P. Parvatha Reddy

Biointensive Integrated Pest Management in Horticultural Ecosystems

Springer

Biointensive Integrated Pest Management in Horticultural Ecosystems

P. Parvatha Reddy

Biointensive Integrated Pest Management in Horticultural Ecosystems

Springer

Dr. P. Parvatha Reddy
Former Director
Indian Institute of Horticultural Research
Bangalore
Karnataka
India

ISBN 978-81-322-1843-2 ISBN 978-81-322-1844-9 (eBook)
DOI 10.1007/978-81-322-1844-9
Springer New Delhi Dordrecht Heidelberg London New York

Library of Congress Control Number: 2014933684

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

Through ‘Green Revolution’ in late 1960s, India achieved self-sufficiency in food production, which was hailed as a breakthrough on the farm front by international agricultural experts. But still the country has not achieved self-sufficiency in production of horticultural crops. Most of the growth in food production during the green revolution period is attributed to the use of improved crop varieties and higher levels of inputs of fertilizers and pesticides. The modern agricultural techniques such as use of synthetic fertilizers and pesticides are continuing to destroy stable traditional ecosystems and the use of high yielding varieties of crops has resulted in the elimination of thousands of traditional varieties with the concurrent loss of genetic resources. The introduction of high yielding varieties changed the agricultural environment leading to numerous pest problems of economic importance. In the process of intensive farming, the environment has been treated in an unfriendly manner.

Prof. Swaminathan (2000) emphasized the need for ‘Ever Green Revolution’ keeping in view the increase in population. The increase in population and diminishing per capita availability of land demands rise in productivity per unit area. In India, annual crop losses due to pests, diseases, and weeds have been estimated to be about ₹ 600,000 million in 2005. Increasing yields from existing land requires effective crop protection to prevent losses before and after harvest. The challenge before the crop protection scientist is to do this without harming the environment and resource base. This can be achieved by adopting eco-friendly Biointensive Integrated Pest Management (BIPM) strategy.

BIPM is defined as “A systems approach to pest management based on an understanding of pest ecology. It begins with steps to accurately diagnose the nature and source of pest problems, and then relies on a range of preventive tactics and biological controls to keep pest populations within acceptable limits. Reduced-risk pesticides are used if other tactics have not been adequately effective, as a last resort, and with care to minimize risks” (Benbrook 1996).

BIPM incorporates ecological and economic factors into agricultural system design and decision making, and addresses public concerns about environmental quality and food safety. The benefits of implementing BIPM can include reduced chemical input costs, reduced on-farm and off-farm environmental impacts, and more effective and sustainable pest management.

An ecology-based Integrated Pest Management (IPM) has the potential of decreasing inputs of fuel, machinery, and synthetic chemicals-all of which are energy intensive and increasingly costly in terms of financial and environmental impact. Such reductions will benefit the grower and society.

The information on biointensive integrated pest management (insect, mite and nematode pests, and diseases caused by bacteria, fungi, virus/mycoplasma) in horticultural ecosystems (fruits, vegetables, ornamentals, medicinal, aromatic, tuber, plantation, and spice crops) is very much scattered. There is no book at present which comprehensively and exclusively deals with the above aspects. The present book deals with the most recent biointensive integrated approaches utilizing components such as bioagents [predators, parasitoids, and pathogens (bacteria, fungi, viruses)], botanicals (biofumigation, oil cakes, FYM, compost, crop residues, green manuring, and other organic amendments), endomycorrhizae, physical methods (hot water treatment of planting material, soil solarization), cultural methods (crop rotation, summer ploughing, fallowing, intercropping, pruning, mulching, spacing, planting date, trap cropping, etc.), biorational chemicals (pheromones) and resistant cultivars. The book is illustrated with excellent quality photographs enhancing the quality of publication. The book is written in lucid style, easy to understand language along with adoptable recommendations for pest management.

This book can serve as a useful reference to policy makers, research, and extension workers, practicing farmers and students. The material can also be used for teaching post-graduate courses. Suggestions to improve the contents of the book are most welcome (E-mail: reddy_parvatha@yahoo.com). The publisher, Springer, deserves commendation for their professional contribution.

Bangalore, India
5 Mar 2014

Dr. P. Parvatha Reddy
Indian Institute of Horticultural Research

Contents

I Introduction

II Biointensive Integrated Pest Management in Fruit Crops

About the Author

Dr. P. Parvatha Reddy obtained his MSc (Agri.) degree from Karnataka University, Dharwad, and 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 period the Institute was honoured with *ICAR Best Institution Award*. He also served as the Head, Division of Entomology and Nematology at IIHR and gave tremendous impetus and direction to research, extension and education in developing bio-intensive 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 involved in developing an F1 tomato hybrid *Arka Varadan* resistant to root-knot nematodes. He has also developed bio-intensive integrated pest management strategies in horticultural crops using eco-friendly components such as bio-control agents, botanicals and arbuscular mycorrhizal fungi.

Dr. Reddy has over 237 scientific publications to his credit, which also include 25 books. He has also guided two PhD students at the University of Agricultural Sciences, 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, bio-intensive and eco-friendly integrated pest management strategies in horticultural crops.

Dr. Reddy served as a member of the Research Advisory Committee of the National Centre for Integrated Pest Management, New Delhi; the National Research Centre for Citrus, Nagpur and the Project Directorate of Biological Control, Bangalore. He also served as a Member of the ICAR Scientific Panel for Nematology, Member, QRT to review the progress of AICRP on Nematodes and AINRP on Betelvine. 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 organized *Fourth International Workshop on Biological Control and Management of Chromolaena odorata, National Seminar on Hitech 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.*

Part I

Introduction

1 Introduction

Through 'Green Revolution' in late 1960s, India achieved self-sufficiency in food production, which was hailed as a breakthrough on the farm front by international agricultural experts. But still the country has not achieved self-sufficiency in production of horticultural crops. Most of the growth in food production during the green revolution period is attributed to the use of improved crop varieties and higher levels of inputs of fertilizers and pesticides. The modern agricultural techniques such as use of synthetic fertilizers and pesticides are continuing to destroy stable traditional ecosystems and the use of high yielding varieties of crops has resulted in the elimination of thousands of traditional varieties with the concurrent loss of genetic resources. The introduction of high yielding varieties changed the agricultural environment leading to numerous pest problems of economic importance. In the process of intensive farming, the environment has been treated in an unfriendly manner.

Prof. Swaminathan (2000) emphasized the need for 'Ever green revolution' keeping in view the increase in population. The increase in population and diminishing per capita availability of land demands rise in productivity per unit area. In India, annual crop losses due to pests, diseases and weeds have been estimated to be about ₹ 600,000 million in 2005. Increasing yields from existing land requires effective crop protection to prevent losses before and after harvest. The challenge before the crop protection scientist is to do this without harming the environment and resource base. This can be achieved in horticultural ecosystems by adopting eco-friendly biointensive integrated pest management (BIPM) strategy.

1.1 Integrated Pest Management

Integrated pest management (IPM) is an important principle on which sustainable crop protection can be based. IPM allows farmers to manage pests in a cost effective, environmentally sound, and socially acceptable way. According to Food and Agriculture Organization (FAO), IPM is defined as 'A pest management system that in the context of the associated environment and the population dynamics of the pest species utilizes all suitable techniques and methods, in a compatible manner as possible and maintains the pest populations at levels below those causing economic injury'.

1.2 Biointensive Integrated Pest Management (BIPM)

BIPM incorporates ecological and economic factors into agricultural system design and decision making, and addresses public concerns about environmental quality and food safety. The benefits of implementing BIPM can include reduced chemical input costs, reduced on-farm and off-farm environmental impacts, and more effective

P. P. Reddy, *Biointensive Integrated Pest Management in Horticultural Ecosystems*,
DOI 10.1007/978-81-322-1844-9_1, © Springer India 2014

and sustainable pest management. An ecology-based IPM has the potential of decreasing inputs of fuel, machinery, and synthetic chemicals—all of which are energy intensive and increasingly costly in terms of financial and environmental impact. Such reductions will benefit the grower and society.

Over-reliance on the use of synthetic pesticides in crop protection programmes around the world has resulted in disturbances to the environment, pest resurgence, pest resistance to pesticides, and lethal and sublethal effects on non-target organisms, including humans. These side effects have raised public concern about the routine use and safety of pesticides. At the same time, population increases are placing ever-greater demands upon the 'ecological services', i.e., provision of clean air, water, and wildlife habitat for a landscape dominated by farms. Although some pending legislation has recognized the costs to farmers of providing these ecological services, it is clear that farmers will be required to manage their land with greater attention to direct and indirect off-farm impacts of various farming practices on water, soil, and wildlife resources. With this likely future in mind, reducing dependence on chemical pesticides in favour of ecosystem manipulations is a good strategy for farmers.

BIPM is defined as 'A systems approach to pest management based on an understanding of pest ecology. It begins with steps to accurately diagnose the nature and source of pest problems, and then relies on a range of preventive tactics and biological controls to keep pest populations within acceptable limits. Reduced-risk pesticides are used if other tactics have not been adequately effective, as a last resort, and with care to minimize risks' (Benbrook 1996).

The primary goal of BIPM is to provide guidelines and options for the effective management of pests and beneficial organisms in an ecological context. The flexibility and environmental compatibility of a BIPM strategy make it useful in all types of cropping systems. BIPM would likely decrease chemical use and costs even further.

1.2.1 Components of BIPM

An important difference between conventional IPM and BIPM is that the emphasis of the latter is on proactive measures to redesign the agricultural ecosystem to the disadvantage of a pest and to the advantage of its parasite and predator complex. At the same time, BIPM shares many of the same components as conventional IPM, including monitoring, use of economic thresholds, record keeping, and planning.

1.2.1.1 Planning

Good planning must precede implementation of any IPM programme, but is particularly important in a biointensive programme. Planning should be done before planting because many pest strategies require steps or inputs, such as beneficial organism habitat management, that must be considered well in advance. Attempting to jump-start an IPM programme in the beginning or middle of a cropping season generally does not work.

When planning a BIPM programme, some considerations include:

- Options for design changes in the agricultural system (beneficial organism habitat, crop rotations).
- Choice of pest-resistant cultivars.
- Technical information needs.
- Monitoring options, record keeping, equipment, etc.

When making a decision about crop rotation, consider the following questions: Is there an economically sustainable crop that can be rotated into the cropping system? Is it compatible? Important considerations when developing a crop rotation are:

- How might the cropping system be altered to make life more difficult for the pest and easier for its natural controls? What two (or three or several) crops can provide an economic return when considered together as a biological and economic system that includes considerations of sustainable soil management?
- What are the impacts of this season's cropping practices on subsequent crops?

- What specialized equipment is necessary for the crops?
- What markets are available for the rotation crops?

Management factors should also be considered. For example, one crop may provide a lower direct return per hectare than the alternate crop, but may also lower management costs for the alternate crop, with a net increase in profit.

1.2.1.2 Pest Identification

A crucial step in any IPM programme is to identify the pest. The effectiveness of both proactive and reactive pest management measures depends on correct identification. Misidentification of the pest may be worse than useless; it may actually be harmful and cost time and money. Help with positive identification of pests may be obtained from university personnel, private consultants, the Cooperative Extension Service (CES), and books and web sites.

After a pest is identified, appropriate and effective management depends on knowing answers to a number of questions. These may include:

- What plants are hosts and non-hosts of this pest?
- When does the pest emerge or first appear?
- Where does it lay its eggs?
- For plant pathogens, where is the source(s) of inoculum?
- Where, how, and in what form does the pest overwinter?

Monitoring (field scouting) and economic injury and action levels are used to help answer these and additional questions.

1.2.1.3 Monitoring

Monitoring involves systematically checking crop fields for pests and beneficials, at regular intervals and at critical times, to gather information about the crop, pests, and natural enemies. Sweep nets, sticky traps, and pheromone traps can be used to collect insects for both identification and population density information. Leaf counts are one method for recording plant growth stages. Records of rainfall and temperature are sometimes used to predict the likelihood of disease infections.

The more often a crop is monitored, the more information the grower has about what is happening in the fields. Monitoring activity should be balanced against its costs. Frequency may vary with temperature, crop, growth phase of the crop, and pest populations. If a pest population is approaching economically damaging levels, the grower will want to monitor more frequently.

1.2.1.4 Economic Injury and Action Levels

The economic injury level (EIL) is the pest population that inflicts crop damage greater than the cost of control measures. Because growers will generally want to act before a population reaches EIL, IPM programmes use the concept of an economic threshold level (ETL or ET), also known as an action threshold. The ETL is closely related to the EIL and is the point at which suppression tactics should be applied in order to prevent pest populations from increasing to injurious levels.

ETLs are intimately related to the value of the crop and the part of the crop being attacked. For example, a pest that attacks the fruit or vegetable will have a much lower ETL (i.e., the pest must be controlled at lower populations) than a pest that attacks a non-saleable part of the plant. The exception to this rule is an insect or nematode pest that is also a disease vector. Depending on the severity of the disease, the grower may face a situation where the ETL for a particular pest is zero, i.e., the crop cannot tolerate the presence of a single pest of that particular species because the disease it transmits is so destructive.

1.2.2 BIPM Options

BIPM options may be considered as proactive or reactive.

1.2.2.1 Proactive Options

Proactive options, such as crop rotations and creation of habitat for beneficial organisms, permanently lower the carrying capacity of the farm for the pest. The carrying capacity is determined by the factors like food, shelter, natural enemy complex, and weather, which affect the reproduction and survival of a pest species. Cultural control practices are generally considered to be proactive strategies. Proactive practices include crop rotation, resistant crop cultivars including transgenic plants, disease-free seed and plants, crop sanitation, spacing of plants, altering planting dates, mulches, etc.

The proactive strategies (cultural controls) include:

- Healthy, biologically active soils (increasing below-ground diversity).
- Habitat for beneficial organisms (increasing above-ground diversity).
- Appropriate plant cultivars.

(i) Intercropping Intercropping is the practice of growing two or more crops in the same, alternate, or paired rows in the same area. This technique is particularly appropriate in vegetable production. The advantage of intercropping is that the increased diversity helps 'disguise' crops from insect pests and, if done well, may allow for more efficient utilization of limited soil and water resources.

(ii) Strip Cropping Strip cropping is the practice of growing two or more crops in different strips across a field wide enough for independent cultivation. It is commonly practiced to help reduce soil erosion in hilly areas. Like intercropping, strip cropping increases the diversity of a cropping area, which in turn may help 'disguise' the crops from pests. Another advantage to this system is that one of the crops may act as a reservoir and/or food source for beneficial organisms.

The options described above can be integrated with no-till cultivation schemes and all its variations (strip till, ridge till, etc.) as well as with hedgerows and intercrops designed for beneficial organism habitat. With all the cropping and tillage options available, it is possible, with creative and informed management, to evolve a biologically diverse, pest-suppressive farming system appropriate to the unique environment of each farm.

(iii) Disease-free Seed and Plants These are available from most commercial sources and are certified as such. The use of disease-free seed and nursery stock is important in preventing the introduction of disease.

(iv) Resistant Varieties These are continually being bred by researchers. Growers can also do their own plant breeding simply by collecting non-hybrid seeds from healthy plants in the field. The plants from these seeds will have a good chance of being better suited to the local environment and of being more resistant to insects and diseases. Since natural systems are dynamic rather than static, breeding for resistance must be an ongoing process, especially in the case of plant disease, as the pathogens themselves continue to evolve and become resistant to control measures.

Perhaps the greatest single technological achievement is the advance in breeding crops for resistance to pests. Cultivation of resistant varieties is the cheapest and best method of controlling pests. One of the important components of IPM is the use of resistant cultivars to key pests. Under All India Co-ordinated Research Projects of Indian Council of Agricultural Research, a large number of highly/moderately resistant varieties are released to the farmers (Table 1.1).

(v) Biotech Crops Gene transfer technology is being used by several companies to develop cultivars resistant to insects, diseases, and nematodes. An example is the incorporation of genetic material from *Bacillus thuringiensis* (*Bt*), a naturally occurring bacterium, into brinjal and potatoes, to make the plant tissues toxic to shoot and fruit borer and potato beetle larvae, respectively.

Whether or not this technology should be adopted is the subject of much debate. Opponents are concerned that by introducing *Bt* genes into plants, selection pressure for resistance to the *Bt* toxin will intensify and a valuable biological control tool will be lost. There are also concerns about possible impacts of genetically modified (GM) plant products (i.e., root exudates) on non-target organisms as well as fears of altered genes being transferred to weed relatives of crop plants. Whether there is a market for gene-altered crops

Table 1.1 Horticultural crop varieties resistant to pests/diseases

Horticultural crop	Pest/disease	Resistant varieties
Banana	*Radopholus similis*	Kadali, Pedalimoongil, Ayiramkapoovan, Peykunnan, Kunnan, Pisang Seribu, Tongat, Vennettu Kunnan, Anaikomban
	Panama wilt (*Fusarium oxysporum* f. sp. *cubense*)	Robusta, Dwarf Cavendish
Citrus	*Tylenchulus semipenetrans*	Trifoliate Orange, Swingle Citrumelo
	Gummosis, leaf fall, fruit rot (*Phytophthora* spp.)	Cleopatra mandarin, Rangpur lime, Trifoliate orange rootstocks
Grapevine	Root-knot nematode, *Meloido-gyne incognita*	Black Champa, Dogridge, 1613, Salt Creek, Cardinal, Banquabad
Papaya	Ring spot virus	Rainbow, Sun Up
Passion fruit	Root-knot nematode, *M. incognita*	Yellow, Kaveri
Potato	Late blight	Kufri Sutlej, Kufri Badshah, Kufri Jawahar (in plains), Kufri Jyothi, Kufri Giriraj, Kufri Kanchan, Kufri Meghad (in hills)
Tomato	Bacterial wilt	Arka Abha, Arka Alok, Arka Shreshta, Arka Abhijit, Megha, Shakthi, Sun 7610, Sun 7611
	PM	Arka Asish
	Fusarium and *Verticillium* wilt	Vaishali, Rupali, Rashmi
	Leaf curl virus	Avinash-2, Hisar Anmol
	Root-knot nematode	Hisar Lalit, Pusa Hybrid-2, Arka Vardaan
Brinjal	Bacterial wilt	Arka Nidhi, Arka Keshav, Arka Neelkant, Arka Anand, Swarna Shree, Swarna Shyamali, Surya, Ujjwala
	Phomopsis blight	Pusa Bhairav
	Little leaf	Pusa Purple Long, Pusa Purple Cluster (Field resistant)
Chilli	TMV, CMV, leaf curl	Pusa Sada Bahar, Punjab Lal, Pusa Jwala
	Thrips	NP 46 (T)
	PM	Arka Suphala (T)
	Dieback and PM	Musalwadi (T)
	Mosaic, leaf curl	Pant C-1
	Leaf curl and fruit rot	Jawahar 218 (T)
	Viruses	Arka Harita, Arka Meghana
French bean	Angular leaf spot, mosaic	Pant Anupama
	Rust, bacterial blight	Arka Anoop
	Rust	Arka Bold, Swarna Priya, Swarna Latha, Arka Anoop
	Rust, *Alternaria* leaf spot	Arka Bold
Pea	PM	Pusa Pragati, Jawahar Matar 5, Jawahar Peas 83
	PM, rust	Arka Ajit, Arka Karthik, Arka Sampoorna
	Fusarium wilt	JP Batri Brown 3, JP Batri Brown 4
Cowpea	Bacterial blight	Pusa Komal
Pigeon pea	*Fusarium* wilt	Maruti
Field bean	Viral diseases, jassid, aphid, pod borer	Pusa Sem-2, Pusa Sem-3
Cluster bean	PM, *Alternaria* leaf spot	Gomah Manjari
Okra	YVMV	Pusa Sawani, Arka Abhay, Arka Anamika, Hisar Unnat, DVR-1, DVR-2, IIVR-10, Varsha Upkar, P-7, Pusa A-4, Parbhani Kranti (T), Punjab Kesari, Punjab Padmini, Sun-40, Makhmali
	YVMV and fruit borer	Pusa A-4

Table 1.1 (continued)

Horticultural crop	Pest/disease	Resistant varieties
Cucumber	PM	Swarna Poorna
	PM, DM, angular leaf spot, anthracnose	Poinsette
Cabbage	Black rot	Pusa Mukta
	Black leg	Pusa Drum Head
Cauliflower	Black rot	Pusa Snowball K-1
	Black rot and curd blight	Pusa Shubhra
	Curd blight	Pusa Synthetic
	DM	Pusa Hybrid-2
Onion	Purple blotch, basal rot, thrips	Arka Pitamber, Arka Kirtiman, Arka Lalima
	Purple blotch, *Alternaria porri*	Arka Kalyan
Garlic	Purple blotch, *Stemphylium* disease	Agri-found White
Muskmelon	PM	Arka Rajhans, Pusa Madhuras (MR)
	PM, DM	Punjab Rasila
	Fusarium wilt	Pusa Madhuras, Durgapura Madhu, Arka Jeet, Punjab Sune-hari (MR), Harela
Watermelon	PM, DM, anthracnose	Arka Manik
Pumpkin	Fruit fly	Arka Suryamukhi
Ridge gourd	PM, DM	Swarna Uphaar
Bottle gourd	Blossom end rot	Arka Bahar (T)
	CMV	Punjab Komal
Carrot	PM, root-knot nematode	Arka Suraj
Amaranth	White rust	Arka Arunima, Arka Suguna (MR)
Palak	*Cercospora* leaf spot	Arka Anupama
China aster	Root-knot nematode, *M. incognita*	Shashank, Poornima (MR)
Tuberose	Root-knot nematode, *M. incognita*	Sringar, Suvasini (T)
Mentha	Root-knot nematode, *M. incognita*	Kukrail, Arka Neera
Black pepper	Root-knot nematode, *M. incognita*	IISR Pournami (T)
	Foot rot, *Phytophthora capsici*	IISR Shakthi
Cardamom	Mosaic	IISR Vijetha
	Rhizome rot	IISR Avinash
Ginger	Root-knot nematodes	IISR Mahima
	Soft rot	Maran
Cumin	*Fusarium* wilt	GC-4

CMV cucumber mosaic virus, *DM* downy mildew, *MR* moderately resistant, *PM* powdery mildew, *T* tolerant, *TMV* tobacco mosaic virus, *YVMV* yellow vein mosaic virus

is also a consideration for farmers and processors. Proponents of this technology argue that use of such crops decreases the need to use toxic chemical pesticides.

Transgenic crop varieties in horticultural crops (tomato, potato, brinjal, beans, cabbage, cauliflower, musk melon, banana, coffee) have been developed by cloning *Bt* endotoxin genes which are cultivated in large areas. In 2011, India is the fourth largest GM crops growing country (10.6 million ha) in the world only next to USA (69 million ha), Brazil (30.3 million ha), and Argentina (23.7 million ha) (Clive James 2011). Combining a host gene for resistance with pathogen-derived genes or with genes coding for antimicrobial compounds provides for a broad

Table 1.2 Development of transgenics in vegetable crops in India

Vegetable crop	Target pathogen	Transgene(s)	Institute
Potato	Tuber moth	*Bt* Cry 1Ab	CPRI, Shimla
	Potato virus Y	Coat protein	CPRI, Shimla
Tomato	Leaf curl virus	Leaf curl virus sequence	IIHR, Bangalore IAHS, Bangalore
		Replicase gene	IARI, New Delhi
	Fungal diseases	Chitinase and glucanase	IIHR, Bangalore
		Alfalfa glucanase	IAHS, Bangalore
		Oxalate decarboxylase (OXDC)	JNU, New Delhi
	Lepidopteran pests	*Bt* Cry 1Ab	IARI, New Delhi Proagro PG-S (India) Ltd.
Brinjal	Fungal diseases	Chitinase, glucanase, and thaumatin encoding genes	
	Lepidopteran pests	*Bt* Cry 1Ab	IARI, New Delhi Proagro PG-S (India) Ltd.
Cabbage	Lepidopteran pests	*Bt* Cry 1Ab	IARI, New Delhi Proagro PG-S (India) Ltd.
		Cry 1H/Cry 9C	Proagro PG-S (India) Ltd.
Cauliflower	Lepidopteran pests	*Bt* Cry 1Ab	IARI, New Delhi Proagro PG-S (India) Ltd.
		Cry 1H/Cry 9C	Proagro PG-S (India) Ltd.

and effective resistance in many host–pathogen combinations (Table 1.2).

(vi) Sanitation It involves removing and destroying the overwintering or breeding sites of the pest as well as preventing a new pest from establishing on the farm (e.g., not allowing off-farm soil from farm equipment to spread nematodes or plant pathogens to your land). This strategy has been particularly useful in horticultural and tree-fruit crop situations involving twig and branch pests. If, however, sanitation involves removal of crop residues from the soil surface, the soil is left exposed to erosion by wind and water. As with so many decisions in farming, both the short- and long-term benefits of each action should be considered when tradeoffs like this are involved.

(vii) Spacing of Plants It heavily influences the development of plant diseases. The distance between plants and rows, the shape of beds, and the height of plants influence air flow across the crop, which in turn determines how long the leaves remain damp from rain and morning dew. Generally speaking, better air flow will decrease the incidence of plant disease. However, increased air flow through wider spacing will also allow more sunlight to the ground. This is another instance in which detailed knowledge of the crop ecology is necessary to determine the best pest-management strategies. How will the crop react to increased spacing between rows and between plants? Will yields drop because of reduced crop density? Can this be offset by reduced pest management costs or fewer losses from disease?

(viii) Altered Planting Dates This can at times be used to avoid specific insects or diseases. For example, squash bug infestations on cucurbits can be decreased by the delayed planting strategy, i.e., waiting to establish the cucurbit crop until overwintering adult squash bugs have died. To assist with disease management decisions, the CES will often issue warnings of 'infection periods' for certain diseases, based upon the weather.

In some cases, the CES also keeps track of 'degree days' needed for certain important insect pests to develop. Insects, being cold-blooded, will not develop below or above certain threshold temperatures. Calculating accumulated degree days, i.e., the number of days above the threshold development temperature for an insect pest, makes the prediction of certain events, such as egg hatch, possible. *University of California* has an excellent web site that uses weather station data from around the state to help California growers predict pest emergence.

Some growers gauge the emergence of insect pests by the flowering of certain non-crop plant species native to the farm. This method uses the 'natural degree days' accumulated by plants. For example, a grower might time cabbage planting for 3 weeks after the *Amelanchier* species (also known as saskatoon, shad bush, or service berry) on their farm are in bloom. This will enable the grower to avoid peak egg-laying time of the cabbage maggot fly, as the egg hatch occurs about the time *Amelanchier* species are flowering (Couch 1994). Using this information, cabbage maggot management efforts could be concentrated during a known time frame when the early instars (the most easily managed stage) are active.

(ix) Optimum Growing Conditions Plants that grow quickly and are healthy can compete with and resist pests better than slow-growing, weak plants. Too often, plants grown outside their natural ecosystem range must rely on pesticides to overcome conditions and pests to which they are not adapted.

(x) Mulches Living or non-living mulches are useful for suppression of insect pests and some plant diseases. Hay and straw, for example, provide habitat for spiders. Research in Tennessee showed a 70 % reduction in damage to vegetables by insect pests when hay or straw was used as mulch. The difference was due to spiders, which find mulch more habitable than bare ground (Reichert and Leslie 1989). Other researchers have found that living mulches of various clovers reduce insect pest damage to vegetables and orchard crops. Again, this reduction is due to natural predators and parasites provided habitat by the clovers.

Mulching helps in minimizing the spread of soil-borne plant pathogens by preventing their spread through soil splash. Winged aphids are repelled by silver- or aluminium-coloured mulches. Recent springtime field tests at the Agricultural Research Service in Florence, South Carolina, have indicated that red plastic mulch suppresses root-knot nematode damage in tomatoes by diverting resources away from the roots (and nematodes) and into foliage and fruit (Adams 1997).

1.2.2.2 Reactive Options

The reactive options mean that the grower responds to a situation, such as an economically damaging population of pests, with some type of short-term suppressive action. Reactive methods generally include inundative releases of biological control agents, mechanical and physical controls, botanical pesticides, and chemical controls.

(i) Biological Controls

Biological control is the use of living organisms—parasites, predators, or pathogens—to maintain pest populations below economically damaging levels, and may be either natural or applied. A first step in setting up a BIPM programme is to assess the populations of beneficials and their interactions within the local ecosystem. This will help to determine the potential role of natural enemies in the managed horticultural ecosystem. It should be noted that some groups of beneficials (e.g., spiders, ground beetles, bats) may be absent or scarce on some farms because of lack of habitat. These organisms might make significant contributions to pest management if provided with adequate habitat.

(a) Natural Biological Control It results when naturally occurring enemies maintain pests at a lower level than would occur without them, and is generally characteristic of biodiversity systems. Mammals, birds, bats, insects, fungi, bacteria, and viruses all have a role to play as predators, parasites, and pathogens in a horticultural system. By their very nature, pesticides decrease the biodiversity of a system, creating the potential for instability and future problems. Pesticides, whether synthetically or botanically derived, are powerful tools and should be used with caution.

Creation of habitat to enhance the chances for survival and reproduction of beneficial organisms is a concept included in the definition of natural biocontrol. *Farmscaping* is a term coined to describe such efforts on farms. Habitat enhancement for beneficial insects, for example, focuses on the establishment of flowering annual or perennial plants that provide pollen and nectar needed during certain parts of the insect life cycle. Other habitat features provided by farmscaping include water, alternative prey, perching sites, overwintering sites, and wind protection. Beneficial insects and other beneficial organisms should be viewed as mini-livestock, with specific habitat and food needs to be included in farm planning.

The success of such efforts depends on knowledge of the pests and beneficial organisms within the cropping system. Where do the pests and beneficials overwinter? What plants are hosts and non-hosts? When this kind of knowledge informs planning, the ecological balance can be manipulated in favour of beneficials and against the pests.

It should be kept in mind that ecosystem manipulation is a two-edged sword. Some plant pests (such as the tarnished plant bug and lygus bug) are attracted to the same plants that attract beneficials. The development of beneficial habitats with a mix of plants that flower throughout the year can help prevent such pests from migrating en masse from farmscaped plants to crop plants.

(b) Applied Biological Control It is also known as augmentative biocontrol, involves supplementation of beneficial organism populations, for example, through periodic releases of parasites, predators, or pathogens. This can be effective in many situations—well-timed inundative releases of *Trichogramma* egg wasps for codling moth control, for instance.

Most of the beneficial organisms used in applied biological control today are insect parasites and predators. They control a wide range of pests from caterpillars to mites. Some species of biocontrol organisms, such as *Eretmocerus californicus*, a parasitic wasp, are specific to one host—in this case the sweet potato whitefly. Others, such as green lacewings, are generalists and will attack many species of aphids and whiteflies.

Information about rates and timing of release is available from suppliers of beneficial organisms. It is important to remember that released insects are mobile; they are likely to leave a site if the habitat is not conducive to their survival. Food, nectar, and pollen sources can be 'farmscaped' to provide suitable habitat.

The quality of commercially available applied biocontrols is another important consideration. For example, if the organisms are not properly labelled on the outside packaging, they may be mishandled during transport, resulting in the death of the organisms. A recent study by Rutgers University noted that only two of six suppliers of beneficial nematodes sent the expected numbers of organisms, and only one supplier out of the six provided information on how to assess product viability.

While augmentative biocontrols can be applied with relative ease on small farms and in gardens, applying some types of biocontrols evenly over large farms has been problematic. New mechanized methods that may improve the economics and practicality of large-scale augmentative biocontrol include ground application with 'biosprayers' and aerial delivery using small-scale (radio-controlled) or conventional aircraft.

Inundative releases of beneficials into greenhouses can be particularly effective. In the controlled environment of a greenhouse, pest infestations can be devastating; there are no natural controls in place to suppress pest populations once an infestation begins. For this reason, monitoring is very important. If an infestation occurs, it can spread quickly if not detected early and managed. Once introduced, biological control agents cannot escape from a greenhouse and are forced to concentrate predation/parasitism on the pest(s) at hand.

An increasing number of commercially available biocontrol products are made up of

Table 1.3 Biological control of fruit crop pests

Fruit crop	Pest	Biocontrol agent/dosage
Apple	Woolly aphid, *Eriosoma lanigerum*	*Aphelinus mali*—1,000 adults or mummies/infested tree
	San Jose scale, *Quadraspidiotus perniciosus*	*Encarsia perniciosi*—2,000 adults/infested tree
	Codling moth, *Cydia pomonella*	*Chilocorus infernalis*—20 adults or 50 grubs/tree; *Trichogramma embryophagum*—2,000 adults/tree; *Steinernema carpocapse*
Citrus	Cottony cushion scale, *Icerya purchasi*	*Rodolia cardinalis*—10 beetles/infested plant
	Mealy bug, *P. citri*	*C. montrouzieri*—10 beetles/infested plant; *L. dactylopii* 3,000 adults/ha
	Red scale, *Aonidiella aurantii*	*Chilocorus nigrita*—15 adults/infested tree
	Scale insect, *Coccus viridis*	*Verticillium lecanii*—16×10^4 spores/mL + 0.05 % Teepol
	Leaf miner, *Phyllocnistis citrella*	*S. carpocapse*
Grapevine	Mealy bug, *Maconellicoccus hirsutus*	*C. montrouzieri*—2,500–3,000 beetles/ha or 10 beetles/vine
Guava	Green shield scale, *Chloropulvinaria psidii*	*C. montrouzieri*—10–20 beetles/infested plant
	Aphid, *Aphis gossypii*	*V. lecanii*—10^9 spores/mL + 0.1 % Teepol

microorganisms, including fungi, bacteria, nematodes, and viruses.

Of late, biological suppression of pests has become an intensive area of research because of environmental concerns. About 60 % of the natural control of insect pests is by the natural enemies of pests such as parasitoids, predators, and pathogens. The Australian lady bird beetle, *Cryptolaemus montrouzieri* has been found very effective against mealy bugs infesting grapes, guava, citrus, mango, pomegranate, ber, and custard apple. The encyrtid parasite, *Leptomastix dactylopii*, is effective against mealy bug, *Planococcus citri* on guava, citrus, pomegranate, ber, and custard apple (Mani 2001). *Bt* is effective against tomato fruit borer, okra fruit borer, and diamondback moth on cabbage and cauliflower.

Several methods of enrichment and conservation of natural enemies include providing nesting boxes for wasps and predatory birds; retaining pollen- and nectar-bearing flowering plants like Euphorbia, wild clover on bunds to provide supplementary food for natural enemies; and placing bundles of paddy straw in fields for attracting predatory spiders. In addition, erecting perching sites, water pans, retaining bushes (Acalypha, Hibiscus, Crotons) help in retention of predatory birds.

The last decade has witnessed a tremendous breakthrough in biological control of diseases and nematodes like *Rhizoctonia, Pythium, Fusarium, Macrophomina, Ralstonia,* and *Meloidogyne* in banana, tomato, egg plant, pea, grapes, cucumber, black pepper, cardamom, ginger, and turmeric, especially by using species of *Trichoderma, Pochonia, Pseudomonas,* and *Bacillus* (Tables 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 1.10, 1.11, 1.12).

(c) Avermectins The avermectins are a new class of macrocyclic lactones derived from mycelia of the soil actinomycete, *Streptomyces avermitilis* (soil inhabiting which is ubiquitous in nature). These compounds were reported to be possessing insecticidal, acaricidal, and nematicidal properties (Putter et al. 1981). They are commonly distributed in most of the cultivated soils and are in widespread use, especially as agents affecting plant parasitic nematodes, mites, and insect pests. The water solubility of avermectin B1 is approximately 6–8 ppb and its leaching potential through many types of soil is extremely low. These physical properties also confer many advantages upon the use of avermectins as pesticides. Their rapid degradation in soil and poor leaching potential suggest that field applications would not result

Table 1.4 Biological control of fruit crop diseases

Fruit crop	Disease(s)/Pathogen(s)	Potential biocontrol agent(s)
Banana	Panama wilt, *F. oxysporum* f. sp. *cubense*	*Trichoderma viride, Aspergillus niger, Pseudomonas fluorescens, T. viride + P. fluorescens*—sucker treatment
Citrus	Root rot, *Phytophthora* spp.	*T. viride/Trichoderma harzianum* at 100 kg/ha; *Penicillium funiculosum*, *Pythium nunn*—soil treatment
	Canker, *Xanthomonas campestris* pv. *citri*	*A. niger* AN 27
Strawberry	Grey mold, *Botrytis cinerea*	*T. harzianum*
Mulberry	Leaf spot, *Cercospora moricola*	*T. viride, T. harzianum, P. fluorescens*
	Cutting rot, *Fusarium solani*	*Trichoderma virens, T. harzianum, Trichoderma pseudokoningii*
Grapevine	Powdery mildew, *Uncinula necator*	*Ampelomyces quisqualis*—dispersal from wick cultures at 15 cm of shoot growth and bloom
	Downy mildew, *Plasmopara viticola*	*Fusarium proliferatum* weekly spray starting from 15 cm of shoot growth—10^6 spores/mL
Guava	Anthracnose, *Pestalotia psidii, Colletotrichum gloeosporioides*	*T. harzianum*
	Wilt, *Gliocladium roseum* and *F. solani*	*Penicillium citrinum, A. niger* AN 27, *T. harzianum*
Mango	Anthracnose, *Colletotrichum gloeosporioides*	*T. harzianum, Streptosporangium pseudovulgare*
	Powdery mildew, *Oidium mangiferae*	*S. pseudovulgare*
	Bacterial canker, *X. campestris* pv. *mangiferaeindicae*	*Bacillus coagulans*
Apple	Scab, *Venturia inaequalis*	*Chaetomium globosum, Aureobasidium pullulans, Microsphaeropsis* sp., *Cladosporium* spp., *Trichothecium roseum*—Foliar spray
	Collar rot, *Phytophthora cactorum*	*Enterobacter aerogenes, Bacillus subtilis*—Soil treatment; *T. virens*—soil treatment
	White root rot, *Dematophora necatrix*	*T. viride, T. harzianum, T. virens*—soil treatment
Pear	Blue mold, *Penicillium expansum*; Grey mold, *B. cinerea*	*Cryptococcus infirmo-miniatus* YY6, *Cryptococcus laurentii* RR87–108, *Rhodotorula glutinis* HRB6—fruit spray 3 week or 1 day prior to harvest—10^8 cfu/mL; *Pantoea agglomerans* CPA-2—post-harvest fruit dipping in 8×10^8 cfu/mL
	Fire blight, *Erwinia amylovora*	*P. fluorescens*—foliar spray
Peach	Brown rot, *Monilinia fructicola*	*B. subtilis* (B-3)—post-harvest fruit line spray at 5×10^8 cfu/g); *Pseudomonas syringae*-post-harvest fruit dipping in 10^7 cfu/mL
	Twig blight, *Monilinia laxa*	*Penicillium frequentans*—spray shoots in early growing season—10^{8-9} spores/mL
	Crown gall, *Agrobacterium tumefaciens*	*Agrobacterium radiobacter* K84, K1026—root dip treatment
Strawberry	Grey mold, *B. cinerea*	*Trichoderma* products (BINAB TF and BINAB T), *Bacillus pumilus, Pseudomonas fluorescens, G. roseum*—spray flowers and fruits—white flower bud to pink fruit—10^6 spores/mL; *G. roseum*—bee vectoring of flowers—10^9 cfu/g of powder
Passion fruit	Collar rot, *Rhizoctonia solani*	*T. harzianum, Trichoderma* sp
Amla	Bark splitting, *R. solani*	*A. niger* AN 27

Table 1.5 Biological control of vegetable crop pests

Vegetable crop	Pest	Biocontrol agent/dosage
Beans	Mite, *Tetranychus* spp.	*Phytoseiulus persimilis*—10 adults/plant or release 1–6 leaves with predatory mites.
Pigeon pea	Pod borer, *Helicoverpa armigera*	*Ha* NPV-250 LE/ha
Potato	Cut worm, *Agrotis ipsilon, Agrotis segetum*	*S. carpocapse, Steinernema bicornutum, Heterorhabditis indica*
Tomato	Fruit borer, *H. armigera*	*Trichogramma brasiliensis/Trichogramma chilonis/T. pretiosum*—50,000/ha; *Ha* NPV-250 LE/ha
Brinjal	Fruit and shoot borer, *Leucinodes orbonalis*	*S. carpocapse, H. indica*
Chilli	Fruit borer, *H. armigera*	*Ha* NPV—250 LE/ha
Cabbage	Diamondback moth, *Plutella xylostella*	*S. carpocapse, Steinernema glaseri, Steinernema feltiae, S. bicornutum, Heterorhabditis bacteriophora*
Mushroom	*Lycoriella auripila, Lycoriella mali, Lycoriella solani, Megaselia halterata*	*S. feltiae*

in persistent residues or contamination of ground water.

Avermectins offer an outstanding alternative to any of the available synthetic pesticides. Their novel mode of action, high potency, and specific physico-chemical properties make the avermectins excellent candidates for further insecticidal, acaricidal, and nematicidal studies.

Scientists at the Indian Institute of Horticultural Research, Bangalore, for the first time in India, have isolated six strains of *S. avermitilis* and showed their effectiveness for the management of root-knot nematodes infecting tomato, egg plant, chilli, carnation, and gerbera; and red spider mite on carnation and gerbera (Reddy and Nagesh 2002; Table 1.13). Avermectins are also effective against other insect pests (potato leaf miner, *Liriomyza huidobrensis*; chilli thrips, *Scirtothrips dorsalis*; cabbage diamondback moth, *Plutella xylostella*; bean leaf miner, *Liriomyza huidobrensis*; rose thrips, *Rhipiphorothrips cruentatus, Scirtothrips dorsalis*; poinsettia whitefly, *Trialeurodes vaporariorum*), mite pests (chilli yellow mite, *Polyphagotarsonemus latus*; bean spider mite, *Tetranychus urticae*; rose red spider mite, *Tetranychus urticae*), and nematode pests (banana nematodes, *Meleidogyne javanica, Radopholus similis*; citrus nematode, *Tylenchulus semipenetrans*; tomato reniform nematode, *Rotylenchulus reniformis;* cucumber root-knot nematode, *M. incognita*; garlic stem and bulb nematode, *Ditylenchus dipsaci*).

(ii) Mechanical and Physical Controls

Methods included in this category utilize some physical components of the environment, such as temperature, humidity, or light, to the detriment of the pest. Common examples are tillage, flaming, flooding, soil solarization, and plastic mulches to kill pests.

Heat or steam sterilization of soil is commonly used in greenhouse operations for control of soil-borne pests. Floating row covers over vegetable crops exclude flea beetles, cucumber beetles, and adults of the onion, carrot, cabbage, and seed corn root maggots. Insect screens are used in greenhouses to prevent aphids, thrips, mites, and other pests from entering ventilation ducts. Large, multi-row vacuum machines have been used for pest management in strawberries and vegetable crops. Cold storage reduces post-harvest disease problems on produce.

Although generally used in small or localized situations, some methods of mechanical/physical control are finding wider acceptance because they are generally more friendly to the environment.