *Melilotus indica*	84.0	67.3	16.4	Awan et al. (2009)
(Sorghum + Brassica) + Pendimethalin	Canola	*T. portulacastrum*, *C. rotundus*, *C. album*, *C. didymus*	42.8–91.3	37.4–94.1	39.9	Jabran et al. (2008, 2010a, b)
(Sorghum + Sunflower + Rice) + Butachlor	Rice	*E. crus-galli*, *C. iria*, *Dactyloctenium aegyptium*	74.0–67.0	66.0–76.0	61.0	Rehman et al. (2010)

sunflower with one-third and half the recommended dose of pendimethalin suppressed weeds in a canola field and increased yields (Jabran et al. 2008, 2010a, b). Further, most effective weed suppressions in the canola were to the extent of 67.58% and 66.21% at 40 and 60 DAS, respectively, by the application of rice and sorghum water extracts in combination with a half-dose of pendimethalin, while the maximum canola seed yield of 2.6 Mg ha^{-1}, which was 39.99% more than the control, was obtained with a combined application of sorghum and sunflower water extracts (15 L ha^{-1}) + 600 g ha^{-1} pendimethalin (600 g ha^{-1}) (Jabran et al. 2008, 2010a, b).

18.4 Insect Pest Management

Management of insect pests can be achieved by using potent weapons like natural compounds which have the advantages of biodegradation, easy handling, economic affordability, and environmental safety (Farooq et al. 2011a). Many plants utilize the natural defense mechanism against insect pests through the arsenal of secondary metabolites. For example, allelochemicals such as azadirachtin, nimbin, and salannin in neem (*Azadirachta indica*) reduce or inhibit the growth of several insect pests like green cicadellid (*Jacobiasca lybica*) and whitefly (*Bemisia tabaci*) (Farooq et al. 2011a). Further, neem oil exhibits antifeedant action against strawberry aphids (*Chaetosiphon fragaefolii*) (Lowery and Isman 1993). Similarly, aphids and sucking insects of *Brassica* spp. were managed by allelopathic water extracts of mulberry, mustard, sorghum, and sunflower (Farooq et al. 2011a). Likewise, Hongo and Karel (1986) reported that flower thrips (*Taeniothrips sjostedti*) and pod borer (*Heliothis armigera*) in common beans were effectively controlled by plant extracts of tomato (*Lycopersicon esculentum*). The Mediterranean fruit fly (*Ceratitis capitata*) is suppressed by the allelochemicals such as coumarins and flavonoids from a scented plant common rue (*Ruta graveolens*).

Plant extracts of California pepper tree (*Schinus molle*) were effective against adults of the elm leaf beetle (*Xanthogaleruca luteola*) by killing 100% of the population (Huerta et al. 2010). Allelochemicals from weeds like chick weed (*Ageratum conyzoides*), great ragweed (*Ambrosia trifida*), and Spanish flag (*Lantana camara*) were not only inhibitory to insects such as cowpea weevil (*Callosobruchus maculatus*) but also effective in controlling weeds and diseases (Kong 2010).

Stored grain insect pests can be managed by using allelochemicals produced by some plants. For example, Saljoqi et al. (2006) found that some allelochemicals produced by bakain (*Melia azedarach*), habulas (*Myrtus communis*), lemon grass (*Cymbopogon citratus*), and mint (*Mentha longifolia*) act as insecticides against rice weevil (*Sitophilus oryzae*). Similarly, chickpea beetle (*Callosobruchus chinensis*) can be managed by secondary metabolites produced from bhang (*Cannabis sativa*), black pepper (*Piper nigrum*), elephanta (*Elephantia* sp.), garlic (*Allium sativum*), red chilies (*Capsicum annuum*), and tea (*Thea chinensis*) (Zia et al. 2011). Likewise, rice moth (*Corcyra cephalonica*) is sensitive to volatile oils from eucalyptus (*Eucalyptus globulus*).

Table 18.5 Allelopathic effect of several plant extracts on suppression of different insect pests

Allelopathic source	Application rate/ mode	Insect suppression	References
NeemAzal-T/S	20 g a.i. ha^{-1}	91.88% mortality of *J. lybica* nymphs	El Shafie and Basedow (2003)
California pepper tree (*S. molle*)	Ethanol extract (4.7% w/v)	91.77% mortality of elm leaf beetle (*X. luteola*)	Huerta et al. (2010)
	Water extract (5.6% w/v)	27.78% mortality of elm leaf beetle (*X. luteola*)	
Fig-leaf goosefoot (*Chenopodium ficifolium*)	Ethanol extract (5000 mg mL^{-1})	86% control of aphid (*Aphis gossypii*)	Dang et al. (2010)
	Acetone extract (5000 mg mL^{-1})	47% control of aphid (*A. gossypii*)	
Eucalyptus (*Eucalyptus camaldulensis*)	Oil volatiles	Reduction in male (78%) and female (66.67%) adults of *C. cephalonica*	Pathak and Krishna (1991)
Neem (*A. indica*)	Oil volatiles	Reduction in male (26%) adults of *C. cephalonica*	
Neem	Seed kernels water extract (2%)	Reduction in flower thrips (*T. sjostedti*) (54%) and pod borer (*H. armigera*) (32%) incidence	Hongo and Karel (1986)
	Leaf water extract (4%)	Reduction in flower thrips (*T. sjostedti*) (45%) and pod borer (*H. armigera*) (24%) incidence	
Tomato (*L. esculentum*)	Leaf water extract (4%)	Reduction in flower thrip (*T. sjostedti*) (32%) and pod borer (*H. armigera*) (12%) incidence	
Hot pepper (*C. annuum*)	Fruit water extract (2%)	Reduction in flower thrips (*T. sjostedti*) (54%) and pod borer (*H. armigera*) (31%) incidence	

The allelopathic effect of several plant extracts on different insect pests is presented in Table 18.5.

18.5 Disease Management

Allelochemicals have shown a potential role in managing fatal pathogens such as bacteria, fungi, viruses, and some nematodes through plant defense mechanism. Application of plant extracts like canola, different cereals, lentil, and sweet clover at low concentrations was very effective in suppressing the fungus *Sclerotinia sclerotiorum* in beans (Huang et al. 2007). The allelochemicals produced by rice (momilactone A and momilactone B) exhibited antibacterial, antifungal, antioxidant, and anticancer activities in vitro, while the flavones (5,7,40-trihydroxy-30,50-dimethoxyflavone) and cyclohexenones (3-isopropyl-5-acetoxycyclohexene-2-one-1) from rice had suppressed spore formation of *Pyricularia oryzae* and *Rhizoctonia solani* (Farooq et al. 2011a). Wheat rust is controlled by leaf extracts of jimson weed (*Datura stramonium*) (Hassan et al. 1992). Cheema et al. (2012) showed that plant extracts of *Calotropis procera*, garlic, onion, and parthenium showed inhibitory effects on different fungal strains; while 50% growth reduction of *Fusarium solani* was caused by leaf water extracts of eucalyptus, neem, and tulsi (*Ocimum sanctum*) (Joseph et al. 2008).

Allelochemicals are released by residues of cover crops during their decomposition which improves soil nutrient status and deter plant pests, particularly soil-borne disease pathogens (Conklin et al. 2002; Gallandt and Haramoto 2004).

Intercropping can also be utilized to manage plant pathogens as they create a microclimate, which is helpful for reducing disease intensity (Gomez-Rodríguez et al. 2003). Intercropping of tomato with Chinese chive (*Allium tuberosum*) suppressed bacterial wilt (*Ralstonia solanacearum*) through allelochemicals present in root exudates (Yu 1999). Similarly, intercropping of tomato with marigold (*Tagetes erecta*) controlled tomato early blight disease caused by *Alternaria* by more than 90% through the release of certain volatile allelochemicals exuded from the aerial parts (Yu and Matsui 1997). Likewise, bacterial wilt of tomato (*R. solanacearum*) has been well managed by intercropping tomato with cowpea (Michell et al. 1997).

Application of 4% crop extracts of barley, oat, or sweet clover significantly reduced the *S. sclerotiorum* lesion severity index on bean leaves (Huang et al. 2007). Plant oils of basil (*Ocimum basilicum*), cumin (*Cuminum cyminum*), and rose geranium (*Pelargonium graveolens*) applied to the seed and soil were found to be effective not only in reducing root rot disease in cumin, caused by *Fusarium oxysporum*, *F. moniliforme*, *F. solani*, *F. lateritium*, *F. equiseti*, and *F. dimerum*, but also in improving growth parameters (fresh weight, plant height, branch numbers, etc.) (Hashem et al. 2010). Likewise, treatment of sorghum seeds with seaweed extract at 0.3% concentration was effective in suppressing pathogens like *Alternaria alternata*, *A. strictum*, *Aspergillus flavipes*, *Bipolaris sorghicola*, *Cladosporium cladosporioides*, *Curvularia lunata*, *F. oxysporum*, *F. solani*, *F. verticillioides*, *Trichothecium roseum*, and enhancing the activity of defense enzymes such as chitinase, β-1,3-glucanase, peroxidase, and phenylalanine ammonia lyase activity (Raghavendra et al. 2007).

The allelopathic effect of several crops grown in rotation or aqueous plant extracts on different pathogens is presented in Table 18.6.

18.6 Nematode Management

Soil application of allelochemicals from neem leaves or neem cakes reduces the development of root-knot nematodes (*Meloidogyne javanica*) for a long period (16 weeks) (Javed et al. 2007). Soil incorporation of *Brassica* spp. releases volatile

Table 18.6 Allelopathic suppression of pathogens

Allelopathic source	Application mode/rate	Pathogen/disease suppression	References
Barley (*H. vulgare*) + potato	Grown in rotation	55.1% reduction in inoculum intensity of *R. solani*	Larkin and Griffin (2007)
Turnip (*Brassica rapa*) + potato	Grown in rotation	56.2% reduction in inoculum intensity of *R. solani*	
Indian mustard (*Brassica juncea*) + potato	Grown in rotation	45.5% reduction in inoculum intensity of *R. solani*	
Rice (*Oryza sativa*)	Root exudates (1.5 mL)	37% reduction in germination of *F. oxysporum* f. sp. *niveum* spores	Ren et al. (2008)
	Rice root exudates (20 mL)	71.88% reduction in spore reproduction of *F. oxysporum* f. sp. *niveum*	
Neem (*A. indica*)	Leaf water extract (20% w/v)	53.22% reduction in the growth of *F. solani* f. sp. *melongenae*	Joseph et al. (2008)
Sweet wormwood (*Artemisia annua*)	Leaf water extract (20% w/v)	42.20% reduction in the growth of *F. solani* f. sp. *melongenae*	
Eucalyptus (*E. globulus*)	Leaf water extract (20% w/v)	46.76% reduction in the growth of *F. solani* f. sp. *melongenae*	
Tulsi (*O. sanctum*)	Leaf water extract (20% w/v)	43.98% reduction in the growth of *F. solani* f. sp. *melongenae*	
Rhubarb (*Rheum emodi*)	Leaf water extract (20% w/v)	37.19% reduction in the growth of *F. solani* f. sp. *melongenae*	

sulfur compounds (glucosinolates), which are converted into isothiocyanates through biofumigation to suppress nematodes in the soil. A commercial product from the seed meal Ethiopian mustard (*Brassica carinata*) at 2.5 t ha^{-1} was effective in reducing root-knot nematode (*Meloidogyne chitwoodi*) incidence and increasing yield of potato (*Solanum tuberosum*) (Henderson et al. 2009).

The allelopathic effect of aqueous plant extracts of neem cake/neem leaves on root-knot nematodes is presented in Table 18.7.

18.7 Conclusions

Allelopathy is an innovative and novel approach used in crop production for the management of weeds, insect pests, disease pathogens, and nematodes. It can replace the hazardous chemical and mechanical approaches (with high cost and environmental repercussions) being used in crop protection, and thus offers better alternative for pest management due to cost-effectiveness, easy to use, eco-friendly,

Table 18.7 Allelopathic suppression of nematodes diseases

Allelopathic source	Application mode/rate	Nematode suppression	Reference
Neem cake (*A. indica*)	3% (w/w)	61.03% reduction in root-knot nematode (*M. javanica*) females per root	Javed et al. (2007)
Neem cake	3% (w/w)	63.7% reduction in root-knot nematode egg masses per root	
Neem leaves	3% (w/w)	63.7% reduction in root-knot nematode females per root	
Neem leaves	3% (w/w)	60.34% reduction in root-knot nematode egg masses per root	

efficient, and safe. The integration of synthetic herbicides (at reduced rates) and allelopathic plant extracts may be popularized in order to obtain as effective a control as is obtained from the standard dose of herbicides. Genetic improvements by way of developing crop varieties with enhanced allelopathic potential may help in incorporating better resistance to biotic stresses. Biotechnological approaches can also be employed for breeding pest resistant crop cultivars with more allelopathic potential (elevated biosynthesis of secondary metabolites) as well as responsiveness to applied allelopathic water extracts. There is a need for focused research on screening more allelopathic plants, to search potential cultivars producing more allelochemicals, and to identify allelochemicals with more antibacterial, antifungal, and nematicidal effects. Research efforts are also needed for the optimization of suitable concentrations of allelochemicals for crop protection, studies on their modes of action, biochemical and genetic analysis of allelopathic crops, and commercialization of natural water extracts for pest management. The ultimate objective of allelopathy should be to achieve agricultural sustainability, environmental safety, food security, resource conservation, and economic stability.

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Precision Agriculture

19

Abstract

Precision agriculture, also called as precision farming, prescription farming, or site-specific management, is a management strategy that utilizes detailed, site-specific information for management of production inputs such as seeds, fertilizers, and pesticides. The optimization of production inputs within small areas of the field is based on the crop and soil characteristics unique to each part of the field. Application of production inputs only as and where needed for the most economic crop production is the principle behind precision agriculture. The tools and technologies that are used to implement precision agriculture include geographic information systems (GIS), global positioning system (GPS), variable rate technology (VRT), and remote sensing (RS). The management decisions can be applied in a more precise manner by using VRT techniques based on the information collected from GIS in combination with GPS and RS. The agricultural crop production costs and crop and environmental damage can be potentially reduced by following precision farming.

Keywords

Precision farming • Site-specific management • Production inputs • Geographic information systems (GIS) • Global positioning system (GPS) • Pest management • Remote sensing (RS) • Variable rate technology (VRT)

19.1 Introduction

The role of homogeneous vegetation in pest outbreaks, which can also be brought about by the uniform application of insecticides over large areas, has long been recognized by applied entomologists. The simplification of arthropod communities, their impoverishment of many natural enemies, and reduction of their clustered distribution are also brought about by pesticide applications (Johnson and Tabashnik

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1999). A judicious application of pesticides (insecticides, fungicides, and herbicides) at a scale smaller than a field was not possible until recently, due to mechanized large-scale crop production systems. The implementation of precision agriculture, also known as precision farming (PF), prescription farming, or site-specific farming, has made it possible for fine-tuning of inputs in the field, through the new technologies that have become available in the last decade or so. The site-specific pest management systems, combined with an understanding of pest population in time and space, are suggested as one of the strategies to reduce the negative impact of pesticide use and to avoid the traditional applications based on average pest density (Park et al. 2007).

A set of cropping management practices that vary inputs at the appropriate spatial and temporal scales within a field based on predicted economic and ecological outcomes is called precision agriculture. Unlike most definitions, ecological as well as economic criteria and the temporal scale, so important for insect population management, are included in this definition. The recognition that a great deal of variability exists within agricultural fields, which results in large yield differences across the field, is the major conceptual novelty of this cultural practice. Hence, application of variable inputs in different parts of the field in order to optimize the crop response (i.e., yield) is the main goal of precision agriculture.

Optimization of farm profits and minimization of agriculture's impact on the environment constitute a knowledge-based technical management system that is achieved through precision farming or site-specific management, which has been in the market for more than 30 years with new applications each year. Precision farming involves obtaining information about a field and updating it continuously to fine-tune management strategies. It uses the data to correlate responses from specific management decisions for an economic response under those conditions. Precision agriculture determines the exact amounts of production inputs (such as seeds, fertilizers, and pesticides) required for taking management decisions in order to get higher yields and maximum profits.

Based on the spatial variability in pest occurrence and their habitat, how the efficacy of pest management measures could be improved and how adverse environmental impacts could be minimized are discussed in this chapter. This agroecologically based strategy uses new technologies that allow farmers to spatially vary inputs in the field and that are being adopted in precision agriculture based on the ecological effects of plant diversity and pesticide application on the population dynamics and density of pests. Geographic information systems (GIS), global positioning systems (GPS), remote sensing (RS), variable rate technology (VRT), and yield monitors (YM) are some of the new technologies used in precision agriculture for the management of insect pests, diseases, and weeds.

19.2 Ecological Effects of Plant Diversity

The three levels of vegetational heterogeneity occurring in agroecosystems include genetic heterogeneity, landscape heterogeneity, and taxonomic heterogeneity. Genetic heterogeneity occurs within a monospecific plant stand (e.g., a field). The large-scale mechanized commercial cultivation practiced in modern agriculture leads to genetically uniform vegetation in agricultural systems on a large scale, i.e., a single genotype of a given crop may cover hundreds or even thousands of hectares. Landscape heterogeneity includes noncrop land and vegetational differences among fields. The effect of landscape vegetation patterns on insect populations is relatively little known (Stevenson 2002; Schmidt et al. 2004). Taxonomic heterogeneity (species composition) occurs within and near fields. However, the population ecology of pest species is clearly influenced by an important factor, i.e., the spatial arrangement of crops.

The use of monogenotypic crops and monocultures is responsible for wide spread pest problems. Hence, vegetation diversification through the use of multiline cultivars, mixtures of varieties and intercropping have been promoted by applied entomologists (Cromartie 1981; Pickett and Bugg 1998). In view of the adverse effects of vegetation uniformity on pest populations, these approaches suggest how manipulation of vegetation in and around fields may reduce crop losses. In order to rationalize the intensity of pest management and to restore a degree of vegetational diversity within-crop, agroecologically based pest management strategy (precision agriculture) has been proposed.

19.3 Effects of Pesticide Use

Uniform application of insecticides across the field and on an area-wide basis brings in habitat homogeneity which is congenial for pest outbreaks. Similarly, eradication of all noncrop plants in the field and its vicinity by herbicide applications may make it easier for pests to locate crop plants and deprives beneficial predators and parasitoids of important food sources (Shelton and Edwards 1983). Hence, there is a need to improve the efficacy of pest control measures and to minimize adverse environmental impact by responding to the spatial variability in pest occurrence and habitats. Crop diversity through the use of multiline cultivars, varietal mixtures, and intercropping enhances natural enemy populations that reduce the density of pest populations through predation, parasitism, and competitive interactions. The pest population outbreaks can be retarded by fine-tuning pesticide applications that are made only at "hot spots" where pest and weed densities reach their respective action thresholds, which would create a mosaic of communities that differ in species composition and interspecific interactions. The release of toxic chemicals into the environment would be greatly reduced by agroecologically based pest management strategy, i.e., precision agriculture (Weisz et al. 1996; Brenner et al. 1998).

Application of broad-spectrum insecticides is responsible for killing of natural enemies of the target pest, which can also lead to the resurgence of pest populations

(Hardin et al. 1995). Site-specific applications through precision farming would minimize the exposure of insect predators and parasitoids to insecticides, and favor biological control, which subsequently reduces pest damage. This technology also slows down the rate of selection of resistant pest populations, since it would create spatial refuges of susceptible pests unexposed to the toxins and conserve natural enemies (Fleischer et al. 1999). Site-specific pest management is responsible for the buffering effect of interpatch dispersal and would make pest population outbreaks less likely because it links sink and source populations. Sampling procedures are considerably influenced by the alteration of pest distribution patterns in the field (approaches random or even distribution) requiring less sampling effort.

The environmental pesticide load is significantly reduced by precision farming leading to the reduction of material costs, as the necessary pesticide amount is 8–10% lower (calculated in active ingredient) than in case of traditional treatment. Takács-György et al. (2014) estimated that the amount of pesticides saved on the level of EU-25 countries is 31.7–84.5 thousand tons in case 15% of farms apply precision farming and 63.4–169.1 thousand tons in case 25% of them introduce it, while in the most favorable case (40%), it is 126.8–338.1 thousand tons.

19.4 Precision Farming

The information needed to make soil and crop management decisions that fit the specific conditions found within each field is provided by precision farming (PF) that combines the best available technologies. It enables to take more informed management decisions by using GPS, GIS, and RS to revolutionize the way data are collected (at resolutions of 1–5 m) and analyzed. Precision farming has the potential to have detailed records covering every phase of the crop production process, thus enhancing sound management decisions.

19.4.1 Benefits

The numerous benefits provided by PF are as follows:

- Better scheduling, sequencing of equipment, planning of field operations, equipment movement, etc. are possible due to improved equipment efficiency.
- Increased documentation of food safety.
- Monitoring and supervision, including better records of field operations, location of equipment, production output, and employee performance are improved.
- More accurate and precise application of chemicals and fertilizer to reduce the potential for leaching and runoff helps to enhance environmental stewardship. This is more important because environmental stewardship is incorporated throughout the PF decision support system.
- Production processes, crop conditions, and required inputs are facilitated by improved records.

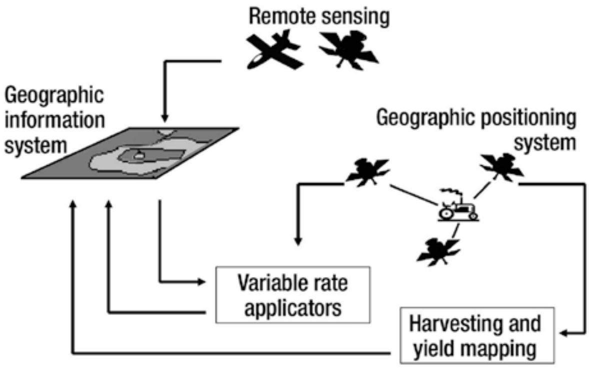

Fig. 19.1 Components of map-based precision agricultural systems

- Reduced variability in growing conditions, improved varietal choices, crop rotation, etc. are responsible for risk reduction.
- The ability to identify, diagnose, and communicate crop and field problems is greatly improved.

These are map-based methods (Fig. 19.1) for the implementation of precision agriculture based on data obtained by grid sampling used to generate a site-specific map, which is then coupled with a variable-rate applicator in the field. The aerial or satellite images (remote sensing, RS) can also be used to generate such site-specific maps. It is possible to correct deficiencies (nutrient, pests, etc.) in specific parts of the field by using various filters and imaging techniques (e.g., infrared photography), in order to detect variations in the health and stand of crop plants.

In a second method of precision agriculture, the spatial variation in a variable is measured using real-time sensors, and this information is immediately utilized to control a VR applicator. For instance, weed stands are detected by mounting a sensor in front of a tractor, and switching it on when weed density exceeds a predetermined threshold.

The precision farming methods are primarily adopted for crop management purposes (including pest management) by a growing number of farmers based on information pertaining to plant characteristics that are used to differentially apply fertilizer, gypsum, lime, pesticides, and water to various parts of the field. This site-specific application of agricultural inputs has been found economical and has greatly reduced the release of contaminants into the environment.

Data collection, data analysis/interpretation, and application/variable rate technology are the three management components in PF (Fig. 19.2). For precision pest management, these three components should be combined with a decision support system to facilitate the delivery of variable levels of a specific management practice to various parts of the field and in a single field operation.

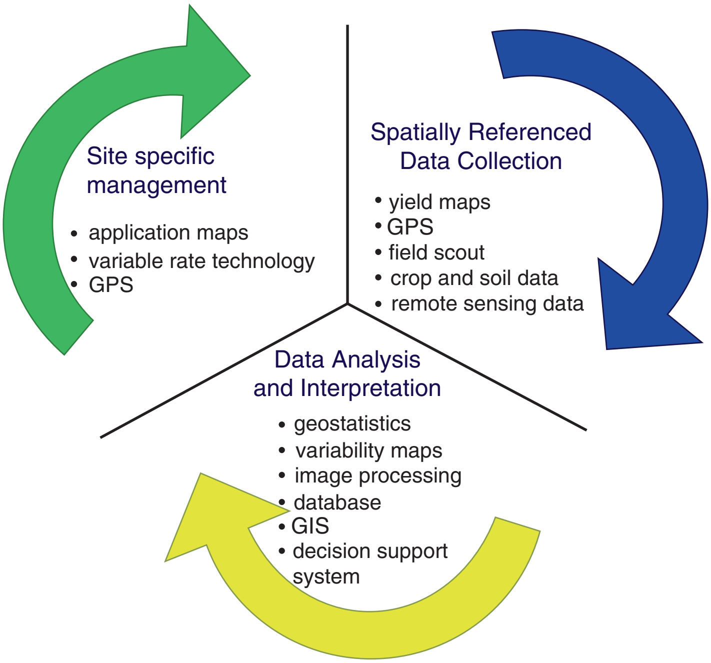

Fig. 19.2 Data processing and management cycles for site-specific management

19.5 Precision Farming Tools

The main tools that have recently become available to make precision agriculture a realistic farming practice today include geographic information system (GIS), global positioning system (GPS), remote sensing (RS), variable rate technologies (VRT), and yield monitors (YM).

19.5.1 Global Positioning System (GPS)

GPS is a locating system based on a satellite that identifies an Earth-based position using latitude, longitude, and, in some cases, elevation (Fig. 19.3). For applications in agriculture, it is used for machine guidance and control (variable-rate-input applications) to provide line-of-sight signals and 24 h coverage by orbiting 20,200 km above the Earth. The satellites complete orbits in slightly less than 12 h by traveling in one of six orbital planes.

19.5.2 Geographic Information System (GIS)

GIS is a specifically designed data management system to store spatial data in order to create variable-intensity maps. For crop production purposes, it collects

Fig. 19.3 Global positioning system

information pertaining to field history, input operations, GPS-based yield maps and soil surveys, aerial photography, satellite imagery, and pest or pathogen scouting data from various sources. The information about the current crop, to assess treatments, and to potentially generate projected harvest maps, input data needs to be collected on weather, insect and weed problems, nematode densities, seed varieties, and planting populations.

19.5.3 Variable Rate Technologies (VRT)

VRT are application equipment which is mounted on fertilizer applicators and sprayers in order to control their delivery rates in different parts of the field based on a decision support system and (or) management plan. All the data collected from various sources like GPS referenced data, RS images, and GIS generated maps are used to produce a site-specific application plan based on sound agronomic principles.

19.5.4 Remote Sensing (RS)

The acts of detection and/or identification of electromagnetic energy (ultraviolet, near infrared, or thermal infrared) phenomena, such as light and heat, without having the sensor in direct contact with the object are called remote sensing (RS) (Frazier et al. 1997). A wide range of potential applications, including the detection of crop stress and monitoring the variability in crops, soils, weeds, insects, and plant disease, is provided by remote sensing.

19.5.5 Yield Monitors (YM)

YM sensors are used for monitoring yield during the harvest to quantify yields across the field. The data on crop performance (grain flow, grain moisture, area

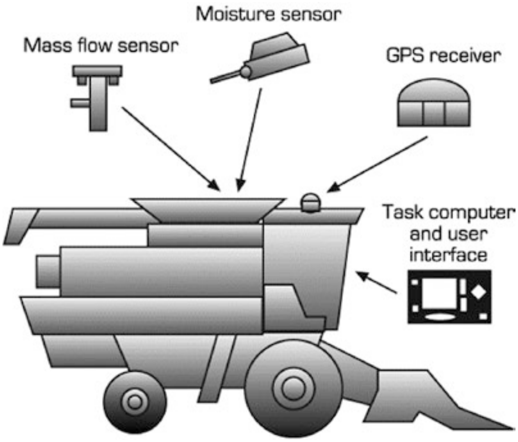

Fig. 19.4 Components of a yield-monitoring system

covered, and location) for a particular year are collected from a yield monitor (an electronic tool), coupled with global positioning system (GPS) technology (Fig. 19.4). Yield monitors for commodities like cotton, forage silage, peanuts, and sugar beets are readily available in the market.

19.6 Pest Management

The primary objective of precision pest management is to produce a healthier crop by adjusting needed inputs within the field rather than at the field level through spot treatment of only those areas of the field needing pest control, resulting in the reduction of pesticide costs and environmental degradation. Site-specific management of insect pests, disease pathogens, nematodes, and weeds is an area that is fast developing. Crops can be managed better, with fewer trips across the field, resulting in more economic returns and reducing potential negative impacts of agricultural activities on the environment by linking soil, crop, pest, and environmental features into one program.

Integrated pest management (IPM) has been the approach of choice for pest management for the last three decades, and several principles of IPM are highly compatible with the ideology behind precision farming, which include:

- Off-the-farm inputs like pesticide applications to be reduced.
- Use of action thresholds, i.e., taking corrective measures based on economic and ecological criteria.
- Use of cultural and biological control measures, and resistant varieties, to enhance sustainability.

The optimization of inputs such as fertilizers and pesticides, and minimization of economic and environmental damages provided in precision agriculture, is similar to IPM. However, the spatial component so central to precision agriculture is lacking in IPM.

The most challenging step toward the use of precision agricultural technologies for pest management is the creation of management maps and control VR applicators by collecting reliable data on pest density across the field (Fleischer et al. 1999). In view of the technological limitations arising from the cryptic and dynamic nature of insect pests and disease pathogens, the application of precision agriculture to pest management has been a slow process. However, the clustered distribution of crop pests (insects, pathogens, and weeds) makes them suitable for management through precision farming. The use of precision farming methods for pest management is certainly justified in light of the severe adverse effects of pesticides on the environment, and the potential for drastically reducing the release of toxic chemicals.

19.6.1 Insect Pests

The visual clues such as defoliation and sooty mold-contaminated honeydew that is secreted by homopteran pests can be utilized to detect infested hot spots by RS to create pest management maps (Chaing et al. 1976). The detected hot spots can then be treated with target-oriented control measures, like the use of biological control agents and selective insecticides. The infrared aerial photography was used to monitor brown soft-scale populations in citrus (Hart and Myers 1968) and to detect sooty mold on aphid-infested corn plants.

The optimal arrangement of crops in area-wide pest management programs is facilitated by GIS. The data presented to illustrate the effect of crop association and rotation on pest density, pesticide use, and yield in cotton revealed that cotton plants near chickpea and sunflower attracted more *Helicoverpa armigera* moths than those near other cotton fields. All the three crops are known host plants of *H. armigera*, and the pest appears to move into cotton after it builds up a population on the earlier sunflower and chickpea crops. Further, higher cotton yields were obtained in cotton adjacent to other cotton fields rather than in those near sunflower and chickpea. Significantly less insecticide applications were recorded when cotton crop was rotated with nonhost crops.

19.6.2 Diseases

A high potential in detecting diseases and in monitoring crop stands for sub-areas with infected plants has been demonstrated by using remote sensing techniques. Diseases often have a patchy distribution in the field, since the occurrence of plant diseases depends on specific environmental and epidemiological factors. Chlorophyll fluorescence, hyper-spectral sensors, and thermography are some of the most promising sensor types. Imaging systems are preferable to nonimaging systems for the detection and monitoring of plant disease. A wide range of potential applications, including the detection of plant disease, is provided by remote sensing (Fig. 19.5).

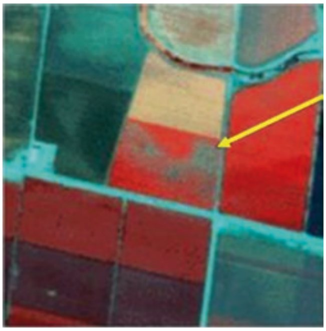

Fig. 19.5 Satellite imagery for detection of club root disease on cauliflower. Displaying satellite imagery with infrared band makes the crop's characteristics easily visible to naked eye

A multidisciplinary approach—including plant pathology, engineering, and informatics—is required to utilize the full potential of these highly sophisticated, innovative technologies and high-dimensional, complex data for precision crop protection.

The stage for rapid advancement of the application of GPS technology has been set for disease control in view of recent advances in GPS and application equipment. An important tool in the precision farming is to predict where the potential foci of infection are likely to occur, for spot application of fungicides, especially protectant fungicides that cannot stop the infection once it has begun (Zadoks 1999). Precision farming has the potential to predict the areas with visible and latent infections that could be applied with a systemic fungicide. A protectant fungicide could be sprayed to the invisible latent infections, as well as to adjacent infection sites that may have been contaminated with spores but not yet infected. The chances of resistance development by the pathogen and also to reduce application costs (many of the protectant fungicides are cheaper than the systemics) can be achieved by differential fungicide applications.

19.6.3 Weeds

Site-specific management for weeds is the newest of the pest disciplines that offers the most economical and environmental benefits. The soil type and site-specific postemergence herbicide applications for site-specific weed management are based on variable rate soil treatments. The treatment of only those areas where weeds are present with the appropriate herbicide material at the right rate is the goal of site-specific postemergence application. The savings in herbicide use can be to the extent of 30,000 tons (calculating with the current dose level in the EU-27) in an optimistic scenario after switching over to site-specific weed management.

The weed patches could be detected through RS, since the distribution of weeds in the field is relatively stable, and most crops form a regular pattern when planted in rows (Zwiggelaar 1998). Site-specific herbicide application could result in significant savings because herbicides represent the biggest single variable cost in

Fig. 19.6 Strider—a decision support technology offering farmers a relatively simple data aggregation and pest management tool

crop protection (Brightman 1998). Further, some delay in the application of herbicides may be tolerated.

19.7 Strider: Computer Model (www.strider.ag)

The reduction in the usage of pesticides, based on precise dosages, better timing, and trustworthy/actionable information, is achieved by the Strider, which is a mobile application and a geo-based "big-data engine" (Fig. 19.6).

- A heavy-duty collector is used to collect information in the field.
- Areas affected by pests and diseases are calculated by the smart processing.
- Alerts to undertake corrective actions are based on reports with managerial indicators.

19.7.1 Benefits

19.7.1.1 Digital Record of Pest Samples

- The sample's exact position in the field is certain.
- The attention spots are accurately guided by map orientation on the collector's screen.
- Photos taken at the locale confirm diagnoses by agronomists.
- Pheromone traps' location and maintenance.

19.7.1.2 An X-Ray of Crop's Health Every Day

- Corrective actions are indicated based on smart processing to delineate areas affected by pests with varying levels of damage through samples sent by collectors.

19.7.1.3 App with a Smart Map for Managers and Property Owners

- Alerts to undertake corrective actions are based on an app that presents the farms where inspections have taken place, the status of pheromone traps, and the areas affected by pests.
- App is accessible without Internet facility.

19.7.1.4 More Trustworthy Monitoring

- Trusted information is created using field sample collection process.

19.7.1.5 Savings in Pesticide Use

- Pest management is more effective.
- Less production loss and stress.

19.7.1.6 More Effective Pest Control

- Decreased use of pesticides is expected with areas well demarcated and fast reactions.

19.7.2 Features

- Digital samples with photos and GPS.
- Heavy-duty collectors with map.
- Plant development.
- Precision analysis.
- Trap and sensor monitoring.

19.7.2.1 Digital Samples with Photos and GPS

- Few hours of training are required as the collector’s user interface is simple.
- Photos that corroborate diagnoses are always accompanied by the samples.
- The collector works without access to Internet. Precision analysis of data can be undertaken when a Wi-Fi connection is available.

19.7.2.2 Heavy-Duty Collectors with Map

- Water- and fall-resistant collectors with 7-inch touch screens equipped with a camera, GPS, and an extra battery are used to collect the information in the field.
- The collector and the technician orient themselves on the farm for location of fields, areas affected by pests, points of action, and traps facilitated by a map with GPS.

19.7.2.3 Plant Development

- Beyond pest sampling, the system also allows for the recording of plant development levels, like the number and height of plants.
- The collected levels are compared to expected values for the crop planted.
- Delays in plant development are marked on the map as attention spots.
- Accompanying the plant development levels is a good strategy to identify possible factors of production loss caused by unmonitored pests and diseases.

19.7.2.4 Precision Analysis

- The consolidation of samples sent by all the collectors from the beginning of the crop is used to calculate areas affected by pests and diseases, with varying levels of damage, through smart processing.
- Different colors are used on the map to highlight affected areas.
- Important indicators of production performance are calculated, and alerts with corrective actions to be taken are defined based on the size and distribution of the affected areas.
- Further, identification of neglected areas and the quality level of monitoring are done by the precision analysis to reconstruct the technicians' path through the fields.

19.7.2.5 Trap and Sensor Monitoring

- Setting-up and maintenance of hundreds of pheromone traps are used to formulate a defense system against Japanese beetle.
- Levels of pest infestation are based on efficient management of the traps, guaranteed quality monitoring, and trustworthy information through Strider.
- Fast localization of the traps in the field is facilitated by the map and GPS.
- The frequency of inspections and maintenance, set-up, take-down, and pheromone replacement are controlled by Strider.

19.8 Conclusions

Deployment of new technologies for pest management in precision agriculture through several approaches has been discussed. Information on pest biology (e.g., typical within-field distribution patterns) and parameters correlated with pest infestation (e.g., soil/plant nitrogen levels, climatic factors) are essential for site-specific control of insect pests. The management tools to reduce risk to the farmers are provided by GIS, GPS, and RS. The more informed management decisions can be made by producers, since they have simultaneous access to the numerous types of data needed. A more intimate knowledge of the system at hand is needed to understand how biotic and abiotic factors affect pest populations, yield, and the fate of pesticides in the environment for attaining greater precision in plant protection programs. Some equipment have already been developed, such as herbicide sprayers equipped with sensors to detect weed patches and control delivery rate, and a soil sampler that will characterize not only nutrient content but also the potato cyst nematode levels in the soil, which are readily available in the market (Legg and Stafford 1998). Further, there is a need for new tools for the monitoring of pests on a small spatial scale (Fleischer et al. 1999), for geo-statistical analyses to detect spatial relations between variables in the environment (Liebhold et al. 1993), and for the delivery of variable rates of pest control measures other than pesticides, such as mass release of biological control agents.

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The Way Forward

20

Abstract

A biological, then ecological, orientation has underlain the development of crop protection over the last five decades. Several technical innovations have been proposed based on the spectacular success of the recent advances in biotechnology and by genuinely taking into consideration the need to preserve the biodiversity. This has led to reexamination of farming systems as traditionally practiced, through an innovative agro-ecological approach. Agro-ecological pest management is based on ecological processes occurring between the crops and its pests, and also the natural enemies of these pests, in a quest for increased beneficial interactions that keep pest populations in check. This crop protection strategy helps to maintain bio-ecological balance between pests and crops within agro-ecosystems, while also preserving and improving the soil health and plant biodiversity. This chapter explains how agro-ecological concepts and principles are applied for the sustainable management of crop pests. Future lines of work on research and development, transfer of technology and policy support are outlined.

Keywords

New paradigm • Aagroecological intensification • Ecosystems management • Therapeutics • Minimal disruptions • Conserving resources • Supportive policies

20.1 Introduction

"Green Revolution" (through greater inputs of fertilizers, copious water, indiscriminate use of chemicals, and monocropping) has doubled global food production in the past five decades (FAO 2001; Tilman et al. 2001), and reduced hunger, improved nutrition, and enhanced crop productivity (FAO 2001), without area expansion for agriculture (Waggoner 1995). Despite this increase in crop production, nearly 800 million people continue to suffer from hunger and malnutrition around the world.

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Ecological principles were continuously ignored, as the agricultural intensification progressed that resulted in negative externalities. Hence, the increased agricultural production should be achieved through environment-friendly and economically sustainable manner.

The United Nations Food and Agriculture Organization has predicted that food production needs to increase by 70% globally in order to feed the population of over 9 billion by 2050 (Alexandratos 1999; Cassman 1999; Cohen and Federoff 1999). Since there is no scope to increase the land available for cultivation, the increase in production should come from intensification of agriculture—getting more crops out of the same amount of farmland (Postel 1999), without compromising the environmental integrity (Tilman et al. 2001; Carpenter et al. 1998) and public health (Gorback 2001).

The bioaccumulation of persistent organic agricultural pesticides poses a great threat to the agroecosystems. Nutrients and toxins are increased in surface water and ground water due to heavy applications of fertilizers and indiscriminate use of pesticides.

Pesticides can harm human health. Questions are raised on present input-intensive agricultural systems, in view of the costs on the use of fertilizers, pesticides, and herbicides. Sustainable intensification aims to enhance productivity without area expansion, and protecting the environment by means of minimizing the need for toxic pesticides (Daily et al. 2000).

20.2 New Direction

The use of chemical pesticides for management of pest epidemics dominated for long in developing pest management strategies. Despite the use of 3.5 billion kg of pesticide active ingredients with a value of US$45 billion global market per year (herbicides—42% of sales, insecticides—27%, fungicides—22%, and other agrochemicals—9%), crop losses due to pests have significantly increased (FAOStat 2014). Some of the important drawbacks with chemical pesticides include pest resistance, pest resurgence, emergence of secondary pests, and toxic crop residues. Alternative management practices, such as the use of nontoxic pesticides, biopestcides, predators, and parasitoids, protect the environment, but are slow to act on pests.

Agroecological intensification is essential to achieve long-term pest management resolutions. The basic agroecological principles need to be incorporated to evolve eco-friendly alternatives for management of pests (Benbrook 1996). There is a need for redesigning cropping systems to enhance natural enemies to manage crop pests.

In order to achieve agroecological pest management, three approaches can be developed:

- Interactions of plant characteristics with pests, natural enemies, and crops
- Ecosystem management
- Biopesticides without ecological disturbances

20.2.1 Interactions of Plant Characteristics with Pests, Natural Enemies, and Crops

Plant characteristics can play an active role in interactions which influence pests and their biological control agents. The herbivore feeding is discouraged by toxins and other chemicals that are present in plants. For instance, the predators and parasitoids are attracted to volatile chemical cues produced by plants, which in turn attack the herbivores (Dicke et al. 1990; Turlings et al. 1990). The natural enemies identify pest-affected crops from unaffected adjacent crops from volatile chemical cues. For example, cotton plants release terpenoids due to feeding from *Spodoptera exigua* juveniles, which are receptive to the natural enemy *Cotesia* species. Further, the volatile chemical cues released due to herbivore damage are ten times higher in some naturalized varieties of cotton as compared to commercial cultivars (Röse et al. 1996).

The vital food resources for foraging parasitoids, such as floral and extrafloral nectaries and pollen, are provided by crop plants to natural enemies for the management of *Helicoverpa zea* and *Heliothis virescens* on *Gossypium* spp. (Stapel et al. 1997).

The toxins and antifeedants produced by certain plants are directed specifically toward herbivores (*Solanum tuberosum* and *Lycopersicon esculentum* on caterpillar pests) (Ryan and Farmer 1991).

A novel strategy has been developed by introducing *Bacillus thuringiensis* (Bt) gene in crop plants through genetic engineering for the production of Bt toxin. For instance, Bt endotoxin gene is inserted in commercial cotton varieties which exhibit resistance to lepidopteron pests.

20.2.2 Ecosystem Management

Planting of cover crops in fields encourages biological control agents which manage crop pests (Blumberg and Crossley 1983; McPherson et al. 1982). For example, strip tilling of cotton with legume cover crops (crimson clover) enhances the population of biological control agents for pest management on *Gossypium* spp. (Phatak 1993). Likewise, Ruberson et al. (1994) reported that the green clover worm, *Plathypena scabra*, which acts as a host to the natural enemy *Cotesia* sp., is parasitic on *Spodoptera frugiperda* and *Anomis flava* in *Gossypium* spp.

Combination of conservation tillage and appropriate cover crops is responsible for several agronomic benefits including reduced soil erosion and enhanced weed and herbivore suppression (Phatak 1993; Bugg et al. 1991). Habitat management and crop rotation practices can prevent pest outbreaks (Altieri 1994; Olkowski et al. 1991). For instance, two common weeds such as fleabane and horsetail attract *Lygus* spp. from *Gossypium* spp. (Fleischer and Gaylor 1987).

The elucidation of interactions at the ecosystem level to establish the knowledge base for agroecologically based pest management systems is crucial, since the landscape ecology practices exert a variety of desired effects on cropping systems (All and Musick 1986).

20.2.3 Biopesticides without Ecological Disturbances

Biopesticides have a valuable role to play in the agroecologically based pest management strategies. Pheromones can also be used for trapping crop pests. Natural enemies such as parasitoids and pathogens are commercially marketed, which are important eco-friendly components that can be employed for pest management. But these therapeutic components of pest management should play a supporting role in the preventive measures like cropping systems and habitat management.

20.3 Agroecological Pest Management

Agroecological approaches to pest management for sustainable agriculture have been practiced for over five decades (FAO 1966; Smith and Doutt 1971). They reduce input costs and increase yields and sustainability through ecological processes.

20.3.1 Environmental Factors of Production Affecting Effective Pest Management

The following strategies need to be adopted to enhance pest management and to increase crop productivity under sustainable intensified agricultural systems:

20.3.1.1 Crop Varietal Resistance

Crop varieties resistant to pests and tolerant to weeds can be developed using conventional breeding and genetic engineering approaches. A broad genetic base is the prerequisite for plant breeding.

20.3.1.2 Soil Management

Agroecological approaches like provision of refugee and food supplements to increase natural enemy population, and building organic matter in soil to enhance biological processes help in sustainable pest management.

20.3.1.3 Spatial and Temporal Arrangement of Crops

The population of biological control agents and pollinators are influenced by spatial and temporal arrangement of crops. The level of pollination services by honey bees can be increased by decreased use of chemical pesticides and provision of flowering plants through habitat management.

20.3.1.4 Water Regulation

Proper water regulation can be adopted to manage certain pests and weeds in the production system.

20.3.2 Ecosystem-Based Strategy

Some notable successes in world agriculture have been achieved by IPM programs both in developed and in developing countries. Agroecological approaches form the back bone for the development of IPM programs (Alexandratos 1999). Development of agroecological pest management strategy is based on the following aspects:

20.3.2.1 Examine Reasons for Pest Epidemics

A combination of factors may be involved in pest outbreaks, and strategies may be developed accordingly to solve the problems. For instance, plowing spreads weeds due to intensification of agricultural practices. In such cases the practices will need to be modified accordingly. Similarly, the invasive pests like locusts can be managed by using natural enemies.

20.3.2.2 Determine How Much Production Is at Risk

Pest management strategy can be based on economic injury threshold and how much production is at risk.

20.3.2.3 Undertake Contingency Planning

Contingency planning should be implemented when a significant pest threat emerges. Some of the contingency planning measures include fallowing, use of selective pesticides, and resistant or tolerant cultivars.

20.3.2.4 Undertake Surveillance to Track Pest Patterns

Information by survey, mapping, and analytical instruments may be used for georeferenced systems for plant pest surveillance, and the response can be adjusted.

20.3.2.5 Use an Ecosystem Approach

The intensified crop production system is likely to attract potential pest problems. Hence, a diverse production system needs to be adopted by the use of cropping systems and habitat management. Eco-friendly approaches such as natural enemies, therapeutics, and selective chemicals should be employed to overcome pest problems.

20.4 Potential Benefits

Natural resources like energy conservation, nonrenewable resources, crop diversity, and habitat management have been given due importance in agroecological pest management. It also gives a boost to job opportunities and human health and

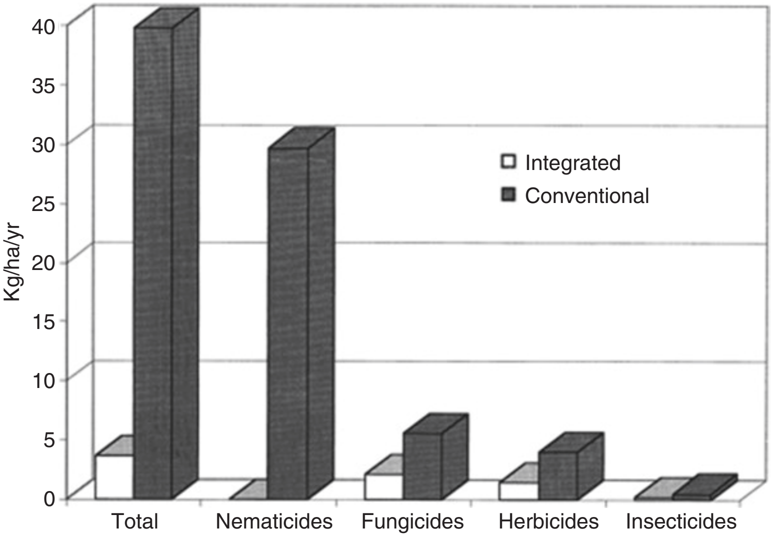

Fig. 20.1 Effect of agroecological pest management on reduction in pesticide use

well-being as long-term sociological benefits (Wijnands and Kroonen-Backbier 1993). Agroecological intensification also gives importance to sustainable pest management using biological control agents, resistant or tolerant cultivars, while reducing pesticide use over 90% on the integrated farms (Fig. 20.1).

Significant yield increases are obtained by way of improvements in the management of herbivores, crop disease pathogens, and weeds. Plant breeders have successfully developed pest-resistant or pest-tolerant cultivars and achieved enhanced crop productivity. However, there is no guarantee whether these cultivars can perform for long periods. Hence, agroecological approaches and genetic engineering should assume importance in the future (DeVries and Toenniessen 2001; Ortiz 1998). Conventional plant breeding benefits may be short-lived, since the pathogens develop new pathogenic races to overcome the resistance (Palumbi 2001). Likewise, pests are also known to develop resistance to pesticides. Similarly, bacterial pathogens develop resistant strains against antibiotics. Likewise, herbicide-resistant weeds were observed within a short period (Palumbi 2001). Use of agroecological practices such as crop rotation and spatial or temporal crop diversity, and development of safer chemicals, can overcome the problems of conventional breeding. The effective elimination of a pathogen can also be achieved through varietal mixtures or multiline cultivars with genotypic diversity, and by developing genetically modified pest-resistant cultivars (Zhu et al. 2000).

Beneficial herbivores can provide both crop pollination and parasitoids for effective management of many agricultural pests. Weeds and other agricultural pests can also be managed through buffer strips. Landscape-level management is helpful in providing such ecosystem services.

The agroecological approaches for sustainable agriculture have fulfilled the following Sustainable Development Goals (SDGs):

- Eradicate extreme poverty and hunger
- Ensure environmental sustainability
- Develop a global partnership for development

20.5 Future Lines of Work

The implementation of agroecological intensification of crop protection is limited by several factors. The following policy and institutional changes are needed to support agroecological intensification in the long term:

- In the registration processes, less hazardous pesticides should be given preference by countries, ensuring that the farmers should only apply those chemicals. The subsidies for development and adoption of alternative pest management practices should be financed from pesticide-use fees or pesticide taxes.
- There is a scope for development of small-scale local industries in view of large-scale adoption of agroecological pest management, which is expected to increase demand for biocontrol agents, biopesticides, commercial monitoring tools, microorganisms, and pollination services. The expansion of local industry should take place by producing quality bioproducts based on bacteria, viruses, fungi, protozoa, and nematodes (Ruttan 1999).
- Hazardous chemical-free produce obtained from more stable and sustainable agroecosystems should form the perspective for the food processing industry. The farmers can access new markets by labeling their food products with an AICP or similar label to enhance additional farm income.
- The transfer of technology can be accelerated by supplying agroecological pest management inputs to farmers.

20.5.1 Research and Development

The following research and development aspects need to be emphasized:

- Development of agroecological crop protection inputs
- Development of diagnostic tools and pest population forecasting systems, for effective decision-making systems
- Development of practical agroecological crop programs and pest management strategies
- Monitoring efficacy of biological control agents on crop pests and development of habitat management strategies for their survival and multiplication under field conditions

20.5.2 Transfer of Technology

- Training of extension personnel, farmers, and related staff in adopting agroecological pest management practices through field demonstrations, Farmers' Field Schools and electronic media
- Promotion of agroecological pest management programs through input dealers, distributors, farmers, and school children

20.5.3 Policy Support

The support of policymakers is essential to support agroecological pest management programs at the local, regional, or national scale. However, the success of agroecological intensification for the management of pests and diseases ultimately rests with farmers who make key management decisions. The following aspects need the support of policymakers in implementing agroecological intensification:

- Provision of technical assistance from researchers and extension support for transfer of technology to farmers in adopting the technologies
- Areas like biological control, host plant resistance to pests and diseases, innovative approaches to field pest management, practical monitoring and surveillance, and development of safer chemicals (including biopesticides) need targeted research.
- Policy and institutional changes are needed for abolishing subsidies for hazardous chemical pesticides.

20.6 Conclusions

Pest management through conventional toxic pesticides has been replaced with agroecological approaches for sustainable agriculture. Emphasis needs to be placed on redesigning cropping systems and habitat management to encourage survival and multiplication of natural enemies under field conditions. Transfer of agroecological pest management technologies should be given emphasis so that the farmers adopt these practices and increase crop productivity to feed nine billion people by 2050.

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Annexures

Annexure I: Glossary

Abiotic Factor. A nonliving component of the environment, such as soil, nutrients, temperature, or moisture.

Action Threshold. This basically refers to the point when a pest becomes a problem that must be dealt with right away to prevent it becoming an even bigger problem.

Active Ingredient. This is the ingredient/s found in a pest control product that produces the toxic effect.

Afforestation. The conversion from other land uses into forest, or the increase in the canopy cover to above the 10% threshold.

Agricultural Biodiversity. The component of biodiversity that is relevant to food and agriculture production. The term agrobiodiversity encompasses genetic species and ecosystem diversity.

Agricultural Intensification. Refers to any practice that increases productivity per unit of land area at some cost in labor or capital inputs.

Agro-Ecology. In general, it has three meanings or forms related to the application of ecology to agricultural systems: (1) a scientific discipline, (2) an agricultural practice, and (3) a social movement. While there are many different definitions, one of the broadest definitions is "the integrative study of the ecology of the entire food system, encompassing ecological, economic and social dimensions." Alternatively, agro-ecology refers to "the study of purely ecological phenomena within the crop field, such as predator/prey relations, or crop/weed competition. Agro-ecology often incorporates ideas about a more environmentally and socially sensitive approach to agriculture, one that focuses not only on production, but also on the ecological sustainability of the productive system and goes well beyond the limits of the agricultural field."

Agro-Ecosystem. A relatively artificial ecosystem in an agricultural field, pasture, or orchard.

Agro-Forestry. Collective term for land-use systems and technologies in which woody perennials are deliberately used on the same land management unit as agricultural crops and/or animals, in some form of either spatial arrangement or temporal sequence.

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Allelopathy. The suppression of plant growth by chemicals produced by other plants or microbes.

Alley Farming (Cropping). It is an agro-forestry practice that consists in planting perennial trees or shrubs on the sides of crops.

Alternative Agriculture (Agricultura Alternativa). Agricultural approach that attempts to provide a balanced environment, sustained yields, and soil fertility, and natural pest control through the design of diversified agro-ecosystems and the use of self-sustaining technologies, based on ecological principles.

Antagonists. Organisms that release toxins or otherwise change conditions so that activity or growth of other organisms (especially pests) is reduced.

Arthropod. Any insect, crustacean, or spider having jointed appendages and segmented body.

***Bacillus thuringiensis* (Bt)**. A bacterium that causes disease in many insects, especially caterpillars; formulations of the bacteria are used as insecticides.

Beneficial Insects. Some insects that provide a benefit to crop production: (1) plant reproduction (pollinators), (2) waste biodegradations (decomposers), and (3) natural resistance of agro-ecosystems/natural control of harmful species (natural enemies, predators, and parasitoids).

Biodiversity. The variability among living organisms from all sources including terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within and among species and diversity within and among ecosystems.

Biological Control. The action of parasitoids, predators, or pathogens in maintaining another organism's population density at a lower average level than would occur in their absence. Biological control may occur naturally in the field or result from manipulation or introduction of biological control agents by people.

Biomass. The total mass of living organisms in a given area or volume; recently dead plant material is often included as dead biomass.

Biorational. Having a minimal disruptive influence upon the environment and its inhabitants (e.g., a biorational insecticide).

Biotic. Living organisms that make up the biotic parts of ecosystems**.**

Biotic Disease. Disease caused by a pathogen, such as a bacterium, fungus, mycoplasma, or virus.

Biotype. A strain of a species that has certain biological characters separating it from other individuals of that species.

Broadcast Application. The application of a material such as fertilizer or herbicide to the entire surface of a field.

Broad-Spectrum Pesticide. A pesticide that kills a large number of unrelated species.

Burn-Down Herbicide. A nonselective herbicide used to kill all plants in the application area.

Carbon Sequestration. The process of increasing the carbon content of a carbon reservoir other than through the atmosphere.

Caterpillar. The larva of a butterfly, moth, sawfly, or scorpion fly.

Certified Seed or Planting Stock. Seeds, tubers, or young plants certified by a recognized authority to be free of or to contain less than a minimum number of specified pests or pathogens.

Chemical Pest Control. Using either synthetic or natural derivative pesticides.

Climate Change. Climate change refers to any long-term trends in climate over many years or decades, around which climate variability may be evident year on year. Hence, a single warmer or cooler year on its own is not sufficient evidence to assert that climate is changing, but systematic changes in average conditions over many years do provide evidence of a changing climate. The United Nations Framework Convention on Climate Change (UNFCCC) defined climate change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition and climate variability attributable to natural causes.

Companion Planting. The practice of planting certain plant species – often herbs – in close association with crop plants to repel pests.

Competition. Interaction between individuals, brought about by a shared requirement for a resource and leading to a reduction in the survivorship, growth, and/or reproduction of at least some of the competing individuals concerned.

Composting. Natural process of "rotting" or decomposition of organic matter by microorganisms under controlled conditions.

Conservation. Any biological control practice designed to protect and maintain populations of existing natural enemies.

Conservation Agriculture (CA). Conservation agriculture aims to achieve sustainable and profitable agriculture and subsequently aims at improved livelihoods of farmers through the application of the three CA principles: minimal soil disturbance, permanent soil cover, and crop rotations. To do so, it promotes no-tillage to safeguard soil biodiversity, uses several organic fertilization practices such as rotations and mulching, but allows the use of genetically modified organisms (GMOs) and chemical inputs, namely pesticides.

Conservation-Tillage Farming. It is a practice used to reduce the effects of tillage on soil erosion; however, it still depends on tillage as the structure-forming element in the soil.

Cover Crops. Cultivation of a second type of crop primarily to improve the production system for a primary crop; examples include grasses or legumes maintained in orchards or vineyards and legume or other crops grown during the winter season to improve soil condition.

Crop Diversification. Crop diversification refers to varied crop associations and/or rotations (involving annual and/or perennial crops including trees). Crop diversification is intended to give a wider choice in the production of a variety of crops in a given area so as to expand production-related activities on various crops and also to lessen risks. Crop diversification is generally viewed as a shift from traditionally grown less remunerative crops to more remunerative crops.

Crop Residue. The part of the crop plants that remain in the field after harvest.

Crop Rotations. The practice of alternating the species or families of annual and/or biannual crops grown on a specific field in a planned pattern or sequence so as to break weed, pest, and disease cycles, and to maintain or improve soil fertility and organic matter content.

Cultivar. A specially developed agricultural plant variety.

Cultural Control. Pest management practices that rely upon manipulation of the cropping environment (e.g., cultivation of weeds harboring insect pests).

Damping-Off. Destruction of seedlings by one or a combination of pathogens that weaken the stem or root.

Deforestation. The conversion of forest to another land use or the long-term reduction of tree canopy cover below the 10% threshold.

Density. In pest control terms, density refers to the number of pests within a certain specific area.

Direct Seeding. Planting directly into untilled soils, without seedbed preparation.

Disease. Any disturbance of a plant that interferes with its normal structure, function, or economic value.

Disturbance. A cause, a physical force, agent, or process, causing a perturbation in an ecological component or system, relative to a specific reference state and system, defined by specific characteristics.

Drip Irrigation. Technique for achieving a low-rate, high-frequency, or long-duration water delivery through pipes to drip nozzles located near the plants.

Dwarfing. A stunting of normal growth characterized in plants by smaller-than-normal leaves and stems.

Ecology. The study of an organism's interrelationship with its environment.

Ecological Intensification. Ecological intensification refers to maximization of primary production per unit area without compromising the ability of the system to sustain its productive capacity. This entails management practices that optimize nutrient and energy flows and use local resources, including horizontal combinations (such as multiple cropping systems or polycultures), vertical combinations (such as agro-forestry), spatial integration (such as crop-livestock or crop-fish systems), and temporal combinations (rotations). A further definition is the following: an alternative approach for mainstream agriculture to meet current challenges. Ecological intensification aims to match or augment yield levels while minimizing negative impacts on the environment and ensuing negative feedbacks on agricultural productivity, by integrating the management of ecosystem services delivered by biodiversity into crop production systems.

Ecosystem Health. A measure of the stability and sustainability of ecosystem function or ecosystem services that depends on an ecosystem being active and maintaining its organization, autonomy, and resilience over time.

Ecosystem Services. The benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as flood and pest control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services such as nutrient cycling that maintain the conditions for life on Earth.

Economic Threshold. A level of pest population or damage at which the cost of control action equals the crop value gained from control action.

Ecosystem. The interactive system formed from all living organisms and their abiotic (physical and chemical) environment within a given area. Ecosystems cover a hierarchy of spatial scales and can comprise the entire globe, biomes at the continental scale, or small, well-circumscribed systems such as a small pond.

Ectoparasite. A parasite that lives on the outside of its host.

Endoparasite. A parasite that lives inside its host.

Entomophagous Nematodes. Nematodes that eat insects.

Entomopathogenic. An organism that attacks insects.

Erosion. The process of removal and transport of soil and rock by weathering, mass wasting, and the action of streams, glaciers, waves, winds, and underground water.

Evapotranspiration. The loss of soil moisture due to evaporation from the soil surface and transpiration by plants.

Extrafloral Nectary. A nectary located outside the flower.

Fallow. Cultivated land that is allowed to lie dormant, with no crops growing on it, during a growing season.

Farmer Field School (FFS). FFS refers to group-based learning methodology that has been used by a number of governments, NGOs, and international agencies to promote integrated pest management. It brings together concepts and methods from agro-ecology, experiential education, and community development.

Field Capacity. The moisture level in soil after saturation and runoff.

Food Security. Situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life.

Fumigation. Treatment with a pesticide active ingredient that is a gas under treatment conditions.

Fungus (Plural: Fungi). Any of numerous plants lacking chlorophyll, ranging in form from a single cell to a body of branched filaments. Includes yeasts, molds, smuts, and mushrooms.

Gall. Localized swelling or outgrowth of plant tissue often formed in response to the action of a pathogen or other pest.

Gene. A biochemical unit of hereditary, often coding for an entire protein.

Genetic Engineering. The manipulation of the genetic material of an organism in order to achieve desirable characteristics.

Genetically Modified Organism (GMO). Organism in which the genetic material has been changed through modern biotechnology in a way that does not occur naturally by multiplication and/or natural recombination (e.g., a plant may be given Bt genetic material that increases its resistance to pest).

Green Manuring. The cover crop grown to help maintain soil organic matter and increase nitrogen availability.

Green Bridge. Crop plant volunteers and weeds growing out of season that provides an environment for carryover and buildup of crop diseases and insects.

Ground Cover. Any of various low- and dense-growing plants used for covering the ground, as in places where it is difficult to grow grass.

Habitat. The particular environment or place where an organism or species tend to live, a more locally circumscribed portion of the total environment.

Habitat Manipulation. Manipulation of agricultural areas and surrounding environment with the aim of conserving or augmenting populations of natural enemies (e.g., the planting of a refuge for natural enemies).

Herbicide. A pesticide used to control weeds.

High-Residue Farming. An umbrella term that covers cropping systems where the volume of the soil that is tilled is reduced in order to maintain residue cover of the soil.

Honeydew. The sugary liquid discharge from the anus of certain insects (Homoptera) such as aphids and scales.

Host. The host is the organism that a parasite lives on or in. For example, if a plant has a pest, the plant is the host and the pest is the parasite.

Host Plant Resistance. The relative amount of heritable qualities possessed by a plant that reduces the degree of damage to the plant by a pest or pests.

Immune. Exempt from infection by a given pathogen.

Incorporate. To mix a material such as crop residue/organic matter into the soil by mechanical action.

Indigenous. The opposite of exotic, meaning it is native to a certain area.

Infection. The entry of a pathogen into a host and establishment of the pathogen as a parasite of the host.

Infestation. The presence of a large number of pest organisms in an area or field, on the surface of a host or anything that might contact a host, or in the soil.

Inoculum. Any part or stage of a pathogen, such as spores or virus particles, that can infect a host.

Inorganic. Containing no carbon; generally used to indicate materials (e.g., fertilizers) that are of mineral origin.

Integrated Pest Management (IPM). A pest management strategy that focuses on long-term prevention or suppression of pest problems through a combination of techniques such as encouraging biological control, use of resistant varieties, and adoption of alternate cultural practices such as modification of irrigation or pruning to make the habitat less conducive to pest development. Pesticides are used only when careful monitoring indicates they are needed according to preestablished guidelines and treatment thresholds, or to prevent pests from significantly interfering with the purposes for which plants are being grown.

Intensification. Intensification in conventional agriculture is understood primarily as using a higher input of nutrient elements and of pesticides per land unit. It also means more energy (direct for machinery and indirect for inputs).

Intercropping. Growing two or more crops as a mixture in the same field at the same time.

Juvenile. Immature form of a nematode/insect that hatches from an egg and molts several times before becoming an adult.

Land Cover. The physical coverage of land, usually expressed in terms of vegetation cover or lack of it that is influenced by land use.

Landscape. Landscape is an area of land that contains a mosaic of ecosystems, including human-dominated ecosystems.

Larva (Plural: Larvae). The immature form of insects/nematodes that develops through the process of complete metamorphosis including egg, several larval stages, and adult. In mites, the first-stage immature is also called a larva.

Lepidopterous. Of or pertaining to the Order Lepidoptera, the moths and butterflies.

Living Mulch. A cover crop that is interplanted with the primary crop(s) during the growing season.

Mechanical Control. Using screens, traps, or other mechanical means to control pests.

Microbial Pesticides. Pesticides that consist of bacteria, fungi, viruses, or other microorganisms used for the control of weeds, invertebrates, or plant pathogens.

Microorganism. An organism of microscopic size, such as a bacterium, virus, fungus, viroid, or mycoplasma.

Mite. Tiny, actually minute organisms that belong to the phylum Arthropoda, class Arachnida.

Modification of Environmental Factors. Factors such as moisture and heat, and, in the case of certain organic materials that decay, to gradually improve soil quality. Plant derived in organic or synthetic materials may be used.

Monitoring. Carefully watching and recording information on the activities, growth, development, and abundance of organisms or other factors on a regular basis over a period of time, often utilizing very specific procedures.

Monoculture. This refers to a cultivation system in which a single crop species covers a plot of land.

Mosaics. Mosaics are evident at all scales from submicroscopic to the planet and universe. All mosaics are composed of spatial elements (patches, corridors, and matrix). Those at the landscape scale are commonly called landscape elements, and those at the regional scale are landscapes.

Mulch. A layer of material placed on the soil surface to prevent weed growth/conserve soil moisture.

Multiple Cropping Systems. Planting two or more species in the same field during the same growing season is multiple cropping systems. It can take the form of double-cropping, in which a second crop is planted after the first has been harvested, or relay cropping, in which the second crop is started amid the first crop before it has been harvested.

Mycorrhizae. Beneficial associations between plant roots and fungi.

Natural Control. The suppression of pest populations by naturally occurring biological and environmental agents.

Natural Enemies. Predators, parasitoids, or pathogens that are considered beneficial because they attack and kill organisms that we normally consider to be pests.

Natural Selection. The process by which adaptive traits increase in frequency in a population due to the differential reproductive success of the individuals that possess the traits.

Necrosis. Death of tissue accompanied by dark brown discoloration, usually occurring in a well-defined part of a plant, such as the portion of a leaf between leaf veins or the xylem or phloem in a stem or tuber.

Nectar. The sugary liquid secreted by many flowers.

Nectary. A gland that secretes nectar.

Nematode. A triploblastic, bilaterally symmetrical, unsegmented, pseudocoelomate, and vermiform animal parasitic in animals, insects, or plants, or free-living in soil or water.

Niche (Ecological). All of the interactions of a species with the other members of its community including competition, predation, parasitism, and mutualism are niche. A variety of abiotic factors, such as soil type and climate, also define a species' niche. Each of the various species that constitute a community occupies its own ecological niche.

Nonpersistent Virus. A virus that is carried on the mouthparts of its insect vector and is lost after the vector feeds once or a few times, stylet-borne virus.

Organic. A material (e.g., pesticide) whose molecules contain carbon and hydrogen atoms. Also may refer to plants or animals which are grown without the use of synthetic fertilizers or pesticides.

Organic Agriculture. Holistic production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity, is organic agriculture. It emphasizes the use of management practices in preference to the use of off-farm inputs, taking into account that regional conditions require locally adapted systems.

Organic Matter. Plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population.

Overwinter. A period of rest or hibernation by which insects survive the winter.

Oviposition. The laying or depositing of eggs.

Parasite. An organism that derives its food from the body of another organism, the host, without killing the host directly; also an insect that spends its immature stages in the body of a host that dies just before the parasite emerges (this type is also called a parasitoid).

Parasitoid. An animal that feeds in or on another living animal, consuming all or most of its tissues and eventually killing it.

Participatory Plant Breeding. Farmers participate in the selection of parent materials and in on-farm evaluations.

Pathogen. A disease-causing organism.

Perennial. A plant that can live three or more years and flower at least twice.

Persistent Virus. A virus that systemically infects its insect vector and usually is transmitted for the remainder of the vector's life.

Pest Resurgence. The rapid rebound of a pest population after it has been controlled.

Pesticide. Any substance or mixture intended for preventing, destroying, repelling, killing, or mitigating problems caused by any insects, rodents, weeds, nematodes, fungi, or other pests.

Pesticide Resistance. The genetically acquired ability of an organism to survive a pesticide application at doses that once killed most individuals of the same species.

Pheromone. A substance secreted by an organism to affect the behavior or development of other members of the same species; sex pheromones that attract the opposite sex for mating is used in monitoring certain insects.

Photosynthesis. The process by which plants convert sunlight into energy.

Phytotoxicity. The ability of a material such as a pesticide or fertilizer to cause injury to plants.

Plant Genetic Resources. Inter- and intra-specific diversity of crops, varieties, and related wild species which are central to agricultural development and improvements.

Polyculture. Complex form of intercropping in which a large number of different plants maturing at different times are planted together.

Pollinator. The agent of pollen transfer, usually bees.

Postemergence Herbicide. Herbicide applied after the emergence of weeds.

Predator. Any animal (including insects and mites) that kills other animals (prey) and feeds on them.

Preemergence Herbicide. Herbicide applied before emergence of weeds.

Primary Inoculum. The initial source of a pathogen that starts disease development in a given location.

Protectant Fungicide. Fungicide that protects a plant from infection by a pathogen.

Quarantine. A period of enforced isolation that is required to prevent movement of undesirable organisms.

Reduced-Till. Reduced-till systems are somewhat similar to mulch till in that they involve full-width tillage, use the same implements, and may use one to three tillage trips. Reduced-till, however, leaves 15–30% residue on the soil surface after planting. Weed control is accomplished with crop protection products and/or row cultivation.

Relay Cropping. Cropping systems in which two or more crops are grown in sequence in the same field in the same year, with little or no overlap in time. Not a true form of polyculture because very little interspecies interaction usually occurs in these systems.

Residue Management. Management of crop straw and stubble after harvest.

Resistant. Able to tolerate conditions (such as pesticide sprays or pest damage) harmful to other strains of the same species.

Resurgence. This refers to a return of pests that were previously controlled. For instance, if you had basically eradicated the pest population on your farm and then they came back, this would constitute resurgence.

Rogue. To remove diseased plants from a field.

Rootstock. An underground stem or rhizome; lower portion of a graft which develops into the root system.

Rotation. The practice of purposefully alternating crop species grown on the same plot of land.

Row Covers. Any fabric or protective covering placed over rows of plants to protect them from pest damage, prevent virus vectors or harsh climate.

Sanitation. Any activity that reduces the spread of pathogen inoculum, such as removal and destruction of infected plant parts, cleaning of tools and field equipment.

Scion. The portion above a graft that becomes the trunk, branch, and tree top; the cultivar or variety.

Selective Herbicide. A herbicide that kills only certain groups of plants, for example, one that kills broadleaf plants but not grasses.

Selective Pesticide. Pesticides that are toxic primarily to the target pest (and perhaps a few related species), leaving most other organisms, including natural enemies, unharmed.

Smallholder. The definition of smallholders differs between countries and between agro-ecological zones. In favorable areas of smallholder subsistence agriculture with high population densities, smallholders often cultivate less than one hectare of land, whereas they may cultivate ten hectares or more in semiarid areas or manage up to ten heads of livestock.

Soil Health. The capacity of soil to function as a living system.

Soil Organic Matter (SOM). Soil organic matter is any material produced originally by living organisms (plant or animal) that is returned to the soil and goes through the decomposition process. At any given time, it consists of a range of materials from the intact original tissues of plants and animals to the substantially decomposed mixture of materials known as humus.

Solarization. The practice of heating soil to levels lethal to pests through application of clear plastic to the soil surface for 4–6 weeks during sunny, warm weather.

Stoma (Plural: Stomata). Natural opening in a leaf surface that serves for gas exchange and water evaporation and has the ability to open and close in response to environmental conditions.

Strip-Till. A system where the soil is tilled and crop residue removed or buried in a 15- to 30-cm wide strip where the next crop will be planted. The residue-covered area between the strips is left undisturbed.

Sucker. Shoot arising from the trunk or rootstock.

Sustainability. A characteristic or state whereby the needs of the present and local population can be met without compromising the ability of future generations or populations in other locations to meet their needs.

Sustainable Development. Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Systemic. Capable of moving throughout a plant or other organism, usually in the vascular system.

Target Pest. A pest species that a control action is intended to destroy.

Tolerance. Inherent lack of susceptibility to a pesticide. Also, the ability of a plant to grow in spite of infection by a pathogen.

Transformed (Bt-Transformed). Transfer and expression of a gene (e.g., for Bt toxin) into another organism.

Transgenic Plants. Transgenic plants are plants possessing a single or multiple genes, transferred from a different species.

Trap Crop. A crop or portion of a crop intended to attract pests so they can be destroyed by treating a relatively small area or by destroying the trap crop and the pests together.

Variety. An identifiable strain within a species, usually referring to a strain which arises in nature as opposed to a cultivar which is specifically bred for particular properties, sometimes used synonymously with cultivar.

Vector. An organism able to transport and transmit a pathogen to a host.

Vegetative. Plant parts or plant growth not involved in the production of seed, such as roots, stems, and leaves.

Virus. A very small organism that can multiply only within living cells of other organisms and is capable of producing disease symptoms in some plants and animals.

Volunteer Crop. The undesired emergence of a significant stand of a self-seeded, previously planted crop in a field purposely planted with another crop.

Weed Seed Bank. The reserve of viable weed seeds present on the soil surface and scattered in the soil profile.

Zero Tillage. No-till farming (sometimes called zero tillage) is a way of growing crops from year to year without disturbing the soil through tillage.

Annexure II: Acronyms

AF	Agro-Forestry
AMF	Arbuscular Mycorrhizal Fungi
ATP	Adenosine Triphosphate
BPH	Brown Plant Hopper (Rice)
Bt	*Bacillus thuringiensis*
BYDV	Barley Yellow Dwarf Virus
CA	Conservation Agriculture
CAP	Common Agricultural Policy
CBB	Coffee Berry Borer
CBC	Conservation Biological Control
CEC	Cation Exchange Capacity
CGMC	Cover/Green Manure Crop
CMV	Cucumber Mosaic Virus
CP	Coat Protein
CPB	Colorado Potato Beetle
CRM	Crop Residue Management
DBM	Diamondback Moth
DADS	Diallyl Disulfide
DAP	Days After Planting
DAS	Days After Sowing
DMDS	Dimethyl Disulfide

DNA	Deoxyribonucleic Acid
ECB	European Corn Borer
EBPM	Ecologically Based Pest Management
EPM	Ecological Pest Management
ET	Ethylene
ET	Evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
FFS	Farmer Field School
FMV	Feathery Mottle Virus (Sweet Potato)
GHG	Greenhouse Gas
GIS	Geographic Information Systems
GM	Genetically Modified
GMO	Genetically Modified Organism
GPS	Global Positioning System
GR	Glyphosate Resistant
GSL	Glucosinolates
GUA	Genotype Unit Areas
HCN	Hydrogen Cyanide
HIPVs	Herbivore-Induced Plant Volatiles
HPR	Host Plant Resistance
HT	Herbicide-Tolerant
ICIPE	International Center of Insect Physiology and Ecology
IPM	Integrated Pest Management
ITCs	Isothiocyanates
IWM	Integrated Weed Management
LER	Land Equivalent Ratio
LF	Leaf Folder (Rice)
MB	Methyl Bromide
MDGs	Millennium Development Goals
MT	Mulch Till
NPV	Nuclear Polyhedrosis Virus
NSKE	Neem Seed Kernel Extract
NSPE	Neem Seed Pulverized Extract
NT	No Till
ODP	Oviposition-Deterring Pheromone
OM	Organic Matter
PCN	Potato Cyst Nematode
PGPR	Plant Growth-Promoting Rhizobacteria
PGR	Plant Genetic Resources
PF	Precision Farming
PLRV	Potato Leaf Roll Virus
PPV	Plum Pox Virus
PRSV	Papaya Ring Spot Virus
PSD	Plant Species Diversity
PTC	Perimeter Trap Cropping

PTGS	Posttranscriptional Gene Silencing
PTM	Potato Tuber Moth
PVY	Potato Virus Y
RNA	Ribonucleic Acid
RS	Remote Sensing
RT	Ridge Till
SAR	Systemically Acquired Resistance
SB	Stem Borer (Rice)
SDGs	Sustainable Development Goals
SI	Sustainable Intensification
SOC	Soil Organic Carbon
SOD	Superoxide Dismutase
SOM	Soil Organic Matter
ST	Strip Till
ToMV	Tomato Mosaic Virus
TSWV	Tomato Spotted Wilt Virus
USDA	United States Department of Agriculture
VRT	Variable Rate Technology
VOCs	Volatile Organic Compounds
WMV	Watermelon Mosaic Virus
YM	Yield Monitors
ZYMV	Zucchini Yellow Mosaic Virus

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