



Food and Agriculture Organization
of the United Nations

Eggplant Integrated Pest Management

AN ECOLOGICAL GUIDE



TRAINING RESOURCE TEXT ON CROP DEVELOPMENT, MAJOR AGRONOMIC
PRACTICES, DISEASE AND INSECT ECOLOGY, INSECT PESTS,
NATURAL ENEMIES AND DISEASES OF EGGPLANT



FAO Inter-Country Programme for Integrated Pest Management
In Vegetables in South and Southeast Asia

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For more information about FAO's involvement and association with IPM FFS Programmes in Asia, useful links are: www.cottonipmasia.org or www.communityIPM.org/http://.

The Global IPM Facility: www.fao.org/globalipmfacility.

Why this guide?

About this guide

This Eggplant Ecological Guide is developed by the FAO Inter-Country Programme (ICP) for IPM in Vegetables in South and Southeast Asia. This guide is the third in a series of vegetable ecological guides produced by FAO-ICP. The first two are: "Cabbage Integrated Pest Management: An Ecological Guide" and "Tomato Integrated Pest Management: An Ecological Guide". Similar ecological guides are completed by National IPM programmes and FAO-ICP (Rice Integrated Pest Management Ecological Guide, Indonesia, ca. 1990; Integrated Rat Management Ecological Guide, Vietnam, 1998), and by other organizations such as CIDSE Vietnam (Tea Integrated Pest Management Ecological Guide, 2001), and the International Potato Center, Indonesia (Farmers' Field Schools for Integrated Crop Management of Sweetpotato: Field Guide and Technical Manual, 2000).

The objective of this ecological guide is to provide general technical background information on eggplant production, supplemented with field experiences from the National IPM programmes connected to FAO's Vegetable IPM Programme, and from related organizations active in farmer participatory IPM. Reference is made to exercise protocols developed by Dr. J. Vos of CABI Bioscience (formerly IIBC/ CAB International) for FAO. The exercises are described in "Vegetable Integrated Pest Management Exercise Manual", December 2000, which contains examples of practical training exercises that complement the technical background information from this guide.

Who will use this guide?

National IPM programmes, IPM trainers, and others interested in IPM training and farmer participatory research.

How to use this guide

The ecological guides are technical reference manuals. They give background information and refer to exercises/studies that can be done in the field during training of trainers (TOT), farmers' field schools (FFS) and farmer participatory research to better understand a topic.

The information in the guides is not specific for one country. Rather, this guide is an *inspirational guide* that provides a wealth of technical information and gives ideas of IPM practices from several countries, mainly from the Asian Region, to inspire IPM people world-wide to conduct discovery-based IPM training and to set up experiments to see if such practices would work in their countries and continents of assignment. This guide does not contain information about the training methodology. This is because no one can learn how to be an IPM facilitator or set up IPM studies just by reading a book or guide: the field remains the main learning base. This is why the link with the exercise manual mentioned above is important.

National programmes can use the guides to prepare training materials like hand-outs specific for a training activity. The ecological guides can be used as 'working copies' or as basis for preparation of IPM curricula and materials for farmer-trainers.

The FAO Intercountry programme hopes that this guide may be an

inspirational tool

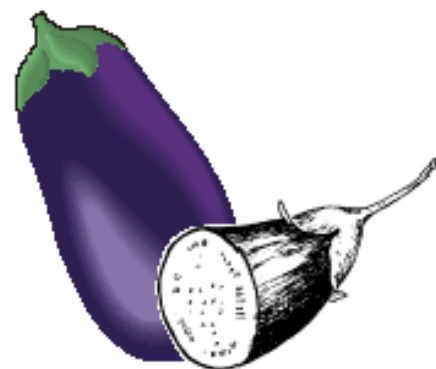
for discovery-based IPM training and farmer participatory research.



1 INTRODUCTION

1.1 Integrated Pest Management: beyond bugs...

Integrated pest management, IPM, is still strongly associated with pests. However, it is much more than just pest control. IPM is not about eliminating all pests; in fact, low level populations of some pests are needed to keep natural enemies in the field. The aim of IPM is to reduce pest populations to avoid damage levels that cause yield loss. The entry point of an IPM programme may often be focused on reduction of pesticide use. However, the basis of good crop management decisions is a better understanding of the crop ecosystem, including that of the pests, their natural enemies, and the surrounding environment. Monitoring of the crop is the first step in understanding ecosystems, making sound decisions about all aspects of growing a healthy crop, taking IPM beyond bugs and plant protection.



Experiences over several years with vegetable IPM show that good crop management practices may lead to reduction of inputs (including pesticides), without reduction in yield. In fact, yields often increase in IPM fields.

IPM strategies are different for each crop, for a country, for a region, even for one location, depending on local varieties used and local agronomic practices. IPM can never be delivered in a “package”, it needs to be developed, adapted, tailor-made to fit local requirements. Yet, experiences from one area, or from other countries may be helpful to set up field studies for testing the components that may lead to tolerable pest populations and a high yield of good quality produce. Some of these experiences and practices are summarized in this guide.

1.2 The vegetable IPM Programme

The FAO Inter-Country Programme to strengthen IPM training and sustain IPM practices among Vegetable farmers in South and Southeast Asia (Phase II) is a five-year regional program (July 2002 – June 2007). This programme builds on the success of Phase I of the Inter-Country Programme (ICP) for Vegetable IPM which, since April 1996, has carried out applied research, extension and farmer education activities to promote and support Integrated Pest Management in vegetables by Asian smallholder farmers. During Phase I, the ICP focused on enhancing the Governments' and NGOs' capability to implement training programmes in seven countries using the "Training of Trainers" (TOT) and "Farmer Field School" (FFS) approach. More than 600 trainers and 30,000 farmers have been trained since the beginning of Phase I.

Phase II of the ICP, funded by the Netherlands and Australia, operates through governments and NGOs in Bangladesh, Cambodia, China, the Lao PDR, Indonesia, the Philippines, Thailand and Vietnam. The Phase II of the ICP will emphasize vegetable IPM farmer participatory training and research in five countries in the Greater Mekong Subregion, with a sharper focus on major crops and pests. Specifically the Programme will:

1. Strengthen and expand the capability of government agencies and NGOs to carry out IPM training and continuing field activities;
2. Create and strengthen groups of smallholder farmers so that they can take collective action in support of ecologically-based vegetable production and marketing; and,
3. Institute sustainable arrangements for the solution of technical problems.

Phase II will be more sensitive to quality control and participatory training and research activities, gender, impact assessment and regional exchanges of experiences on issues related to vegetable IPM program work. The project will provide advice, organize training, arrange exchanges of expertise, and fund field studies and follow-up activities in the field.

These activities will be carried out in close collaboration with other regional, national and local IPM-related projects funded by governments, donor agencies and NGOs.

1.3 Developing vegetable IPM based on rice IPM

The FAO Inter-Country Programme for IPM in Vegetables in South and Southeast Asia has branched off from the Inter-Country Programme for IPM in Rice in South and Southeast Asia. This programme, on rice IPM, has been running for many years and has trained thousands of trainers and nearly one million rice farmers in Asia during its many years of existence (1980-2002). The experiences obtained from IPM training work in rice-based cropping systems has provided important lessons for extending training work to vegetable-based cropping systems.

However, reflecting on ecosystem considerations related to origins of both rice and major vegetable crops in Asia, it is important to note that there are major differences in crop ecosystems which have important implications for pest management strategies in both crops.

Rice is indigenous to Asia; this crop has been grown by farmers for thousands of years. Most vegetables were imported from other parts of the world, even though this may have been done already many years ago. Therefore, rice ecosystems harbour a large and extremely biodiverse population of indigenous natural enemies whereas these may not be present in similar abundance and diversity in vegetable ecosystems. Pest management in rice is mainly based on “informed non-intervention”, i.e. continue monitoring the field but do not apply pesticides. A complex of natural enemies will likely be able to keep pest insect populations low whereas healthy rice plants can compensate for major crop injury without yield loss.

As for vegetables, Shepard and colleagues showed in Indonesia that pesticides could be reduced by 75% without reducing yield, thanks to the presence of native natural enemies. However, in many ecologically depressed vegetable ecosystems, there may not be indigenous natural enemies that are effective enough to keep pest populations low. The pest management strategy needed in vegetable ecosystems is therefore frequently based on “informed intervention”. Often, pest and disease problems will require appropriate and informed intervention to keep these problems under control. This important difference is summarized in the following table.

Differences between Asian Rice and Vegetable IPM and Implications for Management Strategy:

CROP	RICE	VEGETABLES
Origin	Indigenous	Mostly Exotic
Indigenous (Arthropod) bio-diversity	Extremely diverse	Not as diverse
Stability ecosystem	Stable (if not disturbed)	Not as stable
Management strategy	INFORMED NON-INTERVENTION	INFORMED (PREVENTION AND) INTERVENTION

1.4 Eggplant: a bit of history

Eggplant (*Solanum melongena*) is also called **brinjal** (India, Bangladesh) and **aubergine** (in Europe). Like the tomato, potato and pepper it belongs to the Solanaceous family. The fruit can be eaten raw, or served as a baked, grilled, fried or boiled vegetable and can be used in stews or as a garnish.

One of the oldest references to eggplant is in a fifth century Chinese book. A black dye was made from the plant and used by ladies of fashion to stain their teeth, which, after polishing, gleamed like metal.

Wild eggplant occurs in India and was first cultivated there. Arab traders took it to Spain, the Spaniards brought it to the Americas, and the Persians to Africa. The eggplants received in various European countries in the sixteenth and seventeenth centuries varied greatly in shape and color. The first known eggplants were probably of the class now grown as ornamentals, the fruit white and resembling an egg. By 1806, both the purple and white ornamentals were growing in American gardens. Modern eggplants are oval, round, or elongated and have shiny purplish black, white or green fruit.

2 EGGPLANT CROP DEVELOPMENT



SUMMARY

This chapter describes general growth stages for eggplant. Accurate growth stage descriptions are very useful in pest management since plant susceptibility to pests varies with the growth stage. Some growth stages can tolerate damage by certain insect pests or diseases whereas in other stages crop damage may result in yield loss. Trials to study the ability of the eggplant to compensate for pest injury at particular growth stages is an important element of IPM field studies.

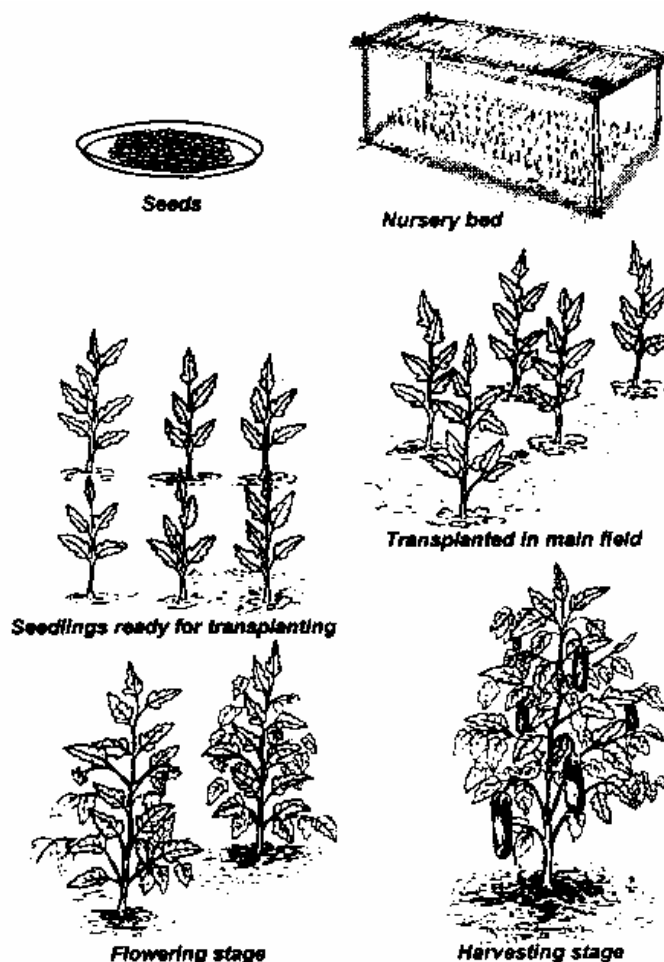
A table in this chapter indicates the susceptibility of growth stages to injury from various insect pests and diseases. It can be used to develop, with farmers, a more appropriate growth stages description (or cropping calendar) for your area, based on locally used varieties and terminology.

2.1 Eggplant growth stages

Eggplant completes a life cycle, from seed to seed, in one season. Eggplant is usually grown for a few months, although it can be cropped for over one year when growing conditions (water, fertilization, etc.) are optimal and plants are not exhausted by diseases or insect pests.

General growth stages for eggplant are:

- Seed.
- Seedling stage: usually the period from emerging seed to transplanting to the main field.
- Early vegetative stage: plant with up to two branches (up to about 40 days after transplanting depending on variety, climate, fertilization, water availability, etc.).
- Late vegetative stage: period of branching until onset of flower buds (period from about 40 to 60 days after transplanting, depending on variety, climate, fertilization, water availability, etc.).
- Flowering stage: plant with flower buds and open flowers.
- Fruiting stage: plant with small to full-sized fruits.
- Harvesting stage: period when plant yields mature fruits.
- Post-harvest stage: the time after the fruit has harvested, and before it is consumed or processed.



These growth stages are overlapping in time, because mature fruits and flower buds can develop at the same time. When eggplant is cut back (ratoon), a second vegetative stage develops, followed by a flowering, fruiting and harvesting stage.

2.2 Susceptibility of eggplant growth stages to pests

Whether various pest and disease species that attack eggplant will cause economic loss partly depends on the growth stage of the plant. Injury to the older leaves at a late stage in crop development for example, will not influence the final yield. Eggplants can compensate for a lot of injury by producing more leaves, new shoots or bigger size fruits. When plants compensate for crop injury without yield or quality loss, there is no need to implement control practices such as applying a pesticide. This would only be a waste of money and time. Preventing crop damage by implementing a control practice like applying a pesticide is only economically justified if the benefits from implementing that practice are greater than the costs of the practice. For fresh market eggplant fruits for example, the quality could be reduced if even slight injury occurs on the fruits.

To obtain information about the compensation ability of the eggplant, studies on defoliation and removal of shoots can be conducted. See box below.

Shoot loss compensation study: an example from Bangladesh

A shoot pruning study from Jessore, Bangladesh, led to the conclusion that up to 50% loss of shoots at 75 and 100 days after transplanting could be compensated very well by the eggplants and was not reducing the yield as compared to unpruned control plants (Kumar, TOT Jessore report, 1999). Also see section 4.5 on crop compensation.

Also, removal of infested fruits (to test sanitation practice for fruit and shoot borer (FSB)) may be conducted to see if loss of young fruits leads to lower production in the longer term. An eggplant will put a lot of energy in producing fruits. If a fruit is lost (by removing FSB infested fruits) the plant can put that energy in producing more flowers and fruits or produce fruits of a larger size. This may compensate the loss of that one fruit.

Some pests are present throughout the season and can affect eggplant at any growth stage. They will only affect the quality or yield at susceptible growth stages. Damage will also depend on the season, the eggplant variety grown, and other elements of the ecosystem like natural enemies, weather conditions, fertilizer, water availability and so on.

The following table shows when potential injury from common eggplant pests and diseases may occur at specific growth stages. Please note that these are general values. There may be considerable differences in each region!

Always look at all elements of the agro-ecosystem when making crop management decisions!

Susceptibility of growth stages to eggplant insect pests and diseases:

pest/disease	growth stage	seedling	early vegetative	late vegetative	flowering	fruiting	harvesting
Damping-off (<i>Pythium</i> sp.)		■					
Phomopsis rot (<i>Phomopsis vexans</i>)		■			■	■	■
Red ant (<i>Dorylus orientalis</i>)		■	■	■			
Aphids (<i>Myzus</i> sp./ <i>Aphis</i> sp.)		■	■	■			
Early Blight (<i>Alternaria solani</i>)		■	■	■	■	■	■
Southern stem rot (<i>Sclerotium rolfsii</i>)		■	■	■	■	■	■
Fruit and shoot borer (<i>Leucinodes orbonalis</i>)			■	■	■	■	■
<i>Epilachna</i> beetle (<i>Epilachna</i> sp.)			■	■	■	■	
Basal stem rot (<i>Fusarium solani</i>)			■	■	■	■	
Whiteflies (<i>Bemisia</i> sp.)			■	■			
Rootknot nematode (<i>Meloidogyne</i> sp.)			■	■			
Red spider mite (<i>Tetranychus</i> sp.)				■	■	■	
Jassids (<i>Amrasca</i> sp. & others)				■	■	■	■
<i>Sclerotinia</i> stem rot (<i>Sclerotinia sclerotiorum</i>)				■	■		
Root rot/Fruit rot (<i>Phytophthora</i> sp.)				■	■	■	■
Little leaf (mycoplasma)				■	■		

pest/disease	growth stage	seedling	early vegetative	late vegetative	flowering	fruiting	harvesting
Bacterial wilt (<i>Ralstonia</i> sp.)							
<i>Verticillium</i> and <i>Fusarium</i> wilt							
Thrips (<i>Thrips</i> sp.)							
Anthracnose fruit rot (several fungal species)							

dark gray area: main pest occurrence

light gray area: pest occurs to lesser extent

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

- 2.1. Crop stages and plant parts
- 2.2. Monitor crop stages
- 2.3. Crop needs per crop stage
- 2.4. Plant roots and vessels
- 2.5. How to grow a healthy crop
- 4-A.3. Plant compensation study

3 MAJOR AGRONOMIC PRACTICES



SUMMARY

A few general rules for good agronomic practices are:

- Select a variety suitable for your climate/environmental conditions, possibly with resistance against pest(s) or disease(s).
- Use clean seed, and/or clean planting material.
- Add lots of compost (or other decomposed organic material) to the soil every cropping season, both to nursery sites and to the main field.
- When a lot of organic material is applied, use low amounts of chemical fertilizers.
- Use mulch to cover the soil (both nursery and main field).
- Practice crop rotation to the main crop families.
- Practice proper sanitation by removing all crop left-overs at the end of the season.

In this chapter, the major agronomic practices for eggplant production are described and general background on soil, fertilizers and other elements of crop production is given. Agronomic practices differ in every country, region, and province, even within one village. This chapter gives general guidelines for growing eggplant based on the crop ecosystem. Examples of agronomic practices from several locations are given.

The first element of IPM is “grow a healthy crop”. A healthy crop is obtained by good cultural practices. A healthy crop will have less problems with pests and diseases and it will recover quickly from stressful factors. The management of pests and diseases starts even before buying the vegetable seed. It starts with selecting a variety, with cleaning the field, with soil preparation. It involves nutrient application of the right type, in the right quantity, at the right time. Nursery management is another very important part as many diseases may already start in the nursery. It also involves planning of crop rotation and many other factors. These factors will be described below.

3.1 Climate and site selection

Eggplant can be grown in a wide altitude range: from the sub-tropical plains through to the temperate (mountain) climatic conditions. The variety and sowing dates should be selected to fit the climatic conditions.

Eggplant requires warm climatic conditions over a 6-month growing period to give a satisfactory crop of good-quality fruit. The optimum average monthly temperature range is 21° to 30°C, with a maximum of 35°C and a minimum of 18°C. Long periods of cool weather will reduce both yield and quality of fruits. When temperature and humidity are high, eggplant becomes more vegetative.

Like most vegetables, eggplant does best in well-drained soil. Select a site where eggplant or other solanaceous crops were not grown for at least two seasons. This reduces the chance that the crop is affected by a (soil-borne) disease.

3.2 Selecting a variety

There are many different eggplant varieties. Purple and white varieties are available and there are varieties with mixed colors like light purple with white stripes, purple with green stripes or purple with green and white stripes. Shapes range from oval to elongated. Choice of variety will depend on factors such as availability and price, climatic conditions (lowlands or highlands), time of planting (early or late maturing varieties), insect or disease resistance/tolerance, market requirements, and so on. In Asia, some farmers use their own eggplant seed; others buy seed in local shops.

3.2.1 Hybrids and open pollinated varieties

Many vegetable varieties sold by seed companies are *hybrid* varieties. The terms “hybrid variety” (also called hybrids) and “open pollinated variety” (also called “OP” or “OPV”) are commonly used. But what exactly makes a variety a hybrid or an OP? It all has to do with the way the variety was generated, during the breeding process.

Hybrid variety: seed resulting from the cross-fertilization of two carefully selected lines, to produce plants of exceptional vigor and uniformity. Often called F1 hybrids; “F1” means that these are hybrid varieties of the first generation after crossing. There can also be F2, or second generation hybrids. Many varieties of vegetables are F1 hybrids. These plants usually give higher yields and better quality crop than OP varieties and they are very uniform, tending to mature at the same time. The breeding process involved is more complicated than for OP varieties and that means hybrid seed is usually (much) more expensive. In most cases, they are worth the extra price. Seed should normally not be saved from F1 hybrids because this F2 seed (=next generation) produces variable and inferior quality in the next crop. Hybrid seed therefore has to be bought for every sowing.

Open pollinated variety: seed produced from natural pollination so that the resulting plants are often varied: they may have characteristics from the mother plant, from the father plant or from a combination of the two. Seed from OP varieties can often be multiplied by farmers but requires a bit of selection: only seed of the best fruits and plants should be used. Eggplant flowers are mostly self-pollinating (over 90%) so the selection process may be a bit easier. Depending on the breeding process and the crop, *commercial* OPs can be very homogenous.

3.2.2 Resistant varieties

Another important aspect to consider when selecting a variety is whether the variety is tolerant or resistant against certain insect pests or diseases. Growing a resistant variety is one of the best and most environmentally safe methods of crop protection! Unfortunately, resistant varieties are not always available. Also, resistant varieties are usually not resistant to all pests and diseases that may occur.

And to make it more confusing: term resistance is explained differently by different researchers. For example, in a study in India, the eggplant Pusa Purple Cluster was considered resistant to bacterial wilt when less than 20% of all plants wilted (Gopalakrishnan, 1985). Other studies testing resistance to fruit and shoot borer (FSB) stated the variety was resistant with less than 15% FSB infestation (Tejavathu, 1991). Others may stick to a 0% infection.

Data from TOT and FFS field studies in Philippines showed that hybrid eggplant varieties were more tolerant to pest and disease infestation, and especially to the fruit and shoot borer, as compared to open pollinated varieties (pers.comm. Carlito Indencia, 2001).



Resistant variety: an insect pest or disease cannot survive on the plant. This can be due to long or sticky hairs on a plant that hinder an insect moving and feeding on a plant, or due to the excretion of toxic chemicals by the plant, or the constitution of the plant sap that make it less attractive to insects or diseases.

Tolerant variety: an insect pest or disease can infect the plant but symptoms will not be severe and the effect on yield will be none or minimal. However, infected plants may become a source of infection for other fields!



Susceptible variety: insects or diseases can attack the plant and this may result in yield and quality loss.

The following table lists a number of varieties that have been found “resistant” or “tolerant” to some insect pests or diseases. It is emphasized that NONE of the varieties listed in this table is 100% resistant. All studies compare a number of eggplant varieties, and from this comparison, the least susceptible variety has been marked as “resistant” or “tolerant”. However, the difference in susceptibility between eggplant varieties can be considerable (e.g. 5% FSB infestation in resistant versus 60% in susceptible varieties!). The table gives examples of variety names as inspiration for setting up a varietal trial in your own field. See box below.

Insect/Disease	Resistant/ Tolerant	Country reporting	Varieties	Reference
Little leaf disease	resistant	India	Chaklasi doli, Doli-5, Pusa purple cluster	Jyani, 1995
Bacterial wilt (<i>Ralstonia solanacearum</i>)	resistant	India	Surya, Swetha, Annapurna, Arka Keshav	Singh, 1998
Bacterial wilt	resistant	India	Arka Kasev, Arka Neelkanth	Chaudhary, 1999
Bacterial wilt	tolerant	Bangladesh	Khotkhatia Long, KG Begun, Planpuni, Singnath, Pusakanti, Uttara, Islampuri	Mondal, 1991
Bacterial wilt	tolerant	Bangladesh	Jhumka	pers.comm. Md. Atiur Rahman, 2001

Insect/Disease	Resistant/ Tolerant	Country reporting	Varieties	Reference
Fruit-and shoot borer (<i>Leucinodes orbonalis</i>) (FSB)	tolerant	India	Pusa Purple Cluster, Bhagyamathi, Annamalai, Nurki, Singhnath	Behera, 1999a
FSB	resistant	India	Chaklasi doli, Doli-5, Pusa purple cluster	Jyani, 1995
FSB	resistant	India	Long purple	Mehto, 1981
FSB	tolerant	Ghana	Black Beauty, Florida Market	Duodu, 1986
FSB	tolerant	India	Arka Kusumakar, Nischintapur, Brinjal Long Green, Altapati, Arka Shirish, Manipur, Makra, Chikon long	Gangopadhyay, 1996
Whitefly (<i>Bemisia tabaci</i>)	tolerant	India	Manjari gota	Patel, 1995
Epilachna beetle (<i>Epilachna vigintiocto-</i> <i>punctata</i>)	tolerant	India	Makra, Altapati, Gourkajli, Brinjal 72, Puni, Chicon Long, S. incanum and S. macrocarpon	Gangopadhyay, 1997
Rootknot nematode (<i>Meloidogyne</i> sp.)	tolerant	Indonesia	Dingras Long Purple, La Granja Long Purple, Florida Market	Valdez, 1981
Rootknot nematode	resistant	India	Maroo Marvel	Reddy, 1986
<i>Verticillium</i> wilt (<i>Verticillium dahliae</i>)	resistant	USA	Florida Market, Harris 468, Special Hibush, Harris Hybrid 7631	O'Brien, 1983
<i>Fusarium</i> wilt (<i>Fusarium oxysporum</i>)	tolerant	India	Padampur local, Bargarh local	Mishra, 1994
<i>Phomopsis vexans</i>	resistant	USA	Florida Market, Black pride, Special Hibush	Peet, www1
Aphids (<i>Aphis gossypii</i>)	tolerant	India	Manjari gota, Pusa kranti, Arka kusumkar	Patel, 1995

✓ Test eggplants in a varietal trial

Many seed companies are willing to support demonstration plots of different varieties. For the seed company, the demonstration plot may be a promotion and they will often provide the seed for free. For farmer groups it may be worth the effort contacting a few companies and testing a number of varieties under local conditions. Some varieties may be interesting with regard to insect pest and disease resistance or tolerance. Make sure to include the locally used varieties for comparison and do weekly observations on crop growth and health.

3.3 Seed selection

It is obvious that good quality seed is the basis of a good crop. Many farmers in South Asia use seed from a previous eggplant crop. Few farmers however, actually produce quality eggplant seed. Some issues that are important for the selection of good quality seed:

- Select fruits from the first harvest period.
It is noted that many farmers take the last fruits from the crop (the final harvest) for seed extraction. By that time, plants may be infested with diseases that can spread with the seed to the next crop. Seed-borne eggplant diseases are for example early blight (*Alternaria solani*), and fungal wilt (*Fusarium* sp. and *Verticillium* sp.). Early in the harvest stage, usually fewer diseases are affecting the crop. In addition, selecting early maturing fruits for seed may give early maturing fruits in the next season. This is often a good selection method for farmers to improve locally used varieties.
- Select mature fruits.
The quality/viability of seed depends on the maturity of the fruit from which seed is extracted. Fully mature fruits usually contain the best seed.
- Select healthy, large-sized fruits from healthy plants that grow vigorously and produce many fruits. Seed extracted from large-sized fruits may give large fruits in the next crop.

- Select large seed only.
These will usually give strong plants.
- Discard seed that is spotted, or has black areas.
This might indicate a fungal or bacterial infection. Unfortunately, healthy looking seed may also be infected with pathogens, so removing spotted seed does not guarantee disease-free seed but it does reduce the chance.
- Store seed cool and dry.
Viable seed from mature fruits can lose its viability when stored improperly. Generally, seed should be kept at low temperature and low humidity conditions. Seed also loses viability when stored several years.

✓ **A float test for seed:**

A seed usually contains an embryo inside and some food reserve to provide the energy for germination. When eggplant seed are put into water, a proportion of the seed sinks and another proportion floats. Seed that sink has a higher germination rate. It can be expected that the floating seed is not filled well and may not germinate as readily as the sinking seed. By using only sinking seed, the overall quality of a seed lot could be improved. This method could be used to compare germination rates of floating/sinking seed (Vos, 1998, Vegetable IPM exercise manual).

3.4 Seed extraction

To extract eggplant seed, fruits are cut in two and seed is removed from the inside. The seed is properly washed on a sieve, then spread out to dry. During washing in a container, seed that float in water can be removed (see box above).

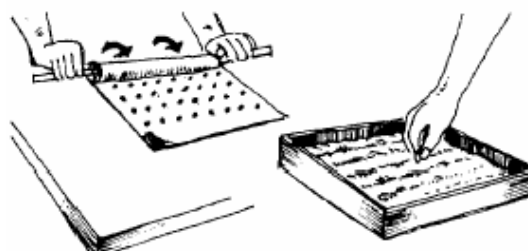
Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

2-A.9. Seed multiplication methods

3.5 Seed germination

Seed is of good quality when more than 70% of the seed germinates and germination occurs within approximately 7 – 14 days. Irregular germination results in seedlings of different size. High germination percentage is especially important when hybrid seed is used because this is often the most expensive input of production!

Most seed companies have their own minimum seed germination standards. Actual germination depends on seed age and storage conditions. Some countries, for example Thailand, have a “Seed Law” which lists minimum germination percentages for various crops.



Seed germination test on moist tissue paper
(see exercise 2-A.10)

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

2-C.4. Testing of cultivars

2-A.10 Test for seed germination

3.6 Seed treatments

Two reasons to treat seed are:

1. to control diseases attached to or inside the seed (seed-borne diseases),
2. to protect against diseases in the soil that can attack seed, emerging roots or young seedlings (soil-borne diseases).

Seed-borne diseases

Seed can become infected with fungal spores or bacteria (seed-borne diseases). Infection can occur during the growing season, when seed is still on the plant or it may occur after the seed has been extracted from the plant. Common seed-borne diseases of eggplant are early blight (*Alternaria solani*), and fungal wilt (*Fusarium* and *Verticillium*).

Most seed companies do not normally treat eggplant seed. Instead, the growing conditions of the seed production fields are thoroughly checked. Only when a seed-borne infection is suspected, seed lots may be treated with diluted hydrochloric acid or sodium phosphate. Other sterilization methods are listed below.

Soil-borne diseases

Seed can also become infected after it has been sown in the soil. Pathogenic fungi or bacteria living in the soil (soil-borne diseases) may attack the seed and cause death of the seed or the emerging roots even before the seedling has emerged above the soil. A common soil-borne disease affecting seed and seedlings is damping-off, caused by a complex of fungi. See section 8.1.1.

When to treat

When seed is bought from reliable seed companies, it will usually be disease-free. When seed is locally produced, it is probably better to sterilize it before sowing. When soil has given problems with damping-off disease before, it can be helpful (next to cultural practices such as rotation, and possibly soil sterilization, see sections 3.10.1 and 3.17) to coat seed before sowing.

It should be noted that seed treatment methods may reduce germination percentage!

How to treat

There are four main methods for seed treatment:

1. Physical: by soaking seed in hot water.
2. Chemical: by sterilizing seed with chemicals or by coating seed with a layer of fungicide.
3. Botanical: by coating seed with a layer of plant extract.
4. Biological: by coating seed with a layer of antagonistic fungi (see also section 7.10).

None of these treatments will completely prevent pathogen attack in all circumstances!

In addition to seed treatment, it is important to select a field that is free of soil-borne diseases. Some management practices for soil-borne diseases include crop rotation (using soil that has not been used for growing eggplant or other solanaceous crops for at least 2 years) and the use of resistant or tolerant eggplant varieties. See also sections 3.2 on variety selection, 3.7 on soil, 3.10 on nursery management, 3.17 on crop rotation, and second box in section 3.7.3.

3.6.1 Physical seed treatment

To kill fungal spores or bacteria attached to or within the seed, seeds should be soaked in hot water at 50°C for 30 minutes.

The right water temperature and the right duration are very important. If the water is too cold, the pathogens are not killed. If the water is too hot, seed germination will be greatly reduced.

The easiest way to treat seed is to heat water to 50°C on a small fire or burner. Carefully check the water temperature with a thermometer. Pour the 50°C water into a thermos flask and add the seeds. It may be easy to wrap the seeds in a cloth to keep them together. Leave the seeds in the flask for 30 minutes. After soaking in hot water, the seeds are placed in clean, boiled, cold water to cool down. Dry by spreading the seeds in a thin layer on paper or on cloth.

In some cases, a fungicide coating is applied after hot-water treatment. See section 3.6.2 below.



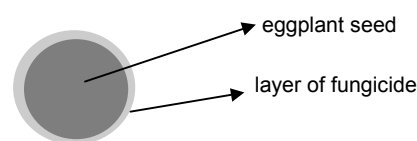
Hot-water treatment is easier, cheaper and more effective than trying to control seed-borne diseases in the field with chemicals.

Solar seed treatment

Another possibility for physical seed treatment is to sterilize seed in the sun. Put seed in a plastic bag and leave this in the sun for a few days (Kerruish, 1991).

3.6.2 Chemical seed treatment

When seed infection is suspected, many seed companies use chemical treatments, such as sodium hypochlorite or sodium phosphate, to sterilize the surface of the seed. Next to this, seed can be coated with a fungicide. This fungicide can sometimes be seen on the seed as a colored coating. The fungicide used should be listed on the seed package. The fungicide can kill spores of diseases that are present on the seed and during germination it gives some protection of emerging roots to soil-borne diseases.



Seed coated with a fungicide

Chemical fungicides for seed protection are relatively inexpensive and cause little environmental damage since they are used in small amounts. However, they are effective only for a short time (at most one month) and they do not spread through the soil with the root system.



Use protective gloves when planting coated seed !

3.6.3 Botanical seed treatment

Seed can be protected from some soil-borne fungi and from cutworms by a coating of a botanical extract such as crushed garlic. Garlic is well known for its strong odor which has a repellent effect on insects, or birds, and it can prevent diseases. See also section 4.11.4 on botanicals. The garlic is thoroughly crushed to obtain juice and pulp. Seed is mixed with this extract. The seed can be immediately sown after this treatment, or left to dry. No "scientific" data are available to compare this method with other seed treatments but it is a common practice in some areas in Bangladesh (pers. comm. Prof. Ahmad, Plant Pathologist University of Mymensingh, Bangladesh, 1998).



garlic

3.6.4 Biological seed treatment

Seed can also be protected with a coating of biological agents. These are usually antagonistic fungi or bacteria that work against soil-borne pathogens. Examples of these antagonists are the fungus *Trichoderma* sp. and the bacterium *Bacillus subtilis*, which is sometimes mixed with a chemical fungicide for commercial seed treatment. See "The Biopesticide Manual" (BCPC, U.K., Copping (editor), 1998) and internet sites such as www14 and www15 (see reference list, chapter 11) for details on commercially available biocontrol products.

The good thing about using biocontrol agents as seed treatment is that they also provide protection of the roots that emerge from the germinating seed. This is because the antagonists grow and multiply in the area around the seedling roots. This way they suppress fungi that cause damping-off and root diseases.

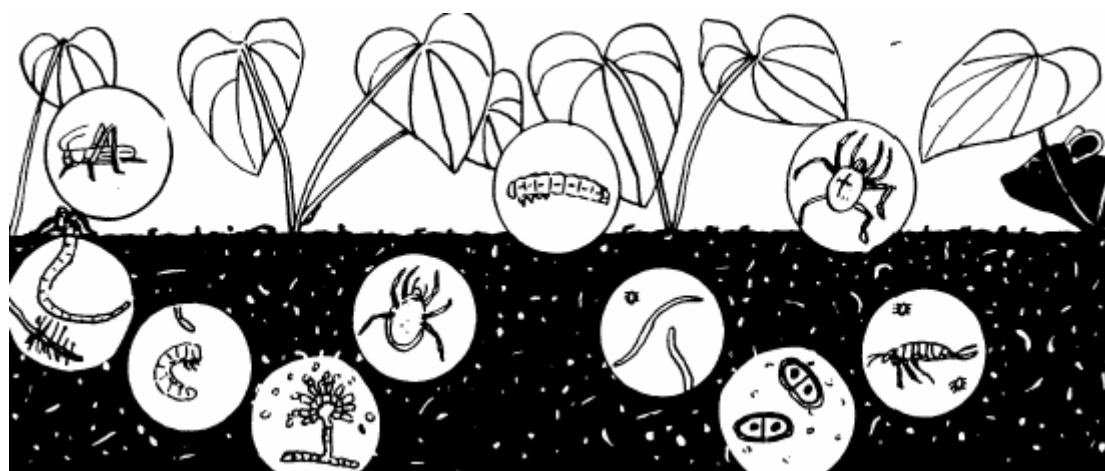
Biological seed protection agents are not yet widely available but research results are promising. One current problem is that biological agents applied to seed will not remain active during storage of seed (Harman, 1998).

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

- 2-A.10. Test for seed germination
2-A.11. Preparing seed for sowing

3.7 Soil**3.7.1 The living soil**

When looking at the soil of a field, it may seem like a lifeless amount of sand and pieces of organic waste. But in fact the soil is very much alive! Many millions of small organisms live in the soil, most of them can only be seen with a microscope. These organisms include small nematodes, earthworms, bacteria, fungi, mites, and spring tails. Little is known about the way all of these organisms interact and restrain each other. But most of them are harmless to the crop and have a beneficial function in decomposing crop left-overs and assisting other conversion processes in the soil. Others may serve as food for predators such as spiders. And some other organisms may be classified as *neutrals*: they do not damage the crop and do not have a clear beneficial function in the agro-ecosystem. Until we know otherwise, it is prudent that we don't harm the neutrals! See also section 3.8.3 on role of micro-organisms.



The Living Soil: soil contains many small organisms like nematodes, fungi, and small insects.
(Picture from Schoubroeck, 1989).

Soil is living and should stay alive, so it is important to:

1. Feed it through regular supply of organic material (=food for micro-organisms),
2. Protect it from water of wind erosion, for example by covering the soil,
3. Remove or reduce disturbing factors such as (broad spectrum) pesticides and high doses of chemical fertilizers.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

2-A.4. The living soil

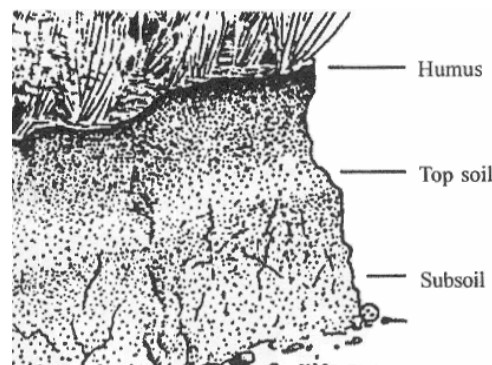
For more exercises on soil, see B. Settles' manual on the website of Community IPM (www.communityIPM.org).

3.7.2 Soil type

Soil is made up of a mixture of different-sized particles, sand, silt and clay. In nature, sand, silt and clay are almost always mixed together in a great variety of combinations which give the soil its characteristic *texture*. Terms such as sand, sandy loam, loam, clay loam, clay, heavy clay indicate the particle size in the soil. Light soil is composed largely of sand and the name indicates the ease with which it is worked. Heavy soil is soil which contains large amounts of silt and clay. The name refers to the difficulty of working and not to the actual weight of the soil.

The term '*structure*' refers to the arrangement of the different particles into soil aggregates. The micro-organisms in the soil are responsible for mixing the soil and building of soil structure. Soil particles are bound together by fungal branches and bacterial gums. These help to bind them into aggregates between which the pores are formed that hold air and water. In the pores between the aggregates, the soil air is found, an important source of oxygen for root respiration. Like humans, most plants and their roots need air (oxygen) for respiration! A good soil structure permits the movement of water through the soil and it facilitates the development of a good root system. A good soil can be compared with a new sponge that can absorb plenty of water.

The best part of the soil is the dark layer of topsoil, which takes many years to develop. Topsoil is rich in plant nutrients and beneficial soil organisms. Under the topsoil is the yellow, light brown or reddish subsoil which may be more acid and is harder for plants to grow in. Humus is the more or less stable fraction of the soil organic matter remaining after decomposition of plant and animal residues. Adding organic material such as well-rotten compost, improves the structure of most soil types including heavy clay and lighter sandy soils. The organic matter should be properly composted (well-rotten).



Eggplant is moderately deep-rooting and can be grown on a wide range of soils. It does best on light-textured soils that are deep and well-drained, such as sandy loam. The optimum soil temperature for growth is 23° to 32°C. A soil pH in the range 6.0–6.8 is desirable. See section 3.7.5 on soil pH.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

- 2-A.3. Soil structure and effects on root growth
- 2-A.8. Soil test kits

3.7.3 Soil infection

Next to the beneficial decomposers or neutral organisms in the soil, soil may also contain organisms that are harmful to the crop. These may include insects and pathogens like fungi, bacteria and nematodes. Soil-borne pathogens can enter a field in numerous ways. They may be attached to pieces of soil on the roots of seedlings, to soil particles on field tools, or with bits of soil on your slippers or shoes! They may also spread with the ground water.

Study example on soil infection: experience from Hai Phong, Vietnam

During studies, farmers conducted pot experiments with tomato and cucumber to study the effect of clean soil and/or irrigation water on disease spread and infection. The group compared plants grown in pots filled with clean soil, with infected soil or combinations of clean soil and infected irrigation water versus clean water. They concluded that disease can be harbored in crop residues, soil or water, and that a combined approach to disease management has to be taken, including field sanitation, roguing of diseased plants and using them for composting, and crop rotation (paddy rice - paddy rice - cucumber) (pers. comm. Dr. J.Vos, March 2000; Vos, www16).

Pathogens are so small that they cannot be seen with the naked eye. Only when they affect the plants do they become apparent. At that point, some injury to the plants has already occurred. And, maybe even more important, once there is a disease in the soil of the field (soil-borne disease), it is very difficult to get rid of it. Many pathogens can survive for a long time in the soil, even without a host plant! Therefore, it is essential to prevent soil-borne diseases from entering the field and attacking the plants.

Preventing soil-borne diseases: some techniques.

Preventing soil-borne diseases is not a single action, there are several factors involved. Some of the main activities include:

1. Crop rotation (see section 3.17).
2. Use of clean seed (see section 3.6).
3. Use of disease-free planting material.
4. Sanitation practices such as:
 - removing left-overs from previous crop,
 - removing weeds,
 - cleaning field tools.
5. Increasing soil organic matter content (increasing organic matter of soil can increase microbial activity, which can lower population densities of soil-borne pathogens (see section 3.8.3).
6. Proper water management: mainly providing drainage to keep soil around roots from becoming waterlogged (see section 3.14).
7. Application of antagonistic fungi such as *Trichoderma* sp. into the soil. See section 7.10.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

- 3.7. Demonstration of spread of pathogens
 3.11. Simulating pathogen spread

3.7.4 Soil sterilization

Once the soil is infected with a pathogen, there are few options for control/management. The best is to reduce the pathogen population with structural methods like crop rotation or the use of resistant varieties. For some crops, such as tomato and eggplant, it is possible to graft a variety to a resistant rootstock. For smaller field sizes, such as nurseries, it is possible to use certain methods to sterilize soil. Such methods include solarization or burning (plant)materials on the soil. These and other methods are described in section 3.10 on nursery management.

It is dangerous to use (non-specific) chemicals for soil sterilization. Such chemicals are not always effective because pathogens may live deep in the soil, or are protected inside plant left-overs, where chemicals do not reach. In addition, residues of pesticides in the soil may cause damage to the next crop and residues may leach into (ground)water causing death of fish, problems with drinking water, and cause damage to micro-organisms in the soil and the aquatic biosystems in general.

New methods, such as *biofumigation*, for “sterilization” (actually control of soil-borne pathogens) of larger field sizes are being studied. Biofumigation refers to the release of certain components (so called “biocides”) by plants that can control soil-borne pests and pathogens. For example, excellent suppression of bacterial wilt (a soil-borne disease attacking solanaceous crops like eggplant and tomato) by mustard green manures was obtained in field studies. See section 3.10.1.4 for details on biofumigation and other options for biological soil sterilization.

3.7.5 Soil pH

An important factor in soil is whether it is *acid* or *alkaline*. This is given in the form of a pH value. These pH values range from 1 to 14. If the pH is less than 7 it means that the soil is acid, and if it is greater than 7, the soil is alkaline. Soil with a pH of around 7 is considered to be neutral.

Soil pH affects the ability of the soil to release nutrients. If the pH level is too high or too low, nutrients can get “locked up” in the soil chemistry and become unavailable to plants. A pH range of approximately 6 to 7 promotes the most ready availability of plant nutrients.

The soil pH can also influence plant growth by its effect on activity of beneficial micro-organisms. Bacteria that decompose soil organic matter are hindered in strong acid soils. This prevents organic matter from breaking down, resulting in an accumulation of organic matter and the ‘lock up’ of nutrients, particularly nitrogen, that are held in the organic matter.

Humus (that comes from the breakdown of organic matter such as compost) has an important function in regulating soil pH. Humus itself is neutral and can absorb acid and alkali shocks from outside.

Application of lots of organic matter into soils is a good and more permanent solution to neutralize soil pH than the application of lime. However, strongly acid soils should also receive lime.

Like many vegetables, eggplant performs best in soil with a pH range of about 6.0 to 6.8.

3.7.6 Measuring and adjusting soil pH

The soil pH can be measured with a pH meter or a soil testing kit which uses chemicals and a color comparison to determine the pH of the soil.

Soil can become acidic as a result of:

1. rainwater leaching away basic ions (calcium, magnesium, potassium and sodium),
2. carbon dioxide (CO₂) from decomposing organic matter and root respiration dissolving in soil water to form a weak organic acid;
3. formation of strong organic and inorganic acids, such as nitric and sulfuric acid, from decaying organic matter and oxidation of ammonium and sulfur fertilizers. Strongly acid soils are usually the result of the action of these strong organic and inorganic acids.

The soil pH can be raised by applying lime or lowered by sulfur application. Lime is usually added to acid soils to increase soil pH. The addition of lime raises soil pH, and provides two nutrients, calcium and magnesium to the soil. Lime also makes phosphorus that is added to the soil more available for plant growth and increases the availability of nitrogen by hastening the decomposition of organic matter (Bickelhaupt, www22).

Types of lime

There are several types of lime available to raise pH. *Hydrated lime*, which is quick acting, should be applied several weeks prior to planting and watered in well to avoid any chances of burning the crop. *Crushed limestone* is much slower acting but longer lasting in its effect. It requires a heavier application but can be used with less chance of burning. *Dolomite limestone* is particularly good because it contains a trace element magnesium, which is an essential fertilizer element for plants. Wood ashes can also increase soil pH. There may be many other types of lime in your area. Check characteristics and application method of lime with the provider.

It should be noted that the correction of an acid soil is a process that takes time - sometimes a few years! It is therefore good to apply lots of organic matter to increase the level of humus in the soil.

The timing of lime application is quite critical as it takes a while before the lime decomposes and the pH goes up. This depends on type of lime used, humidity and temperature. General rule is that lime should be applied about 4 weeks before transplanting and worked into the soil. It is also good to make sure the soil is moist when applying lime or watered immediately afterwards.

The amount of lime needed to correct a soil acidity problem is affected by a number of factors, including soil pH, soil type (amount of sand, silt and clay), structure, and amount of organic matter. In addition to soil variables the crops or plants to be grown influence the amount of lime needed. Some indications are given in table below.

Indication of amounts of lime required to raise pH to 6.5 on different soil types:

Soil pH	Lime required (kg/m ²) to raise to pH 6.5		
	Soil type: Sand	Soil type: Loam	Soil type: Clay
6.0	0.10	0.17	0.24
5.5	0.22	0.37	0.49
5.0	0.32	0.54	0.73
4.5	0.39	0.73	0.97
4.0	0.49	0.85	1.12

Lime for control of soil-borne diseases?

In some areas, lime is applied to the field for disease control. This has only been demonstrated for clubroot control in cabbage. However, lime may change the micro-environment in the soil somewhat, resulting in changes of the population of micro-organisms, including pathogens. It may also have an effect on general crop health: by raising the pH, other nutrients become available, plants may grow better and stronger plants can resist diseases better. Set up an experiment to see what the effects of applying lime would be in your situation.

In Hai Phong province, North Vietnam for example, farmers have tested the effects of applying compost (15 tons/ha) with and without crushed lime in the planting hole during transplanting on disease occurrence in tomato. Results indicated that pest and blossom end rot incidence were similar in all treatments, but AESA led to pesticide applications being reduced from 11 in farmers' practice plots to 7 in the two IPM treatments. Yields were also higher by 37% and 50% for treatments with and without lime, respectively. Profits increased from VND 558,000 in the farmers' practice treatment to VND 787,000 in the plus-lime IPM treatment, and VND 1,007,00 in the no-lime IPM treatment (pers. comm. Dr. J.Vos, 1999; and Vos, 2000, www16).

3.7.7 Soil conservation and erosion control

Many farmers are concerned about how to keep or restore soil fertility in order to maintain good yields. Very often, the emphasis is on adding nutrients, not so much on protecting soil through soil conservation. Fertilization and soil conservation are actually equally important. Nutrients are linked with chemical qualities of the soil, conservation also emphasizes the physical and biological characteristics of soil. Conservation is not only keeping soil parts where they are, but also keeping a good soil structure and stimulating the activity of micro-organisms in the soil.

Some principles of soil conservation and fertilization (modified from Murakami, 1991):

1. Keeping the soil covered.

When soil is uncovered, it is easily attacked by rain, wind and sun heat. This is the main cause for degradation of soil structure and soil erosion. During growth of a crop in the field, the soil can be covered by mulch (such as rice straw) or "living mulch" which is a crop that grows together with the main crop but is not harvested. When no production crop is planted in the field, consider sowing a cover crop. This will keep the soil covered and thus protected from erosion by wind or water and it is a very good way of fertilizing the soil. See section 3.8.3.2. A cover crop can also be used as a *biofumigation* crop to sanitize the soil. See section 3.10.1.4.

2. Regular supply of organic material to the soil.

Adding organic material to soil is essential for good crop production! Organic matter such as compost can supply all necessary nutrients to plants, and helps maintain a balanced pH. Organic matter also stimulates activity of micro-organisms in the soil. Micro-organisms help releasing nutrients from organic material in the soil, help improve soil structure, and help protect roots from diseases. See section 3.8.3 on organic material.

3. Vegetation on field or farm boundary areas.

Another useful practice is to plant trees and grasses in boundary areas of a farm. Such vegetation protects soil from run-off by rain and wind; it becomes a source of organic fertilizer, fodder, fuel, food (fruits), or timber, and it also acts as a windbreaker. When flowering plants are used, they may attract natural enemies such as hoverflies, and provide shelter for natural enemies such as spiders.

4. No use of pesticides on soil.

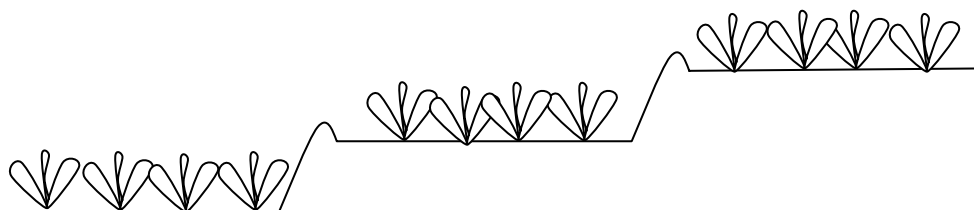
Pesticides disturb the activity of micro-organisms in the soil and may create imbalances in soil fertility.

5. No / Low use of chemical fertilizers.

When large amounts of organic material are supplied to the soil every year, usually no chemical fertilizers need be added. Chemical fertilizers may create an imbalance in the soil ecosystem. They disturb the activity of micro-organisms by adding only a few nutrients. In addition, nutrient supply (e.g. too much nitrogen) has been known to cause disease problems in plants. Nonetheless, in some cases it can be good to use a small amount of fertilizer (e.g. nitrogen) to push plants through a stressful period.

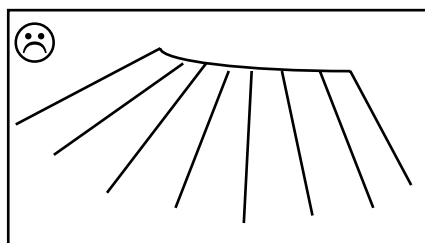
6. Building terraces on steep slopes.

On steep slopes, building horizontal terraces is a common and good practice to prevent soil erosion. Often, a small "dike" is made (or a row of weeds is allowed) at the border of a terrace. A common pattern is the following:

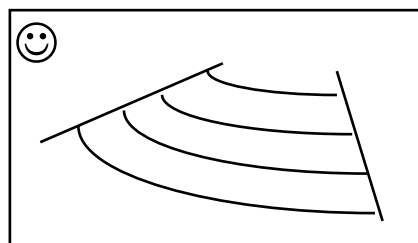


7. Plant along gradient of the slope.

On slopes without terraces, it is recommended to plant the rows of vegetables along the gradient of the slope. When rows are planted top-down, rain and irrigation water flow down hill and may take nutrients, soil particles and organic matter down. Those valuable matters are then lost for the crop. Also, with water, soil-borne diseases like bacterial wilt or nematodes can easily spread into the lower parts of the field.



Top down planting stimulates erosion....



... plant along the gradient of the slope!

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

2-A.2. Soil conservation: why?

3.8 Fertilizer management

Plants use nutrients from the soil in order to grow and produce a crop. Nutrients are also lost through erosion, leaching and immobilization. Fertilizer management aims at compensating this loss of nutrients. This can be achieved by adding organic materials, chemical fertilizers, or a combination.



A well-balanced amount of available nutrients results in healthy plants. A healthy plant can resist pests and diseases better. Well-balanced fertilization is not the same as excessive fertilization! For example, too much nitrogen is known to increase disease occurrence in crops! Also, adding too much (chemical) fertilizer may simply be a waste of money. ☹

The use of compost, green manure or other organic materials, which release nutrients slowly, requires careful planning and consideration of long-term goals such as improving the structure and biological activity of the soil. This requires basic understanding of some of the processes that take place in the soil. The following sections describe some principles of fertilizer management and ways to improve soil structure, fertility and biological activity (Peet, www1).

3.8.1 **Macro and micro nutrients**

Macronutrients are nitrogen (N), phosphorus (P) and potassium (K). These are nutrients that all plants need in relatively large amounts.

Secondary nutrients (calcium, sulfur, and magnesium) and micronutrients (boron, copper, iron, manganese, molybdenum and zinc and chlorine) are essential for growth, but required in smaller quantities than N, P, and K. Usually, secondary and micronutrients are lumped together under *micronutrients*, also called *trace elements*. Addition of micronutrients should be made only when a clear deficiency is indicated, preferably by a soil test analysis.

Some of the micronutrients are found in the mineral particles of the soil but most come from the breakdown of organic matter. The micronutrients exist in very complex forms and have to be broken down into simpler forms which the plant roots can absorb. This process is comparable with the breakdown of leaves in the soil: slowly they will become soft, fall apart into very small pieces and eventually disappear. This breakdown process is done by micro-organisms, mainly bacteria that live in the soil. That is why it is important to stimulate the biological activity in the soil: it results in better soil fertility! To function effectively, the micro-organisms need air, water, neutral soil (pH 6 to 7.5) and lots of organic material.

Organic material usually contains both the macronutrients N, P and K and a mixture of micronutrients.

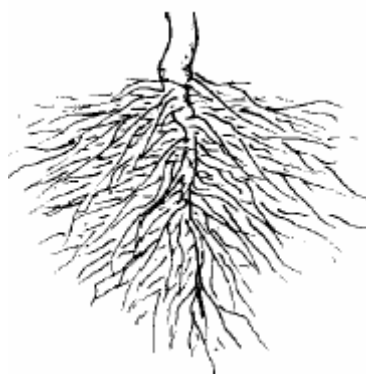
3.8.2 Soil testing

Whether or not chemical fertilizers need to be added depends on the amount of nutrients already available in the soil. A soil-testing service can be a good way to find out if nutrients need to be added, and how much. In some countries, the Department of Agriculture provides a soil-testing service. There are also portable test kits that can examine the main nutrients of the soil. Results and reliability of these portable kits however vary. The test kits are useful to find deficiencies of N, P and K but recommendations for the amount of fertilizer to be added vary, according to local soil conditions.

Soil testing usually does not provide information about soil structure, or biological activity, although some estimate of soil organic matter can be included.

Past field history should be considered when interpreting soil test results. This is particularly important when past fertilization has been in the form of organic materials which release nutrients slowly. In that case, soil tests may under-predict the amount of soil nutrients actually available to plants over the course of the entire season (Peet, www1).

Additional information on possible soil imbalances may be gained by looking not only at the leaves and top growth of the plant, but by carefully digging up a plant, shaking off the soil, and examining the roots for vigor and signs of disease or pest damage. In general, roots growing in a fertile soil are more branched than in a poor soil, and they have a profusion of root hairs. However, the plants must be dug up very carefully to avoid losing the root hairs. If the roots are growing laterally and are long and stringy they are searching for nutrients. If they are long and vertical, they probably need water. If they are growing only near the surface, the soil is too wet. If they are thick and short they may be suffering from a toxic element.



healthy root system

3.8.3 Role of organic matter and micro-organisms

In general, organic matter additions to a soil will increase its ability to hold nutrients in an available state. Organic matter additions will also increase soil biological activity. This, in turn, will affect the availability of nutrients in the soil. Soil which has received organic matter has increased microbial populations and more varied fungal species than soils receiving chemical fertilizer applications. The long-term objective of

organic matter addition is to build up soil humus. Humus is the more or less stable fraction of the soil organic matter remaining after decomposition of plant and animal residues. Also see section 3.7.2 on soil type.

Nutrients: Adding organic matter to the soil stimulates the activity of the many small beneficial organisms that live in the soil. These micro-organisms make nutrients available to plants by producing humus (decomposition) and by releasing nutrients (mineralization). Organic material is food for micro-organisms and these micro-organisms produce food for the crop. The more active micro-organisms, the more humus and nutrients become available for plants. Soils that are rich in organic matter are a good source of nutrients over a long period as the nutrients from the organic material will be released gradually.

If sufficient organic matter is supplied regularly to the soil, usually no chemical fertilizers need to be applied.

Soil water-holding capacity also increases when organic materials are incorporated into the soil. This is especially useful for locations without irrigation facilities.

Soil pH: Humus, formed by micro-organisms, has a regulating effect on soil pH. Soils rich in organic material and humus can absorb acid and alkali “shocks”, e.g. caused by application of chemical fertilizers. See section 3.7.5 on soil pH.

Soil health: micro-organisms in the soil promote soil health. Species of such micro-organisms may include antagonists such as the fungus *Trichoderma* sp., that can control several species of fungi that cause damping-off disease in nurseries. *Trichoderma* occurs naturally in many soils but can also be applied (see section 7.10.1). There are several other species of useful antagonistic organisms occurring naturally in soils.

Organic matter can be added using various methods: compost, cover crops, green manure, organic mulch, etc. A number of organic materials are described in the following sections.

3.8.3.1 Compost

Composting is the most popular practice for improving soil fertility. Composting involves mixing various organic materials such as crop left-overs and manure and leaving it to decompose. The main purpose is to make raw organic matter into humus which is an important source of nutrients and is not harmful for the crop. Mature compost is a brown-black crumbly material, containing humus, dead and living micro-organisms, the more resistant parts of the original wastes and water.



Advantages of compost:

- **Quick action:** the composting process starts very quickly compared with mulch or green manure; in about 10 days. The whole composting process takes about 3 to 4 months, depending on materials used (the softer the material, the quicker) and climate (the warmer, the quicker).
- **Good fertilizer:** good compost can be a rich source of both macro elements N, P, K and many micro nutrients. In addition, the nutrients are distributed in the soil more evenly than direct application. Nutrients are released over a long period compared to the quick release over a short time of chemical fertilizers.
- **Uses locally available materials:** any plant material or organic waste that will rot down can be used to prepare compost. Compost allows the use of materials such as domestic wastes and sawdust that otherwise tie up soil nitrogen.
- **Creates good soil:** organic matter improves the soil structure resulting better water holding capacity of the soil, and soil that is easy to work in. See also section 3.8.3 on role of organic matter.
- **Reduces pathogen populations:** pathogens in the organic material are killed when temperatures during composting reach 65°C and weed seeds are destroyed when temperatures reach 80°C. In addition, researchers report that compost applied to the soil reduces disease problems in plants. This is due to the micro-organisms that are stimulated by the addition of compost. Micro-organisms

compete with pathogens for nutrients and/or they produce certain substances that reduce pathogen survival and growth. See section below.

- **Nitrogen regulator:** compared to use of manure, compost prevents the loss of N through ammonia gas (NH_3) by fixing N into organic forms. However, some N is lost through NH_3 when compost is turned. Compost reduces N below levels that cause burning of plants.

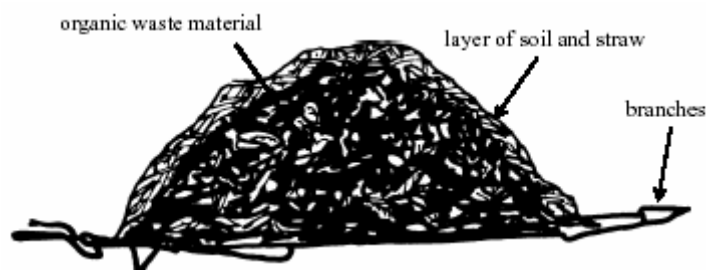
Disadvantages of compost:

- **Large amount of organic matter required:** the ideal amount of compost to apply to a field every year is 20 tons/ha (about 2 kg/m²). If a farmer wants to supply that amount of organic matter through only compost, a huge amount of organic matter is needed. It is very difficult to collect such amounts of organic matter because in some cases, crop left-overs are also used to feed farm animals and manure can be needed for cooking activities. Therefore, in most cases, it will be best to combine use of compost with other fertilization methods such as green manure and mulch.
- **Nutrient loss:** Composting results in loss of nitrogen as ammonia gas (NH_3) when the compost is turned. Also, compost reduces nitrogen availability in comparison to the raw material from which it was made.
- **Laborious:** the process of making compost takes quite a bit of work as it involves collecting material, making the compost pile, turning the compost and carrying the compost to the field. Therefore it is recommended that most organic matter be returned as mulch and other, unsuitable material be used for compost.
- Compost is not as effective as raw organic matter in improving soil structure. As micro-organisms work to decompose raw organic matter, they excrete gels and slimes that bind soil particles together and enhance soil structure (modified from Peet, www1).

How to prepare compost

There are many theories about the best way to prepare compost. Good thing to remember is: however the compost is made, it will benefit the soil!

The simplest method for composting is to pile up organic domestic and field waste material, finally covering the pile with a layer of soil and possibly straw for insulation. Although many publications advise layering of materials, the best way is to thoroughly mix plant materials throughout the pile. Use equal proportions of dry and wet material. Dry material such as straw, sawdust, and corn stalks contain little water and decompose slowly but they provide air to the pile. Make sure that woody material is chopped into smaller pieces for quicker decomposition. Wet material such as fresh weeds, crop residue and fresh manure contain more water and decompose quicker than dry materials. Wet materials contain a lot of nitrogen, and this is food (energy) for micro-organisms. A lot of food stimulates the micro-organisms to “start working” on decomposition quickly.



A simple compost pile: organic waste piled on branches, covered with a layer of soil and straw

Small micro-organisms inside the pile will become active in breaking down the organic material. These organisms also need water and air, so do not press the pile into a very compact pile of material! It is recommended to build the pile on a layer of branches to provide air from underneath and to allow drainage of the pile during rainfall.

Compost starters

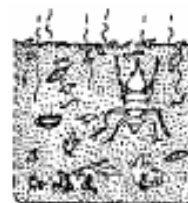
Some sources sell compost starters or compost activators, which they claim are needed to start the decomposition process (the heating) in a compost pile or to speed up the process. Such starters are often composed of high-nitrogen fertilizers, EM supplements or even of dehydrated bacteria. While high-nitrogen fertilizers may be helpful, the benefits of adding more bacteria from a package have yet to be proven. All the bacteria and other micro-organisms you need are usually already present in the soil under the compost pile and, especially, in the material that you add to the pile.

There is no need to add compost starters with “special” micro-organisms!

If you still want to give your compost pile a “boost”, the best source of micro-organisms is finished compost. When fresh planting material (green leaves, grasses) are added, there will be enough nitrogen for the micro-organisms to start decomposing the compost quickly. Fresh manure is another good source of nitrogen and micro-organisms.

During decomposition the temperature inside the pile will rise. It is important to stop adding materials to the pile at some point to let the micro-organisms do their work. Ideal is when the pile is build up in one day. When you keep adding materials to the pile, it may take a very long time before the compost can be used and the temperature may not have increased enough to kill possible pathogens and weeds. Temperatures around 80°C are needed to kill most weed seed.

Almost all of the common pathogens in a compost pile will be killed when the temperature in the whole pile has reached 45 to 65°C. Exceptions are fungi that form thick layered spores or resting structures, possibly *Fusarium* and *Verticillium* wilt, and *Sclerotinia sclerotiorum* (not confirmed by research). Farmers in Lam Dong, South Vietnam, made different piles with healthy crop residues and diseased crop residues for comparison during field studies. Such studies are a very good way to find out if certain diseases are destroyed in a compost pile in your conditions.



Temperatures of 45-65°C kill most of the common pathogens and pests.

**Compost thermometer**

Farmers in Hai Phong, Vietnam, have set up several experiments using compost. To test if the composting process inside the pile has started, they placed a stick in the pile like a “thermometer”. They take out the stick and when it is warm, the decomposition has started. If the stick is still cold after 48 hours, decomposition has not started. This means there may be something wrong in the built of the pile (too compact, too moist, etc). The monitoring of the ‘thermometer’ can be continued daily to check the temperature rise and fall over time to assess when the decomposition is completed or when the pile is ready for turning. A metal rod, placed in the center of the pile, can also be used as thermometer (pers. comm. Dr. J. Vos, 2000).

When a compost pile does not heat up, the problem is either the pile is too small, it is too dry, or it needs more nitrogen. This can be solved by adding green matter.

When the compost has a foul smell, it needs more air and less water. Try turning the pile more often or add more bulking materials such as straw or corn stalks.

The compost pile should be turned a few times (e.g. once every 3 weeks, two times in total). Turning supplies air, needed by the micro-organisms, into the center of the pile and speeds the decay. Turning also mixes material from the outside of the pile into the hot center. When the compost is dry, it can be watered after turning. Cover the pile during rainy periods so it will not get too wet.

Compost piles can best be sited in a shady sheltered place to give protection from sun and wind. It is also possible to dig a pit and pile organic waste material in the pit. This may be especially useful during the dry season, when the pile inside a pit will remain moister than on flat soil.

A compost pile can be of any size as long as it is easy to handle: it will shrink considerably while decomposing. A common recommendation is a pile measuring at least 1 meter in each direction (high, wide and long). A smaller pile will not generate or retain enough heat to effectively kill any harmful pathogens present.

It takes about 3 to 4 months for decomposition to be complete, depending on the climate (the warmer, the quicker) and the contents of the pile (the softer and finer the pieces of the material, the quicker). Compost is ready to use when the pile no longer heats when turned, and the material looks dark and crumbly.

Compost should be sufficiently mature before it is applied. If the original hard parts are still there, the compost is not mature. The breakdown of immature compost and directly incorporated materials will use nutrients in the soil, which no longer become available for the crop. In addition, immature compost may still contain pathogens and weed seed. By adding immature compost to the field, you may actually add diseases and weeds....! (refs: www17; www18; www19)

Disease control with compost

An additional benefit of using compost is that it can reduce disease problems for plants. This is being studied for several years now because it offers an opportunity to further reduce fungicide use. Pathologists describe two different types of disease suppression in compost and soil.

1. General suppression is due to many different micro-organisms in the compost that either compete with pathogens for nutrients and/or produce certain substances (called *antibiotics*) that reduce pathogen survival and growth. Thus an active population of micro-organisms in the soil or compost outcompetes pathogens and will often prevent disease.

This type of suppression is effective on those pathogens that have small propagule (e.g. spores) size. Small spores do not contain many nutrients so for germination they need an external energy (carbon) source. Examples of this mechanism are suppression of damping-off and root rot diseases caused by *Pythium* species and *Phytophthora* species.

2. Specific suppression, on the other hand, is usually explained by one or a few organisms. They exert hyperparasitism on the pathogen or induce systemic resistance in the plant to specific pathogens, much like a vaccination. With specific suppression, the causal agent can be clearly transferred from one soil to another. Pathogens such as *Rhizoctonia solani* and *Sclerotium rolfsii* are examples where specific suppression may work but general suppression does not work. This is because these organisms have large propagules (e.g. spores) that are less reliant on external energy and nutrients and thus less susceptible to microbial competition. Specific hyperparasites such as the fungi *Trichoderma* and *Gliocladium* species will colonize the propagules and reduce disease potential (ref. www20).

Other biocontrol agents (or antagonists, also see section 7.10) that colonize composts include bacteria like *Bacillus*, *Enterobacter*, *Flavobacterium balusstinum*, and *Pseudomonas*; actinomycetes like *Streptomyces*. These antagonists may appear naturally in compost. In some cases, antagonistic fungi or bacteria are added to the compost just after the hot phase, when the compost is cooling down. There are not many micro-organisms present inside the compost at that moment. When antagonists are added at that time, they can quickly build up their populations and this will result in compost with good disease suppressing quality. See box below.

Compost quality plays a role in the degree of disease suppression and the length of suppressive activity. Some general observations:

- Composts that are allowed to mature are more suppressive than piles used straight after the hot phase.
- Compost piles that are in the open (so exposed to naturally occurring micro-organisms), and especially those located near trees, are more suppressive than compost piles sheltered by a roof.

Fortified composts

An interesting option is the use of *fortified* compost. This is compost added with antagonistic organisms such as *Trichoderma* species (especially *T. hamatum* and *T. harzianum*) whereby *Trichoderma* works as a compost process enhancer. Such fortified composts provide both nutrients to the crop (through the composts) and they provide effective control of a range of plant pathogens (mainly through the antagonistic fungi). After the primary heating period of composting is complete, the *Trichoderma* is added to the compost. The fungi increase to high levels in the compost and can effectively reduce diseases caused by *Rhizoctonia solani*, and species of *Pythium*, *Phytophthora* and *Fusarium*. In the USA, fortified composts must be officially registered.

In order for compost to substitute for currently used fungicides, the disease suppressive character must be consistent and somewhat quantifiable to reduce risk for the farmers. In some countries, there are specialized compost companies that produce consistently suppressive composts, especially for the nursery industry.

Professional nursery industries now use disease suppressing composts widely and routinely. Based on the successes there, researchers are testing compost on a number of field crops for potential disease suppression. Results of several studies are very promising.

For example, studies in California, U.S.A., showed that soils on organic farms (using lots of compost) were more suppressive to two tomato diseases than soils from conventionally managed farms, due to differences in soil organic matter, population of micro-organisms, and nitrate level.

Compost extracts

These are liquid extracts of compost, also called *compost teas*. Compost teas look rather promising as preventative sprays to suppress certain leaf diseases, and as a method to restore or enhance the population of micro-organisms in the soil. A number of researchers report that compost extracts were effective in the control of diseases such as late blight (*Phytophthora infestans*) of potato and tomato, *Fusarium* wilt (*Fusarium oxysporum*), and gray mold (*Botrytis cinerea*) in beans.

Compost extracts enable biocontrol of plant pathogens through their action on the leaf surface and on micro-organisms that are present there. A wide range of mechanisms, such as induced resistance, inhibition of spore germination, antagonism, and competition with pathogens, seem to contribute to the suppressive effect.

Factors influencing the efficacy of compost extracts include: age of compost; source of compost (animal manure based composts retain activity longer than composts solely of plant origin); type of target pathogen; method of preparation; mode, timing and frequency of application; and meteorological conditions. The efficacy of compost extracts can be enhanced by adding beneficial micro-organisms.

The methods by which compost watery extracts are prepared are changing as growers and researchers try new methods. One method is to cover compost with tap water at a ratio between 1:5 to 1:8 (volume/volume). This mixture is stirred once and allowed to ferment outdoors. After a soaking period (called "extraction time") the solution is strained through cloth and then applied with ordinary sprayers. Extraction periods ranged from 2 to 21 days, although most were between 3 to 7 days (at temperate conditions with outside temperature between 15° and 20°C) (ref. www21).

Farmers can use farm-produced composts to experiment with extracting teas, and test its effects on diseases.

Other researchers report less disease incidence (even foliar disease such as early blight), dramatic reduction in rootknot nematode damage, and higher yields on composted plots compared to conventional treatment in several crops.

In addition, several researchers are testing the use of compost teas as a foliar spray to prevent and control leaf diseases. See box above.

Bacterial wilt suppression with compost: Study results from Hai Phong, North Vietnam

During field studies on disease management, farmers set up a study on the use of compost to manage bacterial wilt on tomato. Bacterial wilt is a major problem in many solanaceous crops including eggplant. The tomato study was conducted in a field (with history of bacterial wilt) of 1400 m² and consisted of three treatments (three replications):

1. Use of compost (about 14 ton/ha fully mature – applied in planting hole before transplanting), using pesticides only when necessary following agro-ecosystem analysis
2. Use of compost (as in 1) mixed with crushed lime
3. Farmers practice (using only half mature compost – applied in planting hole before transplanting; following local practices in pesticide use)

The insect pest levels and the blossom end rot incidence were similar in all treatments. Bacterial wilt incidence was too low to draw conclusions about the effect of the treatments. Yellow wilt (fungal wilt) was low as well, even though highest in treatment 3. Pesticide use dropped from 11 applications in treatment 3 to 7 applications in treatments 1 and 2. The crop development data in the 3 treatments did not differ a lot, but the farmers and trainers said that the plants were higher and that there were more leaves, flowers and fruits in treatments 1 and 2 than in treatment 3. The yields were higher in treatments 1 and 2 (resp. 1200 and 1100 kg/sao) than in treatment 3 (800 kg/sao). The profits increased from 558,000 VND/sao in treatment 3 to 787,000 VND/sao in treatment 2 and 1,007,000 VND/sao in treatment 1.

Conclusions from the field and pot studies by the farmers and the trainers were: 😊

- Tomato plants develop better and faster with compost than without.
- Compost suppresses bacterial wilt.
- Lime should be used during the composting process rather than mixed with compost before field application. This statement will be tested during follow-up experiments. (pers. comm. J. Vos, Oct. 1999; and www16)

How to use compost

As most vegetables grow best on soils rich in organic matter, compost can always be added as much as possible to the field before planting. Ideal would be 20 tons/ha or 2 kg per square meter of land (1 kg is about as much as you can hold in two hands). In Nepal, the recommendation is to use 30 tons/ha.



It is recommended to mix the compost into the soil about 2 to 4 weeks before planting. This will give time for the micro-organisms to break down the parts of the compost so that the nutritional elements will be available once the seedlings are transplanted. Also some competition with possible pathogens in the soil may have occurred. Compost can also be added to the planting hole during transplanting.

3.8.3.2 Cover crops, Green manure, and Living mulch

Cover crops are crops planted to improve the soil, for weed control, erosion prevention or for lowering moisture loss (during hot season) rather than for harvest. Such crops are also often called “green manure” or “living mulch” although strictly speaking, the terms are slightly different. Cover crops and green manure are usually grown when the land is fallow whereas living mulch can be grown together with the crop. Living mulch is usually a leguminous crop, such as clover or pea grass, which remains low, covers a wide area, and is long lasting as it is being grown over several seasons.

Cover crops can gradually add organic matter to the soil and help retain soil nutrients from one season to the next. The contribution to soil organic matter and soil fertility varies with the kind of cover crop used. For example, legumes decay quickly because residues are high in nitrogen. Therefore, they are more valuable as N sources than as organic matter sources. Grass crops, such as rye or jute, will have a much greater effect on soil organic matter content than legumes because they have a higher carbon to nitrogen (C:N) ratio and decay more slowly.

For a cover crop to be an effective fertilizer, it must also accumulate nutrients that would not otherwise be available to the following crop. Legume cover crops supply some or most of the following crop's nitrogen needs, but some other cover crops also increase plant nutrient availability. For example, buckwheat and sweet clover are able to accumulate phosphorus even in soils with low available phosphorus. Others may have root systems that go deeply into the soil. The decaying year after year of these deep roots leaves stores of organic matter into the soil. This type of deep fertilization cannot be duplicated in any other form so cheaply and easily! In general, cover crops need to be incorporated to speed up nutrient availability to the following crop (Peet, www1).

Green manure is a crop (often a legume crop) planted during a fallow period, grown for several weeks, then ploughed into the soil. About 2–3 weeks is given to allow decomposing of the green manure crop. After that, the main crop, e.g. eggplant, can be planted into the field.

Green manure has some advantage over usual compost in that it supplies the soil with organic matter at the peak of its nutritional benefit. Compost will lose some of its nutrients due to leaching and other actions of the elements. Green manure is a very effective method to supply a lot of organic matter to the soil without having to collect it from outside (such as in case of compost). Disadvantage is that several weeks are involved to produce it, during which the land cannot be used for other crops.

Some examples of crops that can be used as green manure/cover crops:

- alfalfa
- clovers
- cowpea, grass pea, sweet pea, pigeon pea
- soybean, mung bean, velvet bean, jack bean

These are mostly nitrogen-fixing crops. The roots of these plants fix nitrogen from the air into the soil, releasing it slowly to following crops.

Decomposition of green manure crops

After green manure crops have been turned in, the plant tissue starts to decompose. It becomes soft, and slowly, it falls into small pieces. It is important to allow time for decomposition before planting the main crop because:

- Decomposition process will consume oxygen from the soil. This oxygen is also needed by plant roots.
- Decomposition process produces methane, a gas harmful to plant roots.

An exception to this is when green manure crops are grown to suppress certain soil-borne diseases, as a kind of biological soil sterilization. Details of such methods can be found in section 3.10.1.4. Time needed for complete decomposition can be about 3 weeks for legume crops. Exact time depends on temperature, soil moisture, and kind of green manure crop. See also section 3.8.3.3 on manure.

Some farmers use weeds as green manure. They work the weeds into the soil when preparing the field for transplanting. This is easier than sowing a separate manure crop but has certain risks: when the weeds bear flowers and seed you actually sow weeds! And some weeds have long rootstocks which when cut into pieces during the ploughing, will each give a new weed plant. This may eventually lead to more weeds. Most weeds do not fix nitrogen. In addition, some weeds can be hosts for eggplant diseases, particularly weeds that belong to the family of Solanaceae (modified from Peet, www1).

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

2-A.5. Use of green manure

3.8.3.3 Manure

Manure, like composted materials, is used to add nutrients (manure can be especially rich in micronutrients), improve the water-holding capacity of soils and to improve the structural stability of heavy soils. Total benefits from manure sometimes take three or more years to become apparent. This is

because a portion of the nutrients and organic matter in manure is broken down and released during the first year or two, but a portion is also held in humus-like compounds which decompose more slowly.

Determining the correct amount of manure to apply is difficult. Manure samples should be analyzed for nutrient content and levels of metals such as copper, which are often present in poultry litter and pig manure. Nitrogen available to the plant is lower than the content in the samples since some loss occurs through volatilization (through ammonia gas NH_3) with spreading and since only a portion of the organic N becomes available to the plants through mineralization during the growing season. Also, the rate of manure application needed to supply the nitrogen needs of the crop will usually supply phosphorus and potassium in amounts in excess of those the plant can use. This excess application generally does not affect crop growth but can, in the case of phosphorus, pollute water if runoff or erosion occurs. Phosphorus runoff can be minimized by controlling erosion with cover crops or mulches (Peet, www1). Average nutrients available in manure from different sources, and from ashes are listed below .

Type of manure	Nitrogen (N) (%)	Phosphoric acid (P_2O_5) (%)	Potash (K_2O) (%)
cattle dung, fresh	0.3 – 0.4	0.1 – 0.2	0.1 – 0.3
horse dung, fresh	0.4 – 0.5	0.3 – 0.4	0.3 – 0.4
poultry manure, fresh	1.0 – 1.8	1.4 – 1.8	0.8 – 0.9
cattle urine	0.9 – 1.2	trace	0.5 – 1.0
horse urine	1.2 – 1.5	trace	1.3 – 1.5
human urine	0.6 – 1.0	0.1 – 0.2	0.2 – 0.3
Farmyard manure, dry	0.4 – 1.5	0.3 – 0.9	0.3 – 1.9
Ash, coal	0.7	0.5	0.5
Ash, household	0.5 – 1.9	1.6 – 4.2	2.3 – 12.0

(Tata, S.N, 1992, ICAR, Handbook of Agriculture, India).

In general, direct application of manure or other raw animal wastes is not recommended.

Main reasons are:

- Fresh manure may contain diseases that tolerate the digestive passage and may contain insect larvae such as maggots which can destroy roots of eggplant. In fact, decaying manure may attract insects such as maggot adults for egg laying.
- Uncomposted manures are difficult to apply, not only because of their bulk, but because it is easy to apply more nitrogen than the plants can absorb. Too much nitrogen in eggplant may result in stretched plants which fall over easily, and produce lots of shoots but no flowers.
- Direct application can lead to problems of excess nitrates in the plant and runoff of nitrates into surrounding water supplies.
- Excessive raw manure can burn plants and lead to toxic levels of nitrates in leafy greens.
- Decomposition process will consume oxygen from the soil; this oxygen is also needed by plant roots. One case where this process may be tolerable is described in section 3.10.1.5 on soil sterilization of nurseries.
- Decomposition process produces methane, a gas harmful to plant roots. Also see section 3.10.1 on soil sterilization of nurseries.
- Regular supply of fresh manure leads to lower soil pH.

3.8.3.4 Organic mulches

Mulch is any material placed on the soil surface to protect the soil from the adverse effects of rainfall, wind, and water loss. Mulches are also used to control weeds and reduce erosion. Organic mulching materials will break down over time, contributing organic matter to the soil. The use of mulches for weed control is discussed further in chapter 9 on Weed Management. Furthermore, as mulch reduces the need for tillage, plowing labor is reduced.

Many kinds of organic materials can be used as mulch including tree leaves, grasses, crop residues (but only those free of diseases and insect pests!), saw dust, rice straw, etc. Even weeds (without seeds), coconut leaves, water hyacinths and compost can be used as mulch.

When selecting mulch material, it is important to consider your requirements and the characteristics of the material. For soil protection the use of high C/N ratio (high carbon content: usually “dry” materials) material are recommended. Examples of high C/N ratio materials are straw, lemon grasses and coconut leaves. These last for a long time. For soil fertilization purposes, low C/N ratio material (high nitrogen content: usually “wet” materials) are recommended. Examples are leguminous grasses, leguminous crops, and compost.

Leguminous crops, such as clovers, can also be grown as a “living mulch”, together with the main crop. Such living mulch is an effective soil protectant and it provides nitrogen to the main crop. See section 3.8.3.2 above.

Nematode control with manure?

Fresh manure may have an effect on the occurrence of diseases such as rootknot nematodes: some studies report that adding fresh organic matter such as poultry manure, cattle manure and different kinds of green manure greatly reduced infestations of rootknot nematodes. See section 8.1.3 on rootknot nematodes.

Reasons for this control are not clearly understood but may be caused by the ammonia gas (NH₃) that is produced during decomposition of the manure, and the manure may also give plants a growth “boost” allowing extra root growth for compensation of nematode-damaged roots.

In areas where rootknot nematodes are a problem, testing the effects of fresh manure may be an interesting management option.

3.8.4 Chemical fertilizers

Inorganic or chemical fertilizers are usually added for the short term food needs of the plants. The three main elements in chemical fertilizers are nitrogen (N), phosphate (P) and potassium (K). Chemical fertilizers can usually be bought separately or in a combination with different proportions. A combination of the three fertilizers is described by a series of three numbers referring to the content of each element. For example: 25-15-5 means the fertilizer contains 25% N, 15% P and 5% K. Some micronutrients such as boron can be bought separately, however, additions of micronutrients should be made only when a deficiency is indicated, preferably by a soil test analysis.

3.8.5 Comparing organic and chemical fertilizers

The following table lists advantages and disadvantages of organic and inorganic (chemical) fertilizers.

	Organic fertilizer	Inorganic fertilizer
Advantages	<ul style="list-style-type: none"> Rich in nutrients. Usually provides both (part of the) macronutrients N, P & K, and a range of micronutrients. Improves soil structure. Increases water holding capacity of the soil. Gradual release of nutrients over a long period of time. Improves nutrient exchange system. Stimulates activity of micro-organisms that make nutrients from the soil available to plants. 	<ul style="list-style-type: none"> High content of a few nutrients. Fast release of nutrients. Easy to determine dosage. Easy to apply, not labor intensive.
Disadvantages	<ul style="list-style-type: none"> Organic fertilizers such as compost vary widely in composition, depending on the raw material used in their preparation. 	<ul style="list-style-type: none"> Usually very water soluble; may be washed away quickly during wet season. Expensive.

3.8.6 Foliar fertilizers

In some areas, farmers make use of foliar fertilizers. These are solutions of fertilizers that are sprayed on the leaves of the plant. The advantage of using foliar fertilizer is that it is quickly taken up by the plant, quicker than the nutrient uptake from organic or inorganic fertilizers by the roots. They can be used as a corrective measure for example when a deficiency of a certain nutritional element is discovered. A disadvantage is that foliar fertilizers are expensive and act very short term - no gradual release of nutrients, no effect on soil structure. And, when not used correctly, foliar fertilizers may cause burning of the leaves. Also, some pest and diseases can become more serious when crops are too generously fertilized. In eggplant, too much nitrogen (a common ingredient in foliar fertilizers) can result in a vigorous plant with lots of green leaves but no flowers!

To see if foliar fertilizers would be economical for use in your field, compare a small area with foliar fertilizers with another area in which common fertilization is used. Note down cost of fertilizers, incidence of insect pests and diseases and economic returns.

3.8.7 Fertilization needs of eggplant

The table below lists general eggplant nutrient recommendations. These recommendations are very general and the range in doses for the fertilizers is broad. The exact dosage to be applied depends on the nutrients already available in the soil (see 3.9.2 on soil testing), soil type and structure, environment, etc. It is recommended to prefer organic above inorganic (chemical) fertilizers! For example, application of compost releases nutrients over a long period of time. This is important for a crop like eggplant which is flowering and fruiting over a period of several months.

In addition, you can set up a small experiment to test different types and doses of fertilizers to check the ideal combination for your crop and field situation. In Dalat and Hanoi, Vietnam, for example, tomato field studies showed that mixtures of organic and chemical fertilizer were better than only one fertilizer type. It was also advised to include proper economic analysis in field experiments as some of the organic fertilizer was expensive when bought from elsewhere (FAO - Updates on Vietnam Nat. IPM programme in vegetables, 1999).

A general recommendation for type of fertilizers and timing of application for eggplant is given in table below. Part of the recommended nutrients can have organic sources, such as compost or green manure. See section 3.8.3.

Fertilizer type Timing	compost (tons/ha)	Nitrogen** (kg/ha)	Phosphorus (kg/ha)	Potassium (kg/ha)	Boron (kg/ha)
Total application	15 - 20	80 - 150	120 - 250	120 - 250	1-2
Transplanting (at/before)	15 - 20	30 - 50	70 - 200	70 - 200	1-2
3 - 4 WAT*	-	30 - 50	50	50	
6 - 8 WAT*	-	20 - 50	-	-	

WAT = weeks after transplanting
(modified from: Peet, www1 and Collingwood, 1988)

* Fertilizer studies can be set up to establish a fertilizer recommendation table related to growth stage rather than WAT.

** Nitrogen fertilization should not be applied to the crop before the setting of seed in the first fruits, because this will stimulate growth of leaves but not fruits.

Every person, every book or guide will give another recommendation for eggplant fertilization. The only way to determine the best type, amount, timing and application techniques of fertilization for your area, your field, your crop, is to
experiment!

The effects of N, P, K and Mg in eggplant

Nitrogen (N) promotes vegetative growth, but be careful not to apply too much before fruit set. The resulting plants are thick stemmed and dark green.

Note: *too much nitrogen can cause excessive shoot growth but no flowers!*

Phosphorus(P): high level of P throughout root zone is essential for root development and for good utilization of water and other nutrients by the plants. Phosphorus has an effect on the number of flowers that develop. Poor root growth and poor fruit development are associated with low P.

Potassium (K) affects fruit size and fruit quality: higher levels tend to increase fruit size. Increased levels of potassium help in decreasing the incidence of irregular shaped fruits. It also plays a role in the coloration of fruits. Soft fruit and poor condition of skin are associated with low K.

Eggplant is sensitive to deficiencies of magnesium. Magnesium deficiency affects the older leaves, where it causes marginal and interveinal yellowing. If necessary, an application of 40-60 units/ha of magnesium carbonate could be included in the base dressing. On a small scale, magnesium deficiency may be corrected by foliar sprays (usually sulphate of magnesia).

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

- 2-C.5. Fertilizing experiments
- 2-C.6. Use of foliar fertilizers
- 2-A.6. Composting
- 2-A.7. Use of compost

For more background reading and practical exercises on composting, please refer to the report "Guide on Composting Field Studies (draft), 2001", FAO-Vietnam National IPM Program, 2001. See reference list (chapter 11) on how to obtain copies.

3.9 Planting time and pest occurrence

The type and number of pest and diseases can vary in different times of the year. During the dry season for example, diseases such as early blight will usually be less severe. Knowing when a pest or disease is most severe can offer an opportunity to plant the crop during the time that pests and disease are not present in large numbers or just before that time. That gives the plant the opportunity to be well established in the field before an attack by an insect or a disease occurs. Field experiments in Orissa, India, for example, showed that an eggplant crop planted in June was least affected by fruit and shoot borer (*Leucinodes orbonalis*). Maximum fruit damage was recorded on crops planted in October (38.2%) followed by November-planted crops (36.6%) (Tripathi, 1996).

Planting time can be a tool to break the continuity of insect breeding by creating periods without food plants for pests. See crop rotation section 3.17.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

- 2-A.12. Weather conditions and planting time

3.10 Nursery management

3.10.1 Soil sterilization

There are several ways of sterilizing soil, both as a preventive measure against soil-borne diseases (such as damping-off) and as a method to control soil-borne diseases already present. A number of common practices are described below.

To see if any of these soil sterilization methods work in your field, set up a study to compare this method against the common practice!

3.10.1.1 Burning organic material on the soil

A common method of soil sterilization is heating up the soil. The high temperature will cause the death of many micro-organisms, including pathogens in the top soil and insect pest with soil-dwelling stages, such as cutworms. In Bangladesh and India for example, soil sterilization is commonly practiced by burning straw, or dry grass, leaves or waste material on the nursery beds before sowing. It should be noted that straw burns very quickly and the heat does not penetrate deep enough into the soil. This may result in only a very thin top layer of the soil being sterilized. A substantial amount of slow-burning but high-temperature output material would be required on the soil, e.g. wood rather than grass (Bridge, 1996). Rice husk is preferred to straw because it burns slower and the heat penetrates deeper into the soil, resulting in better sterilization.

In Bangladesh, Choudhury and Hoque (1982) demonstrated that by burning a 5-cm thick layer of rice husks (burnt in 90 min) and a 5-cm thick layer of sawdust (burnt in 60 min) on the surface of vegetable seed beds, rootknot nematode galls on the following crop of eggplant were reduced to 23 and 37%, respectively, of the number of root galls in non-treated seed beds. A 15-cm thick layer of rice straw (burnt in 20 min) however only reduced galling to 50% of the control plots.

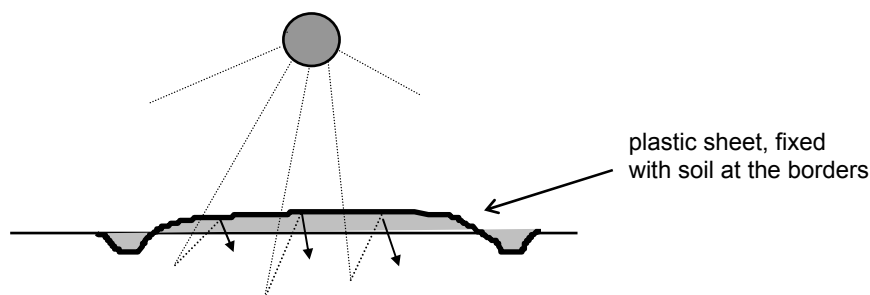
Soil from fire place

Another example of an alternative method of soil sterilization came from Bangladesh, where a farmer used the soil from his fire place to prepare a nursery. This soil had been heated several times over a long period for cooking activities. The heat had killed pathogens in the soil. It would be advisable to mix the soil with compost before sowing seed (pers. comm. farmer Chittagong, Bangladesh, 1998).

3.10.1.2 Solarization

Another soil sterilization method is *solarization* - with help of the sun's energy. Solarization of seedbeds can control soil-borne diseases, weed seeds and some nematodes including rootknot nematodes. However, not *all* pests are controlled.

To solarize soil, the soil is covered with clear polythene/plastic sheets. The best time is during the hot season, when there is plenty of sun. The sun heats up the soil through the clear plastic, and the plastic sheet keeps the heat inside the soil. Usually, the sheets should be left on the soil for at least 4 weeks, depending on the season (hours of sunshine and temperature) and the area (lowland or highlands). The soil should be moist before the plastic sheets are placed and the sheets should be properly fixed on the sides to avoid losing heat. Also check the polythene sheets for holes and repair them where necessary. Ploughing the soil before applying the plastic sheets seems to help to break up crop left-overs and bring nematodes to the surface so the heat can destroy them. Allow the soil to cool down for at least a few days before sowing seed.



Solarization: the sun heats up the soil under the plastic sheet and kills insects, diseases and some weeds.

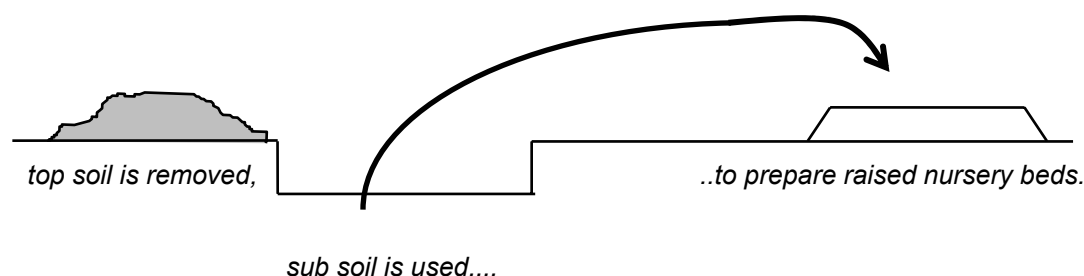
Solarization alternative from Jessore, Bangladesh

A farmer from Jessore had trouble with damping-off disease in his soil. To raise seedlings in a nursery, he took soil, mixed it with cow dung and some water and put this in plastic bags. He placed the bags in the full sun, some on top of his roof, and left them for about 2 weeks. Then, he used the soil to prepare a raised nursery bed in which the seed were sown. He reported no further trouble with damping-off! (Pers. comm. Mr. Yousuf, Jessore, Bangladesh, 1998)

Solarization can be combined with another soil sterilization method described in section 3.10.1.5. With this method a large amount of organic material (e.g. a green manure crop like grass (40 tons/ha) is incorporated into the soil before applying the plastic sheets. A better sterilization effect may be obtained and organic material is added to the soil, which improves soil structure and fertilization. See section 3.10.1.5 for details.

3.10.1.3 Use of sub-soil

When damping-off disease is a problem in an area, and there is no possibility to shift the nursery to another site, the use of sub-soil may be an alternative to reduce the chance of damping-off disease. This method is practiced in parts of Indonesia with very good results. Most of the organisms that cause damping-off live in the top layer of the soil. Remove the top layer of about 30 cm in an area close to the nursery site and dig out the soil below this layer. This soil is used to prepare the raised nursery bed. It is recommended to mix the sub-soil with some compost.



3.10.1.4 Biofumigation

Biofumigation refers to the process by which soil-borne pests and pathogens are suppressed by naturally occurring compounds (principally isothiocyanates) released into soil during decomposition of certain crops, especially Brassica crops. The Brassica crops with biofumigation potential are used as a rotation crop, a companion or a green manure crop.

Australian studies have demonstrated an excellent suppression of bacterial wilt (*Ralstonia solanacearum*) of solanaceous crops (tomato, eggplant, etc.) using Indian mustard (*Brassica juncea*) green manures while for other pathogens (e.g. *Pythium* sp. causing damping-off disease) the effectiveness was poor.

The green manure production for biofumigation is similar to green manure for fertilization purposes: a Brassica crop is grown for several weeks, then some harvesting of green leaves for food/fodder could be done prior to incorporation into the soil of the remaining green manure crop.

The focus for new research projects will be Bacterial Wilt (*Ralstonia solanacearum*) and rootknot nematodes (*Meloidogyne* sp.). Previous research indicates both are susceptible to the suppressive effects of certain Brassicaceous green manures. The aim of the research is to provide information of the Brassicas most effective as biofumigants against different pathogens and on management strategies to enhance this effect (pers. comm. Dr. J. Kirkegaard, 1999 & Dr. M. Whitten, 2001).

3.10.1.5 Biological soil sterilization

Another method of soil sterilization, comparable with biofumigation (see section above) is being studied where soil sterilization is achieved by micro-organisms that occur naturally in the soil. It requires air-tight plastic sheets. Fresh plant material (from previous crop or a green manure crop) is worked into the soil, deep and homogeneously. The field is watered and covered with an air-tight plastic sheet (0.12-0.15 mm thick), properly fixed at all sides. The sheet is left on the field for 6 – 8 weeks (Note: trial results from temperate (Dutch) climatic conditions).

Within a few days of applying the plastic sheet, the oxygen in the soil is gone. The oxygen is consumed by micro-organisms in the soil. Without oxygen, the micro-organisms cannot break down the organic material the usual way (into carbon (CO₂) and water (H₂O)) so they switch to fermentation. During this

fermentation, several degradation products are formed and after some time, a biogas, methane, is formed in addition. Also, the concentration of carbon in the soil increases. The fermentation products, the biogas methane and the carbon are thought to play an important role in the suppression of some soil pathogens and nematodes. The effects are better at higher temperatures.

In small scale field trials in the Netherlands, the effect of this method was studied on survival of the soil-borne fungus *Fusarium oxysporum*. The organic matter used was grass (40 tons/ha) or broccoli. Results showed that good control was achieved in the soil layer where plant material was present. Below this layer, the effect disappeared. It is planned to test the method on larger scale production fields.

Similar studies showed that biological soil sterilization was effective against the many soil-borne fungi: *Fusarium oxysporum*, *Rhizoctonia solani* and *R. tuliparum*, *Verticillium dahliae*, *Sclerotinia sclerotiorum* and different nematode species (*Meloidogyne* and *Pratyenchus*).

This soil sterilization method can be combined with solarization (see section 3.10.1.2). Under the Dutch temperate conditions (with low amount of sunshine), the plastic used was non-transparent to prevent weeds from germinating under the plastic and produce oxygen, thus reducing the sterilization effect. However, when using transparent plastic under tropical conditions, the expectation is that the soil temperature rises enough to kill weed seeds. When incorporating organic matter into the soil before placing the plastic sheets, three effects may be obtained:

- Soil sterilization by fermentation processes caused by degradation of organic material by micro-organisms under anaerobic (no oxygen available) conditions,
- Soil sterilization by rise of soil temperature due to sunshine and plastic sheets,
- Addition of organic material through the green manure crop to improve soil structure and soil fertilization.

(Blok, 1998; pers. comm. Dr. W. Blok, Wageningen Agr.Univ., 1999).

3.10.1.6 Boiled water

Although not proven, the use of boiling water for soil sterilization may be an option for soil sterilization. A farmer from Bangladesh used this method: he boiled water and pored it one to three times over the nursery soil to kill pathogens and possibly insects and/or nematodes in the seedbed. He let the soil drain and cool down before sowing the seed (pers.comm. farmer Chittagong, Bangladesh, 1998).

It would however be advisable to set up an experiment (possibly with pot trials) to test if this method would be appropriate for your area.

***To see if any of these soil sterilization methods work in your field,
set up an experiment to compare the method against the common practice!***

3.10.2 Sowing

Eggplant can be sown directly in the field or sown in a nursery and transplanted later. Usually, transplanted eggplants show earlier ripening and give higher yields than directly seeded ones. Therefore, most commonly, eggplant is sown in a nursery. This nursery should be located at a sunny place where the soil is not too wet. High humidity may provoke diseases like damping-off which can destroy all seedlings in a very short time. If possible, the nursery should be sited on land which has not grown solanaceous crops like eggplant, tomato, pepper or potato for 3 years or more. This is the most effective precaution against the occurrence of (soil-borne) diseases.

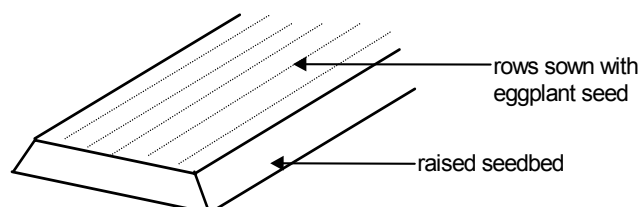
3.10.2.1 Flat field and raised seedbeds

Proper drainage and aeration are necessary to prevent soil-borne diseases like damping-off. A good option is to prepare raised seedbeds which will dry up more quickly than flat-field plantings.

Compost can be mixed in the seedbeds to get a fine soil structure with sufficient nutrients. Make sure the seedbeds are properly leveled. Dig trenches between the seedbeds to facilitate drainage of the nursery. When nursery beds are prepared, it is best to leave the beds for about 10 days to allow the soil to settle. After 10 days, the seeds can be sown.

Seeds are generally sown about 1 - 1.5 cm deep in rows at a spacing of about 3 cm between the plants and 20 cm between the rows. Seeds are either broadcast in the rows and thinned out later or placed individually every 3 cm. Broadcasting the whole seedbed uses a lot of seed (expensive when hybrid seed!) and results in irregular patches of seedlings which need to be thinned out to obtain strong seedlings.

If the seeds are planted deeper than about 1.5 cm, they will need more time to emerge, so you will have to wait longer before transplanting. When seeds are planted less than about 1 cm deep, they will be more susceptible to drought, and will form weaker seedlings. Birds may also eat seeds from the beds.



Precision sowing: inspiration from Jessore, Bangladesh:

A farmer from Jessore sows his eggplant nursery with help of a wooden frame with small pins which he places on the soil of the nursery beds. The pins make small holes in the soil at equal intervals to indicate the positions of the seed. He then sows 2 to 3 seeds in each hole. With this method of precision sowing, this farmer was able to get a good nursery with a small amount of seed. Good idea, especially for expensive hybrid seed! 😊
(pers. comm. Farmer Yousuf, Jessore, Bangladesh, 1998)

Sometimes, the nursery is covered with a layer of mulch, e.g. rice straw or rice husk, to protect the soil from becoming very hot and drying out (during a warm and dry period) and to prevent weed germination. It also prevents birds from roaming around in the beds and eating the seed. Usually, the mulch has to be removed once the seedlings have germinated or it can be moved aside to give enough space to seedlings but still covering the area next to the seedlings. When straw is used as mulch, at least the long pieces of straw should be removed. After germination, it is recommended to thin the plants to 2-3 cm apart to ensure that each plant will have sufficient space and nutrients to become strong.

When necessary, shade and shelter for heavy rainfall can be provided by placing polythene or bamboo mats over the nursery beds. Do not shadow the nursery beds for too long a period as this results in weaker and stretched seedlings.

Seedlings are transplanted to the field when the stems have straightened and the first true leaves have opened. This is usually about 6 weeks after sowing, depending on temperature and variety.

3.10.2.2 Sowing in pots

In areas with heavy soil-borne disease infestation, or with unsuitable soil for a nursery site, it is possible to raise seedlings in pots. Pots can be made out of banana leaf, polybags, jars or other materials. The advantage of using organic material such as banana leaves is that these can be left around the seedlings during transplanting. They will decompose in time. The pots are usually filled with clean soil and some compost. Various soil mixes can be tried, for example sub-soil with compost (see section 3.10.1.3).



One or two seeds are sown in each pot. The pots are watered regularly and protected from full sun or rain if necessary. In Vietnam, some farmers keep the pots under the roof near their houses to protect them from heavy rains.

Potting seedlings versus flatfield beds, an experience from Lao PDR:

In a study in Lao PDR, cabbage seedlings that were raised in polybags were found to recover quicker after transplanting. Compared to traditionally raised seedlings, polybag seedlings suffered less from transplanting shock (less root injury) and they were generally stronger and more resistant against pests and diseases. In addition, they could be harvested 7 to 10 days earlier (pers. comm. A. Westendorp, 2000).

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

- 2-B.1. Farmers' practices and problems during the nursery phase
- 2-B.2. Design and testing of good nurseries
- 2-B.3. Use of clean soil: subsoil versus topsoil
- 2-B.4. Use of clean soil: solarization of the seed bed
- 2-B.5. Use of clean soil: topsoil burning
- 2-B.6. Use of clean soil: steam sterilization
- 2-B.7. Broadcasting versus potting
- 2-B.8. Fertilizing seed beds
- 2-B.9. Roofing and screening of seed beds
- 2-B.10. Mulching of seed beds
- 2-B.11. Overhead or flood irrigation of seed beds
- 2-B.12. Length of raising period
- 2-B.13. Transplanting methods

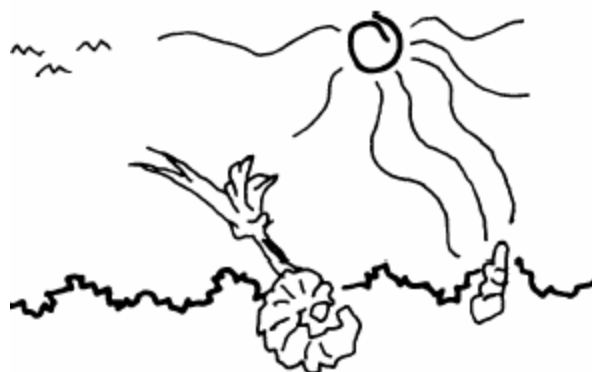
3.11 Field preparation**3.11.1 Working the soil**

Tillage or ploughing is carried out to prepare good plant beds. When turning the soil, insects that live or pupate in the soil may come to the surface and are either dried out by the sun or may be eaten by birds. Ploughing can also control weeds and pests that remain in plant left-overs in the soil. Ploughing however, also disturbs the micro-organisms in the soil and this may reduce soil fertility. To maintain and improve soil fertility, it is important to apply organic materials such as compost every year.

Sustainable soil practices are focused on using less tillage and more organic materials, such as green manure or mulch, to increase biological activity in the soil. Less tillage is possible where enough mulch covers the soil. See sections 3.8.3.2 and 3.8.3.4, and box below on conservation tillage.

Left-overs from a previous crop should be carefully removed and destroyed as it may still contain diseases and pests which can spread into the new crop. These left-overs can be used for composting which, if properly done, will get rid of pathogens.

When drainage of the field is problematic, or when crops are grown during the rainy season, it is advisable to prepare raised beds for growing the crop and dig trenches between the beds for drainage. This is also a good practice when problems with soil-borne diseases can be expected: most pathogens need water to spread and if there is an excess of water all the time, they can easily spread in the field. Excess water in the soil, or even water-logging, results in weak plants which are more susceptible to diseases and pests and give a lower yield.



Ploughing may expose insects and pupae in the soil to predators like birds and to the drying force of the sun.

Conservation Tillage

In conservation tillage, crops are grown with minimal cultivation of the soil. When the amount of tillage is reduced, the stubble or plant residues are not completely incorporated, and most or all remain on top of the soil rather than being plowed into the soil or removed. The new crop is planted into this stubble or small strips of tilled soil. Weeds are controlled with cover crops or herbicides rather than by cultivation. Fertilizer and lime (if necessary) are either incorporated earlier in the production cycle or placed on top of the soil at planting. Because of this increased dependence on herbicides for weed control and to kill the previous crop, the inclusion of conservation tillage as a “sustainable” practice could be questioned. However, farmers and researchers are working on less herbicide-dependent modifications of conservation tillage practices. In general, the greatest advantages of reduced tillage are realized on soils prone to erosion and drought (Peet, www1).

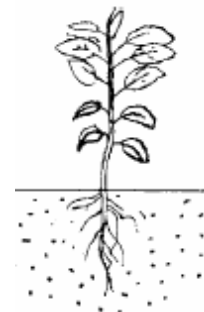
Advantages	Disadvantages
<ul style="list-style-type: none"> • Crops use water more efficiently, • The water-holding capacity of the soil increases, • Water losses from runoff and evaporation are reduced, • Soil organic matter and populations of beneficial insects are maintained, • Soil and nutrients are less likely to be lost from the field, • Less time and labor is required to prepare the field for planting. 	<ul style="list-style-type: none"> • Compaction of the soil may occur, • Flooding or poor drainage may occur, • Delays in planting when fields are too wet or too cold, • Carryover of diseases or pests in crop residue, • Transplanting in stubble is more difficult and may take longer, resulting in delayed or less uniform crop.

3.11.2 Transplanting

Eggplant seedlings can be transplanted to the field when the stems have straightened and the first true leaves have opened. This is usually about 6 weeks after sowing, depending on temperature and variety.

Water plants thoroughly several hours before transplanting to the field. Plants should be dug or cut loose from the soil when being transplanted; ensure the roots are not damaged, or exposed to sun or drying wind for longer periods of time.

Some nurseries harden seedlings before they are sold for transplanting. Seedlings are hardened by the withholding of water and nutrients for several days. Remove netting to expose seedlings to stronger sunlight. Hardened seedlings are more likely to recover quickly from the transplanting shock.



Transplanting should preferably be done in the late afternoon or evening. Set transplants deep, the first true leaves just above the soil level. Irrigate frequently after transplanting during dry periods.

Removing lower leaves at transplanting: a Lao experience

During a Farmer Field School on cabbage in Ban Thanaleng, Lao PDR, farmers studied the effect of removal of two lower leaves at the time of transplanting. Farmers found that transplants with 2 lower leaves removed recovered 1 to 2 days quicker than seedlings transplanted with all leaves. In India and Bangladesh, this is a common practice in eggplant, to limit evaporation and to shorten the recovery phase of the seedling after transplanting.

To see if this method would work for eggplant set up a field study to compare lower leaf clipping with non-clipping (FAO – FFS report: IPM Cabbage FFS Ban Thanaleng, Lao PDR, 1997 – 1998).

3.11.3 Planting density

Planting density varies according to variety, soil fertility, soil moisture and farmer's objectives. The planting density has an effect on crop production and susceptibility to diseases. Wider crop densities result in more space and nutrients to one plant, which will usually result in more fruits and a higher fruit weight per plant. In a study with tomato, it was found that the fruit numbers and fruit weight per plant increased more with wider plant spacing than with wider row spacing (AVRDC, 1987). However, high yields can also be a result of high plant population and high fruit numbers.

Planting density also has an effect on the climate within the crop. In a close planting, wind and sunshine cannot reach to the soil level and as a result, the lower leaves of the crop stay wet longer. This can stimulate disease infection because many diseases need water to infect the plant. When serious problems are present with a pathogen, for example early blight, an option would be to plant at a wider spacing. This will keep the plant dryer and this prevents spores (the 'seed' of a fungus) from germinating and infecting the plant.

In addition, pest insects such as red spider mites (*Tetranychus* sp.) can easily walk from one plant to the next when leaves of adjacent plants touch.

For example, data from Agro Ecosystem Analysis during a Farmers' Field School in Negros Occidental, the Philippines (1998/1999), showed that more insect pests and more mechanical damage from field operations were observed in the "high density" eggplant field (pers.comm. Carlito Indencia, 2001).

Some factors related to spacing are listed in the table below.

Narrow spacing	Wide spacing
more plants per area = higher initial costs	fewer plants per area = lower initial costs
smaller plants	larger plants
might increase disease incidence	might reduce disease incidence
more plants = (possibly) more fruits, but smaller size	lower plant numbers but fruit numbers and fruit weight per plant may increase

Eggplants are typically established in 60 – 90 cm rows with 45 – 60 cm between plants, depending on the variety (smaller growing or larger growing type) and the planting method (single row or double-triple row planting). The time required to reach maturity depends on variety and climatic conditions.

Spacing: space for variation

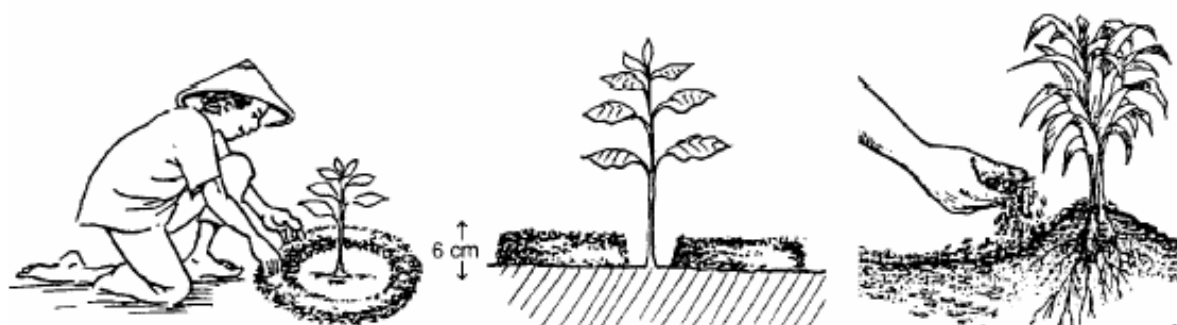
Spacing is much determined by local tradition and varieties grown. In Bangladesh for example, spacing of eggplants varies with area:

Mymensingh practice	60 x 60 cm
Rangpur and Delampar	75 x 60
Chittagong	100 x 75
Jessore	100 x 100

(pers. comm. farmer Yousuf, Jessore, Bangladesh, 1998)

3.11.4 Mulching

Mulching means keeping the soil surface covered with non-transparent material. Mulching reduces weed germination and it will keep the soil cool and moist because the sun cannot shine directly on the soil. Organic mulch can provide shelter for predators such as ground beetles and spiders. Mulching can be done both on the nursery after sowing (also to prevent birds from eating the seed) and after transplanting in the main field. Mulch on the nursery usually needs to be removed once the first seedlings have germinated.



Mulching with organic materials

Mulch can be a layer of organic material, for example, rice straw or a layer of green leaves, saw dust or even pulled out weeds without seed. Mulching can also be done with non-transparent plastic sheets. This is however, quite expensive! Sheets should be non-transparent because that prevents germination of weeds. Seed usually need light for germination. A disadvantage of using black (or non-transparent) plastic sheets can be that the soil temperature is increased. This type of mulch should be removed when temperature becomes excessive (over 32°C) under the covers. In cool areas, a rise in soil temperature may be an advantage as it increases root growth and may induce early yields, and in some cases increase total yields. Plastic waste materials however, do have a negative side effect on the environment! Research is ongoing to develop biodegradable plastic (“bioplastic”) which can be placed, together with crop left-overs, on a compost pile.

Mulching may have a role in reducing pests and diseases. Plastic mulches with aluminium film have been shown to reduce aphid and thrips attacks. The shiny aluminium reflects light and deters aphids and thrips. The repellency could be associated with disturbance of orientation before landing on the crop. In case of thrips, it could also be a result of reduced access to suitable pupation sites in the soil under the crop (Vos, 1994). Silver colored plastic has the same effect, white and yellow plastics to a lesser extent. This is particularly useful where aphids transmit virus diseases, such as in tomato or chili. It is probably not so useful in eggplant because the most important vector-transmitted disease, little leaf, is transmitted by leafhoppers and it is not clear if leafhoppers are repelled by colored mulch.

Diseases that spread with soil particles with splashing water from rain, such as root rot (*Phytophthora* sp.) cannot spread so easily when the soil surface is covered with a mulch. See also section 3.8.3.4 on organic mulch.

Mulching of fruits

In Philippines, farmers use plastic mulch (recycle materials) during the rainy season. They wrap the first 2 or 3 eggplant fruits in plastic to protect them from diseases. Farmers claim loss due to diseases is reduced by 50% through this practice (pers.comm. Carlito Indencia, 2001).

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

- 2-C.1. Farmers' field preparations and problems
- 2-C.2. Plant spacing
- 2-C.7. Mulching of plant beds: organic and inorganic mulches

3.12 Pruning, ratoon crops, and staking

Pruning is recommended to produce good quality fruits. Two or three branches per plant should be kept, all other branches should be removed regularly. It is also advisable to remove older leaves to allow for more air circulation and light within the crop.

Although eggplants will keep growing and flowering for several months if kept picked, they are usually more productive if cut back and allowed to



regrow. In milder regions of the South of the USA for example, plants are often mowed down to heights of 15 – 20 cm following the first crop, or the plants are pruned to just above the first side branch. An additional dosage of nitrogen and potassium is applied to produce vigorous regrowth and stimulate flowering. This regrowth is often very strong because the roots are already there and can provide the nutrition and water from the soil to feed the new shoots. The second crop is ready to be harvested in 4 to 6 weeks. In many parts of Asia, such a second crop is called a *ratoon* crop.

In the Philippines, when severe damage by fruit and shoot borer (*Leucinodes orbonalis*) occurs, farmers cut back the eggplant crop to about 30 cm from soil level and allow it to regrow. Also when the fruiting starts to decline and market requirements are high, farmers in Philippines cut back the eggplants in rows to spread the new production: e.g. by ratooning 4 rows every week. (pers.comm. Julieta Lumogdang, 2001). Eggplant in homesteads/kitchen gardens in Lao PDR and Thailand are regularly pruned for prolonged fruit production for home consumption.

Ratoon crops in Bangladesh: an example from Jessore

Although ratooning is not a wide-spread practice in Bangladesh, it can be commonly seen in Jessore area. In some varieties of eggplant fruiting takes place in flushes. This means fruiting almost stops after 2-3 months of the beginning of the fruiting depending on factors like nutrient status, irrigation water availability etc. After reaching that stage, the farmer cuts down the old foliage of the plant and applies lots of nitrogen and other fertilizers in rings around the stem and irrigates frequently. This results in new stems and consequently much earlier fruiting compared to a young crop planted at same time. This method of ratooning may result in early harvesting. And vegetable prices are directly dependent on the time of availability...!
(pers.comm. P.Kumar, April 2001)

In summary, reasons for ratooning may include:

- Ratooning results in earlier harvesting compared to newly transplanted crops.
- Saves costs for seed, and cost for labour like seedbed preparation, raising seedlings, land preparation, transplanting, etc.
- Diseases of seedlings and newly transplanted crops such as damping-off and *Phomopsis* rot are avoided.
- Crops heavily infested with leaf diseases or insects can be cleaned by removing and destroying all foliage.

See also section 4.5 on crop compensation.

Staking of plants may be necessary later in the season as the number and size of the fruits increase. Branches should be kept off the ground because fruit touching the ground may spoil. Rain, wind and irrigation can cause the branches to break or droop.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

2-C.9. Pruning and crop compensation

3.13 Grafting

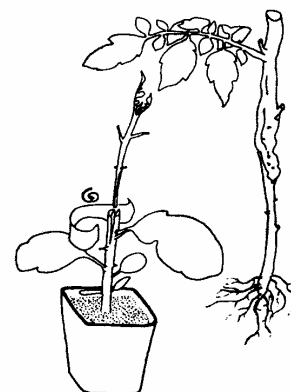
Grafting is forming a union between a shoot (also called *scion*) and a rootstock of different varieties. The shoot is joined to a rootstock so that they eventually fuse and grow together. Often, a “wild” cultivar of a rootstock which has resistance to certain (soil-borne) diseases is merged with a cultivar which forms good fruits. With vegetables it is usually done to obtain disease resistance when resistant varieties are not available. For eggplant, the rootstock *Solanum torvum* is often used for grafting because it is resistant to *Fusarium* wilt, bacterial wilt and rootknot nematode. However, there are reports of the breakdown of the bacterial wilt resistance in *S. torvum* due to high temperatures (day and night temp. above 30°C) and the occurrence of the virulent group IV strain of bacterial wilt (Date, 1994). To overcome problems with the soil-borne disease *Verticillium* wilt (*Verticillium dahliae*), eggplant can also be grafted on a resistant tomato rootstock.

Usually, a collection of both rootstocks and scions is kept. Seeds of the rootstock are directly sown into seedbeds. At the 2-3 true leaf stage the rootstock seedlings are transplanted into polyethylene bags containing soil and decomposed manure/compost. The seedlings continue to grow until the 4-5 true leaf stage and then they are ready for grafting.

The top of the rootstock is removed by a sharp cut. A shoot from the eggplant variety used as scion is cut, and the large leaves are removed to avoid excessive water loss. The lower end of the scion is cut into a V-shape. The top part of the rootstock stem is cut into an opposite V-shape. The two are merged and tied together with a grafting clip or a small elastic band.

The grafted plant should be kept very moist (spray at least 3 times a day) and out of the hot sun. After about 10 days the scion will start to grow on the rootstock. Grafted seedlings can be transplanted into the field after about 3 weeks.

The grafting technique is laborious and requires a lot of experience. In Bangladesh, a grafting compatibility of 95% has been achieved (pers. comm. Md. Atiur Rahman, 2001). Grafting is usually only economical when market prices for eggplant fruits are high and other disease management options are limited.



Grafting: joining a scion with a rootstock
(from: Messiaen, 1992)

3.14 Water management

3.14.1 Drainage

The most important water management practice is providing drainage to keep soil around roots from becoming waterlogged. This is especially important when eggplant (or other vegetables) is rotated with paddy rice, which is usually grown on clay soils that are difficult to drain and stay wet for longer periods of time. Seed and seedlings are likely to rot in wet soil. When soil remains wet and muddy during the rainy season, the plants will grow slower and fruit formation may be hampered. Some diseases can easily spread with the ground water and attack a weakened plant. When the soil tends to stay too wet, dig some trenches to help de-watering. Growing the plants on raised beds and/or plastic covered beds may also help to keep the soil moisture down.

Wet soil and diseases....

When the nursery soil stays wet for a long period, certain soil fungi can cause damping-off disease of the seedlings, and they can even cause death of the small roots emerging from the seed. So seedlings never even emerge above the soil...

When seedlings are grown in wet soil for a long time, they are weakened and more susceptible to diseases. And the fungi causing damping-off can grow and spread easily in wet soil... ☹

3.14.2 Irrigation

Proper irrigation can be critical for maintaining high yields and quality. Soils with adequate organic matter usually have a large water keeping capacity and do not need frequent irrigation. Soil type does not affect the amount of total water needed, but does influence frequency of water application. Lighter soils need more frequent water applications, but less water applied per application. Sandy soils may require water at more frequent intervals as water drains off quicker.

Where irrigation facilities exist, there are sometimes opportunities for manipulating pests. Where the soil is leveled, it is in some cases possible to flood the field with water or to dry the soil out to control pests and weeds. Some pest insects that survive in the soil like cutworms and nematodes and some weeds can be drowned by putting the field under water. Obviously, this is done before transplanting the crop. The field has to be under water for about 4 weeks and will need some time to dry up properly before a new crop is planted. This method does not control all soil-borne diseases!

The irrigation method may also have consequences for the insect and disease populations. Overhead irrigation can increase diseases. The spores of early blight (*Alternaria solani*) for example, can easily germinate when the leaves are wet ☹. The use of ditch or furrow irrigation is usually preferred to overhead irrigation. Ditches also ensure rapid drainage of excess soil moisture during the rainy season.

Flooding the field by rotation with paddy rice

In Indonesia, chili grown in rotation with paddy rice had less problems with soil-borne diseases and nematodes than chili grown in unflooded fields. During the rice production, the field is flooded and nematodes and other pathogens in the soil are killed (Vos, 1994). See section 3.17 on crop rotation.

Other useful water management practices to help keeping foliage dry to prevent spread of water-borne pathogens include:

- Planting in wide rows arranged to increase air flow between rows.
- Orienting rows towards prevailing wind.
- Planting with wide spacing in the rows.
- Irrigating early enough to give plants a chance to dry before evening.
- Working with plants only when leaves are dry.

For eggplants, proper water availability is essential during early growth and during the time of flowering and fruit set. Lack of water during these periods may result in weaker plants, and could lead to reduction in fruit size and yield.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

2-C.8. Flooding and overhead irrigation

3.15 Intercropping and trap crops

3.15.1 Intercropping and barrier crops

Intercropping is the simultaneous cultivation of two or more crops in one field. It can also be called *mixed cropping* or *polyculture*. When plants of different families are planted together it is more difficult for insect pests and diseases to spread from one plant to the next. Insects have more difficulty in finding host plants when they are camouflaged between other plants. Fungus spores may land on non-host plants where they are lost. Natural enemies of insect pests can hide in the other crop. When the intercrop is taller than the eggplants they can form a “barrier” thus reducing spread of insect pests and diseases.



Intercropping: growing two or more crops in one field

Certain intercropped plants excrete chemicals or odors which repel insect pests of other plants. Examples are onion and garlic. The strong smell repels some insects, and they fly away and will not attack other plants growing between the onion or garlic plants. For tomato there are several study results with intercropping, some are given below. For example, intercropped tomatoes with onion or garlic reduced levels of whiteflies and aphids on tomatoes (Tumwine, 1999).

Other plants may have nematicidal activity, killing nematodes in the soil. An example is sesame: root extracts caused mortality of nematodes in laboratory tests (Karshe, 1993). Another “famous” nematode-killer is the flower *Tagetes* sp. (Tumwine, 1999). Pot experiments with eggplant intercropped with garlic, or with the flower *Tagetes erecta* also reduced populations of the nematode *Meloidogyne javanica* (Jain, 1990).

Another study from Bihar, India, reports that lower fruit and shoot borer infestation was recorded when three rows of nigella (*Nigella sativa*) were planted as an intercrop between rows of eggplant, compared to an eggplant monocrop. Intercropping with fennel (*Foeniculum vulgare*) also reduced the pest infestation in eggplant (Gupta, 1999). Other sources mention coriander (*Coriandrum sativum*) sown in a single line to be effective in reducing fruit and shoot borer (*Leucinodes orbonalis*) injury to fruits as compared to eggplant planting alone (Khorsheduzzaman, 1997). Similarly, intercropping with brassicas might control bacterial wilt and nematodes. See section 3.10.1.4 on biofumigation.

Intercrops could also reduce the risk of crop failure by providing an alternative crop and additional income to a farmer. In Vietnam, farmers sometimes grow onion, lettuce or herbs in the tomato field during the first 30 – 35 days after transplanting tomato. These crops are harvested by the time the tomato plants become too large to be intercropped (pers. comm. IPM trainers Hanoi, April 2000). However, when the intercrop is taller than the main crop (e.g. sunflower or sorghum), or grown very close to the main crop, it may cause yield reduction due to competition for light, space and nutrients (Tumwine, 1999).

Other disadvantages include more difficult harvesting operations due to different ripening times of the crops, and the more complicated planning of a crop rotation schedule. Intercropping is usually a bit more labor intensive.

To see if intercropping helps to reduce pest or disease attack in eggplant, set up a study with different types of intercrops.

3.15.2 Trap crops

A trap crop is a crop other than eggplant that attracts insect pests so that these pests will not harm the eggplants. Usually, trap crops are also members of the solanaceous family because they have to attract the same insects that will attack eggplant. Some people find this a disadvantage of planting trap crops because pests are attracted to the field.....!

Trapping jassids with okra

In glasshouse experiments from Philippines, the jassid *Amrasca biguttula biguttula* preferred okra to eggplants for feeding and egg laying (Bernardo, 1990). Where jassids are a problem, an experiment could be set up to test if okra planted along the eggplant field may protect eggplant from crop injury by jassids!

The trap crop is established in the field earlier than the eggplants so that pests will infest the trap crop first. Then the trap crop can be destroyed along with the pest insects but it can also be left in the field. The advantage of leaving the trap crop may be that the infested trap crop attracts natural enemies that will be present when the eggplant is infested by pests. 😊

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:
2-C.3. Mixed cropping versus monocropping

3.16 Harvest and post-harvest

Harvest eggplant fruit when they have developed full bright color for the variety, but while they are still firm to touch. At this stage, the seeds will be young, white, and tender and the flesh firm and white. As the fruit passes the prime stage for eating and becomes over-mature, the fruit surface becomes dull, the seeds harden and darken, and the flesh becomes spongy. Prompt picking stimulates fruit set and increases yields.

Fruits can be snapped from the plant, but less damage usually occurs if they are clipped with a sharp knife or scissors. A short piece of stem is left attached to the fruit. Handle the fruit carefully to avoid damage, wipe it to give a clean, bright appearance.

Staking of plants may be necessary to prevent branches touching the ground later in the season as the number and size of the fruits increase. Rain, wind and irrigation can cause the branches to break or droop. Fruit touching the ground may spoil.

Eggplant fruits lose water and quality quickly at warm temperature after harvest. Ideal would be to store fruits in a cool space (7 to 13°C and a relative humidity of 90-95%).

In some (western) countries, eggplant fruits are wrapped in plastic shrink film to reduce weight loss and maintain firmness, due to the high relative humidity. However, wrapped fruits decay rapidly if the film is not perforated. It is obvious that this practice is very expensive and is only worth it if high prices are fetched in the market.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

2-C.10. Assessment of harvest time

2-C.11. Harvesting practices and crop residue management

3.17 Crop rotation

Crop rotation is necessary to:

1. Avoid build up of large populations of certain pest insects and pathogens.

Some of the more common serious pests and diseases which live in the soil attack a range of plants within the same botanical family - but no others. If the sorts of plants they attack are continually grown in the soil, the pest and diseases can build up to serious populations. Once a soil-borne disease such as bacterial wilt (*Ralstonia solanacearum*) or fungal wilt (*Fusarium oxysporum*, *Verticillium* sp.) has entered a field it is very difficult to eliminate. If there is a break of several seasons or even several years in which other crops (of a different crop family) are grown, their numbers will diminish and they will eventually disappear. This is the main reason for rotating crops.

2. Avoid nutrient deficiency and degradation of soil fertility.

Another reason for crop rotation is that it reduces loss of fertility and nutrient deficiency. When the same crop is planted in the same field every season, there will be a continuous consumption of the same nutrients from the soil. Adding chemical fertilizers will supply only part of the nutrients that are consumed, mostly N, P and K. Adding chemical fertilizers containing the deficient nutrients will not solve the problem. It is necessary to introduce crop rotation and supply organic matter to the soil. Rotating with green manure crop (see section 3.8.3.2) and adding legumes (supplying nitrogen) to the rotation schedule is therefore recommended.

Nutrient consumption is quite different for each crop. In general, nutrient consumption can be ranked from low to high consumption:

1. legumes
2. root crops (e.g. carrot, radish)
3. leaf crops (e.g. cabbage, lettuce)
4. fruit crops (e.g. eggplant, tomato, cucumber)
5. cereals (e.g. rice, barley)

Some examples of main crop families:

Solanaceous	tomato, potato, pepper, chili, eggplant
Crucifers	cabbage, Chinese cabbage, radish, cauliflower, pak choi, broccoli, turnip, mustard, rape
Legumes	pea, all types of beans, groundnut, alfalfa, clovers
Onions	onion, garlic, shallot, leek
Cucurbits	cucumber, gourds, luffa, melons, pumpkins, courgette

Rotation is most effective against diseases that attack only one crop. However, controlling the many diseases that infect several crops in the same plant family requires rotation to an entirely different family. Unfortunately some pathogens, such as those causing wilts and root rots, attack many families and rotation is unlikely to reduce disease.

In addition, some fungi produce resistant, long-lived reproductive structures as well as the immediately infectious forms. For example, the fungi *Pythium* and *Phytophthora* can produce long-lived resting spores. Such spores help these fungi survive during a long time without a host. How long such pathogens can survive without a host plant depends on factors like environment, temperature, ground water, etc. Some indications on "survival rates" per disease are mentioned in the sections on individual diseases. A few examples:

Disease	can stay alive in soil without solanaceous plant for ...
Early blight (<i>Alternaria solani</i>)	at least 1 year
<i>Fusarium</i> & <i>Verticillium</i> wilt	several years (almost "indefinitely")
Southern stem rot (<i>Sclerotium rolfsii</i>)	at least 4 years (sclerotia)

Next to this, you can set up a small trial as described below to check if soil-borne pathogens are still present in a field.

How to check for soil-borne eggplant pathogens in a field:

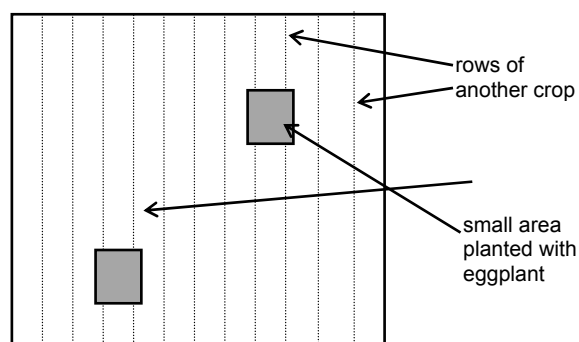
Plant a non-solanaceous crop in your field but leave about 2 or 3 small areas within the field which you plant with eggplant. These are your test areas.

Check at regular intervals whether any soil-borne diseases occur in the test areas. When you find a disease, you know it is still there and you will have to wait *at least* one more season before planting eggplant or another solanaceous crop again.

Check if there still are old eggplant leaves in the neighborhood of your field or in the soil which can be the source of infection. These should be removed.

When no disease occurs you can try planting eggplant again in the whole field next season.

It should be stressed that this test is not 100% fool-proof! Soil-borne diseases are often patchy and a successful test may not give a 100% guarantee that there are no soil-borne diseases. The more test areas you try, the more chance there is to "hit" a soil-borne disease.



Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

2-A.1. Importance of crop rotation

4 ECOLOGY OF INSECT PESTS AND NATURAL ENEMIES



SUMMARY

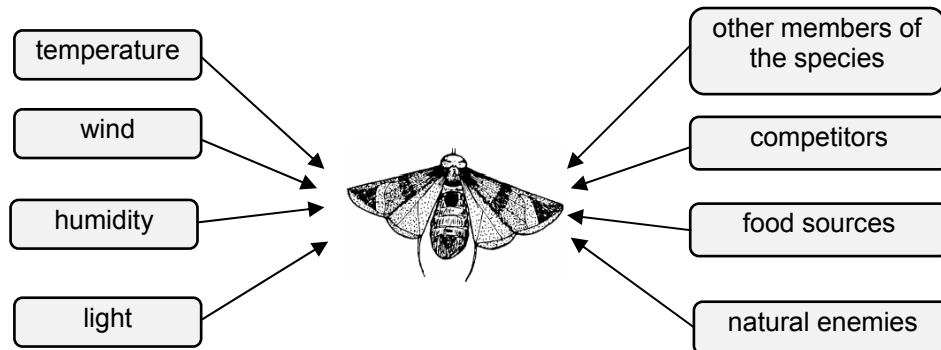
Insect ecology studies insects in their environment. The environment (e.g. climate, food sources, natural enemies) determines whether an insect population becomes a pest or not.

Insects can damage plants by eating leaves, by sucking plant juices, by feeding inside leaves, stems, roots, or fruits. However, not all insect feeding reduces yield! Eggplants can compensate for feeding injury because more leaves and roots are produced than actually needed for shoot and fruit formation. So, not all “pests” are “pests”! Actually, some insects are needed to keep the natural enemy population alive. By setting up insect zoos, the functions and life cycles of insects and natural enemies can be studied.

Natural enemies (predators, parasitoids, pathogens and nematodes) reduce pest insect populations. They can be indigenous or reared and released into the field. The latter is becoming more and more important for many vegetable insect pests. A number of management and control practices for insect pests are described.

4.1 Introduction

Ecology is the study of interrelationships between organisms and their environment. The environment of an insect consists of physical factors such as temperature, wind, humidity, light and biological factors such as other members of the species, food sources, natural enemies and competitors (organisms using the same space or food sources).



Insect ecology: the interrelationships between insect and environment

These interrelationships explain why insect pest species cannot in all circumstances grow to large populations and damage crops. There may be large numbers of predators that eat the pest insects. The weather conditions may be unfavorable for a quick life cycle because insects usually like warm, dry weather. The plant variety may not be very attractive for the pest insects to eat. And there may be many more reasons.

In Agro-Ecosystem Analysis (AESA), insects are considered as populations rather than individuals. One single insect that eats an eggplant leaf will never cause yield loss in a large field but a population of ten thousand leaf-eating caterpillars may do.

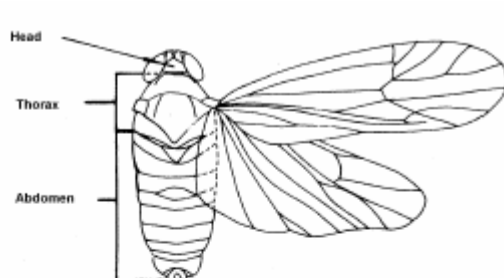
Learning to recognize natural enemies and understanding how they work, and how their impact can be quantified, is very important in pest management. Natural enemies do nothing but reduce pest populations, that is why they are called the “Friends of the farmer”! The work of natural enemies can reduce the need for pesticides. This saves money and time, and is better for the environment and for human health.

In many areas, the use of pesticides is still a common practice for insect and disease control. Most pesticide sprays are very toxic to natural enemies whereas pest insects often develop resistance. The death of natural enemies means that pest insect species can increase in number very rapidly. Normally, natural enemies will remove a large number of the pest insects. When there are no natural enemies, the pest insect population can grow rapidly, especially when there is a lot of food available, like in large fields grown with the same crop, or in areas with many smaller fields grown with the same crop. When the pest insect population is very large, more insecticides will be used. Life cycles of natural enemies generally take longer periods of time to complete than those of pest insects. Once insecticides are being used in the ecosystem, it is difficult to bring back the natural enemies within one season. Insecticides should be used only when there are no other options for control and there is a definite and visible need. This is one of the important reasons to monitor fields regularly (modified from Hoffmann, 1993; and Weeden, www2).

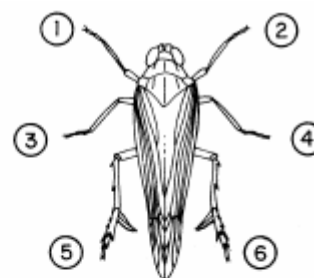
4.2 Insect anatomy

Insects have three body regions: head, thorax, and abdomen. The head functions mainly for food and sensory intake and information processing. Insect mouthparts have evolved for chewing (beetles, caterpillars), piercing-sucking (aphids, bugs), sponging (flies), siphoning (moths), rasping-sucking (thrips), cutting-sponging (biting flies), and chewing-lapping (wasps). The thorax provides structural support for the legs (three pairs) and, if present, for one or two pairs of wings. The legs may be adapted for running, grasping, digging, or swimming. The abdomen functions in digestion and reproduction.

Insects have:



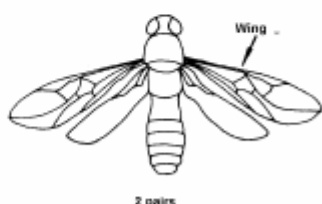
Three body regions



Six legs

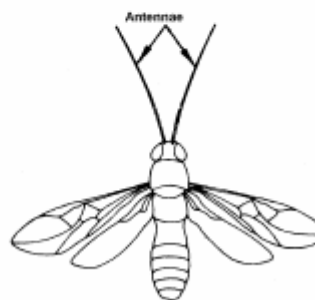


1 pair



2 pairs

One or two pair of wings



One pair of antennae

As simple as it may seem, knowing what type of mouthparts an insect has can be important in deciding on a management tactic. For example, insects with chewing mouthparts can be selectively controlled by some insecticides that are applied directly to plant surfaces and are only effective if ingested; contact alone will not result in death of the insect. Consequently, natural enemies that feed on other insects, but not the crop plant, will not be harmed.



Chewing insects

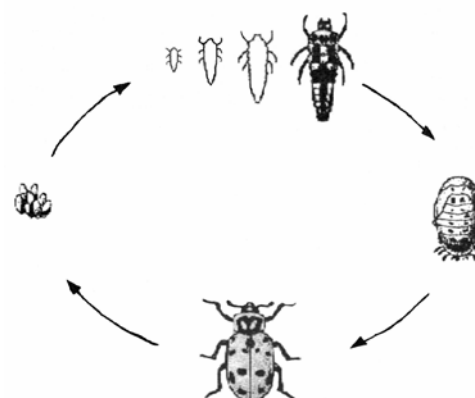


Piercing and sucking

4.3 Insect Life Cycles

Insect life cycles can be complete or incomplete (gradual). In *complete* life cycles, or better: life cycles with a complete metamorphosis, insects pass through the egg, larval, pupal and adult stage. A larva is a young insect that looks very different from the adult. Larvae may also behave differently from the adults. There are generally several larval stages (also called instars). Each larval stage is a bit larger than the previous stage, requiring a molting or shed of the outer skin between the stages. Complete life cycles can be found with moths, butterflies, beetles, flies and wasps.

In *incomplete* life cycles, or better: life cycles with an incomplete metamorphosis, insects go through egg, nymph and adult stage. There are generally several



Complete metamorphosis: ladybeetle: egg, 4 larval stages, pupa, adult

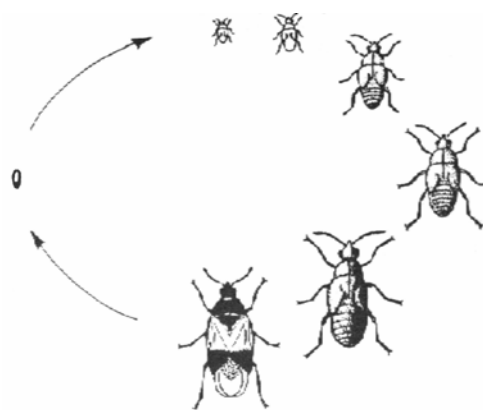
(from: Hoffmann, 1993)

nymphal stages. A nymph is a young insect that resembles the adult except that they lack wings and the nymph may be colored differently to the adult. No pupal stage is present. Nymphs and adults usually have similar habitats and have similar hosts. Each nymphal stage is a bit larger than the previous stage and requires a molting or shedding of the outer skin between the stages. Incomplete life cycles can be found with bugs, grasshoppers and aphids.

Insects' growth rate depends on the temperature of their environment. Generally, cooler temperatures result in slower growth; higher temperatures speed up the growth process. If a season is hot, more generations of an insect may occur than during a cool season.

Every insect species will have its own optimum temperature for development. Some insects can live and reproduce only at lower temperatures whereas others need high temperatures. That is why you will often find other insect species in the tropics than in temperate regions. This also applies for plant pathogens.

Understanding how insects grow and develop will contribute to their management. Some insects are active predators or parasitoids during only one specific stage of their life. The hoverfly larvae, for example, are voracious predators but the adults only feed on nectar from flowers. Other insects are susceptible to certain biological or chemical insecticides during one specific stage of their life or none at all. Larvae of leafminers for example, are only found inside plant tissue. Spraying contact insecticides (unfortunately a frequent practice) is simply a waste of money because leafminers will not be affected. Understanding insect life cycles helps making sensible crop management decisions regarding pesticide use.



Incomplete metamorphosis: a flower bug: egg, 5 nymphal stages, adult

(from: Hoffmann, 1993)

Insect Zoo: studying life cycles of insects

To study different stages of a life cycle of insects, try rearing the insects in an insect zoo. Although it may not be easy to study a full life cycle, it is possible to study some stages, for example the stages that cause plant damage. Collect some insects or eggs, pupae or larvae/nymphs from the field and put them in a glass or plastic jar with some fresh leaves from an unsprayed field. When studying life cycles of predators, feed them with the appropriate prey. Put some tissue paper in the jar to avoid condensation.



Close the jars with fine netting that permits air circulation and keep them in the shade. Insect zoos are also suitable to find out what insects (larvae/nymphs to adults) are emerging from egg masses, and to rear larvae or pupae that you find in the field but don't know what species they are.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

- 4.1 Insect zoo
- 4.A.1. Life cycle of caterpillar pests

4.4 How can an insect damage a plant?

A plant needs its leaves to absorb sunlight to make sugars for energy and growth (this process is called *photosynthesis*). The sugars are transported through the veins of the plant to other parts like roots and stems.

When an insect feeds on the leaves and reduces the leaf area, like some caterpillars do, less sugar is produced and the plant has less energy for growth and development.

When insects are sucking on the leaves of the plant, like aphids do, they are sucking the sugars out of the plant cells or the veins. This leaves less sugar available for the plant for its growth and development. In addition, some insects excrete sugary wastes (honeydew) on which fungi can grow. Leaves become black with these fungi and as a result, photosynthesis is reduced.



Other insects like leafminers feed inside the leaf and destroy part of the veins, resulting in less sugar transport. Less sugar available for plants means less plant growth and reduced plant health, and that may eventually lead to an overall lower yield.

It is important to note that not all insect feeding reduces yield! See section on compensation below.

A special case are insects that can transmit virus or mycoplasma diseases. These insects are usually sucking insects like aphids, jassids, thrips and whitefly. The jassid *Cestium phycitis* for example, is an important vector of little leaf disease caused by a mycoplasma (see section 8.2.3). A mycoplasma infected plant has mycoplasma parts in most cells and sometimes inside veins. When an insect feeds on an infected plant, it will also suck with the plant juice some mycoplasma particles. These particles either stick to the mouth parts of the insect or they are swallowed into the stomach of the insect. When the insect starts feeding on a fresh plant, the mycoplasma particles are transmitted from the mouth parts or stomach into the new plant. This plant then becomes infected too.

4.5 Plant compensation

Not all insect feeding reduces yield. Eggplant is able to compensate for feeding because more leaves and roots are produced than are actually needed for fruit formation, and new shoots are regularly formed. Even when the plant is almost completely cut back to about 15 cm above soil level, the plant will produce new shoots and form a new plant (ratooning – see section 3.12). This regrowth is often very strong because the roots are already there and can provide the nutrition and water from the soil to feed the new shoots.

Low levels of insect feeding and minor disease infections on leaves, stems and roots do not significantly reduce yields. Loss of leaves can be caused by feeding damage of *Epilachna* beetles, but also by a person removing diseased leaves in order to reduce the source of disease spread. It depends on the extent of leaf removal and the growth stage if the production is reduced or delayed. See box below.

Summarized field data on plant compensation studies from 4 Training of Trainers held in Bangladesh, eggplant could compensate for 50% loss of leaves up to 85 DAT without affecting yield (pers. comm. Md. Atiur Rahman, May 2001).

Leaf compensation study results from Jessore, Bangladesh:

A study was set up to determine if eggplants could compensate for loss of leaves. There were 6 treatments for this trial, based on the probable infestation time of the important defoliators.

25 and 50% leaf cut at 35 DAT (at plant establishment stage)

25 and 50% leaf cut at 55 DAT (at pre-flowering stage)

25 and 50 % leaf cut at 65 DAT (early fruiting stage)

This resulted in the following data:

- A. 25 and 50% leaf cut at 35 DAT took 34 and 42 days respectively to compensate the loss of leaf. It was observed that more cut took more time to compensate.
- B. 25 and 50% leaf cut at 55 DAT took 21 and 35 days respectively to compensate for the loss of leaf. It also implies that the plant at pre-flowering stage recovers quickly.
- C. 25 and 50 % leaf cut at 65 DAT took 25 and 35 days respectively to compensate for the loss of leaf.

The highest yield was achieved in the 25% leaf cut at 35 DAT treatment. This could be due to better utilization of sunlight and less shading effect.

Generally it was observed that the plants can compensate for defoliation quite well.

(Kumar, TOT Jessore report, 1999)

Similarly, when eggplant shoots are lost, for example due to feeding damage of fruit and shoot borer larvae (FSB) the plant can also compensate for this loss by producing more shoots. Whether there is an effect of shoot loss on yield depends on the growth stage in which the damage occurs. See box below.

Shoot compensation study: an example from Jessore:

In a compensation study in Jessore, Bangladesh, complete shoots were cut off the plant to simulate the effect of the fruit and shoot borer (FSB), *Leucinodes orbonalis*. The shoot pruning was done as follows:

- Control – no shoot pruning
- 20, 30 and 50% pruning at 75 DAT.
- 20, 30 and 50% pruning at 100 DAT.

In all treatments, the average number of branches, the plant height (125-142 cm), and leaf size (80-85 cm)

were not significantly different. Fruit yield in all treatments varied from 3150-3270 kg/ha, but was higher in the 30% pruning at both 75 and 100 DAT.

The group concluded that loss of shoots is not reducing the yield of eggplant significantly because damage to the shoots by FSB could be compensated for well by the plants.

(Kumar, TOT Jessore report, 1999)

Loss of leaves or shoots does not necessarily lead to production loss!

It is important to remember that spraying for insects that are not causing yield loss is a waste of money and time, and it may cause needless health problems and environmental pollution.

However, even small injury to fruits results in considerable loss of quality and inherent lower product prices.

Set up a field study to find out how much defoliation/shoot loss at what growth stage your eggplant variety can tolerate under local conditions without production delay or yield reduction.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

4.A.3. Plant compensation study

4.6 A pest or not a pest insect...: how to find out!

Many insects can be found in an eggplant field. Not all of them can be called “pests”, in fact, very few insects have the potential to cause yield loss to eggplant. The few insects that do cause some yield loss in some fields in some seasons, are called “pest insects”. As the pest insects do not cause yield loss in all fields all the time, a better term to use would be “herbivores”. Herbivores do not just eat plants or suck the plant juices, they have an additional function: they serve as food or as a host for natural enemies.

There are many potential “pest insects” that do not build up in populations large enough to cause economic yield loss. They may eat a few leaves here and there but this does not affect the yield or quality of the eggplant. In fact, their presence keeps the population of natural enemies alive so one could almost say at that time they are “beneficial”!



The goal of growing eggplants is to produce as much yield as possible without spending a lot of money. If there are no pests to control, do not waste money on pesticides that can damage the natural enemy population, the environment and your personal health!

When you find insects in the field, it is sometimes difficult to judge whether they are actually damaging the plants or not. Some insects may just be *crop visitors* passing by and resting on the plants or on the soil, or *neutrals* that live in the crop but do not eat from the plants nor influence the pest populations as natural enemies directly. Neutrals can be a food source for natural enemies.

When you find insects and you are not sure what they are: pests, natural enemies, or crop visitors/neutrals, set up an *insect zoo* to find out what the function of that insect is. See box below. When you find that an insect is eating the eggplant leaves, it could be classified as a “pest insect”. But again, as explained above, not all plant damage results in yield loss. Thus, not all “pest insects” are actually “pests”!

Whether or not a pest insect is a pest depends not only on the population of that insect but also on the growth stage of the crop in which it occurs. For example, the fruit and shoot borer (*Leucinodes orbonalis*) may cause some injury to leaves and shoots at the vegetative stage of the crop but, depending on the amount of injury, the plant can compensate for this by producing new leaves and shoots. However, during fruiting stage, larvae of the fruit and shoot borer attacking fruits cause direct quality loss of fruits.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

- 1.6. Show effects of beneficials incl. natural enemies
- 4.1. Insect zoo
- 4-A.4. Assessment of impact of ground-dwelling predators
- 4-A.5. Measuring the parasitism level of caterpillars

Insect Zoo: check functions of insects

To set up an insect zoo, take a few glass/plastic jars, or plastic bags, put in some fresh leaves from an unsprayed field together with the insect. Close the jar with fine netting that permits air circulation and keep it in the shade. Monitor if the insect starts feeding on the leaves in the next hours, up to 2 days. If that insect did not eat the leaves, it may not be a pest insect. (do not keep the insect inside for more than 3 days when it does not eat: remember that when a person is locked in a room with nothing but a book, he may get so hungry after a few days that he will start chewing the book..... that does not prove that humans eat books.....!).



Similarly, to find out if the insect is a predator, put it in a jar and give it some prey (e.g. small caterpillar larvae) with some leaves. Observe if it feeds on the prey in the next hours up to about 2 days. Similarly you can test if predators eat neutrals.

4.7 The Friends of the Farmer

Natural enemies are the friends of the farmer because they help the farmer to control insect pests (herbivores) on eggplants. Natural enemies are also called *beneficials*, or *biocontrol agents*, and in case of fungi and bacteria, *antagonists*. In countries like Bangladesh, natural enemies are called *crop defenders*.

Most natural enemies are specific to a pest insect. Some insect pests are more effectively controlled by some natural enemies than by others.

Natural enemies of insect pests can be divided into a few larger groups: predators, parasitoids, pathogens, and nematodes. Nematodes are often lumped together with pathogens. Some of the main characteristics of natural enemies of insect pests are listed in the table below. The major natural enemies of eggplant insect pests are described in more details in chapter 6. Antagonists, natural enemies of plant diseases, are described in section 7.10.



CHARACTERISTICS OF NATURAL ENEMIES OF INSECT PESTS:**Predators**

- Common predators are spiders, ladybeetles, ground beetles, and syrphid flies.
- Predators usually hunt or set traps to catch a prey to feed on.
- Predators can feed on many different species of insects.
- Both adults and larvae/nymphs can be predators.
- Predators follow the insect population by laying more eggs when there is more prey available.

Parasitoids

- Parasitoids of eggplant pests are commonly wasps or flies.
- Attack only one insect species or a few closely related species.
- Only the larvae are parasitic. One or more parasitoid larvae develop on or inside a single insect host.
- Parasitoids are often smaller than their host.

Pathogens

- Insect-pathogens are fungi, bacteria or viruses that can infect and kill insects.
- Pathogens require specific conditions (e.g. high humidity, low sunlight) to infect insects and to multiply.
- Most insect-pathogens are specific to certain insects groups, or even certain life stages of an insect.
- Commonly used insect-pathogens are *Bacillus thuringiensis* (Bt), and NPV (virus).

Nematodes

- Nematodes are very little worms.
- Some nematodes attack plants (e.g. rootknot nematode). Others, called insect-killing nematodes, only attack and kill insects.
- Insect-killing, or *entomopathogenic* nematodes can be effective against pest in the soil, or against borers such as fruit and shoot borer (*Leucinodes orbonalis*).

😊 **Natural enemies of insect pests do not damage plants** 😊
and they are harmless to people!

4.8 Natural enemy efficiency

A successful natural enemy should

- have a high reproductive rate: so that populations of the natural enemy can rapidly increase when hosts are available,
- have good searching ability,
- have (some) host specificity,
- be adapted to different environmental conditions, and
- occur at the same time as its host (the pest).

It is probably impossible for any one natural enemy to have all these attributes, but those with several of them will be more important in keeping pest populations low.

Efficiency of predators, in addition, is determined by their appetite. For example, ladybeetle adults may eat as much as 50 aphids per day. To check the appetite of predators, the following experiment is easy to do.

The Predator Appetite Test...!

Catch a predator, e.g. a spider, ladybeetle or a hoverfly larva, and place it carefully in a jar, together with some fresh leaves and a paper tissue to avoid condensation of water. Put a leaf with a known number of prey in the jar, e.g. 20 aphids.

Take another jar and place a leaf with the same number of aphids inside, but without the spider, ladybeetle or hoverfly. This is the control, to see how quickly a group of 20 aphids can multiply.

After 2 or 3 days, count the number of aphids alive in both jars. Discuss if the predator has eaten the prey and how effective it will be in field situations.



Appetite is one factor to determine effectiveness. Ladybeetles, for example, are effective predators when pest populations are high. They are thought to be less effective at lower pest densities.

In case of parasitoids, the number of adults emerging from one host (the pest insect) can be an important factor to determine efficiency. Many adults emerging from a pest insect can each again parasitize a new host. This way parasitoid population builds up more rapid than when only one adult emerges from a host.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

- 4-D.1. Predation on sucking insects in insect zoo
- 4-D.2. Cage exclusion of natural enemies in the field
- 4.7. Direct observations of consumption rates of predators in the field
- 4.5. Studying predators in the field.
- 4-A.5. Measuring the parasitism level of caterpillars

4.9 Managing natural enemies

Just as the crop and pest insects are managed, natural enemies also must be managed. There are management practices that kill pests but also kill natural enemies. It is obvious that management practices for natural enemies should be focused on preserving them and as much as possible increasing their numbers. Indigenous natural enemies are adapted to the local environment and to the target pest, and their conservation is generally simple and cost-effective. Natural enemies that are introduced from outside (for example those that are reared in insectaries and released into the field), often require a different way of augmentation. Conservation methods are often similar.

Some techniques for conservation and augmentation of natural enemies:

1. Allow some insect pests in the field: these will serve as food or as a host for natural enemies. Eggplants can compensate for quite some injury and not all insect feeding results in yield loss. Monitor the field regularly!
2. Be extremely careful when using pesticides: most pesticides (even several fungicides!) are toxic to natural enemies. Even pesticides that claim to be very selective and harmless to natural enemies may still cause problems. You can test this yourself! See box below.
3. Do not use insecticides before there is a serious infestation of a pest insect. Don't apply "just in case" or "because my neighbor is also spraying". This is not only a waste of money but may actually result in MORE problems with pest insects because they can increase their population quickly when there are no natural enemies around.

Effects of pesticides on natural enemies: a study example

1. Prepare hand sprayers with the pesticide to be tested.
2. Select a few plants in the field. Label plants with name of treatment and spray them with the pesticide. Let leaves dry on the plant.
3. Pick one or several leaves from each labeled plant and place these in jars (use gloves!).
4. Collect predators, e.g. spiders or ladybeetles from the field (use a small brush).
5. Place predators in the jars, close the lid and place a piece of tissue paper between the lid and the jar to avoid condensation inside.
6. Check condition of predators after 8 and 24 hours.

Instead of leaves, a piece of cloth can be sprayed with pesticides. Rest of study as above.

Note: When handling pesticides wear protective clothing and wash with plenty of soap and water afterwards.

4. If an insecticide is needed, try to use a selective material in a selective manner or very localized, on infested plants only (spot application).
5. When the borders of the field are covered with weeds, especially when they are flowering weeds, these borders can provide a shelter for natural enemies. Mixed plantings can have a similar effect. Adult natural enemies (e.g. hoverflies) may also be attracted to flowers for feeding on the nectar inside the flowers. Many adult parasitoids live longer, and are therefore more effective, when there are sufficient flowers to feed on. Such practices are easily incorporated into home gardens and small-scale commercial plantings, but are more difficult to accommodate in large-scale crop production. There may also be some conflict with pest control for the large producer because of the difficulty of targeting the pest species and the use of refuges by the pest insects as well as natural enemies.
6. Many adult parasitoids and predators also benefit from the protection provided by refuges such as hedgerows and cover crops. Other shelters may be provided for natural enemies to survive. An example is given in the box below.

Manipulation of Natural Enemies in rice straw bundles

Some of the predators present in rice fields are also present in vegetables. Spiders and other predators seek refuge in rice straw bundles at the time of rice harvest. If these straw bundles or tents are placed in rice fields when the crop is harvested and natural enemies are allowed to colonize them, the bundles may be moved to vegetable plots where predators could colonize vegetables more quickly. Thus, conservation/augmentation of natural enemies through manipulation of straw bundles could be useful in reducing the impact of vegetable insect pests.



Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:
4.9. and 4.10. Importance of flowers as food source to adult parasites.

4.10 Purchase and Release of Natural Enemies

In several countries in Asia, commercial or non-commercial insectaries rear and market a variety of natural enemies including several species of parasitoids, predaceous mites, ladybeetles, lacewings, praying mantis, and pathogens such as NPV (virus), and *Trichoderma*. Availability of (commercially) available natural enemies in a country also depends on the regulations of each country regarding registration (Regulatory Affairs).

Numerous examples from Asia exist on the use of reared natural enemies for release in the field. In eggplant, good results have been reported with egg parasitoid *Trichogramma* sp. for the control of fruit and shoot borer (*Leucinodes orbonalis*). When *Trichogramma chilonis* was released at fortnightly intervals in study in Tamil Nadu, India, it significantly reduced pest damage and produced fruit yield of 20.30 t, compared to the control yield of 13.06 t (Raja, 1998). *Trichogramma japonicum* was released in eggplant field in a study in Andhra Pradesh, India, and resulted very good control of shoot and fruit borer as compared to control (Sasikala, 1999). Check with your Extension Service or Biocontrol Agencies for availability of these natural enemies.

Introduction of natural enemies is often a long process that includes training in parasitoid rearing, establishing an efficient rearing facility, setting up (field) experiments and farmer training (Ooi, Dalat report, 1999). Success with such releases requires appropriate timing (the host must be present or the natural enemy will die or leave the area) and release of the correct number of natural enemies per unit area (release rate). In many cases, release rates vary depending on crop type and target host density.

This guide does not make specific recommendations about the purchase or release of the (commercially) available natural enemies, but it does provide information about the biology and behavior of some commercially reared species that are important for eggplant insect and disease control. This information could be helpful in making decisions regarding their use. See chapter 6. In addition, addresses of institutions providing or marketing natural enemies in Asia can be found in manuals such as "The Biopesticide Manual" (BCPC, 1998) and on several sites on the Internet, for example that of the US department of Agriculture, at [www14](#) and [www15](#) (see reference list).

4.11 Management and control activities for pest insects

Next to biological control by natural enemies, pest populations may be managed by other methods. The use of insecticides is a common alternative but there are other options that may be valuable. Some of these options are listed in this section.

Specific management and control practices, like many cultural methods, that are important for managing pest insect populations in the field are mentioned in the next chapter, for each pest insect individually.

4.11.1 Use of insect netting

Cultivation under "net houses" is increasingly receiving interest. A net house, or insect cage, is a frame of wood a little higher than the eggplants, covered with fine mesh netting. The netting prevents insects entering the crop from outside, particularly lepidopterous pests like moths and butterflies but also aphids may be prevented from entering the plants when the netting is fine enough. Net houses do not prevent insects coming from the soil like cutworms. Often, the net houses are placed over nurseries, to prevent damage from caterpillars to the young plants. Also, in eggplant, net houses on nurseries can provide good initial control against jassids which may carry little leaf disease.

	<p>Net house: plants in, pests out!</p> <p>Good experience with the use of a net house in eggplant was obtained from a field study in Bangladesh. A net house was made out of bamboo poles and nylon nets. Plant left-overs and pupae found in the top layer of the soil were removed before placing the net house over the eggplants. Less insect infestation of shoots and fruits was found on the net house plants as compared to the uncovered plants.</p> <p>Unfortunately, some of the studies were not successful because the nets were stolen from the field...! (pers. comm. Prabhat Kumar, 1999, Bangladesh).</p>	
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Net houses may also be higher: about 2 - 3 meters. These can be used for both nurseries and production fields. For good insect prevention, they need to be fully closed!

Although initial investment for preparing the net houses is high, savings from reduced sprayings can make it attractive. When properly prepared and maintained, net houses can be used more than once. Inside a net house, the temperature may be a bit lower due to shading effect of the net and the humidity may be a bit higher than outside. This may result in a quicker growth of the crop but it may also result in more disease problems.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:
2-B.9. Roofing and screening of seed beds

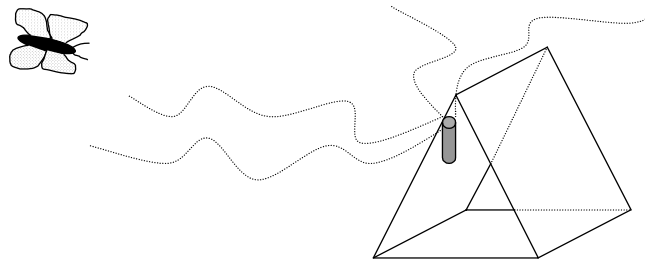
4.11.2 Use of traps

There are several types of traps to catch insects. Most traps will catch adult insects. These traps are often used for monitoring of populations rather than actual control. However, since some traps catch large quantities of insects they are often considered as control measures in addition to monitoring.

If traps are used in isolation, information from them can be misleading. A low number catch will not indicate the timing of a pest attack, let alone its severity. Similarly, the number of insects caught in one crop cannot be used to predict the number that will occur in other crops, not even when the crops are in adjacent fields.

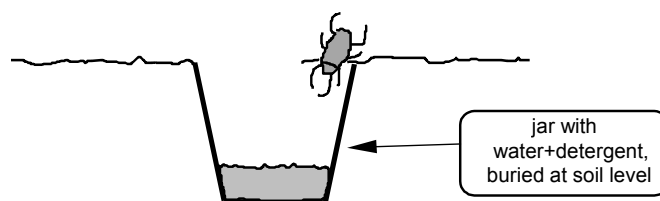
The most common types of traps used in the field are shortly described below.

Pheromone traps: these are traps that contain a sticky plate and a small tube with a chemical solution called a *pheromone*. Pheromones are chemicals produced by insects that cause strong behavioral reactions in the same species at very small amounts. They are usually produced by females to attract males of the same species for mating. Such chemical is called 'sex pheromone'. The males will fly to the pheromone trap and are trapped on the sticky plate. Pheromones have been developed for several vegetable pests including fruit and shoot borer (*Leucinodes orbonalis*). Pheromones are mainly used for detecting and monitoring pests, to a lesser extent for control of pest populations. One of the reasons is the high cost of pheromones, which have to be synthesized in a laboratory.



A pheromone trap attracts male adults

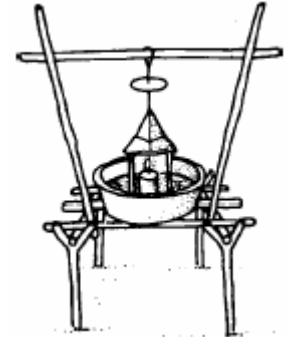
Pitfall traps: are plastic or glass jars, half-filled with water and a detergent like soap, buried into the soil up to the rim of the jar. These traps are good for catching ground-dwelling insects like ground beetles. Purpose of these traps is purely for monitoring as many ground beetles are active during the night and you may miss them when monitoring the field during the day. Pitfall traps may also be used without water and detergent, to catch living insects for insect zoos. However, good climbers will escape.



A pitfall trap

Yellow sticky traps: these are yellow colored plates, covered with glue or grease. They can also be made from empty yellow engine oil jars and many lubricants are suitable as grease. The yellow color attracts some insect species like moths, aphids, flea beetles and whitefly. The trap is especially suitable to monitor the adult population density. To a lesser degree, it can be used as a control measure, to catch adult pest insects. However, not only pest insects are attracted to the yellow sticky traps but also numbers of beneficial natural enemies. Thus, care should be taken when considering using sticky traps and it would be advisable to place just one as a trial and monitor in detail which insects are caught. If large numbers of natural enemies stick to the glue it might be better to remove the traps.

Light traps: Light traps are usually made of a light (can be electronic, on a battery or on oil-products) switched on during the night, and either a sticky plate or a jar filled with water or other liquids. Insects (mainly night-active moths) are attracted to the light, and are caught on the sticky plate or fall into the water and die. Various types of traps are used, and they normally serve only as supplementary measures to other control methods. When adult moths are found in the trap, look for egg masses and young larvae in the field. However, natural enemies may also be attracted to light traps. When large numbers of natural enemies are caught it may be better to remove the traps.



A light trap

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

- 4.2. Sampling for arthropods with light trap
- 4.3. Sampling for arthropods with sticky board
- 4.4. Sampling for arthropods with water pan trap
- 4.6. Soil-dwelling predators

4.11.3 Use of threshold levels

The decision to take control action against an insect population requires an understanding of the level of damage or insect infestation that a crop can tolerate without affecting the yield. Very often the term *action threshold level*, *economic threshold level (ETL)*, or *tolerance level* is mentioned. These terms are often explained as “the level of infestation or damage at which some action must be taken to prevent an economic loss”. Traditionally, you had to look for the population of a certain insect in the field and when the population was higher than the value given for ETL, you were advised to spray.

There are many formula to calculate economic thresholds. One of them is the following:

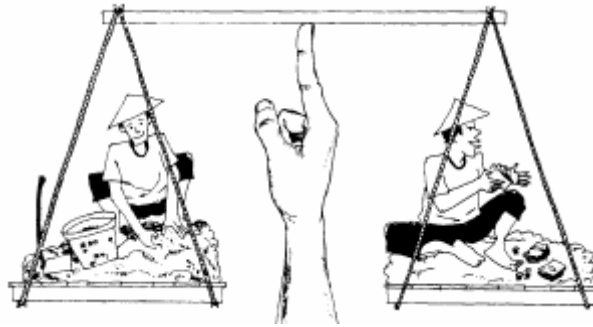
$$\text{ETL} = \frac{\text{cost of control (price/ha)}}{\text{commodity value at harvest (price/kg) x damage coefficient (kg/ha/\#pest/ha)}}$$

The formula basically says that economic damage (=financial loss) begins at the point where costs of damage (yield loss due to insect/disease damage) are equal to the cost of control (costs of pesticides for example). However, to actually calculate the threshold level for your own field situation is very difficult as most of the values that should be included in the equation are not known today, or can just be roughly estimated. That results in a very theoretical value!

The thresholds vary with stage of crop growth, with costs of pesticides or labor, with environmental conditions, with market prices, etc., etc. and can therefore be very different for a region, for a season, for a field!

Nonetheless, in practice, most economic threshold levels are based on fixed infestation values. These single values do not consider the natural enemy population, the ability of the crop to compensate for damage from insects, and many other factors such as weather conditions, market prices and personal health that are part of IPM agro-ecosystem analysis (AESA).

The next list gives examples of a number of factors involved in decision making for ETL and for AESA.



Picture from Fliert and Braun

ETL

- cost of control
- harvest value of crop (estimation)
- loss of income due to pests (estimation)

Agro-ecosystem Analysis (AESA)

- growth stage
- weather conditions
- crop development factors (incl. compensation ability)
- type and number of insect pests
- type and amount of diseases
- type and number of natural enemies
- type and amount of natural disease control agents
- type and amount of weeds
- water availability (irrigation, drainage)
- soil fertility status
- fertilizer applications
- activities in the field since last week
- other observations

Economic Threshold Levels may give a very general indication for the number of insects that can be tolerated on a crop but they are seldom specific for the situation in your field today. Be very critical to these threshold levels and monitor your field regularly to check for yourself in your own field what decisions need to be taken.

4.11.4 Use of botanical pesticides

Some plants have components in the plant sap that are toxic to insects. When extracted from plants, these chemicals are called *botanicals*. Generally botanicals degrade more rapidly than most conventional pesticides, and they are therefore considered relatively environmentally safe and less likely to kill beneficials than insecticides with longer residual activity. Because they generally degrade within a few days, and sometimes within a few hours, botanicals must be applied more often. More frequent application, plus higher costs of production usually makes botanicals more expensive to use than synthetic insecticides. When they can be produced locally they may be cheaper to use than synthetic insecticides. Toxicity to other organisms is variable, although as a group, they tend to be less toxic than non-botanicals to mammals (with the exception of nicotine).



Using botanicals is a normal practice under many traditional agricultural systems. A well-known and widely used botanical is neem, which can control some insects in vegetables. In Vietnam, vegetable farmers have utilized several botanical pesticides, including extracts from Derris roots, tobacco leaves and seeds of *Milletia*, which they claim to be effective. However, in addition to pest insects, some natural enemies may be killed by botanicals!

A few commonly used botanicals will be briefly described below.

Neem, derived from the neem tree (*Azadiracta indica*) of arid tropical regions, contains many active compounds that act as feeding deterrents and as growth regulators. The main active ingredient is *azadiractin*, which is said to be effective on 200 types of insects, mites and nematodes. These include caterpillars, thrips and whiteflies. It has low toxicity to mammals.

Both seeds and leaves are used to extract the oil or juices. A neem solution loses its effectiveness when exposed to direct sunlight and is effective for only eight hours after preparation. It is most effective under humid conditions or when the plants and insects are damp.

High concentrations can cause burning of plant leaves! Also, natural enemies can be affected by neem applications (Loke, 1992).



neem



Nicotine, derived from tobacco, is extremely toxic and fast acting on most animals, including livestock such as cows and chicken. **It can kill people.** The nicotine of half a cigarette is enough to kill a full-grown person! After an application, food plants should not be eaten for 3-4 days. This time is required for the nicotine to decompose. In parts of West Africa, the tobacco plant is intercropped with maize because it is said to lower numbers of borer insects on the maize. Nicotine kills insects by contact, or if inhaled or eaten. The most common use is to control soft-bodied insects such as aphids, mites and caterpillars.

An additional danger of using tobacco leaf extract is that this extract may contain a virus disease called Tobacco Mosaic Virus, or TMV. This virus disease affects a wide range of plants, mainly solanaceous crops. When spraying tobacco extract, chances are that you actually apply TMV!

Rotenone is extracted from the roots of bean legumes, especially *Derris* sp. Rotenone is a contact and stomach poison. It is also toxic to fish, pigs and honey bees! It irritates the human skin and may cause numb feelings in mouth and throat if inhaled. *Derris* roots must be stored in cool, dry and dark places otherwise the rotenone breaks down. Rotenone has very low persistence so once a spray is prepared it must be used at once.



Pyrethrum is a daisy-like Chrysanthemum. In the tropics, pyrethrum is grown in mountain areas because it needs cool temperatures to develop its flowers. Pyrethrins are insecticidal chemicals extracted from the dried pyrethrum flower. Pyrethrins are nerve poisons that cause immediate paralysis to most insects. Low doses do not kill but have a “knock down” effect. Stronger doses kill. Human allergic reactions are common. It can cause rash and breathing the dust can cause headaches and sickness.

Both highly alkaline and highly acid conditions speed up degradation so pyrethrins should not be mixed with lime or soap solutions. Liquid formulations are stable in storage but powders may lose up to 20 percent of their effectiveness in one year. Pyrethrins break down very quickly in sunlight so they should be stored in darkness.



Pyrethroids are synthetic insecticides based on pyrethrins, but more toxic and longer lasting.

They are marketed under various trade names, for example Ambush or Decis. Some pyrethroids are extremely toxic to natural enemies! Pyrethroids are toxic to honey bees and fish. Sunlight does not break them down and they stick to leaf surfaces for weeks killing any insect that touches the leaves. This makes them less specific in action and more harmful to the environment than pyrethrin. In addition they irritate the human skin.



Marigold is often grown in gardens for its attractive flowers. They are cultivated commercially for use as cut flowers. In addition, marigold can have a repellent effect on insects and nematodes.

In Kenya for example, dried marigold when incorporated into the nursery soil was found an effective treatment in terms of overall seedling health.

Chili or chillipepper: the ripe fruits and seed contain insecticidal compounds. Dried chili powder is highly irritant and difficult to work with, but good results can be obtained on control of aphids, ants, several leaf-cutting insects, whiteflies, and other pest insects in vegetable gardens.

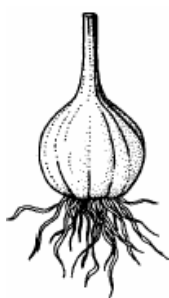
Studies in cabbage fields in Kenya showed that chili sprays reduced pest numbers by 50% in the first week after application but these build up again so farmers concluded from this experiment that chili needs to be sprayed every 14 days for effective control (Loevinsohn, 1998). This probably applies for a period with low rainfall, as the solution is easily washed off with rain.



Several mixtures of chili with other botanicals such as neem or marigold are known to have insecticidal properties. Set up a field study to experiment!

A chili recipe from the Philippines:

Boil 500 g of thinly sliced ripe chili peppers in 3 liters of water for 15-20 minutes. Add 30 g of soap as a sticker. Then add 3 more liters of water, allow to cool down and then filter. Apply once a week if there is no rain, but 2-3 times per week if it rains (Stoll, 2000).



Garlic has been long known for its insecticidal activity. It can also protect crops against a variety of fungal and bacterial diseases. Garlic contains garlic oil and alliline, which have insecticidal and bacterial effect. It can be used as a water extract, for example in a solution of 0,5 l water with 100 garlic cloves, and a little soap. The price of garlic can make this recipe expensive. Garlic solutions should be tested on small plots first! Garlic can also be used as a seed coating, to prevent infection by soil-borne diseases or damage by soil insects. See section 3.6.3. In some cultivation practices such as biological production, garlic is sometimes used as an intercrop for other crops. Its strong odor may repel insects. See section 3.15.



Despite being “natural” and commonly used in some regions, from the characteristics listed above it is clear that botanicals can be very dangerous to use. Some botanicals may be more dangerous to the user than chemical pesticides! And in addition they may be very toxic for natural enemies.

Always set up a study first on the effects of botanical pesticides on the ecosystem and on the economics. Do not just replace chemical insecticides with botanicals. First understand the ecosystem and how botanicals influence it!

4.11.5 Use of mineral based pesticides

Ash from the remains of cooking fires is often used for general insect control. It seems that ashes can protect leaves from chewing insects. The ashes must be crushed, then thinly and evenly spread. This can be done by putting them into a coarse textured bag, which is shaken over the crop. Ashes provide more protection in the dry than in the rainy season. Another practice is to spread ash on nursery beds and homestead gardens to repel ants, commonly done in Bangladesh. In Nepal, a mixture of mustard seed kernels (1 part) and ashes (3 parts) is used against red ants. No research data are available to confirm this practice.



When washed off the leaves ashes fertilize the soil very effectively. Wood ash is a known source of potash and commonly used for fertilization of soils. Unleached wood ash can contain around 5% potash in the form of potassium carbonate, which is alkaline and helps increase soil pH. Ashes contain small quantities of nitrogen and phosphorus in addition.

Kerosene and fuel oil kill plants as well as insects. They can be useful against insects that congregate. Nests of ants can be dipped. Spent motor oil can be used for this operation; the oil kills ants in seconds. The oil is very flammable. Kerosene and fuel oil should not be used frequently and on large scale as it is detrimental to the environment.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

1.4. Effect of pesticides on spiders and other natural enemies

4.11.6 Use of soap

Soap, both the soft soap and washing powders and liquid detergents, can kill insects on contact. Soaps are complex mixtures of fats or oils with alkalis (soda or potash) and metallic salts. They seem to destroy insect membranes. Small insects such as aphids, die instantly. Soaps and detergents are harmless to animals, birds and people. They act as insecticides at concentrations under 1% but at higher concentrations can injure plants! Care should be taken when making soap solutions.



Depending on concentration soaps have three distinct and separate uses:

1. In low concentrations soaps reduce surface tension so that water-drops spread flatly. This brings any pesticide carried by the drops into close contact with the leaf surface. It also helps to spread the chemical evenly over insects. In this way soaps improve the power of pesticides. In addition they make mixing easier by aiding the dispersal of other substances, powder or liquid, into the water.
2. In concentrations from 0.5 – 0.8% (5 – 8 g per liter) they kill insects. At 0.5% aphids and small caterpillars are instantly killed. Large caterpillars and beetles need concentrations of around 0.8%.
3. High concentrations (over 1%) damage or kill plants. Some farmers use them as herbicides (weed killers).

Soaps kill only when wet, once dry they lose their insecticide action. This limits their action to insects hit at the time of spraying. Thus solutions made to the right concentration are in effect, specific to the target insect, provided the user sprays carefully.

For sale: Insecticidal soap!

For many years, farmers have known that soap and water kill insects, but because the mixtures sometimes damage plants users have to be careful.

Research has isolated some of the insecticidal compounds in soap and they are sold as insecticidal soaps, non-injurious to plants. Such commercial packs are expensive and of little interest to farmers. Solutions of soap and water can be easily and cheaply home-made, taken into account the above listed points.

4.11.7 Use of biopesticides

Biopesticides, biological pesticides, biocontrol agents, or microbials, are pesticides that contain a living organism or virus as “active ingredient”. Examples are preparations of *Bacillus thuringiensis* (Bt) and nuclear polyhedrosis virus (NPV). Biopesticides are described in chapter 6 on natural enemies of eggplant insect pests and in chapter 7 (section 7.10) on antagonists.

Another classification of pesticides is “biorationals”. These are pesticides that include biopesticides, but also chemical pesticides often with naturally occurring biochemicals, such as pheromones and growth regulators. See box below.

The Rationale of Biorationals....

Insecticides may be divided into two broad categories: (a) conventional or chemical and (b) biorational.

Conventional or chemical insecticides are those having a broad spectrum of activity and being more detrimental to natural enemies. In contrast, insecticides that are more selective because they are most effective against insects with certain feeding habits, at certain life stages, or within certain taxonomic groups, are referred to as “biorational” pesticides. These are also known as “least toxic” pesticides.

Because the biorationals are generally less toxic and more selective, they are generally less harmful to natural enemies and the environment. Biorational insecticides include the microbial-based insecticides such as the *Bacillus thuringiensis* products, chemicals such as pheromones that modify insect behavior, insect growth regulators, and insecticidal soaps.

4.11.8 Use of chemical pesticides

If all other integrated pest management tactics are unable to keep an insect pest population low, then use of an insecticide to control the pest and prevent economic loss may be justified. They can be relatively cheap, widely available, and are easy to apply, fast-acting, and in most instances can be relied on to control the pest(s). Because insecticides can be formulated as liquids, powders, aerosols, dusts, granules, baits, and slow-release forms, they are very versatile.



Types of pesticides

Insecticides are classified in several ways, and it is important to be familiar with these classifications so that the choice of an insecticide is based on more than simply how well it controls the pest.

When classified by mode of action, insecticides are referred to as stomach poisons (those that must be ingested), contact poisons, or fumigants.

The most precise method of classifying insecticides is by their active ingredient (toxic component). According to this method the major classes of insecticides are the organophosphates, chlorinated hydrocarbons, carbamates, and pyrethroids. Others in this classification system include the biologicals (or microbials), botanicals, oils, and fumigants.

Very often, pesticides are grouped into systemic or non-systemic products. Systemic pesticides are taken up by plants through the roots, stems or leaves. Once inside the plant, systemic pesticides move through the plant's vascular system to other untreated parts of the plant. Systemic pesticides can be effective against sucking, boring and mining insects and nematodes.

Non-systemic pesticides are not taken up by the plant but form a layer on the sprayed insects or on plant parts.



Non-systemic: pesticide forms layer on the plant

Systemic: pesticide is taken up by the plant and transported to other parts

The advantage of systemic pesticides is that they can control pest insects that are difficult to reach because they are protected inside a plant, such as thrips. It is important to check the persistence (how long it stays “active”) of such a pesticide. Most systemic pesticides should not be applied shortly before harvest because the pesticide may still be inside the plant or the fruit when it is harvested and eaten.

4.11.9 WHO classification of pesticides

The World Health Organization (WHO) has designed a classification table in which 4 toxicity categories for pesticides are described. Most pesticides are classified by their potential risk to human health, usually based on acute oral LD₅₀ levels. LD₅₀ is based on experiments with animals and is the number of mg of pesticide per kg of body weight required to kill 50% of a large population of test animals. Based on chemical data and tests, a chemical pesticide is classified in one of the four categories.

Biological pesticides (biocontrol agents) such as Bt, NPV or *Trichoderma* are not included in the WHO classification because the methods of testing the safety of these products are different from testing chemical pesticides.

Examples of classification of some common pesticides available in Vietnam, Cambodia and Indonesia.

Note that some pesticides are banned.

Class Ia Extremely hazardous	Class Ib Highly hazardous	Class II Moderately hazardous	Class III Slightly hazardous	Class IV* unlikely to present acute hazard in normal use
Methylparathion (Folidol) ²	Methamidophos (Monitor ^{1,2} , Tamaron) ³	Fenitrothion (Ofatox) ¹	Trichlorfon (Dipterex) ¹	Kasugamycin (Kasai) ¹
Mevinphos (Mevinphose) ²	Edifenphos (Hinosan) ¹	Dimethoate (Bi58) ¹	Dicofol (Keltthane) ³	Zineb ¹
Alachlor (Lasso) ³	Dichlorvos (DDVP) ²	Cypermethrin (Sherpa ¹ , Vifenva ² , Cyrin) ²		Validamycin A (Validacin) ¹
	Monocrotophos (Azodrim) ²	Fenvalerate (Sumicidin) ^{1,3}		Diafenthiuron (Pegasus) ²
	Metomil (Lannate) ³	Deltamethrin (558) ¹		Atrazin (Gesaprim, others) ³
		Fenobucarb (Bassa) ¹		Benomyl (Benlate) ³
		2,4-D ³		Maneb ³
		Endosulfan (Thiodan, a.o.) ³		
		Paraquat (Gramoxone) ³		

¹ Murphy, Helen, 1999. Data collected from farmers in Vong Xuyen village, Phuc Tho district, Ha Tay province, Vietnam.

² Murphy, Helen, 1998. Data collected from farmers from two locations (Banteay and Kandal) in Cambodia.

³ Murphy, Helen, 1998. List of pesticides available in Indonesia 1989 – 1997.

4.11.10 Pesticides and health in IPM training

In a few countries in Asia, a health component has been added to IPM training programmes. Previously, health studies were aimed to change national pesticide policies. While some of the more hazardous pesticides were banned or restricted, frequently these bans or restrictions were not enforced. Health studies were redesigned to allow farmers to conduct their own studies to change farmer's 'personal pesticide policy'.

Farmer groups in Cambodia, Vietnam and Indonesia are conducting health studies within their own communities among their fellow farmers that include:

- Analysis of the chemical families and WHO health hazard categories of the pesticides in use (and/or available in local pesticide shops).
- Analysis of the numbers of pesticides (and types) mixed together in one tank for spray operations.
- Analysis of liters (or approximate grams) of pesticide exposure per season or year.
- Field observations of hazardous pesticide handling.
- Interviews and simple examinations for any signs and symptoms of pesticide poisoning: before, after and 24 hours after spraying.
- Household surveys to determine hazardous pesticide storage and disposal practices and occurrences of pesticide container recycling or repackaging.

Children who are participating in IPM schools are also conducting similar studies with their parents and neighbors through the Thai and Cambodian government educational programs.

Through the experience of gathering, analyzing and presenting this data back to fellow farmers, a more fundamental understanding of the health as well as the ecological hazards of inappropriate pesticide use is gained. These studies motivate farmers to join IPM, sustain IPM principles on better field observation based decision making on pest control, and also can be used to measure the impact of IPM. For example, the Vietnam IPM program is measuring the impact of community IPM by conducting health studies before and after initiating community IPM in 4 areas.

This is especially critical to vegetable IPM where the most indiscriminant use of pesticides is occurring. Too many chemical products are mixed and applied together too often during a single growing season. This results in numerous cases of mild to moderate pesticide poisoning among the farmers, increased pest or disease resistance, and significant disruptions to the local ecology.

For example, Indonesian shallot farmers were mixing up to 9 different products in one tank (average 4) and spraying 2-3 times per week (Murphy, 2000). The Cambodian farmer is mixing on average 5 pesticides per tank that is applied up to 20 times per season (Sodavy, 2000). Up to 20% of all spray operations were associated to witnessed pesticide poisoning among wet shallot farming in Java (Kishi, 1995). During a single spray session among Sumatran women (of whom 75% were using an extreme, high or moderately hazardous to human health pesticide), 60% had an observable neurotoxic sign of pesticide poisoning (Murphy, in press). In a survey conducted by IPM farmers, in Cambodia among 210 vegetable growers, 5% had a history of a serious poisoning event while spraying (loss of consciousness) and another 35% had a moderate episode.

Therefore among vegetable growers from the perspective of farmers' health alone there is a tremendous need for alternatives to indiscriminant toxic pesticide use. Not enough safe pest-control strategies exist for farmers to protect the personal health and that of their crops and the surrounding environment (pers. comm. Murphy, 2000).

For more background and practical exercises on pesticides and health, please refer to the reports "Guidelines for Farmer-to-Farmer IPM Health Studies, 1998", "Exercise Guide on Health and Pesticides", and "Field guide exercises for IPM in cotton: pesticides" from the FAO-Vietnam National IPM Program. Contact the FAO-ICP office in Bangkok to obtain copies (address in section "Acknowledgements" in this guide) or for more information. In addition, two manuals by Helen Murphy are available from Danida Thailand both in Thai and English language, and can be downloaded from their website: http://www.ipmthailand.org/en/download_documents.htm.

4.11.11 Pesticide associated problems on insects and natural enemies

Despite the advantages of conventional insecticides, there are numerous problems associated with their use. These include:

1. The resurgence of pest populations after elimination of the natural enemies

A well-known phenomenon is that when natural enemies are killed by pesticide applications, pest insects (which often have a high reproduction rate) can increase their numbers very quickly. This eventually results in yield and quality loss of the crop. Even pest insects that, under no or low pesticide applications cause no problem (populations are kept low by natural enemies) can cause outbreaks and yield loss when natural enemies are eliminated, especially insects or mites that have developed resistance against pesticides. An example is red spider mite, which has many natural enemies but can cause severe problems in heavily sprayed fields.

2. Development of insecticide-resistant populations

The development of resistance is one of the more serious problems in pest management. Resistance means an insect can tolerate a pesticide without being killed. This is more likely to occur in a pest than in a natural enemy. Many insect pest species now have resistance to some or several types of insecticides, and few chemical control options exist for these pests.

The number one resistant insect is the aphid, *Myzus persicae* (Homoptera: Aphidae). This aphid is resistant to more insecticides than any other insect. The numbers two and three notoriously resistant are the Colorado potato beetle, *Leptinotarsa decemlineata*, and the diamondback moth, *Plutella xylostella* (ref. www23). In some areas, the diamondback moth has even become resistant to biological control agents like Bt (*Bacillus thuringiensis*).

3. Negative impacts on non-target organisms within and outside the crop system

Numerous cases exist of negative impact of pesticides on humans and livestock. Many farmers participating in FFSs have experience with pesticide poisoning, or side-effects on health from pesticides.

Natural enemies are generally more adversely affected by chemical insecticides than the target pest. Because predators and parasitoids must search for their prey, they generally are very mobile and spend a considerable amount of time moving across plant tissue. This increases the likelihood that they will get in contact with the pesticide. They also feed on or live inside poisoned prey. In addition to killing natural enemies directly, pesticides may also have sublethal effects on insect behavior, reproductive capabilities, egg hatch, rate of development, feeding rate, and life span.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

- 1.3 Spray dye exercise
- 1.4 Effect of pesticides on spiders and other natural enemies
- 1.5 Role play on insecticide resistance
- 4-A.13 Comparison of biological and chemical pesticides used in caterpillar control
- 4-D.8. Spot application of acaricides to manage mites

The "International Code of Conduct on the Distribution and Use of Pesticides (Revised Version), 2003", developed by FAO with participation of Government experts, NGOs, the pesticide industry and other United Nations organizations, established voluntary standards of conduct for all public and private entities engaged in, or associated with, the distribution and use of pesticides. This Code of Conduct supports increased food security, while at the same time protecting human health and the environment. Since its adoption this Code of Conduct has served as the globally accepted standard for pesticide management. Full text can be retrieved from: <http://www.fao.org/AG/AGP/AGPP/Pesticid/>

*A useful manual about **organic agriculture** (no use of pesticides and chemical fertilizers) is the "IFOAM Training Manual for Organic Agriculture in the Tropics". This manual can be downloaded from: <http://www.fibl.ch/english/publications/training-manual/preface.php>*

5 MAJOR EGGPLANT INSECT PESTS



SUMMARY

The major insect pest of eggplant in Asia is the fruit and shoot borer (*Leucinodes orbonalis*). This insect can cause serious damage especially during the fruiting and harvesting stage. Other pests such as *Epilachna* beetle, red spider mite, and red ant can be important locally. Biological control of the fruit and shoot borer may include use (or conservation) of indigenous parasitoids such as *Trathala* sp. and release of *Trichogramma* sp. Other eggplant insect pests also have natural enemies that may greatly reduce pest populations if fields are unsprayed with pesticides.

Several cultural practices such as weed removal, removing infested plant material, use of trap crops, flooding the field (in dry season), and hand-removal of egg-masses and larvae can provide additional insect control. For most eggplant insect pests, insecticide use is not effective or economically justified and may in some cases (e.g. red spider mite, whitefly) even aggravate pest problems.

In the following sections an indication of the number of generations per year, and the duration of parts of the insect's life cycle are given. It is emphasized that these figures are indications only as they depend on local climate (temperature, humidity). In general: the warmer, the quicker the insect's life cycle. The actual duration of the life cycle of a specific insect or natural enemy from your area can be checked by setting up an insect zoo experiment (see section 4.3).

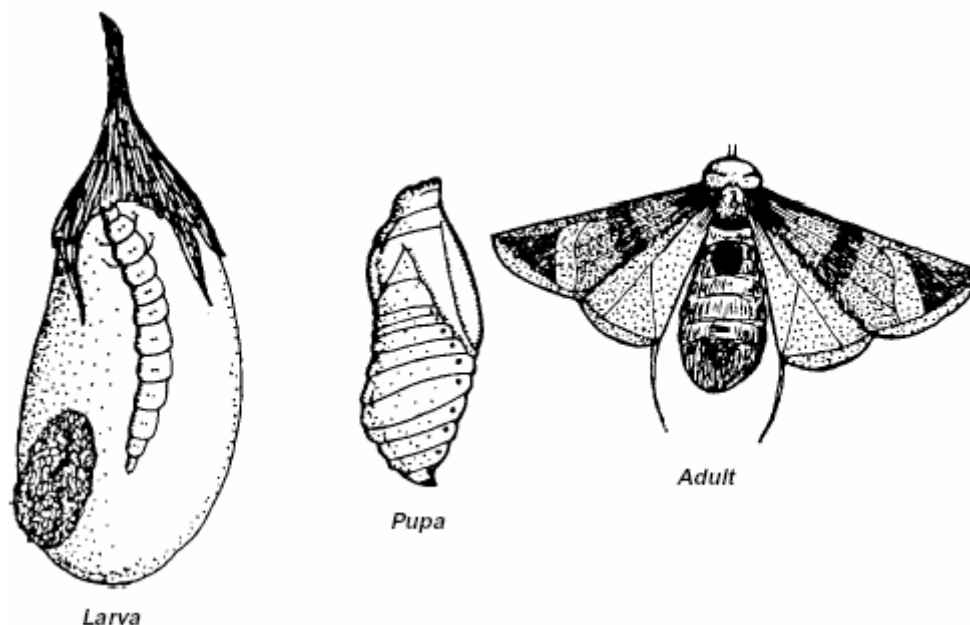
5.1 Fruit and Shoot Borer - *Leucinodes orbonalis*

See photos 3, 5, 6, 7 (page 175, 176).

Fruit and shoot borer (FSB) is probably the most serious insect pest of eggplant in South Asia. This insect is also called brinjal fruit borer or eggplant fruit borer.

Description and life cycle

The adult moth is gray with a pink or bluish tinge and brown to black spots on its wings. The adults are active during nights. All major activities like feeding, mating and finding a place for egg-laying take place during night. During the day, adults hide in nearby shady plots. Only dying adults can be found in an eggplant field. Adults live for only about 4 days. The adult male dies after mating and the female moth dies after laying eggs.



(from: Kar et al, 1995, CARE Bangladesh)

Creamy-white eggs are laid singly or in groups on the underside of the leaves, on stems, flower buds, or at the base of the fruits. Up to about 260 eggs can be laid by a single female moth. The eggs are sticky and they are firmly attached to the leaf surface. Eggs are very small and it is difficult to find them in the field.

The eggs hatch between 7 to 19 days after laying. Upon hatching, the larvae crawl for about 30 – 60 minutes to locate a suitable site for penetration. Then they bore inside a top shoot or a fruit. The fruits are preferred to shoots. The young caterpillar is whitish in color and turns light pink to light brown as it matures. There are five or six larval instars. First instar larvae are less than 1mm in length, the last instar larva is 15 – 18 mm long. The larval period varies from 12 – 15 days in summer and 14 – 25 days in winter.

Larvae can be found inside wilted shoots and inside fruits. Fruit damage will not be obvious, especially in round varieties where the entry hole closes quickly upon growth of the fruit. The first indication is a small hole in the fruit stalk or in the fruit itself. This is where the insect has entered. Cut the fruit near this entry hole and you will find areas where the larva has tunneled. The tunnels contain frass and insect remains. If you continue to cut around this area you may locate the live larva. Several larvae can be found in one fruit.

The fully grown caterpillars come down from the plant for pupation. They hang on a silken thread and pupate on the first surface they touch. This occurs on stems, under dried leaves or debris in soil. The pupal period varies from 7 to 10 days.

Fruit and shoot borer insects are active in summer months, especially during the rainy season. Peak populations are often reported in June-August. They are less active during November to February. The total life cycle varies from 22 to 55 days. Development of the different stages of the insect takes longer during the winter months. FSB populations are reported to increase with average temperature, relative humidity and rainfall.

Host range

The FSB feeds on solanaceous plants such as eggplant, tomato and potato and solanaceous weeds such as *Solanum nigrum* (e.g. Isahaque, 1983; Das, 1970). FSB has also been reported on other vegetables such as peas but these observations are not confirmed by research.

Plant damage and compensation

FSB larvae bore into a shoot. While they eat inside of the shoot, the top of the shoot dies. When the shoot dies, the leaves wilt. The rest of the plant may still be healthy. Plants may be able to compensate for loss of a shoot by producing another shoot but it may take longer before the plant starts to flower and bear fruits. Larvae also feed on flowers, reducing fruit set and yield.

FSB larvae prefer fruits to shoots. When fruits are available, larvae bore into fruits and start eating the fruit from inside. There may be small darkened holes surrounded with brownish areas on fruit surface and/or fruit stalks. The inside of the fruit is hollow and filled with frass. The fruit is not marketable or fetches a lower price. FSB infestation can be very serious with up to 75% of the fruits being damaged.

For sale: FSB Fruits....! 

In Bangladesh general prices (1997) for eggplant:

2 Taka/kg for FSB damaged fruits,
10 Taka/kg for undamaged fruits.

The problem with FSB is that damage to fruits is irreversible. Once larvae are inside the fruit, damage is done even when they can be controlled while inside the fruit. Management practices would be most effective when focusing on *prevention* of FSB damage to fruits. For practical reasons, most FSB management is directed towards lowering populations.

Natural enemies

- *Trathala flavor-orbitalis*, an ichneumonid wasp, is a frequently reported parasitoid of FSB, for example in India, Bangladesh and Sri Lanka. It can attack all larval instars (1st-5th) of FSB but prefers the later, 3rd- to 5th-instar, larvae. One adult parasitoid emerges from one FSB larva. This parasitoid is not specific to FSB but can also attack the larvae of a number of other insect species like rice leaf folder (*Cnaphalocrocis medinalis*), the cabbage webworm (*Hellula undalis*), the sesame pest *Antigastra catalaunalis* and even a pear pest *Numonia pyrivorella*. The total time for development of the parasitoid is about 20-24 days. This parasitoid is an important asset to management of FSB because it occurs naturally in many areas in SE Asia. In Bangladesh for example, parasitism under natural conditions was 5% (pers. comm. Md. Atiur Rahman, May 2001). It is unclear whether pesticide use influences this figure.



Free help for your field work...!?

During studies in Bangladesh, parasitoids occurring naturally in the field were studied. Two FSB parasitoids: *Trathala* sp. and *Cotesia* sp. were found. The parasitism percentages however, were not very high: on a 30-day sampling period, an average of 5.8% parasitized larvae per day was found in the plot where no pesticides were used, as opposed to 1.3% in the Farmer Practice field (with use of pesticides) (Kumar, 1998).

- In Mymensingh, Bangladesh, the parasitoid *Cotesia* sp. was found in pupa of FSB. Many parasitoids emerged from a FSB pupa. Unfortunately, also the hyperparasitoids *Aphanogmus* were found in the sample. These hyperparasitoids parasitize the *Cotesia* parasitoid! This would reduce the effectiveness of *Cotesia* in controlling FSB in that area.

- The egg parasitoid *Trichogramma* sp. Very good FSB control was obtained with *Trichogramma chilonis* in Philippines. See box below. *Trichogramma* sp. was also tested by a farmer in the Philippines and he reported a 50% control of FSB. No field data are available to confirm this but studies are being conducted at present (pers.comm. Julieta Lumogdang, 2001).

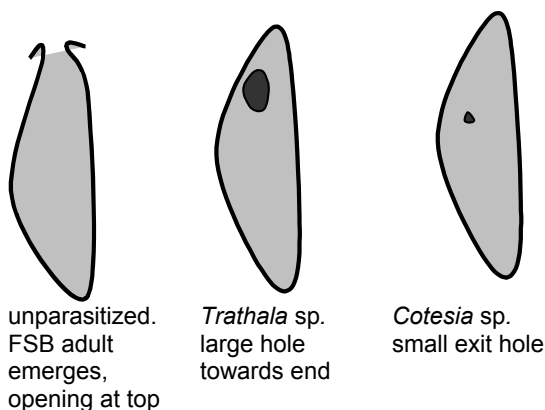
FSB control by *Trichogramma chilonis*: a success story from Philippines

During a Farmers' Field School in Negros Occidental (1998/1999) in the Philippines, release of *Trichogramma chilonis* at a rate of 10 – 20 cards (containing the parasitoid) per hectare at 5-day intervals, depending on the infestation, resulted in 60% control of FSB. The first application was done 2 weeks after transplanting (pers.comm. Carlito Indencia, 2001).

When *Trichogramma chilonis* was released at fortnightly intervals in a study in Tamil Nadu, India, it significantly reduced pest damage and produced fruit yield 20.30 tons, compared with the control yield of 13.06 tons (Raja, 1998).

Trichogramma japonicum was released in eggplant fields in a study in Andhra Pradesh, India, and resulted very good control of shoot and fruit borer as compared to control (Sasikala, 1999).

- *Eriborus sinicus*, another ichneumonid wasp, is a parasitoid of eggplant fruit and shoot borer. In a field study by AVRDC in Taiwan, it was found that this little wasp is a potential natural enemy of FSB. Whether this natural enemy is native to other regions in Asia and how efficient it is as a parasitoid has yet to be determined.
- During a survey for natural enemies of fruit and shoot borer on eggplant in India, *Diadegma apostata* was recorded from the pest (Krishnamoorthy, 1998). More research is needed to study the potential as a natural enemy of FSB.
- Reported in India: the larval ectoparasite *Bracon* sp., found on FSB on eggplant in Karnataka, India. Possibility of its use in the biological control of the pest needs to be further studied (Tewari, 1990).
- Use of *Bacillus thuringiensis* (Bt): In a field experiment in 1995 in Rajasthan, India, treatment with 2 ml/liter of Dipel 8 significantly reduced fruit damage caused by FSB compared with the untreated control (8.78 vs. 12.34%) and produced higher fruit yield than the control (12.07 vs. 9.98 t/ha) (Qureshi, 1998). Other studies however, report that Bt was not effective for FSB control (Patnaik, 1997).
- There are nematodes that can kill FSB larvae, even those inside shoots and fruits (also see section 6.3.4.). Studies done in Bangladesh show that the nematode *Steinernema riobravus* has good potential as biocontrol agent. A solution of nematodes and sticker (to allow the solution to better stick on the plant) is sprayed over the plants. The nematodes land on the eggplant and actively search for a caterpillar. Promising results were obtained with significantly lower FSB infestation in the nematode-treated plots as compared to the unsprayed plots. However, more research is required before a nematode product can be released for commercial use.
- Laboratory studies carried out in India showed that larvae of the FSB were moderately susceptible to infection by the fungus *Fusarium moniliforme* var. *subglutinans*. The pathogen did not harm the eggplant crop (Beevi, 1982). Whether this fungus has potential for field control of FSB needs to be further investigated. In general, fungi that affect insects can contribute to control but this is very dependent on environmental conditions like humidity and temperature. More research is needed to investigate the potential for this biocontrol agent.
- A baculo virus, a virus that can kill insects, was found connected to FSB in studies in India. More research is required to study the potential for applying this virus to the field.

How to recognize a parasitized pupa of FSB:

(pers. comm. P. Kumar, 1999)

Management and control practices**Prevention activities:**

- Tolerant and resistant eggplant varieties have been reported, mainly from India. See table in section 3.2.2 for variety names. However, none of the tested varieties is 100% resistant to FSB, but there are remarkable differences in the percentage infestation. The degree of resistance varies with local conditions. For example, in a field test in Bihar, India, the variety Long purple was rated as resistant with 7.7 % infestation of shoots and 6.7% infestation of fruits (Mehto, 1981). In addition, wild eggplant varieties such as *Solanum indicum* and *Solanum macrocarpon* are highly resistant to FSB (Behera, 1999a; Kumar, 1996). AVRDC found that a landrace of eggplant, EG058, proved to be resistant against FSB in India, Sri Lanka and Thailand, but not in Bangladesh (ref. www36). These genotypes may be interesting for breeding purposes. The best way to find out if a variety is resistant to certain pests is to set up a field trial to compare susceptibilities of different varieties under local conditions.

Eggplant resistance to fruit and shoot borer: an example of research findings.

In a field study in Bhubaneswar, India, 174 eggplant varieties were screened for resistance to fruit and shoot borer. None of the eggplant varieties was immune (=zero infestation) to larval attack of shoots and fruits but there was a remarkable difference in the percentage attack.

The mean percentage of shoot infestation varied from 1.6 to 44.1% and fruit damage varied from 8.5 to 100%. Maximum shoot damage was recorded 75 DAT (days after transplanting), with maximum fruit damage recorded at 76-121 DAT and 99-114 DAT in susceptible and resistant cultivars, respectively. Thus, early fruiting varieties are more liable to fruit attack by fruit and shoot borer.

Leaf hair density and number of shoots/plant played a role in restricting shoot damage. A tight calyx and long fruits increased the resistance of the fruits. *L. orbonalis* attack of fruits was also restricted by tightly packed seeds inside the fruit, low percentages of moisture, nitrogen and potassium, and a high phosphorus content. It is suggested that in order to minimize the incidence of fruit and shoot borer, resistant cultivars such as Pitala Local 1 and Sambalpur Local should be grown (Panda, 1999).

- Breaking the clods of the soil before transplanting also helps reducing populations. Rough soils favor pupation of FSB (pers. comm. P.Kumar, 2001).
- Avoid planting over-aged seedlings (pers. comm. P.Kumar, 2001). When seedlings remain in the nursery too long, they form stretched, weaker seedlings due to competition for space, light, and nutrients. Crowded nurseries can form good breeding ground for FSB.

- Sanitation practices such as cleaning the soil of the field to remove FSB pupae, normally found on dead and fallen leaves (pers. comm. P.Kumar, 2001).
- A study in Bangladesh demonstrated the potential for using net houses to protect eggplants against FSB infestation. Details in box below.

Net houses: keeping the pest away from the plant!

In a field study in Bangladesh, a net house was made out of bamboo sticks, nylon nets and tied together with clips and rope. Height of the net house was about 2m. The net house was covering a number of eggplants. The soil under the net house was carefully checked for pupae and other potential pest insects which were removed. Insects from outside, e.g. FSB adults, could not reach the plants and infestation of insect pests was lower as compared to the control plot, where no net house was placed. Pollination of eggplant flower was not impaired as over 90% of the flowers is self-pollinated.

If a net house lasts for about two or three seasons, the investment in net house materials may be paid back by better fruit quality through less FSB damage. However, in this study, the investment was not paid back because the net house was stolen from the field...



Try it and find out if it works for you!

- Fertilization can have an effect on occurrence of pests: in trials in India (Haryana, 1987), an increase in the doses of nitrogen and phosphorus applied to the eggplant crop resulted in heavier infestation by both jassids (leafhoppers) and FSB, but increased doses of potassium resulted in lighter infestation. Only the interactions between nitrogen and phosphorus, nitrogen and potassium, or phosphorus and potassium (and not those between all 3 elements together) were found to contribute positively towards a marketable yield without infestation of fruit by FSB (Chaudhary, 1987). A similar field study was carried out in India, testing the effects of nitrogen, phosphorus and potash fertilizers on FSB infesting eggplant. The minimum levels of fruit and shoot infestation (12.60 and 7.73%, respectively) were observed after treatment with potash at 100 kg/ha, closely followed by phosphorus; treatment with nitrogen resulted in the highest levels of infestation by the pest (Mehto, 1981). Set up an experiment to test the effect of different fertilizer doses on pest occurrence and yield in your field!
- Intercropping with herbs: A study from Bihar, India, reports that lower fruit and shoot borer infestation was recorded when three rows of nigella (*Nigella sativa*) were planted as an intercrop between rows of eggplant, compared to an eggplant monocrop. Intercropping with fennel (*Foeniculum vulgare*) also reduced the pest infestation (Gupta, 1999). Other sources mention coriander (*Coriandrum sativum*) sown in a single line to be effective in reducing FSB injury to fruits as compared to eggplant planting alone (Khorsheduzzaman, 1997).



Community approach

For proper reduction of FSB populations, it is important that farmers of an area cooperate. This is because FSB can easily fly from one field to the next. If a farmer does not properly control FSB, his field becomes a source of infection for other eggplant fields. ☹️

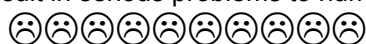
Once FSB is present in the field:

- Sanitation: remove infested shoots, fruits and fallen leaves and destroy or burn them. This helps reduce populations considerably as shown in several field studies (e.g. Sasikala, 1999; FFS Negros Occidental, pers.comm. Carlito Indencia, 2001).
- Flooding the field: during a Farmers' Field School in Negros Occidentale (1998/1999), the Philippines, flooding the eggplant field weekly during the dry season (for irrigation) killed large numbers of FSB pupae present in the soil and on dried leaves. This was discovered by farmer participants who found the dead pupae in the soil 2 days after irrigation (pers.comm. Carlito Indencia, 2001).

- The use of pesticides for the control of FSB is seldom sufficient to increase yield and reduce quality loss. Since the FSB lives mostly inside stems or fruits, pesticides applied will never reach the larvae completely. Chemical control, even with systemic pesticides, is therefore difficult and seldom increases profits.

Insecticides for FSB control: why not?

1. Larvae of FSB are difficult to reach with insecticides. Contact pesticides are not effective because the larvae live outside a plant for a few hours at most! After that they bore into shoots or fruits and usually live inside until pupation or may come out shortly to move to another shoot or fruit.
2. Even use of systemic pesticides seldom provides sufficient control. Besides, systemic pesticides may be inside the fruit when you want to eat it....
3. Adults of FSB usually live outside the field, they migrate to sheltered places. So insecticides aimed to kill adults are a waste of money and time and may do more harm by killing beneficials in the field. Several studies show that beneficials, e.g. the parasitoid *Trathala flavo-orbitalis*, can help control FSB.
4. In 1993 trials in Bangladesh (BARI) showed that even insecticides of the group of synthetic pyrethroids did not give sufficient control of FSB. It was concluded that FSB can built up resistance against these pesticides.
5. Yet, insecticides are widely and intensively used for the control of FSB. AVRDC's baseline survey in Jessore district of Bangladesh showed that farmers are often spraying their eggplant crops 140 times/season or more for control of FSB. Pesticide cost was the single highest cost (32%) of eggplant production (ref. www37).
6. Irrational use of pesticides can result in serious problems to human health and the environment.



- *Bacillus thuringiensis* (Bt) may be tested. See section on natural enemies above.
- Where available and registered, the use of an insect-killing nematode solution like *Steinernema riobravis* might be worth trying.
- The use of sex pheromone (a solution that attracts male adults) may help in the control of eggplant fruit and shoot borer. Since eggplant remains in the field for 6 months or longer, use of sex pheromone for mating disruption may help reduce insect infestation. Several institutes like the AVRDC, a large vegetable research institute in Taiwan, and CABI Bioscience are doing research to determine the components and the best mixture of components for such a pheromone. See also section 4.11.2.

Successful IPM strategies in Negros Occidental, the Philippines

During a Farmers' Field School in Negros Occidental (1998/1999), farmer participants concluded at the end of the training that the combination of the following 4 cultural practices controlled 70% of FSB population in eggplant:

- Flooding the field (dry season) for irrigation (see points above),
- Pruning of older leaves and use of wide spacing (1m x 1,5m),
- Sanitation and proper disposal of FSB-infested plant material,
- Fertilizer use as per recommended rate (on basis of soil testing).

(pers.comm. Carlito Indencia. 2001).

Another successful IPM Strategy

In an AVRDC study in Jessore, Bangladesh an IPM strategy consisting of weekly removal of FSB-damaged shoots, installation of pheromone traps to catch FSB males, and withholding of chemical pesticides to allow natural enemies to control FSB, was developed and tested in farmers' fields. This strategy led to lower production costs and higher net incomes for farmers (ref. www37).



Points to remember about fruit and shoot borer:

1. Fruit and shoot borer (FSB) is the most serious insect pest of eggplant, especially during the fruiting stage. During vegetative stages, eggplants can often compensate for loss of shoots by producing new shoots.
2. Removing infested shoots and fruits helps preventing population build-up.
3. Pheromones, where available, help reduce FSB population by removing large numbers of males.
4. Several naturally occurring parasitoids such as *Trathala* sp. and *Cotesia* sp. attack FSB larvae. Efficacy of these parasitoids under no-spray conditions needs to be further studied.
5. Introduction of *Trichogramma chilonis* may be worth testing because this parasitoid has given good FSB control in some areas, and it affects the eggs of FSB, thus reducing larval populations.
6. Cultural practices such as proper sanitation, leveling soil, flooding, and the use of net houses may reduce populations or prevent/delay crop infestation.
7. Experimental methods to control FSB include the use of insect-killing nematodes.
8. Pesticides are seldom effective for control of FSB.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual

4.1. Insect zoo

4-A.3. Plant compensation study: shoot-pruning at different crop stages

4-C1 Sanitation to control shoot borers

For more background reading and practical exercises on insect-killing nematodes for fruit and shoot borer management, please refer to the report "Participatory Action Research on Vegetable IPM (with emphasis on Fruit and Shoot borer Management)" authored by Prabhat Kumar, FAO Vegetable IPM Training Consultant, Jessore, Bangladesh, 1998. See reference list (chapter 11) on how to obtain copies.

5.2 Epilachna beetle - *Epilachna* sp.

See photos 8, 9 (page 176).

Scientific name: *Epilachna* sp. or *Henosepilachna* sp.

Common names: *Epilachna* beetle, Ladybird beetle, spotted leaf beetle.

Ladybird beetles are well known for their role as predators of aphids, mealy bugs, and other insect pests. However, there is one group of ladybird beetles which is feeding on plants rather than on insects. These are the *Epilachna* beetles.

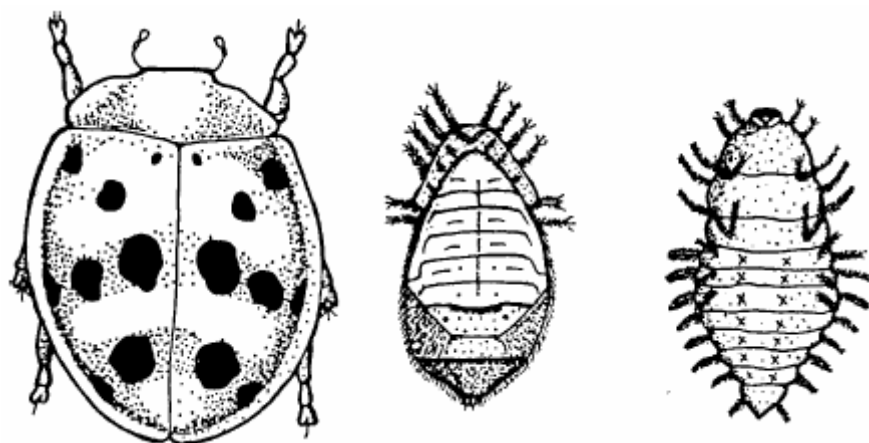
There are many species of *Epilachna* known, but the most important ones are *Epilachna vigintioctopunctata*, *E. duodecastigma*, *E. chrysomelina*, *E. similis*, *E. fulvosignata*, *E. sparsa* and *E. varivestis* (the Mexican bean beetle). *Epilachna vigintioctopunctata* is the most commonly reported eggplant pest. For field situations, it is usually not necessary to identify *Epilachna* beetles to the exact species as the management and control practices for all species are similar.

Description

Adults and larvae are often seen living together. The adult is oval to round in shape, orange-red to brownish-yellow in color and has 12 or 28 black spots on the back. Its body is covered with very fine golden hairs.

The adult female lays clusters of oval, yellow eggs on the undersides of leaves. The larva which emerges about 4-5 days later grows to a length of 6-7 mm. Larvae are pale yellow in color and have black, branched spines covering the back and sides. Fully grown larvae are dark yellow, broad, with a dark head and strong branched spines. Larval development takes about 2 weeks.

Adults and larvae can be found at both sides of the leaves. Adults fall to the ground or fly when they are disturbed. The young normally stay in place. Due to their yellow color, they can easily be found on the plants. Adults are strong fliers.



Epilachna beetle: adult, pupa and larva (from: Kar et al, 1995, CARE Bangladesh)

Life cycle

This insect continues its life cycle throughout the year and has 4 to 5 generations per year. Eggs are pale yellow, elongate-oval and are 0.5 mm long. The eggs are laid in clusters, usually on the underside of the leaves and placed vertically. Each female lays on average 12 clusters, each with up to 50 eggs. The egg stage lasts about 4 days in summer and 9 – 10 days in winter. The larva is sometimes called a *grub*. Larval development takes about 2 weeks.

Pupation generally takes place on the upper parts of the shoots and lower surface of the leaves. The pupa is dark yellow.

Host range

Main hosts are cucurbits such as cucumber, melon and gourd and solanaceous crops like eggplant, tomato and potato. Alternative hosts may include maize, sorghum, millet, rice, wheat, cotton, sesame, lettuce, soybean, cowpea, beans.

Plant damage and compensation

Both adults and larvae damage the leaves by eating the soft outer tissue and leaving “windows” in the leaves. Leaf tissue is eaten between the veins, sometimes being completely stripped to the midrib. When leaves are damaged, less area is left for the energy production (photosynthesis). This results in weaker plants or production delay. In a heavy attack, young plants may be killed. Sometimes, holes are eaten in fruits.

Epilachna beetles are very visible, easy to spot and damage is very obvious. However, plants compensate for loss of leaf area by producing new leaves. When plants are young, severe defoliation may result in death of the plant or serious delay in production. How much defoliation an eggplant can tolerate at a certain growth stage can easily be tested in a small experiment. See section 4.5 and the reference to exercises below.



Epilachna larvae feeding on leaf

Epilachna population dynamics, an example

The population dynamics of *Epilachna vigintioctopunctata* were studied on eggplants in Indonesia in 1981-82. After planting, adult beetles soon colonized and reproduced massively, resulting in rapid population growth for 1-2 months; thereafter, the population increase slowed down due to defoliation. Three to four months thereafter the plants recovered their leaves (compensation!), but leaf quality was less suitable for the *Epilachna* beetle and, as a result, the population remained low during the rest of the study period.

A life table showed that parasitism, and starvation by overcrowding, contributed most to mortality of the *Epilachna* beetles in the immature stages (Nakamura, 1988).

Natural enemies

The little wasp *Pediobius foveolatus* has frequently been reported to be an effective parasitoid of *Epilachna* beetles on eggplant. It has been recorded in countries like India, Bangladesh, China, and Japan. *P. foveolatus* can attack both larvae and pupae but it prefers pupae and late instar larvae. In some western countries like USA this parasitoid is commercially available.

In a Farmers' Field School in Roghurampur, Mymensingh, Bangladesh, 96% control of *Epilachna* beetle by the parasitoid *Pediobius foveolatus* was obtained in the unsprayed field in studies in 1998. Over 80% parasitism of *Epilachna* was found in homestead gardens in Jessore, Bangladesh in 1998 (pers.comm. P. Kumar, 2001).

In a TOT field at Daulatpur, Khulna, Bangladesh, parasitism of *Epilachna* by *Pediobius foveolatus* was (pers.comm.Md. Atiur Rahman, 2001):

<i>Epilachna</i> pupae:	34%
Eggs	41%
Grubs	37%

Epilachna biocontrol: another success story

Epilachna philippinensis became a serious pest of solanaceous crops on Saipan, Mariana Islands, after its accidental introduction in 1948. In 1985, *Pediobius foveolatus* was released into heavily infested mixed plantings of eggplant and tomato. By 1989, the parasitoid was reared from 80% of *E. philippinensis* larvae collected and insecticide applications are now only needed occasionally. Rapid success of the programme may be due to an abundance of solanaceous weeds providing an untreated refuge for parasitoid production (Chiu, 1993).

A species of the wasp *Tetrastichus* was found parasitizing larvae of *Epilachna vigintioctopunctata* on eggplant in Himachal Pradesh, India, during August 1989. This species was also reported as an egg parasitoid of *Epilachna vigintioctopunctata* from Indonesia.

Management and control practices

All stages of the insect are exposed on the plants and may be handpicked. Cultivars *Arka Shirish*, *Hissar Selection 14* and *Shankar Vijay* were reported to resist damage of *Epilachna* beetle, especially *E. vigintioctopunctata*.

Prevention activities:

- Use resistant or tolerant varieties where available. For example, the Indian eggplant varieties Makra, Altapati, Gourkajli, Brinjal 72, Puni, and Chicon Long were relatively resistant to the pest (Gangopadhyay, 1997). See table in section 3.2.2. for other examples.
- Grow a healthy crop: strong plants are better able to compensate for loss of leaves. See section 4.5.
- Sanitation: remove plant debris from a previous crop completely to reduce beetle population. This may reduce early attack of a new crop.

Once *Epilachna* beetle is present in the field:

- When the attack is moderate or on a limited area, hand-picking of the egg masses and insects and pinching them or destroying them outside the field is a cheap means of control.
- Insecticides can kill larvae and adult beetles. As was demonstrated in studies from India, it should be noted that most insecticides, including endosulfan, carbaryl and especially the synthetic pyrethroids deltamethrin (decamethrin), cypermethrin, fenvalerate and permethrin are toxic to the parasitoid *Pediobius foveolatus*, causing up to 98% parasite mortality inside host larvae.

Points to remember about *Epilachna* beetle:

1. *Epilachna* beetle eats leaves of many vegetable crops.
2. Crops can compensate for leaf damage by producing more leaves. See crop compensation section 4.5.
3. The parasitoid *Pediobius* sp. occurs naturally in some areas and can reach high control level if fields are not treated with pesticides.
4. Handpicking and destroying eggs, grubs, and beetles in small-size fields helps to reduce *Epilachna* populations.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual

4.1 Insect zoo

4-A.3. Plant compensation study

4-A.9. Hand picking of eggs and caterpillars

5.3 Red Spider Mite - *Tetranychus* sp.

There are many species of spider mites, the red spider mite just being one of them.

Description

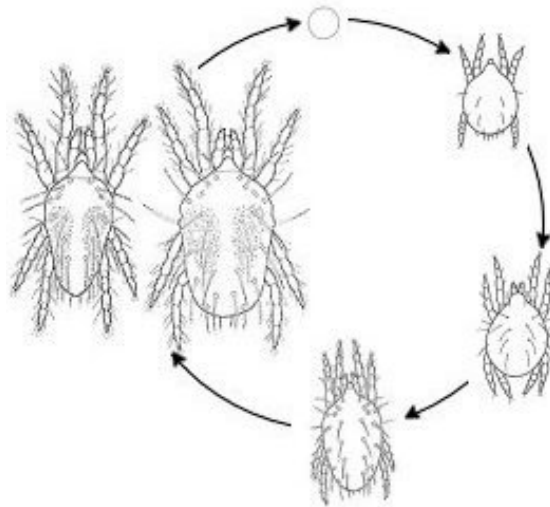
Spider mites inhabit the lower surface of leaves and cause damage by making large numbers of tiny punctures in the leaf and sucking out the sap. Attacked leaves often have a silvery, "peppered" appearance, particularly along the veins. The adults, about 0.5 - 1 mm long and just visible to the naked eye are protected by the fine webs which they spin on the leaf surface. The adults are orange-red to yellow-brown in color. They move slowly and cannot fly.

A mite is not an insect!?

A mite has 8 legs, instead of the 6 that insects have. Also, mites don't have a "waist" like insects do and they do not have wings and antennae. Together with the spiders, mites form a separate class of the *Arachnida*.

Life cycle

The female spider mite can lay more than 100 eggs in its lifetime. This is usually 3 to 12 eggs per day. Eggs are yellow. After a few days, a larva emerges with 6 legs. This first larval stage takes about 3 days, then it moults into a nymph with 8 legs. There can be 2 nymphal stages. Development cycle depends on the temperature and host plant. Usually, there are twice as many females than males in a population.



Spider mite life cycle: egg, 6-legged nymph, 8-legged nymphs, adult
(from: Kerruish et al, 1994)

Host range

The red spider mite has a very broad range of host plants, including many vegetable crops and ornamental plants and trees.

Plant damage and compensation

Spider mites suck sap from the plant. This can result in poor growth of the plant, deformation of leaves and shoots, chlorosis, browning, etc. The leaf is often "peppered" with tiny colorless points alongside the veins, which sometimes give an almost silvered appearance to the leaf. This eventually results in reduced production. The eggplant fruits are attacked only when mite populations are very high.

Natural enemies

- Predatory mite *Phytoseiulus persimilis*. An orange-red mite, about 1 mm long. This mite cannot fly but moves around much quicker than the spider mites. In India, this predatory mite has proved to be effective against spider mite in okra. Also in many European countries and in the USA, this predatory mite can be bought from specialized shops for release in greenhouses or in the field. Results in greenhouses are very good and hardly any chemical pesticides need to be applied for spider mite control. *Phytoseiulus* needs high humidity for effective mite control.
- The predatory mite *Amblyseius tetranychivorus*, indigenous in India, was also found effective against spider mite in okra. This predatory mite is commercially available in some western countries. It is released on fairly large scale for spider mite control in many vegetable crops including eggplant, strawberry, and gourds in China. Numerous research findings are available on how to mass-produce and conserve predatory mites.
- The gall-midge *Feltiella acarisuga*. This is again a commercially available natural enemy of spider mite. It is very successful in European countries. The adult midge is about 2 mm long, pink-brown, with long legs. *Feltiella acarisuga* is often used in greenhouses together with the predatory mite *Phytoseiulus persimilis*, especially in periods with low humidity levels (which hinder the development of *Phytoseiulus*). The gall-midge *Feltiella acarisuga* can fly, which makes it more mobile than *Phytoseiulus persimilis*. High humidity boosts the emergence of gall-midges.
- The predatory bug *Macrolophus caliginosus* is a known predator of spider mites. Its main host is whitefly and to a lesser extent aphids, moth eggs, leaf-miner larvae and thrips. Bug populations develop most rapidly on whitefly. Adult bugs can also survive for some time on plant saps. *Macrolophus* is another commercially available natural enemy, again successful when released in greenhouse environments. Whether this bug occurs naturally in the tropics and how effective it is in spider mite control needs to be further investigated.
- Larvae of the green lacewing *Chrysopa* sp. are predators of spider mite.
- Ladybeetle adults and larvae feed on spider mites.

How effective one predator is, how many prey it eats per day, usually depends on many factors including host plant and temperature. The eating-capacity of a predator can easily be tested in the field with a caged plant or in an insect zoo (glass or plastic jar). See section 4.8.

🎯 Circle of life: mites and predatory mite reproduction examples

In a study from China, 50 red mites inoculated on eggplant cultivated in plastic bags multiplied to 13,000-14,000 individuals after 40 days, and the predatory mite *Amblyseius longispinosus* placed into the bag could subsequently propagate to 500-1,000 individuals after 20-25 days. Not bad...!
(Zhang-YanXuan, 1996).

Management and control practices

Prevention activities:

- In general, vigorous growing plants are less susceptible to pest and disease attack. Creating proper environment, e.g. applying lots of compost to improve the soil structure, applying modest rates of nitrogen, help preventing mite infestation.
- Predatory mites can often be found spontaneously in the field. Like many other predators, these predatory mites are very sensitive to pesticides, especially broad-spectrum pesticides. Avoid the use of such pesticides as much as possible.

Once spider mites are present in the field:

- Small populations can be tolerated because they allow build-up of natural predatory mite populations.
- Mites do not like a wet environment. Plants infested by mites can be hand sprayed with water. Part of the mites will be washed off and population growth will be slowed down. Only applicable at smaller areas or when few plants are infested.

- Release of predatory mites. If predatory mites are available and permitted for field use, this would be the best control option.
- Application of botanicals, such as neem can be effective. Most of these have a broad-spectrum activity against many pests and natural enemies. For this reason, they may best be applied locally, only on infested plants, not on all plants. Most botanicals are not very effective against mite eggs. Application will have to be done at least weekly.
- Numerous acaricides, chemical pesticides that work specifically against mites, exist. Unfortunately, most acaricides also kill predatory mites and some kill other natural enemies as well. Prolonged use may reduce the predator population of spider mite and may even result in more crop damage. See box above. In addition, spider mites can develop resistance to many chemicals quickly because of their high reproduction rate. Many chemicals are already ineffective due to resistance. If acaricides are used at all, try using them very localized, on infested plants only (spot application).

Immunization, a natural vaccination program....?!?

Research on cotton plants at the University of California, USA, showed that when young plants were slightly infested by spider mites, the plants at a later stage were less attractive to spider mites. This method of "vaccination" is already practiced with tomatoes. Tomato plants are infected with a weak virus strain that does not lower plant production, resulting in resistance against more aggressive strains of virus.

Although more research is needed to investigate the potential for pest control, it could be considered to tolerate low levels of insects or mites in the crop and not to try for 100% control.

Points to remember about red spider mite:

1. Red spider mite has become an important pest in areas where pesticides have been used intensively.
2. Many species of indigenous natural enemies such as predatory mites may occur in vegetable fields untreated with pesticides. Several predators are commercially available in some countries.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual

- 4-D.1. Predation on sucking insects in insect zoo
 4-D.2. Cage exclusion of natural enemies in the field
 4-D.8. Spot application of acaricides to manage mites

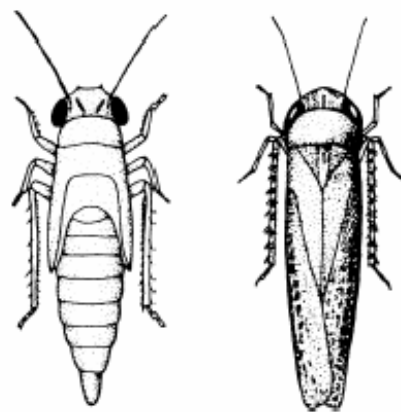
5.4 Jassids / Leafhoppers – several species

See photos 10, 11 (page 176).

Several species are important including *Amrasca biguttula biguttula*, *Amrasca devastans*, and *Cestius phycitis* (formerly *Hishimonus phycitis*).

Description and life cycle

Adults and immatures are found on the underside of leaves. Their nervous behavior makes them difficult to catch. Adults are usually less than 13 mm long, with slender, tapered bodies of various colors from bright green to yellow-green with shiny wings, depending on the species. These insects are very active. The adults may be found on the foliage in large numbers, and move around by jumping, but fly very readily when disturbed. The nymphs are smaller than the adults and wingless. They move around very rapidly, seeking refuge on the underside of the leaves if disturbed.



Nymph and adult jassid
(from: Stoll, 1987)

A female may lay more than 50 eggs. Eggs are greenish, banana-shaped and less than 1 mm long. They are embedded in one of the large leaf veins or in the leaf stalks. Hatching occurs after about 6 to 10 days.

There are 5 nymphal instars; the fully-grown nymphs are yellowish-green, frog-like and about 2 mm long. Nymphs are found on the underside of leaves during the daytime. The nymphal period lasts 14 – 18 days. In warm climates, several generations occur.

Host range

Jassids occur on most types of plants. Different species attack a variety of vegetable crops including eggplant, tomato, okra, beans, lettuce, and squash.

Plant damage and compensation

The jassid species *Cestius phycitis* is particularly harmful in eggplant because it can transmit the eggplant little leaf disease. Some species transmit mosaic virus.

Jassids suck the plant sap and cause the edges of leaves to become yellow, with an upward rolling, giving a spoon-like appearance. Outer leaf areas appear yellowish or burned. Leaves are extremely small and show mosaic pattern, small whitish spots or yellowing. Fruit set may be very low.

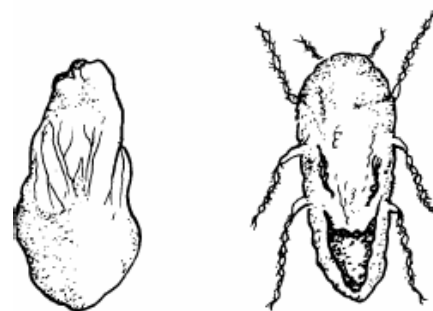
In the case of heavy attacks, the yellowed foliage turns brown and dies, and this may lead to a serious loss in production. Leaf browning due to jassid damage is also called *hopperburn*.

The insect population is greatest during the hot, wet season. The age of the eggplant does not seem to affect the occurrence and multiplication of jassids.

Natural enemies

From field studies in Bangladesh, some cases of fungal infection of jassids have been reported. The exact species of this fungus is unknown at this stage, possibly *Beauveria* sp.

Researchers from India reported that nymphs and adults of the jassid *Amrasca biguttula biguttula* collected from untreated eggplant were found to be infested by larvae of predatory mites of the genus *Bochartia*. (Ghai, 1975). Only the larval stage of *Bochartia* feeds on jassids; the adults and nymphs are free-living predators found in humus or among fallen leaves. Whether this predatory mite species has potential for biocontrol needs to be further studied.



Jassid infested with *Beauveria* sp.

Parasitoids *Anagrus flaveolus* and *Stethynium tridavatum* have been used to kill leafhopper eggs on other crops (ref. www35).

Management and control practices

Prevention activities:

- Resistant and tolerant varieties of eggplant have been reported. See table in section 3.2.2. Check with local seed suppliers for such varieties or set up a field trial to study differences in jassid (and other pests and disease-) susceptibility among eggplant varieties. Cultivars with hairy leaves are reported to be less susceptible to damage.
- In studies from India, jassids populations in eggplant were highest in the middle of February and first week of August (Suresh, 1996). Where jassids are a serious problem changing planting dates, by planting eggplant when the environment is less suitable for jassid multiplication, e.g. during winter, may be an option to reduce jassid infestation. This was confirmed in field studies carried out in Assam, India. Eggplant planted at the end of October had the lowest incidence of the jassid *Amrasca biguttula biguttula* (Borah, 1994).
- Fertilization may have an influence on the infestation of jassids. In studies on eggplant carried out in India, an increase in the doses of nitrogen and phosphorus resulted in heavier infestation by both jassids and fruit and shoot borer, but increased doses of potassium resulted in lighter infestation (Chaudhary, 1987). Fertilization and the effect on pest and disease occurrence and on yield can be tested in a field trial. See section 3.8.

- Reflective mulches, such as strips of aluminum foil, are helpful to deter jassids, especially when plants are young. Such mulches also help deterring aphids and thrips. The shiny mulch reflects the (sun-)light and deters jassids, aphids and thrips, which will then not land on the crop. See section 3.11.4.
- The use of trap crops, for example okra, is a promising strategy. Farmers can grow okra along borders, "trap" the leafhoppers there, and focus sprays on those plants. See box below.

Trapping jassid with okra?!?

In glasshouse experiments from Philippines, the jassid *Amrasca biguttula biguttula* preferred okra to eggplants for feeding and egg-laying (Bernardo, 1990). During the TOT in Mymensingh, Bangladesh, participants found that two rows of okra, if planted 3 weeks ahead of eggplant, could substantially reduce jassid populations in the field (FAO-TOT Mymensing, 1999).

In areas where jassids are a major problem, try planting okra as a trap crop along the eggplant field to protect eggplant from damage by jassids. Find out if the jassids also prefer okra to eggplant in your field!

Once jassids are present in the field:

- When populations are low, usually no control measures need to be taken. Proper monitoring is necessary to determine the size of the jassid population and the extent of crop damage.
- Some farmers, e.g. in Bangladesh, use wood ash to control nymphs of jassids. It also seems to control aphids. If applied in large quantities, early morning when leaves are wet with dew, ash may stick to the leaves and hinder the energy production (photosynthesis) by the leaves.

Points to remember about jassids:

1. Jassids on eggplant are important because they can transmit little leaf disease.
2. Several cultural practices such as use of resistant varieties, changing planting dates, use of reflective mulches, and trap crops may help reduce jassid infestation.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual

4-D.1. Predation on sucking insects in insect zoo

4-D.6. Use of light reflective mulch to manage thrips and/or aphids

3-F.7. Role play on effects of pesticides on virus transmission by insect vectors

5.5 Aphids - *Myzus persicae* / *Aphis gossypii*

Various aphid species can attack eggplants, including *Myzus persicae* and *Aphis gossypii*.

Description

These small insects are often globular in form, and exist generally in large colonies on the underside of leaves, on young shoots and on flower buds. The aphids have small syphons (looking like small antennae) at the back of their body. Syphons are a good way to recognize aphids.

The color of the insect varies according to the species, the host crop and the stage of development, and can be ashy-gray, black, brown, green or yellow. Most of the aphids are without wings but have winged generations at certain times in their development cycle. The winged aphids are slightly longer than the wingless ones and have a dark-colored head and body. The veins on the wings appear brown to black in color.



Aphids can colonize a crop within several days, usually attacking young tissue.



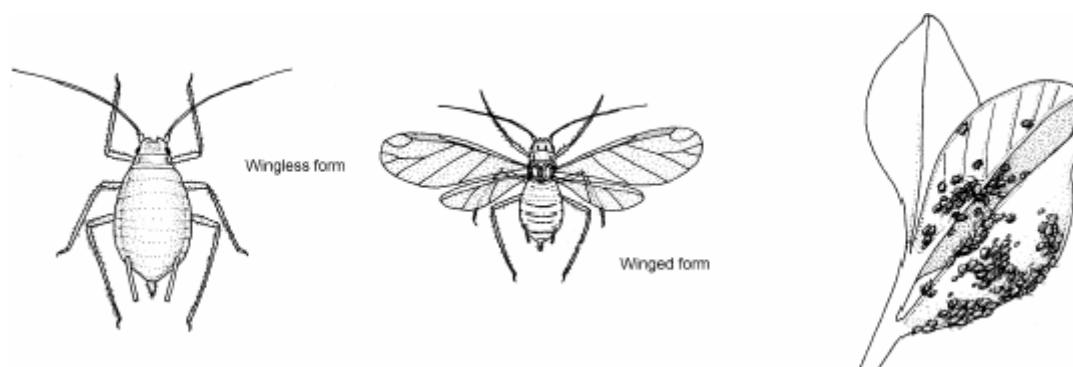
Aphid reproduction: no males needed!?!

Aphids can reproduce asexual: that means that males and females don't have to mate in order to produce young. One female gives birth directly to small nymphs. That means large numbers of aphids can be produced in a very short time! Only in cool areas, eggs are produced after mating. The eggs overwinter and young nymphs emerge when the temperature rises.

All winged aphids are females. In the tropics, most unwinged aphids are probably also females because most reproduction in the tropics will be asexual so males are not needed.

Life cycle

In cooler areas, the aphid overwinters as small, shiny black-colored eggs laid particularly around leaf scars of stems of plants that remain in the field throughout the winter. When the temperature rises, the aphids hatch and colonize the new emerging flowering stems or harvested vegetable crops that have not been ploughed in. Then, winged aphids fly away to colonize new host plants. They produce wingless aphids. These aphids produce more young aphids that form new colonies. They feed on the tender, actively growing shoots and leaves, often on the underside of leaves where they are protected from the sun and rain. When aphid numbers outrun food supply, winged forms reappear and migrate to nearby plants to renew the growth cycle. This happens regularly during the growing season.



*Wingless aphid, winged aphid, and aphid colony on young leaves.
(from: Stoll, 1987)*

In warm, tropical environment, aphids usually continue the asexual reproduction cycle without producing eggs. Warm, dry weather favors a rapid build-up of aphid colonies.

Host range

The aphid is a serious pest of many vegetables and other crops like cotton. Some aphid species are specific for one crop, e.g. the cabbage aphid only infests cabbage or other cruciferous crops. Aphids on eggplant are usually common species that infest many crops.

Plant damage and plant compensation

Aphids can damage a crop in several ways:

1. They suck plant sap. At high aphid populations, less sap with nutrients is left for the plant resulting in poorer growth and lower production of fruits. Leaves wrinkle and can remain very small.
2. They produce honeydew, which forms a sticky layer on the plant and fruits and make it 'dirty'. Fungus mould can start growing on the honeydew.
3. Aphids can transmit virus diseases (when there are winged aphids).
4. Aphids (and their moulded skins) on products lowers quality and price.

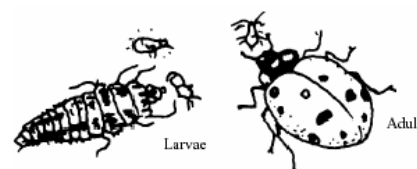
Aphids appear very localized: they usually colonize just a few plants but can be very abundant on one plant.

Natural enemies

The weather is a major natural agent restricting the build-up of aphid infestation in cold, temperate regions and mountainous areas. In dry, warm seasons the population of aphids often rapidly builds up whereas in wet, cool seasons the aphid population remains small. In a period of frequent rain, aphid populations will be very low if not absent.

Predators such as ladybeetles and hoverflies (*Syrphids*) and parasitoids like the wasp *Diaeretiella rapae* and *Aphidius* sp. are important natural enemies of the aphid. See chapter 6 for details on these natural enemies.

In wet years, outbreaks of fungi that kill aphids may occur (*Entomophthora* sp. and *Verticillium* sp.). This often coincides with period of high humidity and rain. Dead aphids may be seen covered with white or green colored fungus growth on the body. These fungi can reduce aphid populations rapidly.



Ladybeetle larva and adult: important aphid predators

Discovery of an insect-killing fungus

During a TOT for Eggplant IPM in Bangladesh, 1997, study fields of yardlong bean (grown as second crop) were severely infested by aphids. Aphid populations dropped suddenly, and participants discovered this was due to a fungal infection of the aphids. The participants successfully experimented with transferring fungus-infected aphids to uninfected aphid colonies in the eggplant crop (FAO-TOT report Mymensingh, 1997).

Management and control practices

Prevention activities:

- Aphid infestation often occurs when plant condition is slightly poor, for example just after transplanting, or when too much or too little fertilization is added, or when the soil structure is poor. Healthy, quickly growing plants are the best way of preventing many pests and diseases. Start with selecting healthy transplants, free from aphid infestation (or other pest insects or disease symptoms!).
- Some varietal resistance has been reported. See table in section 3.2.2. However, there is little chance of producing an eggplant variety with a durable resistance to aphids. This is because there are many biotypes (individuals with slightly different genetic characteristics) of aphids are present in the field and new biotypes can form easily. It is very difficult to produce a variety that has a resistance against all these biotypes.
- Sanitation: solanaceous plants that remain in the field after harvest are largely responsible for large numbers of aphids staying over. Therefore, an effective prevention and control measure is to eliminate as many of these sources of infestation as possible to prevent the aphids from spreading to the new crop. The crop left-overs can be buried into the soil, fed to farm animals, added to a compost heap or collected to a heap, slightly dried and burnt. Removing crop left-overs is also very valuable for disease prevention.
- Intercropping (planting rows of another crop in the eggplant field) or planting a barrier crop (growing around the eggplant field) may help reducing aphid infestation. See section 3.15.
- Trials to test the use of plastic or aluminium foil mulching to repel aphids in chili cultivation have been conducted in Malaysia. The best repelling material was aluminium painted plastic sheet, followed by silvery, white, and yellow plastic sheets. This practice is particularly valuable for crops that are susceptible to virus diseases transmitted by aphids and thrips. See section 3.11.4 and box in section 5.6 under prevention activities.

Once aphids are present in the field:

- Aphid populations build up rapidly but locally. It is important to monitor plants regularly, both in seedbeds and in the field. When aphids are found but the number of infested plants is low and at the same time there are natural enemies like ladybeetles present, no additional control measures are necessary. Remember that low pest insect populations are needed to attract and to feed natural enemies! Monitor the field regularly to check population growth.
- On a small scale, aphids can be washed off the plants with water or with a soap solution. See section 4.11.6.

- Small populations can also be removed by picking the infested leaves by hand and destroying these.
- When large populations of aphids are present in the field at an early stage (newly transplanted or young plants) and the weather is warm and dry, chances are that the aphid population will expand very quickly. Monitor the field closely for presence of natural enemies (particularly ladybeetles, and aphid “mummies” and in wet season: fungi (see chapter 6)). When there are large numbers of natural enemies, do not apply insecticides but continue monitoring. When natural enemy populations are low compared to the aphid population, and removal by hand is not feasible, consider localized sprays. See next point.
- There are insecticides that control aphids. However, insecticides can kill ladybeetles and many other natural enemies of aphids and other pest insects! Balance the benefits of spraying against the harm done to the beneficials! When applying insecticides is considered necessary, apply only on those plants that have aphid colonies, not on all plants. This reduces the amount of pesticides needed and may save at least part of the beneficials present in the field.
- Some botanical extracts are reported to control eggplant aphids. For example, an extract of lemongrass prepared by grinding 10 g of green leaf in 1 liter water caused reduction in aphid population in trials in India (Asari, 1974). Neem kernel oil is another botanical regularly used for aphid control. It should be noted that botanicals may also destroy natural enemies. This can be tested in an insect zoo. See box in section 4.9.

Points to remember about aphids:

1. Good crop sanitation, healthy plants, intercropping, and use of reflecting mulches may all help prevent or delay aphid infestation.
2. Aphids have many natural enemies, e.g. ladybeetles, hoverfly larvae, several parasitoid species, and fungi (in the wet season).
3. Aphids can be controlled by hand rubbing, application of botanicals, or spot application of insecticides (only when infestation is severe at early vegetative growth stages), and they can be washed off with water or soap solutions.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual

- 4-D.1. Predation on sucking insects in insect zoo
 4-D.2. Cage exclusion of natural enemies in the field
 4-D.3. Screen caging in nursery
 4-D.6. Use of light reflective mulch to manage thrips and/or aphids

5.6 Thrips - *Thrips* sp.

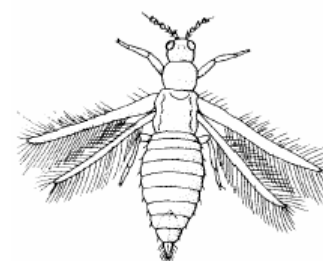
See photos 12, 13 (page 176).

Various species, most commonly *Thrips tabaci* and *Thrips palmi*.

Description

The adult thrips is a very small insect, about 1 mm long, brownish-yellow in color with two pairs of long, narrow wings (the fore-wings are longer than the hind wings), both pairs of which are fringed around their edges with hair-like structures. The nymphs are pale yellow, almost transparent when newly hatched, and similar to the adults but smaller and wingless.

There is a “pre-pupal” stage which is white in color with short wing-sheaths and antennae which are held straight in front of the head. The “real” pupa is about 1 mm long and brownish in color.



Thrips adult

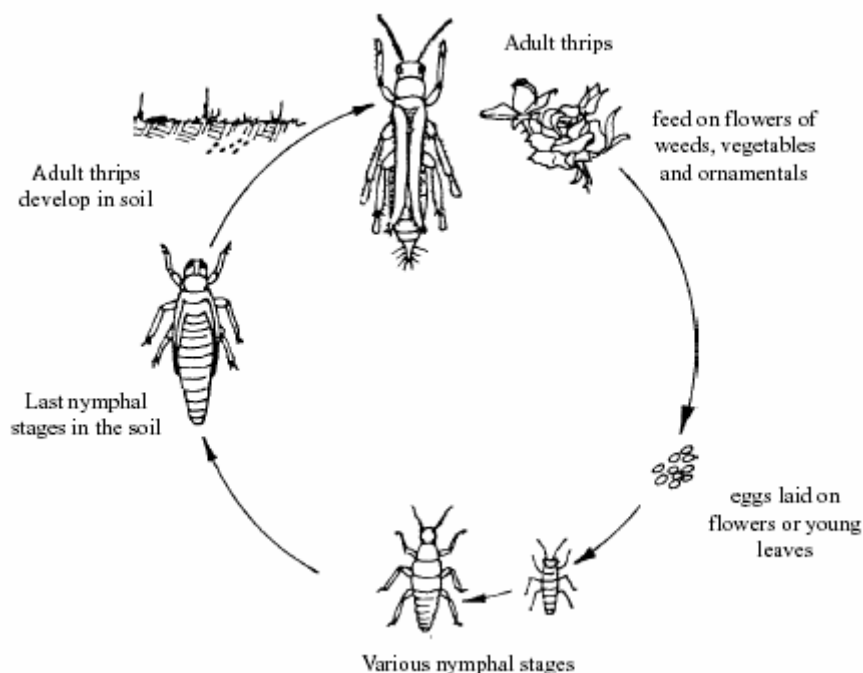
Thrips are gregarious insects and large numbers are often found together on single leaves.

The insects can be found during the day at the base of the plant, on the underside of the leaves, at the sections with healthy tissue that border areas of brown or damaged tissue. Pupae are found in the soil. Thrips move frequently to new locations to make more feeding incisions. They fly weakly, but they may be carried great distances on wind and air currents.

Life cycle

Eggs are laid in notches of up to 100 eggs within the tissue of the leaves and stems of young plants. They are white, and take 4-10 days to hatch.

Thrips develop through two nymphal instars, a prepupal form and one or two more or less immobile pupa-like stages. These developmental stages are of similar general appearance to the adults but without wings.



Life cycle of thrips (from: Kerruish et al, 1994)

Nymphs moult twice in about five days, they are white or yellow. The nymphs usually can be found among debris or in the surface layers of the soil before changing to prepupae. After about 2 days, prepupae change into pupae. These resting stages do not feed but are capable of slow movement in response to suitable stimuli e.g. they tend to avoid light. Pupation occurs in the soil, usually at the base of the plant.

The life-cycle spans about 3 weeks. There are generally several generations per year. Warm, dry weather favors thrips development.

Host range

Thrips are polyphagous and have been recorded on more than 300 species of plants, including watermelon, muskmelon, bottle gourd, cucumber, chili pepper, tomato, eggplant and potato crops.

Plant damage and compensation

Both nymphs and adults rasp the surface tissue of the leaves causing wounds from which flows the sap on which the thrips feeds. Damage is most obvious on the underside of the lower leaves, where areas appear brownish and dried up. Similar damage is seen along the mid-vein on the upper leaf surface. The leaves of attacked plants are silvered with blotches and may shrivel. Heavy attacks lead to stunted leaf-growth, wilted shoots, reduced fruit size and in extreme cases, death of the plants. Fruits can be damaged by small necrotic spots.

Natural enemies

- Predatory mite *Amblyseius cucumeris*. This predatory mite eats various thrips species; both hatching eggs and larvae. Predatory mites also eat spider mites, several other mites, honeydew and pollen. Very good results are obtained in various countries with release of this predatory mite for control of spider mites and thrips. In Indonesia for example, *Amblyseius cucumeris* was introduced from the Netherlands, where it is commercially available, for testing its effect on *Thrips parvispinus* on hot peppers.
- Natural enemies of *Thrips palmi* had not been recorded from Southeast Asia until they were discovered in Thailand during 1987-88. Among eight species discovered, the larval parasitoid *Ceranisus menes*, a wasp, the larval predator *Bilia* sp., and *Orius* sp., both bugs, were evaluated as effective natural enemies of *T. palmi* in Thailand. Neither classical biological control of *T. palmi* nor inundative release of its natural enemies is considered necessary for South East Asia because *T. palmi* is native to this region and should have effective natural enemies in this region. Studies in Thailand and Japan support the view that the increase of *Thrips palmi* is due to the exclusion of natural enemies after insecticide application.
- Lacewings (*Chrysopa* sp.) are predators of thrips. The green lacewing, *Chrysopa carnea*, is the most common species. Because larvae of lacewings are generalist predators, (larvae feed on thrips, whitefly, aphids, jassids, and small caterpillars) they can be used in a wide variety of agricultural crops. In various countries, lacewings are commercially available.
- There seem to be fungi that attack thrips. Fungal infestation however, requires high humidity and thrips are important mainly in the dry season. The potential for pathogens for the control of thrips seems therefore not very high.

Parasitism of thrips on eggplant in Thailand

In a field survey, 40 – 60% parasitism of thrips by *Ceranisus menes* was found in eggplant gardens, which were not treated with insecticides. In commercial production fields sprayed with insecticides, no parasitism was found. The survey also showed that the thrips population was always higher in the sprayed than in the unsprayed plots (Hirose, in Talekar, 1991).

This, at first sight controversial, phenomenon can be explained as follows. Insecticide application may kill part of the thrips population but will seldom eradicate all thrips. Parasitoids are more sensitive to pesticides and usually need more time to build up an effective population. By the time a small new population of parasitoids is build up, the thrips are already abundant and damage to the crop may occur.

AND, to make it all worse: in fields where thrips were not a problem before, they can become a major pest after insecticide applications. Again, this is because the natural enemies of thrips are killed and thrips can expand into damage causing levels.

Insecticides used for the control of pests other than thrips in fact contribute to its resurgence.... 😞

Some scientists say that the increased incidence of *Thrips palmi* in Southeast Asia could be the result of increased insecticide applications in some areas of this region for the past 10 years.

Management and control practices

Prevention activities:

- Resistant varieties: Differences in varietal reaction to thrips attack have been recorded in a number of vegetables, but not in eggplant. The erratic nature of thrips infestation makes screening for host-plant resistance in eggplant difficult. The breeding for resistance of eggplant to other insect pests such as fruit and shoot borer, which in most areas is the most serious insect pest of eggplant, should be strengthened. Crop varieties resistant to these pests will reduce the need for the use of insecticides. Non-chemical control of other pests will similarly help preventing thrips outbreaks.

- Mulching has potential in reducing thrips damage. White-plastic or silvery plastic mulch can reduce thrips infestation considerably. See box below. However, these mulching materials are expensive. Straw mulch can also be used. Colored paper or colored plastic sheets attract thrips.

Reflecting mulches to prevent aphid and thrips infestation?!?

In countries like U.S.A. (California), some farmers place aluminium film on the soil around and among plants. The reflection of (sun)light deters aphids and thrips and they will not land in the crop but fly elsewhere. For the best prevention, 50% of the soil should be covered with the reflecting mulch.

The repellency could be associated with disturbance of orientation before landing on the crop. In case of thrips, another possibility is the reduced access to suitable pupation sites in the soil under the crop (Vos, 1994).

- Flooding the field seems to have potential in reducing thrips populations, presumably drowning thrips pupae in the soil. This may be feasible in areas where vegetables are rotated with rice. Another option is to flood the field during the dry season for irrigation. When the field is flooded for longer period of time, pupae in the soil may be killed. More research is needed.
- Intercropping: there are no consistent effects reported on thrips populations. Not advisable.
- To reduce thrips infestations at seedling stage, which reduces plant vigor later on, seedlings could be raised inside a fine-mesh net cover, fine enough to exclude thrips. However, this type of screen is extremely expensive. It is only justified when problems with thrips (or thrips transmitted diseases) are severe.
- Excessive use of fertilizer which increases vegetative growth beyond the normal needs of the plant should be discouraged. Excessive growth does not increase yield but it does provide shelter for thrips.
- Avoid unnecessary applications of pesticides to prevent secondary outbreaks of thrips.

Once thrips are present in the field:

- When numbers are low, and symptoms of plant injury are not severe, no control measures need to be taken. Continue monitoring population growth and check for parasitoid presence.

Points to remember about thrips:

1. Thrips have probably become an important pest as a result of increased use of pesticides which killed the natural enemies of thrips.
2. Thrips have several natural enemies, e.g. predatory mite species, predatory bugs, and lacewings.
3. Cultural practices that help prevent/delay crop infestation include flooding the field, and use of silvery plastic mulch.
4. Avoid unnecessary pesticide applications to prevent secondary thrips outbreaks.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual

4-D.4. Thrips feeding symptom development

5.7 Leafroller - *Eublemma (Autoba) olivacea*

See photos 14, 15, 16 (page 176).

Scientific name: *Eublemma olivacea* or *Autoba olivacea*

Description

Caterpillars are purple-brown with many cream-colored hollow bumps and long hairs on the back and sides. The adult is an olive green moth that is active at night.

The caterpillar can be found inside the rolled leaf, where it chews on the leaf surface.

Life cycle

The female moth lays eggs in masses on the young leaves. Each mass may have 8 – 22 eggs. The caterpillar feeds for about 4 weeks and then pupates inside the rolled leaf. In favorable climates there may be 3 to 4 generations each year.

Host range

Solanaceous plants.

Plant damage and compensation

Young leaves are rolled lengthwise. Rolled leaves are brown and eventually dry. In heavy infestations entire portions of plants appear brown and leaf drop occurs. When the leaves turn brown or drop, the plant will have less leaf area for the energy production (photosynthesis). Less energy will result in weaker plants and lower or even no production.

At some locations plant infestation can be very high, e.g. in the late '96 season in Assam, India, 65% plant infestation was reported. In general however, leafrollers seldom pose a threat to crop development and yield.

Natural enemies

The wasp *Cotesia* sp. is a larval parasitoid of leafroller. This wasp was found in field studies in Mymensingh, Bangladesh in 1998.



Cotesia wasp on caterpillar

Management and control practices

Prevention activities:

- **Grow a healthy crop:** strong, healthy plants can resist insect pests and diseases better. Healthy plants can probably compensate for loss of leaves by leafroller. See section 4.5.
- **Changing planting dates:** Field tests in Assam, India, showed that the incidence leafroller on eggplant was lowest on late (Nov.- Dec.) planted crops (Bohra, 1995).

Once leafrollers are found in the field:

- When low numbers are found, handpicking the infested leaves and destroying them outside the field may be an option.
- Nematodes that kill insects, such as *Steinernema* sp., may be a control option when these nematodes are available. See section 6.3.4 on nematodes.



Points to remember about leafroller:

1. In general, leafrollers seldom pose a threat to eggplant crop development and yield.
2. Handpicking and destroying infested leaves helps reduce populations.
3. The parasitoid *Cotesia* sp. has been found parasitizing leafroller larvae.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual

- 4.1. Insect zoo – life cycle study
- 4-A.3. Plant compensation

5.8 Whitefly - *Bemisia tabaci*

Bemisia tabaci is a very common species of whitefly. However, there are several other species of whitefly, for example *Aleurodicus dispersus* (spiraling whitefly), and *Trialeurodes vaporariorum* (common whitefly).

Other common names: tobacco whitefly, cotton whitefly or sweet potato whitefly.

Description and life cycle

The adult whitefly is very small: about 1 mm long, silvery-white in color and with wings of a waxy texture. It is found often on the underside of the foliage where it sucks the plant sap.



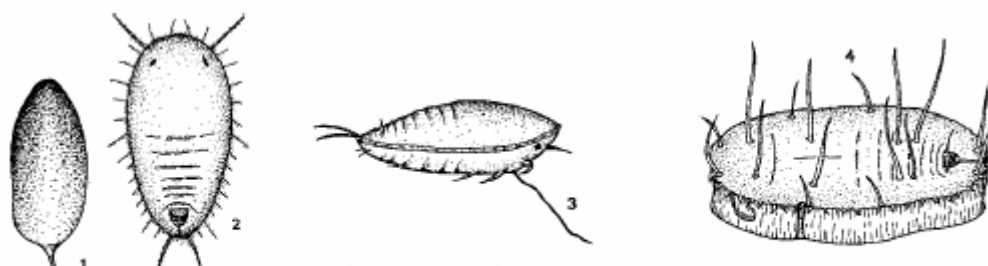
Adult whitefly

(from: Kerruish et al, 1994)

When a plant containing whiteflies is shaken, a cloud of tiny insects flutter out but rapidly resettles. The adult has 4 wings and is covered with a white, waxy bloom. Adults can fly for only short distances but may be dispersed over large areas by wind. Females usually lay their first eggs on the lower surface of the leaf on which they emerged, but soon move upwards to young leaves. The female may lay 100 or more eggs. The egg is pear-shaped and about 0.2 mm long. It stands upright on the leaf. The eggs are anchored by a stalk which penetrates the leaf through a small hole made by the female. Water can pass from the leaf into the egg, and during dry periods when there are high numbers of eggs, the plant may become water-stressed.

Eggs are white when first laid but later turn brown. Early in the season, eggs are laid singly but later they are laid in groups. They hatch in about 7 days.

When the nymphs hatch they only move a very short distance before settling down again and starting to feed. Once a feeding site is selected the nymphs do not move. All the nymphal instars are greenish-white, oval and scale-like. The last instar (the so-called "pupa") is about 0.7 mm long and the red eyes of the adult can be seen through its transparent back. The total nymphal period lasts 2 - 4 weeks depending on temperature. Nymphs complete 3 moults before pupation.



1. Egg (actual size about 0.24 mm long)
2. & 3. Top and side view of 1st stage nymph
4. 4th stage nymph (actual size about 0.75 mm long)

(from: Kerruish et al, 1994)

Eggs and early instar nymphs are found on the young leaves and larger nymphs are usually more numerous on older leaves.

Attacks are common during the dry season. Whiteflies disappear rapidly with the onset of rain.

Host range

Whitefly species currently are known to attack over 500 species of plants representing 74 plant families. They have been a particular problem on members of the squash family (squash, melons, cucumbers, pumpkins), tomato family (tomato, eggplant, potato), cotton family (cotton, okra, hibiscus), bean family (beans, soybean, peanuts), and many ornamental plants.

Plant damage and plant compensation

Direct crop damage occurs when whiteflies suck juices from the plant. With high populations plants may wilt, turn yellow and die.

Whiteflies also excrete honeydew, a sweet sticky fluid which may cover the leaves completely. On this honeydew, mould fungi grow and the leaves may turn black in color. This reduces the capability of the leaves to produce energy from (sun)light (photosynthesis) and may lower fruit quality.

In some hosts, damage can result from whitefly feeding toxins that cause plant disorders such as irregular ripening of tomato. Plant viruses also can be transmitted by whiteflies, such as leaf curl in tomatoes. Plant disorders and virus transmission are of particular concern because they can occur even when a whitefly population is small. There are no records of any virus transmission by whiteflies in eggplant.

Natural enemies

There can be many indigenous natural enemies of whiteflies in your area.

Natural enemies of whitefly, to name but a few....

Studies carried out between 1985 and 1987 in Andhra Pradesh, India, on cotton showed the occurrence of nymphal parasitism of whitefly due to the parasitoid wasps *Eretmocerus serius*, *Eretmocerus* sp. and an unidentified parasitoid wasp. Populations of predators included the coccinellids *Brumoides suturalis*, *Verania vincta*, *Menochilus sexmaculatus*, *Chrysoperla carnea*, and the predatory mite *Amblyseius* sp. Fungal pathogens found included *Aspergillus* sp., *Paecilomyces* sp. and *Fusarium* sp. (Natarajan, 1990)

• predators

Whiteflies are controlled by predatory insects such as green lacewing (*Chrysopa* sp.) or ladybeetles (Coccinellidae).

The predatory bug *Macrolophus caliginosus* is another known predator of whitefly and to a lesser extent spider mites, aphids, moth eggs, leafminer larvae and thrips. Bug populations develop most rapidly on whitefly. Adult bugs can also survive for some time on plant saps. In countries like the U.S.A. *Macrolophus* is a commercially available natural enemy. It is successfully released in greenhouse environments. Whether this bug occurs naturally in the tropics and how effective it is needs to be studied.



ladybeetle

• parasitoids

Whiteflies can be controlled by parasitic wasps such as *Encarsia* or *Eretmocerus* species. Parasitism can be quantified by counting the number of empty whitefly pupal cases with a circular exit hole (created by the emerging adult wasp) rather than a "T" shaped split (created by the normal adult whitefly emergence).

Numbers and activity of whitefly parasites and predators can be encouraged by avoiding broad-spectrum insecticides, planting of refuge crops, and, in some areas, augmentative releases.

• pathogens

Whiteflies can be controlled by fungal diseases such as *Beauveria*, *Paecilomyces* or *Verticillium* species. These fungi often occur naturally.

Whitefly mortality from pathogenic fungi often reaches high levels in greenhouses where relative humidity is constantly high and spores naturally accumulate. Pathogenic fungi can be applied as a spray treatment and are effective at any population density. Insect pathogens used for whitefly control must be applied with good coverage and under proper environmental conditions (high relative humidity) to be effective. The fungus *Verticillium lecanii* is commercially available in Europe for the control of greenhouse whitefly. Other products are being tested in commercial production fields and greenhouses, but the economic feasibility of their use has yet to be determined.



pathogen spores

Another fungus, *Paecilomyces fumosoroseus*, is also commercially available for whitefly control. It can be applied as a spore solution and it has some activity against aphids, thrips and spider mites.

Management and control practices

Whitefly management in a crop will depend on the severity of damage caused in that crop, and the number of whiteflies required to cause this damage. Very few whiteflies are required to transmit viruses, so where this is the major concern, a farmer will want to avoid even small numbers of whiteflies. Where low levels of whiteflies are tolerable, which is the case in most eggplant growing areas, other methods such as biological control can be more effective.

Prevention activities:

- Plant resistant or tolerant eggplant varieties where available. Some resistance has been reported from India. See table in section 3.2.2. Check local seed supplier in areas where whitefly is a serious problem.
- Proper monitoring of the whitefly population should be done regularly to detect early infestation. The easiest method of monitoring for whiteflies is leaf inspection. Sampling 100 leaves per field (one leaf on each of 100 randomly selected plants) can provide a very good estimate of the average whitefly population density in the field, but fewer samples are usually all that is needed to make a management decision. Check for natural enemies, they may be many of them!
- The movement of whitefly adults can be monitored with yellow sticky traps. This method can provide a relative measure of general population trends over an extended area. In China for example, these traps are widely used in both greenhouses and in the open field. Careful monitoring of the types and numbers of insects caught on the traps should be done as yellow traps may also attract large numbers of useful natural enemies! When this happens, the traps are better removed from the field.
- Destroy old crop residues that harbor whitefly infestations unless large numbers of natural enemies of whitefly are detected. Destroy all crops residues infected with virus.
- Susceptible crops should not be grown continuously because whitefly populations expand rapidly if there is a continuous supply of food.
- Avoid planting next to crops infested with whitefly and avoid carry-over from infested plant material.
- To protect seedlings, insect netting or screen cages of very fine wire mesh, placed over nurseries, helps reducing initial whitefly infestation of young plants. This is especially useful to prevent early infection with virus diseases, transmitted by the whitefly. Floating row covers (generally made out of a light fiber mesh and placed over newly planted crops) also exclude whiteflies during the vegetative growth of the crop. Screen cages and floating row covers work very well for early-season protection, but can be expensive. For eggplant, it is probably too expensive to consider.
- Under field conditions, there are several types of barriers that can reduce whitefly problems. These include reflective mulches that tend to repel whiteflies, oil-coated yellow mulches that act as a trap for whiteflies, and intercropping. For example, intercropping tomato with sorghum reduced whitefly population and had the best yields and effects on predators (Tumwine, 1999).
- Planting time also can be an effective tool to avoid whiteflies because they reproduce more rapidly under hot, dry conditions. Thus, planting during or shortly after rainy season allows crops to be established and even mature before conditions are favorable for rapid population increases.
- Establishing a host-free period by careful choice of planting site and date is now a commonly accepted recommendation for reducing whitefly populations in many areas of the southern U.S.A. that are severely affected by this pest. This practice requires regional cooperation to be effective.
- Avoid unnecessary applications of pesticides to prevent secondary outbreak of whiteflies (due to elimination of natural enemies).

Spraying insecticides resulting in MORE whiteflies??!!

There is a possibility that treating a resistant whitefly population with certain insecticides could actually accelerate population growth. This could be because more eggs are laid when the insect is under biochemical stress, or because natural enemies are eliminated.

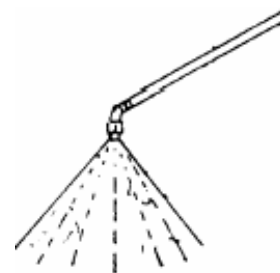
To minimize this potential problem, insecticide applications should be used as little as possible, judiciously and combined with non-chemical control tactics (ref. www25).

Once whiteflies are present in the field:

- Chemical control of whiteflies is both expensive and increasingly difficult.

Many systemic and contact insecticides have been tested for control of whiteflies, but few give effective control. Besides the cost of treatment, other factors involved in chemical control decisions are:

- the need for thorough coverage: whiteflies are located on the undersides of leaves where they are protected from overhead applications, and the immature stages (except for the first one) are immobile and do not increase their exposure to insecticides by moving around the plant,
- the risk of secondary pest outbreaks (due to elimination of natural enemies),
- the risk of whiteflies developing insecticide resistance (a very serious threat!), and
- the regulatory restrictions on the use of insecticides.



Points to remember about whitefly:

1. Whitefly is usually not a major pest in eggplant.
2. Whitefly has many natural enemies which can keep populations low.
3. Avoid unnecessary application of pesticides to prevent secondary outbreak of whiteflies due to elimination of natural enemies. Treating pesticide-resistant whitefly populations in addition, can accelerate population growth.
4. Fungal biocontrol products, where available, may offer good whitefly control under certain conditions.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual

- 4-D.1 Predation of sucking insects in insect zoo
- 4-D.7 Parasitism of whitefly
- 3-F.2 Raise seedlings in a screen cage
- 3-F.3 Application of light reflective mulch in field to manage virus incidence
- 3-F.5 Effect of sanitation on spread of virus

For more background reading and practical exercises on whiteflies, please refer to the report of CABI Bioscience: "Whitefly ecology exercises – CABI Whitefly workshop, KL, Malaysia, Sept 2000". See reference list (chapter 11) on how to obtain copies.

5.9 Red ant - *Dorylus orientalis*

Common name: Oriental army ant.

There are many species of ants. Some species have found to be good predators of pest insects, for example weavers ants (*Oecophylla* sp.).

Many predatory ants also collect honeydew (the excretion of e.g. aphids). These species often interfere with biological control measures because they may protect the aphid colony from other intruders that want to attend the aphids. The ants thus often reduce the effectiveness of other aphid predators and parasitoids.

Red ant is considered a “pest” because it can remove seeds from the seedbed, damage newly emerging seedlings, or cause injury to the shoots of eggplant.

Description and life cycle

Ants are social insects, living in colonies of variable size. There are at least three morphologically different forms: queens (fertile females), males and workers. The males are short-lived and die after the nuptial flight. Females, or queens, are also winged but lose their wings after the nuptial flight. Their reproductive organs are well-developed, and all females are able to lay eggs. The number of queens per colony may vary between a single queen and several queens. Workers are wingless female progeny, which are generally smaller than the queen. In contrast to the queens, whose sole function is to produce eggs, workers are responsible for brood care, foraging and colony defense.



Eggs are usually laid in specific egg chambers, where workers care for them. Larvae are maggots without legs and eyes. Larval development is usually completed within four instars. Adults are long-lived, with queens often reaching an age of >10 years.

Host range

Besides eggplant, the ant also attacks potato, cauliflower, cabbage, radish, turnip, groundnut and beans.

Plant damage and plant compensation

Red ant is a serious problem in some parts of India, in Mymensingh (Bangladesh) and especially in Nepal. It attacks mainly young plants. During a TOT in Mymensingh, Bangladesh (1999), participants found that ants made small holes on growing tips of eggplant shoots and fed on the sap emerging from the wound.

Red ants can also remove or damage seeds in the seedbeds.

Eggplant can probably compensate for shoot damage by ants, depending on the amount of damage and the growth stage.

Natural enemies

Unknown.

Management and control practices

In Bangladesh, traditional methods of control include:

- Use of turmeric powder. Turmeric, a perennial plant, has excellent pest repellent properties.
- Use of wood ash.
- Use of wheat flour: this distracts ants from feeding on plants or seeds in the nursery. Other scattering food pieces such as rice grains, breadcrumbs etc. can also be used. Some farmers found that the smaller the pieces of food, e.g. wheat flour, the longer it took the ants to remove them.
- Baiting the ants with paper soaked in vegetable oil.

(pers.comm. Dr. Lim Guan Soon, 2001; CAB International, Crop Protection Compendium, 2000).

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual

4-A.3. Plant compensation study

6 MAJOR NATURAL ENEMIES OF EGGPLANT INSECT PESTS

PESTS



SUMMARY

Predators, parasitoids and pathogens are the main groups of natural enemies that can control large numbers of eggplant insect pests. This is why they are called “Friends of the farmer”.

Predators: are usually generalists: not specific for one insect species or stage, in fact they may even eat other predators or “neutrals” when there is not much food available. Examples are ladybeetles, spiders, lacewings and hoverflies. Predators are often the first “line of defense” when pest insect populations build up and they follow host insect population by laying more eggs when there are more host insects available. Predators are often effective natural enemies when pest populations are high. Some species such as ladybeetles and lacewings are (commercially) available for field release.

Parasitoids: are usually specific for 1 insect and/or 1 stage, e.g. larval parasitoids attacking only moth larvae. Many parasitoids of eggplant insect pests occur naturally. Others can be introduced into the field, e.g. *Trichogramma chilonis*, for control of fruit and shoot borer. Proper field monitoring is essential to note parasitoid activity.

Pathogens: are usually specific for 1 insect and/or 1 stage, and require specific climatic conditions (usually high humidity) to be effective. Some pathogens, e.g. *Bacillus thuringiensis* (Bt) and NPV are (commercially) available for field application. Nematodes such as *Steinernema* sp. are also increasingly available for insect control and may be useful for control of fruit and shoot borer (*Leucinodes orbonalis*).

Natural enemies (NEs):

- Are easily killed by (broad-spectrum) pesticides.
- (Indigenous) NEs can be attracted and conserved by not spraying pesticides, allowing small numbers of insects in the crop, planting flowering plants or a trap crop at field borders, and providing shelter (e.g. straw bundles). Plant material carrying parasitized insects can be brought from an area with high parasitoid populations to an area with lower parasitoid density.

6.1 Predators

Predators are animals that kill and eat other animals. They can be very large animals like lions that kill and eat deers, cats that eat mice, or spiders that eat moths.

Predators usually hunt or set traps to get their prey. They can kill or consume many preys and are generally larger than their prey. They are often generalists rather than specialists and can attack immature and adult prey. When there is not enough prey around they may even eat each other!

Predators of insect pests can be divided into groups such as beetles, true bugs, lacewings, predatory flies, predatory mites and others like spiders and praying mantis.

Predators are especially important natural enemies because they can often survive when there are no insect pests around. They can switch to other food sources like crop *visitors* or *neutrals*, insects that live in the field but do not attack eggplants. They may even eat each other in times of low food availability or move to the borders of the field to find prey. Predators are therefore often the first crop defenders against pests. Predators follow the insect population by laying more eggs when there is more prey available. When no predators are around, pests that arrive in the field can easily increase their population.

In this section, a number of predators that are important for eggplant pest insect control are described.

6.1.1 Ladybeetles - *Coccinellidae*

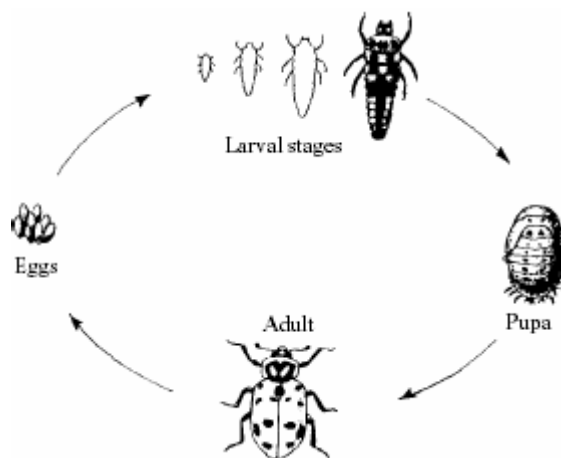
Also called ladybugs, ladybird beetles or coccinellid beetles. There are many different species of ladybeetles. However, not all ladybeetles are predators. Some, like *Epilachna* sp., are herbivores, particularly on solanaceous crops. Check feeding habits in insect zoo studies (section 4.6)!

Primary prey: aphids, mites, whiteflies, small insects, insect eggs.

Predatory stages: both adults and larvae.

Description and life cycle

Adult ladybeetles are small, round to oval in shape. The typical species present in many vegetables has black markings on red, orange or yellow forewings. Different species of ladybeetles have a different color or different markings. Both larvae and adults of ladybeetles are predators: they eat aphids, small caterpillars, mites and insect eggs. Many ladybeetles prefer a diet of aphids but may switch to other prey when there are not enough aphids. The larvae have a very different appearance from the adults. They are dark and look a bit like an alligator with 3 pairs of legs. There are usually 4 larval instars. Ladybeetles can consume many prey on a day and can also travel around quite far (larvae may travel up to 12 m) in search of prey.



Life cycle of ladybeetle (from: Hoffmann et al, 1993)

A female can lay 200 to more than 1000 eggs over several months. The more food there is, the more eggs it lays. That way, it can keep up with the pest insect populations. Eggs are usually deposited near prey such as aphids, often in small clusters in protected sites on leaves and stems. The eggs are small (about 1 mm), cream, yellow or orange in color.

The last larval instar pupates attached to a leaf or other surface. Pupae may be dark or yellow-orange in color. Pupal stage takes about 3 to 12 days, depending on temperature and species. Adults live for a few months up to a year and have several generations in a year.

Effectiveness

Ladybeetles are voracious feeders. As an adult, they may eat as many as 50 aphids per day. Each larva eats 200 to 300 aphids as it grows. They are effective predators when the pest population is high: one adult may eliminate all aphids from a seriously infested plant in just a few days. Ladybeetles are thought to be less effective when pest densities are low. There may also be some crop damage before ladybeetles have an impact on an aphid population.



Ladybeetle larva eating an aphid

Because of their ability to survive on other prey or on pollen when there are not so many aphids, ladybeetles are very valuable.

In Thailand, at Regional Institutes of Biological Agriculture and Farmers' Field Schools, ladybeetles are reared and available to farmers for field releases.

Conservation

Like many other natural enemies, ladybeetles are easily killed by broad-spectrum insecticides. Avoid the use of these pesticides as much as possible!

Ladybeetles benefit from shelter for protection from adverse weather conditions and for refuge when crops are harvested. This shelter can simply be some plants around the field.

6.1.2 Ground beetles - Carabidae

Primary prey: soil-dwelling beetles and fly eggs, larvae, pupae, other insect eggs, small larvae and soft-bodied insects, some caterpillars.

Predatory stages: both adults and larvae are predators.

Description and life cycle

There are many species of ground beetles. Adult ground beetles may be very small (about 3 mm) to large (12 - 25 mm). Many are dark, shiny beetles, often with prominent eyes and threadlike antennae. Adult ground beetles are found under stones and left-overs and they are active mainly at night. They can run rapidly when disturbed or when in search of prey. Night-active species are black. Those that are active during the day may be brightly colored or metallic in appearance.



ground beetle

Eggs are usually laid singly on or in the soil near prey, sometimes in specially constructed cells of mud or twigs. The eggs can be soft, cylindrical with rounded ends and about 0.5 mm long. Some species lay only a few eggs, others may lay hundreds of eggs. Generally, the more food there is for a ground beetle, the more eggs it lays. That way, it can keep up with the pest insect populations.

The larvae usually have large heads with large jaws for holding and piercing prey. They look very different from the adults. Most species pupate in the soil.

You can catch ground beetles with pitfall traps in the field. See section 4.11.2.

Effectiveness

The larvae and adults of several ground beetle species have been shown to eat many prey if given the opportunity. There is little field data on the efficacy of ground beetles. Their ability to cover large distances in search of prey makes them a valuable addition to other natural enemies.

Conservation

Ground beetles are easily killed by (broad-spectrum) insecticides. Avoid using these pesticides when possible.

Shelter belts can provide refuge for the adult beetles and can help them through a period of harvest and field preparations for the next crop.

6.1.3 Lacewings - *Chrysopidae*

Primary prey: aphids, spider mites (especially red mites), thrips, whitefly, eggs of leafhoppers, moths, and leafminers, small caterpillars, beetle larvae.

Predatory stages: larvae, adults of some species.

There are several species of green lacewings (*Chrysopa* and *Chrysoperla* sp.). The common green lacewing, *Chrysopa carnea*, is native to much of North America, several countries in Europe and India. *Apertochrysa* sp. was also found in India (Tamil Nadu). Another green species is *Chrysopa rufilabris*, which may be more useful in areas where humidity tends to be high. Another species is the brown lacewing, which is brown in color and about half the size of the green lacewing.



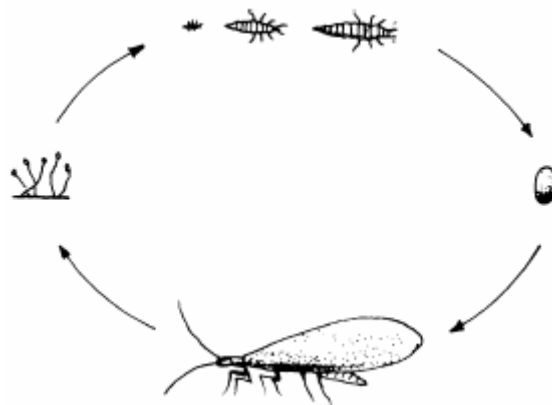
Adult lacewing

Because in several areas in SE Asia, the common green lacewing *C. carnea* is the predominant species, this important predator is reviewed in this section.

Description and life cycle

Adult green lacewings are pale green, about 12-20 mm long, with long antennae and bright, golden eyes. They have large, transparent, pale green wings and a delicate body. Adults are active fliers, particularly during the evening and night and have a characteristic, fluttering flight. Adults feed only on nectar, pollen, and aphid honeydew, but their larvae are active predators.

Oval shaped eggs are laid singly at the end of long silken stalks and are pale green, turning gray in several days. Several hundred small (less than 1 mm) eggs are laid, sometimes in clusters. The larvae, which are very active, are gray or brownish and alligator-like with well-developed legs and large pincers with which they suck the body fluids from prey. Larvae grow from less than 1 mm to about 6-8 mm, through 3 instars in about 2 – 3 weeks.



Life cycle of the common green lacewing, *Chrysopa carnea*.
(from: Hoffmann et al, 1993; www12)

Mature third instars spin round, silken cocoons usually in hidden places on plants. Emergence of the adults occurs in 10 to 14 days. The life cycle is strongly influenced by temperature: the higher the temperature, the quicker. There may be two to several generations per year.

Lacewings can be found in a range of crops including cotton, sweet corn, potatoes, cole crops, tomatoes, peppers, eggplants, asparagus, leafy greens, apples, strawberries, and other crops infested by aphids.

Effectiveness

Lacewing larvae are considered generalist beneficials but are best known as aphid predators. Laboratory studies from India show that lacewings preferred aphids to whiteflies. The larvae are sometimes called *aphid lions*, and have been reported to eat between 100 and 600 aphids each, although they may have difficulty finding prey in crops with hairy or sticky leaves.



The appetite of lacewing larvae....

In a trial from India it was found that during development, each larva of *Chrysoperla carnea* consumed an average of 419 aphids (*Aphis gossypii*), 329 pupae of whitefly (*Bemisia tabaci*) and 288 nymphs of jassid (*Amrasca biguttula biguttula*). In all cases, 3rd-instar larvae consumed the major portion of the total number consumed (60-80%) (Balasubramani, 1994).

There is potential for commercialization of *Chrysopa* sp. for use against a variety of pests and a lot of research is ongoing on rearing methods and field effectiveness in SE Asia. In Thailand, at Regional Institutes of Biological Agriculture and some Farmers' Field Schools, lacewings are reared and available to farmers for field release. In the USA and in some European countries like the Netherlands, *C. carnea* and *C. rufilabris* are available commercially, and are shipped as eggs, young larvae, pupae, and adults.

C. carnea is recommended for dry areas, *C. rufilabris* for humid areas.

Larvae are likely to remain near the release site if aphids or other prey are available. Newly emerging adults, however, will disperse in search of food, often over great distances, before laying eggs.

☺ Predator of predators....!?! ☹

Natural lacewing populations have been recorded as important aphid predators in potatoes, but mass releases of lacewings have yet to be evaluated against aphids in commercial potato production. In small scale experiments outside the United States, lacewings achieved various levels of control of aphids on pepper, potato, tomato, and eggplant, and have been used against Colorado potato beetle on potato and eggplant. On corn, peas, cabbage, and apples, some degree of aphid control was obtained but only with large numbers of lacewings. Mass releases of *C. carnea* in a Texas cotton field trial reduced bollworm infestation by 96%, although more recent studies show that *C. carnea* predation on other predators can disrupt cotton aphid control.

That's the negative side of a generalist predator.... (ref. www4).

Conservation

Because young larvae are susceptible to drought, they may need a source of moisture. Adult lacewings need nectar or honeydew as food before egg laying and they also feed on pollen. Therefore, plantings should include flowering plants (e.g. at borders of the field), and a low level of aphids can be tolerated to attract and conserve lacewings.

The green lacewing appears to have some natural tolerance to several chemical insecticides although there may be considerable variation. Populations tolerant of pyrethroids, organophosphates, and carbaryl have been selected in the laboratory. Still, when lacewings (and other natural enemies) occur in the field, it is advisable to avoid using pesticides.

6.1.4 Hoverflies - Syrphidae

Hoverflies are also called syrphid flies or flower flies.

Primary prey: aphids, small caterpillars, sometimes thrips, possibly jassid nymphs.

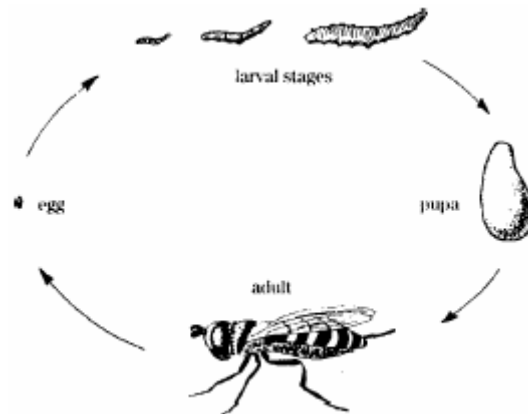
Predatory stages: only larvae of hoverflies are predators.



Description and life cycle

Adults of the hoverfly eat pollen and nectar from flowers. Only the larvae are effective aphid predators. The adult hoverflies look like bees or wasps and are usually seen near flowers. Many species have compact, flattened bodies, large eyes and black and yellow stripes on the body. They vary in size from 9 - 18 mm.

The female lays single, small (about 1 mm), white eggs that lie flat on leaves or shoots near or among aphid populations. Females can lay several hundred eggs. The larvae hatch in 2 - 3 days. The larvae are small maggots without legs, they look more like tiny slugs than adult hoverflies. They vary in color from cream to green to brown, depending on the species and the prey consumed. There are 3 larval instars. The larvae suck out the inside liquids of aphids and small caterpillars until only the skin remains!



*Life cycle of a hoverfly
(from: Hoffmann et al, 1993)*

In about 2 weeks, the larva develops into a pupa which usually is pear-shaped and is cream, green or brown in color. The pupa is attached to leaves or stems, sometimes in the soil.

The period from egg to adult varies from 2 to 6 weeks, depending on the temperature, species and availability of aphids. If there are many aphids for the hoverflies to eat, there can be more generations.

Effectiveness

Larvae of the hoverfly are voracious eaters. One larva may eat up to 400 aphids during its development! On a small scale, larvae can keep aphid populations in check but it is unknown if they manage to control aphids in large fields.

Life cycle and predation efficacy hoverfly: a study example

When you know how many prey the different larval instars of the hoverfly larvae eat in a day, you can calculate the efficacy during the whole larval stage. Collect the smallest sized hoverfly larvae that you can find (using a wetted hair brush to handle them). Rear them in separate pots (or they might eat each other!) and feed them with fresh aphids every day. Handle the hoverfly larvae as little as possible. Observe the changes in size, color and shape as the larva develops and note down the duration of each larval stage. Count how many days it takes for the hoverfly to develop into a pupa. Once it has become a pupa, it stops feeding.

Calculate the total number of prey consumed of one larva with the results of the previous trial (number of prey consumed per day per life stage x number of days the life stage takes).

Conservation

As for almost all natural enemies, hoverflies are easily killed by broad-spectrum insecticides. Avoid use of these pesticides when possible.

Adult hoverflies need flowering plants to feed on. They are attracted to weedy borders and garden plantings. Flowers have an important function in attracting hoverfly adults. See also section 4.9 on conservation of natural enemies.

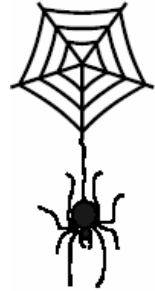
6.1.5 Spiders - Araneae

Primary prey: aphids, mites, moths, flies and beetles, depending on the species of spider. They may also attack other natural enemies.

Predatory stages: nymphs and adults.

Description and life cycle

Spiders are not insects but belong to the order of Araneae which have 8 rather than 6 legs. There are many species of spiders and they can be roughly divided into two main groups: spiders that hunt in search of prey and spiders that make webs and wait for prey to be caught in the web. Both types are very common predators in a vegetable field and they can be very voracious. Most hunting spiders are very mobile and spend a lot of time searching for prey. Web-makers are important predators of flying insects like moths.



Like many other predators, the more prey spiders can consume, the more eggs will be laid by the female. This allows these predators to increase their numbers when the pest population increases.

The number of eggs spiders can lay varies from a few to several hundreds, depending on the species. Some spiders carry the eggs in a little sac until the young spiders hatch from the eggs (e.g. wolf spiders – *Lycosidae*). Others guard the location where the eggs are deposited (e.g. lynx spiders) or place the egg mass in the web or on leaves, covered with fluffy silk. Spiders may live up to 4 months, depending on the species.

Effectiveness

Spiders are voracious predators: it depends on the species how many prey it can eat on a day. Some spiders can eat as many as 5 large insects per day!

Conservation

Mulching, especially organic mulch, can increase the number of spiders in vegetable crops because spiders can hide in the layer of mulch and they find protection from sun and rain. Spiders are easily killed by broad-spectrum insecticides. Avoid using pesticides as much as possible.



6.1.6 Praying mantids - Mantodea

Also called praying mantis. Several species of mantids are found in vegetables.

Primary prey: flies, bees, moths and small spiders.

Predatory stages: nymphs and adults are predators.

Description and life cycle

Both adult and nymphs have large front legs which they hold in a “praying” position. The nymphs look like small adults. The swaying motion allows the mantid to judge how far away its prey is.



Adult praying mantid

The adults are good flyers and can travel long distances. Adults are light green to brown in color and can be 5 - 10 cm long. The eggs are placed in a papery mass ("egg case") attached to a twig.

Effectiveness

Mantids can eat many large insects per day. They do not normally actively search for prey but remain stationary until a suitable prey comes near enough to be attacked and captured. Mantids are not generally considered to be important in regulating insect pest populations.



mantid egg mass

Conservation

Like most natural enemies, praying mantids are easily killed by broad-spectrum insecticides. Avoid use of these pesticides when possible.

When the egg cases of praying mantids are seen attached to trees or places outside the field, they may be carefully removed and placed in the eggplant field. The young nymphs may start feeding on pest insects of eggplant.

6.1.7 Predatory mites

Primary prey: spider mites, thrips.

Predatory stages: nymphs and adults.



Adult predatory mite

Description

Mites are not insects but belong to the order of Araneae which have 8 rather than 6 legs. They are closely related to spiders. Adults have four pairs of legs and two, rather than three, body parts. The species best known to farmers are the plant-feeding spider mites. There are, however, many species of beneficial predatory mites, several of which are mass reared commercially for the management of spider mites, thrips, and other pests in greenhouses and some field-grown crops. They are predatory in both the nymph and adult stages. Predatory mites are one of the most successful commercially available biological control agents of mites.

Predatory mites are about the same size as spider mites, usually teardrop-shaped, long legged when compared to spider mites, and often orange-red, tan, or brown. They move quickly through and around spider mite colonies in search of prey and, unlike spider mites, can move backwards as well as forwards. Eggs are usually oval-shaped and a little larger than the spherical eggs of spider mites. Predatory mite nymphs resemble small adults.

Predatory mites can be found in most crops attacked by spider mites and thrips.

Predatory mites attack all stages of spider mites. Sometimes different species of predatory mites have preference for one or more species of spider mite. Many predatory mite species may also prey on other small insects such as immature thrips, and insect eggs. Predatory mites can also survive on other mites and pollen and can survive for a number of weeks without food.

The most common predatory mite species are:

- *Phytoseiulus persimilis*. An orange-red mite, about 1 mm long. This mite cannot fly but moves around much quicker than the spider mites. In India, this predatory mite has proved to be effective against spider mite in okra and lablab. Also in many European countries and in the USA, this predatory mite is commercially available for release in greenhouses or in the field. Results in greenhouses are very good and hardly any pesticides need to be applied for spider mite control. *Phytoseiulus* needs high humidity for effective mite control.
- *Amblyseius tetranychivorus*, indigenous in India, was also found effective against spider mite in okra.
- *Amblyseius cucumeris*. This predatory mite eats various thrips species; both hatching eggs and larvae. Predatory mites also eat spider mites, several other mites, honeydew and pollen.

Life cycle

The time from egg to adult can range from a few days to weeks, depending on the temperature, humidity, and species. The commercially available species often have high rates of reproduction and short generation times, and are able to match the life cycle of their prey reasonably well. Most commercially available species do not overwinter in cold climates.

In a trial done in Korea, the average longevity of adult females of *Phytoseiulus persimilis* ranged from 16 to 24 days. One successful mating was found to be sufficient for a lifetime's egg production in *P. persimilis* females. The female adults lay 22 to 82 eggs during their lifetimes. Generally the higher the temperature, the more eggs are produced. The results from several studies show that although higher temperatures favor faster development of the pre-adult stages, survival, oviposition and fecundity of females were adversely affected. The most favorable temperature for quick population growth of the predatory mite *Phytoseiulus* was 30°C. Temperatures higher than 35°C reduce population growth.



Effectiveness

Predatory mites can seek out prey in places that may be inaccessible to chemical sprays. These beneficial mites are used against spider mites and several species of thrips by greenhouse flower, ornamental, and vegetable producers in Canada and Europe, and by some United States farmers. Predatory mites are particularly successful in greenhouses partly because of the high degree of control that the farmer has over the environment. However, several predatory species also have been used successfully to suppress spider mites in United States apple, citrus, and avocado orchards and also in field-grown strawberries and raspberries in California. Numerous examples of successful release of predatory mites are reported from Asia.

Some species of predatory mites, particularly *Phytoseiulus*, are among the few biological control agents that will eat all their prey and starve if they cannot locate new colonies of spider mites.

Monitoring the crop is therefore important to ensure proper timing and placement when releasing the predators. It may be necessary to reintroduce the predatory mites if the pest population reoccurs. The ability of predatory mites to seek out prey can be hindered on plants with hairy stems or leaves.

Conservation

Spider mite and thrips populations are resistant to many of the chemicals used against them. Predatory mites are often very susceptible to these same chemicals. In fact, spider mites only became important agricultural pests after the widespread use of broad-spectrum insecticides in the 1950s and 1960s. Pyrethroid sprays, in particular, are known to cause spider mite outbreaks due to the elimination of natural enemies and physiological effects on the mites. Also several brands of fungicides that are applied for disease control, have been shown to harm predatory mite populations. This is caused by a repelling effect on predatory mites and by inhibited egg laying, reduced longevity and reproduction of predatory mites.

Spot spraying of localized outbreaks of thrips and spider mites with short-residual chemicals that are compatible with the predatory mites or, on a small scale, with insecticidal soap or horticultural oil may help to keep infestations under control while the predatory mite population establishes.

Strains of some beneficial mites that are tolerant of organophosphorous and carbamate insecticides, sulfur, and pyrethroids have been selected. Some of these strains are commercially available.

6.2 Parasitoids

There is often confusion between the terms *parasitoid* and *parasite*. Insect parasitoids are organisms that have an immature life stage that develops on or inside a single insect host, consuming all or most of its tissues and eventually killing the host. This is why parasitoids are important as natural enemies of insect pests. Adult parasitoids are free-living.



parasitoid laying egg in pupa

A parasite also lives in or on another organism (the host) during some portion of its life cycle, but this does not always lead to the death of the host.

Most beneficial insect parasitoids are wasps but there are also flies and other insects that are parasitoids.

Parasitoids are usually smaller than their host and they are specialized in the choice of their host. They usually attack only one stage of the host insect: eggs, larvae or pupae. Parasitoids are often called after their stage preference, for example “egg parasitoids” attack only eggs of a particular insect. Only females search for hosts, they usually lay eggs in or near the host.

SEX: male or female...? ♂ ♀

In wasps, the sex of a parasitoid off-spring is determined differently than for other animals. In parasitic wasps, females come from fertilized eggs and males come from unfertilized eggs. So if a female does not mate with a male wasp, she will produce only males. If she does mate, she will produce a mix of both males and females, usually more females. And that is important because only females are able to parasitize other insects! Males are only useful for mating...!

Whereas insect predators immediately kill or disable their prey, pests attacked by parasitoids die more slowly. Some hosts are paralyzed, while others may continue to feed or even lay eggs before they die from the parasitoid attack. Parasitoids, however, often complete their life cycle much more quickly and increase their numbers much faster than many predators.

Parasitoids are following the pest population. Unlike predators, they cannot increase their own population without their host insects. It is therefore always good to have at least a few pest insects in the field. They serve as food and as a host for the natural enemies!

Parasitoids can be the dominant and most effective natural enemies of some pest insects, but because they are so small, their presence may not be obvious. This is why it is so important to monitor fields or the *friends or the farmer* will never be noticed, in fact, will perhaps be treated with pesticides instead of gratitude!

A parasitoid parasitized??

Yes, unfortunately, it is possible: a parasitoid of insect pests can be parasitized by other parasitoids: this is called *hyperparasitism*. Hyperparasitoids are even smaller than parasitoids. Hyperparasitism can be common, and may reduce the effectiveness of some beneficial species, especially in case of introduced natural enemies (those natural enemies that are brought into a field from outside). Little can be done to manage hyperparasitism. ☹

The life cycle and reproductive habits of beneficial parasitoids can be complex. In some species only one parasitoid will develop in or on each pest while in others hundreds of young larvae may develop within a single host.

Most parasitoids only attack a particular life stage of one or several related species. The immature parasitoid develops on or within a pest, feeds on body fluids and organs, and either comes out of the host to pupate or emerges from the host as an adult. The life cycle of the pest and parasitoid can coincide, or that of the pest may be altered by the parasitoid to accommodate its development.

To determine if there is any parasitism and to what extent, it is often necessary to rear samples of pest insects to see if any adult parasitoids emerge. See section 4.3.

Some parasitoids take longer to develop than their host. To study these parasitoids, it is important to be able to rear the collected egg masses or immature stages of the insects. If collected material is kept in suitable containers or cages, be sure to keep specimen for at least one month and even after it looks like everything has already emerged.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual

1.6 Show effects of beneficials incl. natural enemies

6.2.1 *Trathala* sp.

Host: eggplant fruit and shoot borer, many other insects – larvae.

During trials in Bangladesh, the small wasp *Trathala* sp. was found laying eggs inside the larvae of eggplant fruit and shoot borer (FSB). Instead of an FSB adult, one small wasp adult emerges from one FSB pupa. This wasp was only found in the unsprayed plots, as it was very sensitive to chemical pesticide sprays.

Parasitism levels of FSB larvae by *Trathala* mostly remain low. In a 1998 field study in Bangladesh, parasitism of FSB by *Trathala* sp. was less than 20% overall. Similarly, in field studies in India, parasitism of FSB larvae by *Trathala flavo-orbitalis* reached a maximum of 20% in July-August. Other records from India (Haryana) mention a peak in parasitism of 18% of the FSB larvae (Naresh, 1986), and in Bihar, parasitism by this wasp in the field varied from 3.5% in February to 9% in November (Mallik, 1989).



Adult *Trathala* sp.

The ichneumonid wasp *Trathala flavo-orbitalis* is an often reported parasitoid of several important agricultural pests. It was found to be a parasitoid of the eggplant fruit and shoot borer in several countries in Asia, e.g. India and Sri Lanka. The little wasp is also found to be parasitizing other important insect pest species including the rice leaffolder *Cnaphalocrocis medinalis*, the cabbage webworm, *Hellula undalis*, the sesame pest *Antigastra catalaunalis* and even a pest of pear, *Numonia pyrivorella*.

Some of the research findings with regard to life cycle and development of *Trathala flavo-orbitalis* are summarized below. Most of this research has been done in laboratories, not in the field.

The FSB has five larval instars (some references claim there are 6 instars). All instars were 'attacked' by *Trathala*, by laying eggs into the larva (stinging). All first and about 50% of 2nd-instar larvae that were stung were mutilated and died as a result. Successful parasitoid development up to adult emergence occurred mostly in 3rd-, 4th- and 5th-instar host larvae. When given a choice of instars for oviposition, *T. flavo-orbitalis* avoided all 1st- and most 2nd-instar larvae, while 3rd- to 5th-instar larvae were equally accepted (Sandanayake, 1992).

The ovipositor (egg-laying tube of a female insect) of *Trathala* is quite long and the female is able to locate a larva inside an eggplant fruit. The parasitoid can sting through the fruit and put its egg into the larva inside a fruit. When eggplant fruits are large, the parasitoid is probably not able to reach larvae inside the fruits.

The total time for development of the parasitoid was about 20-24 days and this was similar whichever larval instar (2nd to 5th) was parasitized. The parasitized host at pupation contained different stages of the parasitoid, differing in this respect from most other species of larval-pupal parasitoids. Parasitism increased the host pupal period to 11-18 days, as compared with 6-14 for healthy pupae. Adult parasitoids lived for 4-7 days in the laboratory (Mallik, 1989).



Adult *Trathala* sp.
(from: AVRDC,
www35)

Research findings suggest that *Trathala* may be a valuable addition to natural control of the eggplant fruit and shoot borer. However, more field data are required to determine effectiveness.

6.2.2 *Eriborus sinicus*

Host: eggplant fruit and shoot borer - larvae

Eriborus sinicus, an ichneumonid wasp, is a parasitoid of eggplant fruit and shoot borer (FSB). In a field study by AVRDC, a large vegetable research institute in Taiwan, it was found that this little wasp is a potential natural enemy of FSB. Whether this natural enemy is native to other regions in Asia and what its efficiency is for control of fruit and shoot borer has yet to be determined.

6.2.3 *Pediobius foveolatus*

Host: *Epilachna* beetle – larvae and pupae.

This little wasp is a parasitoid of various *Epilachna* beetle species, including the Mexican bean beetle, *Epilachna varivestis*. It is native to India and China, and has been recorded in Bangladesh, Japan, Hong Kong. Possibly it occurs in other countries in Asia as well. It has been successfully released for example in Mariana Islands for the control of the Philippine ladybeetle, *Epilachna philippinensis*, on tomato and eggplant (Chiu, 1993). See box in section 5.2.

The parasitoid is able to parasitize all larval stages of the *Epilachna* beetle but prefers later instars. Parasitized larvae change color from yellow (unparasitized) to tan – brown. This color change is very distinct and can be easily recognized in the field. Parasitized larvae can be found at the underside of leaves and are very firmly attached to the leaf surface.

Peak incidence of the parasitoid on eggplant in India occurred in June at locations Hoskote (South India) and October in Hebbal and Kengeri. In Bangladesh, peaks were reported in July – August. The time taken by the parasitoid to complete one generation was 11-17 days during September-October and 10-13 days during March-April.

Pediobius foveolatus parasitized 3.3-62.0% of the larvae of the coccinellid *Epilachna ocellata* collected from bitter gourd fields during kharif in Madhya Pradesh, India (Dhingra, 1986).

Other studies report that the average number of parasitoids emerging from *Epilachna* larvae under laboratory conditions was 20.2 and from field-collected larvae was 9.6; an average of 12.4 parasitoids emerged from parasitized pupae. The life-span of adult male and female parasitoids was 8 and 10 days, respectively (Patalappa, 1979).

6.2.4 *Tetrastichus* sp.

Host: *Epilachna* beetle – eggs, and larvae.

Tetrastichus, a wasp, is a parasitoid of *Epilachna* beetle eggs, and larvae. In a field study during the rainy season in Madhya Pradesh, India, the wasp *Tetrastichus ovulorum* parasitized 19.3-45.5% of the eggs of the coccinellid *Epilachna ocellata*, collected from bitter gourd fields (Dhingra, 1986). In Sumatra, Indonesia, two species of *Tetrastichus* were found to parasitize the eggs of *Epilachna vigintioctopunctata* on eggplant (Nakamura, 1988).

Tetrastichus sp. are usually metallic blue-green tiny wasps of 1 – 3 mm long. The adults of some species also feed extensively on beetle eggs, leaving collapsed shells that fall from the plant after several days. More than 50% of the host eggs may be damaged. Several wasp larvae develop in each beetle larva. The majority of parasitized beetle larvae may drop from the foliage to form a pupal cell in the ground. They fail to pupate and ultimately, the adult wasps emerge.

A negative point is that species of *Tetrastichus* have been found to parasitize larvae and pupae of the beneficial green lacewing *Chrysopa carnea*, and the beneficial ladybeetle *Coccinella septempunctata*.



6.2.5 *Ceranisus menes*

Host: thrips

In a survey of natural enemies of the thrips species *Thrips palmi* on eggplant in Thailand, the wasp *Ceranisus menes* was found to be the most effective natural enemy. Similarly, *Ceranisus menes* was found on thrips infesting eggplants in Japan (Hirose, 1992). Parasitism by this small wasp was limited to home gardens which were not sprayed with insecticides (Hirose, 1993).

Other researches have found *Ceranisus menes* to be a parasitoid of other thrips species like *Frankliniella occidentalis*, an important pest of greenhouse vegetables in Europe.

Ceranisis menes has been reported from various other countries such as India, Taiwan, and Italy, Spain, Benin (Africa), and USA. *Ceranisis* has been found in association with larval populations of the thrips *F. occidentalis* and other thrips species in several crops.

Strains of *C. menes* collected worldwide are different in biology and behavior, according to their phenotype and geographical origin. There are strains with yellow and with brown abdomen. Yellow strains were generally more effective, produced more offspring but showed a greater variation in development time than brown strains. As host (thrips) size increased, fewer larvae were attacked and parasitized successfully (Loomans, 1995).

Parasitoid development and reproduction depended on temperature. Under laboratory conditions, the development of this parasitoid took 23-30 days at 25°C and 28-34 days at 20°C. Temperatures above 29°C increased mortality of the parasitoid. Development was synchronized with larval development of the host. In rearing units, 35-105 hosts were parasitized per female (Loomans, 1991).

More study is needed to investigate effectiveness of this beneficial wasp under field conditions in SE Asia.

6.2.6 *Trichogramma* species

Trichogramma wasps are usually well-known because there are so many members that are important natural enemies of agricultural pests. Most of them have a wide host range, especially among the moths. Some of the important *Trichogramma* wasps are:

- *Trichogramma chilonis*: parasitoid of borer insects such as tomato fruitworm (*Heliothis armigera*), corn borer (*Ostrinia nubilalis*), eggplant fruit and shoot borer (*Leucinodes orbonalis*).
- *Trichogramma japonicum*: parasitoid of eggplant fruit and shoot borer (*Leucinodes orbonalis*).
- *Trichogramma evanescens*: parasitoid of the cabbage moth (*Mamestra brassicae*).
- *Trichogramma ostriniae*: parasitoid of corn borer (*Ostrinia nubilalis*), corn earworm (*Heliothis armigera*), cabbage looper (*Plusia* sp.), and diamondback moth (*Plutella xylostella*).
- *Trichogramma pretiosum*: parasitoid of many vegetable insect pests.
- *Trichogramma nubilale*: parasitoid of the European corn borer (*Ostrinia nubilalis*).



Trichogramma

Several species have been mass-reared for use in biological control programs. In some countries, *Trichogramma* wasps are commercially available often subsidized by the government. They may also be available from research institutes for trial purposes.

For example in field trials in the Philippines, several species of *Trichogramma* were evaluated for control of fruit and shoot borer of eggplant (*Leucinodes orbonalis*). *T. chilonis* gave the highest parasitism. *T. chilonis* is mass-produced in the Philippines by both government and private sector to control many lepidopterous pests, especially borers such as corn borer, tomato fruitworm, cacao pod borer, sugar cane borer, and rice stem borers. *Trichogramma* pupae are glued to cards ("Trichocards") and clipped to plant parts at several locations in the field (FAO – Dalat report (V. Justo), 1998).

Description and life cycle

Trichogramma wasps are all egg parasitoids. The adult wasps are very small, mostly less than 0.5 mm! Most people have never seen the adults: you need a good lens to even spot them. The presence of the wasps is usually recognized by the parasitized egg masses. The adults are often yellow or yellow and black in color, with bright red eyes, short antennae and a compact body.

A female wasp lays one or more eggs in an egg of the host insect, and one or more parasitoids develop. *Trichogramma* wasps pupate inside the host egg. Eggs usually turn black as the parasitoid develops inside. A small hole in the black host egg indicates that the wasp has emerged.

Development of the parasitoid is favored by warm temperatures and many generations may be produced each season.



Female *Trichogramma* wasp
lays eggs in host egg

Effectiveness

Trichogramma are particularly good natural enemies because they parasitize and kill the pest in the egg stage, before the crop is damaged. Activity of *Trichogramma* can be recognized by monitoring black (=parasitized) egg-masses.

Naturally occurring populations of *Trichogramma* species are known to be important control agents of many crop pests. *Trichogramma* wasps that are mass-reared for release in the field sometimes give ineffective parasitism for many reasons. The choice of host species is one factor. They are sometimes reared on other insects than the ones they should parasitize in the field and this may result in adults that are not able to recognize and parasitize the pest. Also, the field conditions at the time of release are important: there should be host eggs present, heavy rain shortly after the release will wash off the parasitoid eggs, etc. The number of wasps released (the release rate) is another important factor. *Trichogramma* wasps are usually released on small cards containing parasitized egg masses ("Trichocards"). Check with supplier how many cards are needed for a field and where they should be placed.

Regular field monitoring is essential for the success of *Trichogramma*.

Conservation

Spraying insecticides, especially broad-spectrum insecticides, is the surest way to eliminate the tiny wasps. When *Trichogramma* is active (and especially when it is released into the field) and black parasitized egg-masses are found in the field, avoid spraying insecticides.

6.3 Pathogens

Pathogens are bacteria, viruses, fungi, and nematodes. Insects, like humans and plants, can be infected with pathogens which cause diseases. Insect pathogens generally kill, reduce reproduction, slow the growth or shorten the life of a pest insect. Under certain conditions, such as high humidity or high pest populations, these pathogens can cause disease outbreaks that reduce an insect population. This is why such pathogens can be considered *natural enemies* of insects. Most insect pathogens are specific to certain groups of insects and certain life stages of the insect. Some microbial insecticides must be eaten by the target pest to be effective, others work when in contact with the target pest.

Unlike chemical insecticides, microbial insecticides usually take longer to kill or weaken the target pest.



Most insect pathogens are not harmful for other beneficial insects, 😊
and none are toxic to humans.

Pathogens are most effective when pest populations are very high. Pathogens are difficult to manage because their presence and effectiveness strongly depends on factors like temperature and humidity.

Most pathogens are too small to be seen by human eyes. Only the symptoms that insect-pathogens cause can be seen with the eyes: for example a dead insect covered with fungus spores like "hairs" or "dust" or a dead insect which is black and spills fluid out of the body.

Some pathogens have been mass produced and are available commercially for use in standard spray equipment. These products are often called biocontrol agents, microbial insecticides, microbials, bio-insecticides or biopesticides. Some of these microbial insecticides are still experimental, others have been available for many years. The best known microbial insecticide is probably the bacterium *Bacillus thuringiensis* or Bt which is available in many different formulations. NPV is increasingly being used in Asia because it can be produced on-farm. There is no NPV available for eggplant insect pests to date.

Microbial insecticides can be used together with predators and parasitoids. Beneficial insects are not usually affected directly by the use of a microbial insecticide, but some parasitoids may be affected indirectly if parasitized hosts are killed.

Below, some pathogens of eggplant insect pests are described.

6.3.1 *Bacillus thuringiensis* (Bt).

Bacillus thuringiensis (Bt) occurs naturally in the soil and on plants. However, in the field, Bt is usually applied as a microbial insecticide. There are different varieties of Bt. Each Bt variety produces a protein that is toxic to specific groups of insects.

Some of the varieties of Bt with some of their target insect groups are:

Bt var. <i>aizawai</i>	Caterpillars
Bt var. <i>kurstaki</i>	Caterpillars
Bt var. <i>tenebrionis</i> :	Colorado potato beetle, elm leaf beetle
Bt var. <i>israelensis</i>	Mosquito, black fly and fungus gnat larvae

Bt has been available as a commercial microbial insecticide since the 1960s and is sold under various trade names. Since 1985, the importation of Bt in Asia has greatly increased and Bt products are now locally produced, for example, in Vietnam and Thailand.

Formulations of Bt var. *kurstaki* are available for the control of many caterpillar pests of vegetables. Some of the Bt brand names are: Dipel, Javelin, Biobit, MVP, Xentari, Agree. There may be many more brand names and they vary per country.

Mode of action and symptoms

Commercial formulations of Bt contain the toxins and the spores of the Bt. It is the toxins, not the spores, that cause death of the pest insect. The toxin inside the bacterium is only effective when eaten in sufficient quantity by the target insect. The Bt is sprayed over the leaves and when the insect eats the leaves, it will also eat the Bt toxins. The toxin damages and paralyzes the gut of the insect. The toxin can only affect insects that have a specific gut structure, that is why Bt is specific for certain insect groups.

Affected larvae become inactive, stop feeding and die from the combination of starvation and damage of the gut by the toxins of the bacterium. The larva may have watery excrement and the head capsule may appear to be overly large for the body size. The larva becomes soft and dies usually within days or a week. The body turns brownish-black as it decomposes.

Using Bt = patience?!?

It was noted that some farmers concluded after spraying Bt that "it didn't work" because the caterpillars were still alive. Some farmers even sprayed a chemical insecticide only one day after applying Bt.

However, only when looking more closely, they found that the caterpillars were actually hardly eating anymore, they were just sitting on leaves, not moving very much. This is most important: when they stop eating, they stop damaging the crop! Bt is a stomach poison and the toxin paralyzes the stomach. Death by starving takes some time and, caterpillars will be dead after three days (pers. comm. Dr. P.Ooi, 1999).

Effectiveness

To obtain effective control of the caterpillars, it is essential to apply Bt at the correct target species, at the susceptible stage of development, in the right concentration, at the correct temperature and before insects bore into the plants where they are protected. Young larvae are usually most susceptible. Caterpillars have to eat sufficient quantities of Bt in order to be affected and die. When they eat just a little Bt, they may not die but their growth is retarded.

Bt products are generally effective and safe for natural enemies and non-target insects and can be used until close to the day of harvest.

Bt only works at temperatures above 15°C. Bt formulations are deactivated by sunlight. This is a reason that Bt is only effective for one to three days. Rain or overhead irrigation can also reduce effectiveness by washing Bt from the leaves.

☀ Sunshine and Bt, not a good match...!?

The Philippines highland vegetable FFS programme included a specific experiment for farmers to observe the effect of sunlight on the efficacy of Bt products. They compared feeding and death rates when diamondback moth larvae (*Plutella xylostella*) were placed on cabbage leaves which had been sprayed with Bt at different times of day and hence received different sunlight exposures. The results showed that sunlight deactivates Bt. By discussing the results, the farmers were able to decide the best time of day to apply biopesticides, avoiding application when the sun is strongest (CABI, 1996).

Conservation

The Bt formulation strictly speaking, is a chemical insecticide, and is applied like an insecticide. Bt formulations become inactive after one to three days. That means the bacterium inside the formulation is dead. Bt spores do not usually spread to other insects or cause disease outbreaks on their own. Therefore, conservation methods, as is important for predators and parasitoids, are not relevant for Bt.

Testing Bt: a case from Dalat, Vietnam

Testing Bt is not like testing chemical insecticides. In pesticide studies, usually the number or percentage of dead caterpillars is counted. Bt works differently from pesticides. It is important to help farmers recognize that Bt is working if there is less damage on the leaf, less frass production, and less caterpillar activity. Therefore, a different scoring system is needed to analyze data from Bt trials. Caterpillars affected by Bt do not die immediately. They usually stop feeding after 6 hours. This results in less damage to the leaf and less frass production. At 24 hours after exposure to Bt, larvae are dying: they do not move much and are lethargic. Larvae die after about 3 days.

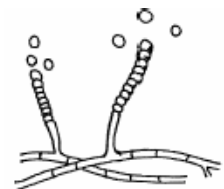
For Bt trials studying the effects of different types of Bt on DBM, the following scoring system to evaluate larval activities after Bt sprays was found to be very useful by farmers in Dalat, Vietnam:

A. Leaf damage	1 = low	2 = moderate	3 = high
B. Frass production	1 = none	2 = little	3 = much
C. State of DBM larvae	1 = dead	2 = dying	3 = active

Farmers in Dalat were very excited about this scoring system because it provided a better opportunity to study how Bt works. They observed that just counting dead caterpillars in Bt studies is not enough and may even lead to a false conclusion (Ooi, 1999).

6.3.2 Fungi

There are fungal species that can infect and kill insects. These fungi are called *insect-pathogenic* fungi or *entomopathogenic* fungi. These fungi are very specific to insects, often to particular insect species, and do not infect other animals or plants. Most insect-pathogenic fungi need humid conditions for infection and development but some fungus species can also infect insects when it is dry.

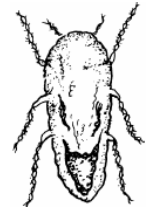


There are also fungal species that infect and reduce fungi that cause plant diseases. These are called *antagonists*. An example of an effective antagonist is *Trichoderma* (*Gliocladium*). This section describes insect-pathogenic fungi only. Antagonists are described in section 7.10.

There are several fungal species naturally present in ecosystems and these may control some insect species when conditions like humidity and temperature are favorable. Such fungi can spread quickly and some may also control sucking insects like aphids and whiteflies that are not susceptible to bacteria (e.g. Bt) and viruses. Management practices may be focused on preserving and possibly augmenting these natural enemies. Some fungi are commercially available in some countries in formulations that can be applied using conventional spray equipment. Some experiences from Asia are listed below.

Some common insect-pathogenic fungi:

- *Beauveria bassiana*: this fungus is found naturally on some plants and in the soil. It is commonly found infecting soil inhabiting insects. It needs warm, humid weather for spread and infection. Infected insect larvae eventually turn white or gray. This fungus has a broad host range: it can infect larvae of rice insects like black bugs and rice seed bugs but also pests of other crops like corn borer, Colorado potato beetle and Mexican bean beetle. It is being tested for use against many other pest insects. Unfortunately, some natural enemies such as ladybeetles can be susceptible to *Beauveria*. One possible application method that may avoid harming beneficial insects is the use of fungus-contaminated insect baits that are only attractive to pest species. In Indonesia (West Sumatra), *Beauveria* is used as a spraying solution for control of different pest insects in chili (FAO Dalat report, 1998).
- *Entomophthora* sp.: these fungi are fairly specific with regard to the groups of insects affected. Susceptible insects include aphids and several species of flies (in case of *Entomophthora muscae*).
- *Metarhizium* species: are being tested as natural enemies of corn rootworm, white grubs, some root weevils and several other pest insects. It has a very broad host range and most species occur widely in nature. *Metarhizium anisopliae* (also known as *Entomophthora anisopliae*) can be used to control a range of coleoptera and lepidoptera pests. *Metarhizium* can be an important control agent of aphids. In Indonesia (West Sumatra), *Metarhizium* is used as a spraying solution for control of different pest insects in chili. In Philippines, *Metarhizium* effectively reduced populations of rhinoceros beetles in coconut (FAO Dalat report, 1998). *Metarhizium* is commercially available as a foliar spray. See “The Biopesticide manual” (BCPC, 1998) for product names and manufacturers or check internet sites such as www14 and www15 (see Reference list).
- A species of *Paecilomyces* was found infecting whiteflies on cabbage in Cebu, Philippines. Researchers from the Regional Crop Protection Center have isolated the species and are now mass-producing it on artificial media (FAO Dalat report, 1998). In other countries, for example USA, *Paecilomyces fumosoroseus* is commercially available for whitefly control. It can be applied as a spore solution and it has some activity against aphids, thrips and spider mites.
- *Verticillium* sp. is used in Europe against greenhouse whitefly, thrips and aphids, especially in greenhouse crops where controlled environment favors fungus effectiveness. *Verticillium lecanii* is commercially available in Europe and USA for the control of greenhouse whitefly.



Jassid infected with *Beauveria*

😊 It is not important to know all the scientific names of insect-pathogenic fungi! 😊

What is important is that you can recognize them in the field and realize that they are killing insects and this is to the benefit of the farmer!

Mode of action and symptoms

Fungi penetrate the skin of insects. Once inside the insect, the fungus rapidly multiplies throughout the body. Death is caused by injury to the tissue or, occasionally, by toxins produced by the fungus. The fungus emerges from the insect's body to produce spores that can sometimes be seen as a “dusty” appearance. When dispersed by wind, rain or contact with other insects, the spores can spread the infection.

Infected insects stop feeding and become lethargic. They may die rapidly, sometimes in a position still attached to a leaf or stem. The dead insect's body may be firm or it may be an empty shell. The fungus is often seen as “hairs” or “dust” in various colors around the insect's body or on parts of the body.

Effectiveness

Insect-pathogenic fungi usually need moisture to cause infection. Natural infections are therefore most common during the wet season. The effectiveness of fungi against insect pests depends on many factors: having the correct fungal species with the susceptible insect life stage, at the appropriate humidity, soil texture (to reach ground-dwelling insects), and temperature. The fungal spores which can

be carried by wind or water, must contact the pest insect to cause infection. When insect-pathogenic fungi are applied, for example through a spore-solution, good spray coverage of the plants is essential.

Primary ① or secondary ② ???

When you leave a plate of food with, for example, some chicken meat in your kitchen for a few days, you may find the meat covered with fungus when you look again. This fungus is called a *secondary infection*: it was not the reason the chicken died (the chicken was probably killed for meat). The infection came in after the chicken was dead.

Similarly, when insects are dead, some fungi may start growing on the dead insect. This is also called a secondary infection. These fungi that cause secondary infection are part of the “trash men team” of nature: they make sure dead things are decomposed quickly. When the fungi actually cause a living insect to die, like insect-pathogenic fungi do, it is called a *primary infection*.

Interesting, but why bother?

When searching for beneficials in the field, it is important to distinguish between pathogens causing primary infection and those causing a secondary infection. Insects with a secondary infection may often be already partly decomposed.

Knowing that there is a fungus controlling pest insects in your field, should make you extra careful when considering pesticide applications, especially fungicides. Fungicides can quickly kill the beneficial fungi!

How to use this...?

When a primary infection is suspected and there are many insects dead and covered with fungus, you may consider making your own bio-insecticide from these dead insects. Collect as many as you can find in the field, put them in a jar with water, crush them a little and stir firmly. This will release fungus spores into the water. Filter the water slightly to remove large insect parts. The remaining solution can be used to test its effectiveness in insect zoos. Spray the solution over insects that are placed in a jar, or (better!) dip leaves into the solution and place it in the jar. Check if these insects become infected over the next days. Use water as a control. See also box in section 4.9. If it works, similar solutions can be applied to the field. It might give additional control of pest insects.

Free help from Mother Nature! 😊

Conservation

Many insect-pathogenic fungi live in the soil. There is evidence that application of some soil insecticides, fungicides and herbicides can inhibit or kill these fungi. For example, even very low concentrations of some herbicides can severely limit the germination and growth of *Beauveria bassiana* fungal spores in soil samples.

6.3.3 Viruses

Baculo viruses are pathogens that attack insects and other arthropods. Like some human viruses, they are usually extremely small (less than a thousandth of a millimeter across), so they can only be seen with powerful electron or light microscopes. There are two main types of Baculo viruses important for insect pest control:

- Nuclear polyhedrosis virus (NPV) has been successfully used for the control of several caterpillar pests of vegetables including armyworms (*Spodoptera* sp.), tomato fruitworm (*Heliothis armigera*), diamondback moth (*Plutella xylostella*), and cabbage looper (*Plusia* sp.).
- Granulosis virus (GV): have been found in several caterpillar species including cutworm (*Agrotis* sp.), armyworms (*Spodoptera* sp.), diamondback moth (*Plutella xylostella*), cabbage butterflies (*Pieris* sp.), cabbage looper (*Plusia* sp.), and the webworm (*Hellula undalis*).

The majority of baculoviruses used as biological control agents are in the genus NPV. There are different strains (or “varieties”) of NPV and each strain is very specific to a target insect. For example HaNPV is NPV for control of tomato fruitworm *Heliothis armigera* (Ogrodnick, www7). No NPV specific to eggplant insect pests has been found or developed to date. For more details on NPV please see Tomato Integrated Pest Management: An Ecological Guide (FAO December 2000).

6.3.4 Nematodes

There are many species of nematodes (very small worms). Some of them, like rootknot nematodes, attack and damage plants. Other nematode species are beneficial in that they attack pest insects that live in the soil or that spend some time of their life cycle in the soil such as beetle larvae, cutworms, and some armyworms. These nematodes are called *entomopathogenic* nematodes.



Nematodes have life cycles like insects: they usually mate, lay eggs, and there are several larval stages. Yet, they are often lumped with pathogens and not with insects, presumably because of their symbiotic relationship with bacteria, and because the symptoms they cause look like disease symptoms.

Many species of naturally occurring, beneficial nematodes live in the soil and on plant material. The role of most of these species is not known, but some nematode species have received attention as potential biological control agents. Some of these nematodes can be mass produced and are available commercially in some countries. These beneficial nematodes do not harm plants, animals and most beneficial insects (Gaugler, www8). They harbor bacteria which produce the toxins that eventually kill the host insect converting it to food for the nematode.

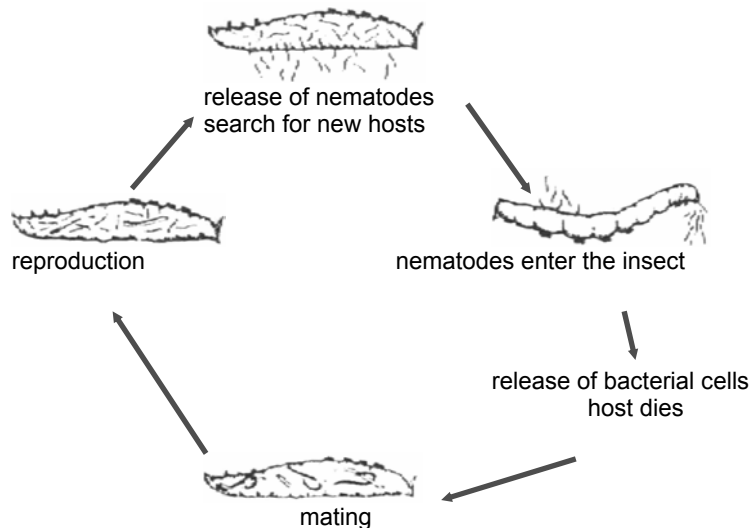
The main species of beneficial nematodes include:

- *Steinernema* species (previously called *Neoplectana*): There are several species of this nematode and all of them have a very broad host range. Different *Steinernema* species carry different strains of a bacteria. Two important members of *Steinernema* are (D'Amico, www3):
 1. *Steinernema riobravis* - potential against eggplant fruit and shoot borer (*Leucinodes orbonalis*). Its host range runs across multiple insect orders. It can be effective against insects such as tomato fruitworm (*Heliothis armigera*) and mole crickets. This is a high temperature nematode, effective at killing insects at soil temperatures above 35°C.
 2. *Steinernema carpocapsae* - effective against lepidopterous larvae, including cutworms (*Agrotis* sp.), armyworms (*Spodoptera* sp.), and some other insects such as mushroom flies. Important attributes of *S. carpocapsae* include ease of mass production and ability to formulate in a state that allows several months of storage under refrigerated conditions. The species *S. riobravis* is more heat tolerant than *S. carpocapsae* and does not need to be stored in the refrigerator.
- *Heterorhabditis* species: carries a different species bacterium than *Steinernema* nematodes but enters and kills insects in a similar way. These nematodes also enter insects through their skins as well as through natural openings. They have a slightly longer life cycle than *Steinernema* species and also a broad host range.

Mode of action and symptoms

Nematodes actively search for suitable hosts, often attracted by the carbon dioxide (CO₂) emitted by their prey. The third stage nematode larvae are the infectious stage and only these can survive outside the host insect because they do not require food. The nematodes carry insect-pathogenic bacteria inside their gut. Different nematode species carry different species of bacteria. Once the nematode penetrates its host, usually through the mouth, the anus or breathing holes, the bacteria multiply and kill the insect. The nematodes feed on the bacteria and on the insect tissue, then mate and reproduce. After 6 to 10 days, young nematodes emerge from the dead insect to seek out and colonize new hosts.

Affected insects usually die within 1 or 2 days. Those killed by *Steinernema* species turn brown-yellow in color from the bacterial infection. The insects are very soft, and easily crack. Insects killed by *Heterorhabditis* nematodes become red and gummy.



Life cycle of insect-killing nematodes
(modified from Hoffmann, 1993)

Effectiveness

Insect-attacking nematodes are best suited for use against pest insects that spend some or most of their life cycle in the soil or in moist, protected places (like inside shoots and fruits). However, nematodes are often not effective against insects feeding on open foliage because they quickly lose effectiveness in dry conditions. They require moisture to travel. Nematodes can travel in the soil over considerable distances and actively seek their prey if temperature and humidity are correct.



Nematode movement through the soil

As with most biological control agents, to use insect-pathogenic nematodes effectively, it is also necessary to understand the life-cycle of the pest insect to ensure that the most susceptible life stage is targeted. Many vegetable insect pests are susceptible to attack by nematodes but for many, the potential of nematodes for field control still needs to be evaluated.

Nematodes can be cultured in living hosts and in artificial media with little chance for contamination. Several species of nematodes are now commercially available. See "The Biopesticide Manual" and internet sites such as [www14](#) and [www15](#) (chapter 11, Reference list).

Nematode solutions, when obtained from elsewhere, can be stored in the refrigerator for a short time after arrival because the nematodes are in a dormant state. Before applying the nematodes, this dormancy must be broken by stirring them in room temperature (over 18°C) water to provide oxygen. After dormancy is broken, the nematode-solution must be used immediately. They prefer a moist soil and are damaged by light and so should be applied in the evening. Beneficial nematodes move faster in sandy soil than clay.

Conservation

Guidelines for conserving native entomopathogenic nematodes have not been well documented. In general, nematodes (both when indigenous and when applied as a spray) need protection from the drying radiation of the sun and from extremes of temperature. Although they need a moist environment to stay alive and move around, they can form a "resting stage" to survive adverse conditions.

Related exercises

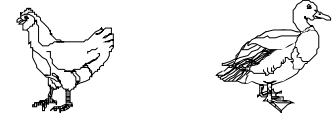
For more background reading and practical exercises on insect-killing nematodes for fruit and shoot borer management, please refer to the report "Participatory Action Research on Vegetable IPM (with emphasis on Fruit and Shoot borer Management)" authored by Prabhat Kumar, FAO Vegetable IPM Training Consultant, Jessore, Bangladesh, 1998. See reference list (chapter 11) on how to obtain copies.

6.4 Other natural enemies

6.4.1 Birds

The value of wild birds as insect predators is clearly demonstrated in many situations. In some areas in India, bird perches are placed in vegetable fields to provide a resting place where birds can lookout for food like caterpillars!

Farmers in various countries have been using chickens in cotton plots to eat the cotton stainers and other bugs that drop to the ground when disturbed. Chickens also eat various caterpillars and pupa that are on the ground.



Birds: insect predators!

In several parts of Southeast Asia ducks have been effectively used against golden apple snails in rice.

6.4.2 Pigs

Sometimes, pigs are allowed to spend some time at the vegetable field after harvest. This is to the advantage of both farmer and pig because the pigs will eat a large part of crop left-overs and may also dig into the soil in search for pupae of insects. When eating crop left-overs, possible diseases and insect larvae and eggs that are still present on the old leaves, are removed and destroyed and cannot spread to the next crop. An exception is clubroot in cabbage: this root disease can tolerate passage through the intestines of farm animals.



**Natural enemies are very valuable:
they help farmers to control pests!**

7 DISEASE ECOLOGY



SUMMARY

Disease ecology studies pathogens that cause plant diseases in relation to their environment. Eggplant diseases can be caused by pathogens such as fungi, bacteria, viruses, mycoplasmas and nematodes.

Most pathogens spread attached to or inside seed or infected plant material, or are carried by wind, water (rain, irrigation water, ground water), through insects and by humans or animals (attached to cloth or skin, and transported with plants/harvested crops).

Pathogens can infect a plant when 1) the variety of that plant is susceptible to the disease, 2) the disease is present and virulent (able to infect the plant), 3) the environment (e.g. humidity, temperature) is favorable for the disease to develop. These 3 elements form the “disease triangle”. Disease management is focused on changing or influencing one of these three elements to prevent the disease from attacking the plant. Studying a disease in the field, or setting up field experiments is an excellent way of finding out if symptoms are caused by a disease, and how some (environmental) factors influence disease development. Knowing the characteristics of a disease will give you clues on how to manage it!

Available fungicides and bactericides are often not effective enough to stop any of the major eggplant diseases, especially during prolonged periods of wet weather, but they may be able to delay disease. If necessary, fungicides should be combined with structural management methods like adding organic material to the soil (compost), crop rotation, sanitation, etc. Adding lots of compost to the soil has good potential to reduce soil-borne diseases such as bacterial wilt.

The antagonistic fungi *Trichoderma* sp. have become widely available in many countries in Southeast Asia. *Trichoderma* sp. can suppress several soil-borne plant pathogens such as damping-off and root rot in vegetables. Other biocontrol agents include non-pathogenic strains of *Fusarium oxysporum*, *Bacillus subtilis*, *Burkholderia cepacia*, and *Streptomyces griseoviridis*. These and other biological agents may become available in Asia for control of plant diseases in the future.

7.1 Plant diseases and pathogens

Diseases are an important part of crop protection, but they are usually very difficult to understand in the field. This is partly because the causal organisms are very small and cannot be seen moving around like insects. You can only recognize diseases by their symptoms which vary from dwarfing of the plant, color changes, leaf spots and necrosis to wilting, (root) malformations and rotting.

Plant diseases are caused by living (biotic) organisms, called *pathogens*. Main pathogens of plants are fungi, bacteria, viruses, and nematodes. Some characteristics of pathogens are listed in the box below. Fungi, bacteria, viruses, and nematodes (and other organisms such as mycoplasmas) are often lumped together under the term *micro-organisms*. Only very few micro-organisms may cause injury to the crop under certain circumstances. Most of them are beneficial: they may be decomposers which play an important role in the nutrient cycle. Several micro-organisms are true “natural enemies”. An example is the virus NPV, which can control several pest insects of vegetables. Likewise, there are fungi that control pest insects like aphids or caterpillars. Insect-pathogens are described in section 6.3.

Some fungi can infect, attack or work against (antagonize) other fungi that cause plant diseases. They are called *antagonists*, the natural enemies of plant diseases, and also friends of the farmer! A well-known antagonist is the fungus *Trichoderma* sp. which can reduce damping-off disease in nurseries (see sections 7.10.1 and 8.1.1).

PATHOGENS

Fungi are plants that feed on other organisms, living or dead. There are many different types of fungi: some are living in the soil breaking up dead plant parts, others feed on living plants and cause wilts and other diseases. Most fungi grow with tiny threads called *mycelium* and for their reproduction they produce spores that serve as seeds. Sometimes a powdery mat that covers the diseased parts of a plant can be seen. This mat is composed of millions of spore-producing structures of the fungus.

Bacteria are very small organisms and can only be seen through a microscope. Few bacteria affect plants. Bacteria can cause rotting of plants, wilting, and leaf spots. Bacteria do not form spores like fungi. They often multiply through cell division (splitting themselves into two). Some bacteria can survive for a long time by surrounding themselves with a protective coating which prevents them from drying out. Bacteria grow in wet conditions.

Viruses are even smaller than bacteria. They can only be seen with a powerful electron microscope. Viruses exist in living cells and cannot live outside a plant or an insect vector. Virus diseases may take a long time to recognize as often the only effect on the crop is a gradual loss of vigor. Symptoms often depend on environmental conditions such as temperature. Plants are small, may be stunted and yields are lower. Sometimes the signs are more obvious when red or yellow streaks appear on the leaves (*mosaic*). Still it is often difficult to distinguish a viral disease from a mineral deficiency. Viruses can infect new plants through seeds or seed tubers, direct contact between plants or indirectly through vectors. The main vectors for plant viruses are sucking insects like aphids, plant hoppers and whiteflies.

Mycoplasmas, or mycoplasma like organisms (MLO) are tiny organisms that resemble viruses or bacteria but because their characteristics are slightly different, they have been placed into a separate classification. MLOs that cause plants diseases live inside plant cells and disrupt normal functioning of plants. This results in symptoms like witches broom, stunting, little leaf, or bunched top in a wide variety of crops. In eggplant, little leaf is an important disease caused by a mycoplasma.

Nematodes are very little worms (about 1 mm long) which usually are present in large numbers in the soil. Nematodes have life cycles like insects: they usually mate, lay eggs, and there are several larval stages. Yet, they are lumped with pathogens and not with insects, presumably because of their symbiotic relationship with bacteria (see section 6.3.4). In addition, symptoms caused by nematodes are often hard to distinguish from other diseases. Some nematode species can cause damage by sucking plant roots. In some cases, roots may form galls due to nematode attack (rootknot nematodes). Some nematode species are damaging because they transmit viruses. Other nematodes may be beneficial because they attack pest insect species.

Plant diseases can also be caused by non-living (abiotic) agents. These are called *physiological disorders* rather than diseases. Symptoms of physiological disorders include discoloration of leaves through deficiency or excess of a certain fertilizer, symptoms from sun burn or pesticide burn. It is often hard to tell the difference between a disease and a physiological disorder. Some guiding questions on factors causing disease-like symptoms on plants are listed in section 7.6.

7.2 How pathogens grow and multiply

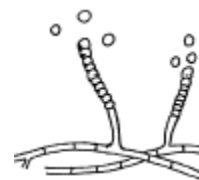
Pathogens have different ways of growing in or on a host plant.

Fungi usually form mycelia, thread-like structures comparable to branches of plants. Some fungi live on top of the plant tissue and have small “roots” (*haustoria*) in the plant that take food from the plant cells to feed the fungus (example: powdery mildew on peas: you can see it as a white downy mould on the upper side of leaves). Others live inside the plant and may even use the plant vessels to spread through the plant (for example bacterial wilt in eggplant). Bacteria and viruses almost always live inside the plant only. Nematodes often have one or more life stages inside a host plant but may also be free-living in the soil.

Fungi have two general ways of reproduction:

Vegetative reproduction: parts of the fungi, e.g. pieces of mycelium that can develop further when placed in a suitable environment.

Reproduction by spores: spores are like “seeds” of a fungus: when they land at a suitable place they germinate and the fungus grows from there. Under suitable conditions the fungus may produce spores again. When conditions are not favorable, the fungus may develop a resting stage, which will settle on left-overs or in the soil, or it may form resting spores that can survive adverse conditions such as drought. *Verticillium* wilt fungi for example, can produce a very strong type of spores that can survive almost indefinitely in fields.



Bacteria usually multiply by cell division: the bacterium cell gets larger and splits into two. This can happen very fast! For example *E. coli* bacteria, under favorable conditions, may double every 20 minutes! That means that starting with one bacterium, there are over 4000 of them in about 4 hours. Usually, lack of food or accumulation of waste products prevents this high speed multiplication from happening. Some bacteria can survive for a long time by surrounding themselves with a protective layer which prevents them from drying out.

Viruses exist in living cells of a plant. Multiplication of viruses is very complex. When a virus has entered a plant cell, it falls apart into specific molecules which “take over” the plant cell. Instead of producing plant tissue, the cell now produces more virus parts.



Nematodes are little roundworms that have life cycles like insects: they usually mate, lay eggs, and there are several larval stages. Some of these larval stages can travel through the soil in search of new host plants.

7.3 How diseases spread

Diseases can spread from one plant to the other, but also from one field to the next and even one location to another. A few general ways in which pathogens can spread are described here.

Direct transmission through:

- **Seed:** pathogens can be carried on or inside a plant seed. Examples are early blight (*Alternaria solani*) and bacterial wilt (*Ralstonia solanacearum*).
- **Vegetative plant parts:** infected transplants may carry diseases from nursery to the main field; similarly diseases can be transmitted by infected tubers, cuttings, runners, grafts, etc.

Indirect transmission through:

- **Growth of the pathogen:** pathogens can spread over short distances by growth of the mycelium. For example wood rotting fungi can spread through the soil from one tree or trunk to the next by active growth.
- **Wind:** fungi which produce spores on the surface of plants can be disseminated by wind. An example is early blight (*Alternaria solani*) of eggplant. There are examples of spores such as grain rust (*Puccinia graminis*) that have been found over 4000 m above an infected field! Often wind blows the spores over certain distances and rain may deposit the spores down. Some bacteria can also be dispersed by wind.
- **Water:** flood or irrigation water may carry pathogens or spores, especially those in or near soil. The splashing of water during rain or heavy dews can spread spores and bacteria to plant parts near the soil or to different parts of the same plant or to neighboring plants. Bacterial wilt of eggplant, for example, can be spread by surface water. Water however is not as important as wind for long distance dissemination.
- **Soil:** soil can contain infected plant left-overs and it contains spores of fungi such as damping-off (e.g. *Pythium* sp.), *Verticillium* and *Fusarium* wilt fungi, and bacteria such as *Ralstonia solanacearum*, causing bacterial wilt. Soil can be a reservoir of diseases which are spread when soil particles are transported, for example attached to seedling roots or attached to tools or shoes of people.

Survival and spread of soil-borne pathogens

Soil-borne pathogens can survive on or in a host plant (including weeds), some survive on dead host plant tissue or on dead organic material, some form resting spores or latent stages (such as thick-walled bacteria or fungus spores to survive in adverse conditions). Root nematodes survive as eggs (egg cysts) or as adults.

Soil-borne pathogens can be spread by wind, water, vectors or humans and carried with soil particles. An example: *Pythium* sp. causes damping-off disease in seedlings. Dying seedlings contain the spore-carrying structures of the fungus. The spores can drop to the soil (and attack seeds or young seedling roots), or be carried by wind or spread by surface water or irrigation water to another location. *Pythium* can be transported attached with soil to the seedling roots during transplanting. And *Pythium* can form thick-walled spores (called *oospores*) that can survive during adverse conditions and persist for several years in the soil.

- **Insects, mites, nematodes:** dissemination of pathogens can occur incidentally when e.g. spores stick to the body of an insect or mite going from one plant to another. More important is in case of insects when an insect becomes a *vector* and carries and transmits a pathogen (for example jassids carrying the mycoplasma causing little leaf in eggplant) from one host plant to another. Most vectors are sucking insects such as aphids, whiteflies and leaf hoppers.

Nematodes can also be transmitters of pathogens. In case of vegetables, it is also likely that nematodes create entry points for bacteria and fungi by making wounds in roots.

- **Humans, animals:** spread of pathogens occurs in two ways: through the person, tools or animals and through the objects that are transported. Persons and



Diseases can be spread by people

animals spread diseases by walking and working in fields with infected plants, spreading spores sticking to the body but also causing small injuries to plants (e.g. during transplanting or field work) which can be entry points for pathogens. Longer distance dissemination by man is usually done by transporting diseased planting materials or infected soil particles.

7.4 How pathogens attack a plant

A spore of a fungus or a piece of the mycelium (the “body” of the fungus) can penetrate a host plant. It can enter a plant through wounds in the plant tissue, through fine root hairs, through natural openings like stomata (the “breathing cells” of a plant) or it can actively penetrate the tissue of the plant. To do this, some fungi produce special chemicals (enzymes) that damage the plant tissue and allow the fungus to enter.

Bacteria cannot actively penetrate plants and need wounds or natural openings to enter.

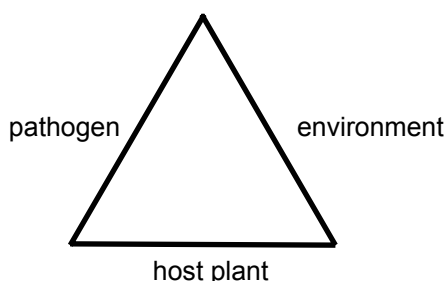
A virus needs a wound to enter, either a mechanical wound or a wound created by an insect. Most nematode species, such as rootknot nematode, can actively penetrate plants.

The differences in the ways of attacking a plant may be the reason that you sometimes see all plants in a field infected with a disease (for example early blight can be present on all plants because it can actively penetrate the plant tissue) whereas another disease may only be visible on a few plants (for example bacterial wilt: it needs a wound to enter the plant).

The infection process by some pathogens can be very quick. Damping-off in seedbeds for example, can kill seedlings in less than a day! That will usually be too short to even notice disease symptoms! Others just parasitize on a plant and do not cause the death of the plant but may reduce yield or quality.

7.5 When can a pathogen attack a plant?

A disease is the result of interactions between a pathogen, a host plant and the environment. These interactions are shown in the *disease triangle*:



The disease triangle shows that a plant will get infected with a disease when:

- the variety of that plant is susceptible to the disease, AND
- the disease is present and virulent (able to infect the plant), AND
- the environment (e.g. humidity, temperature) is favorable for the disease to develop.

Disease management is focused on changing or influencing one of the three elements of the triangle to prevent the disease from attacking the plant. A few examples:

Changing the host plant can be: not growing a host plant, e.g. by crop rotation, or using a resistant variety.

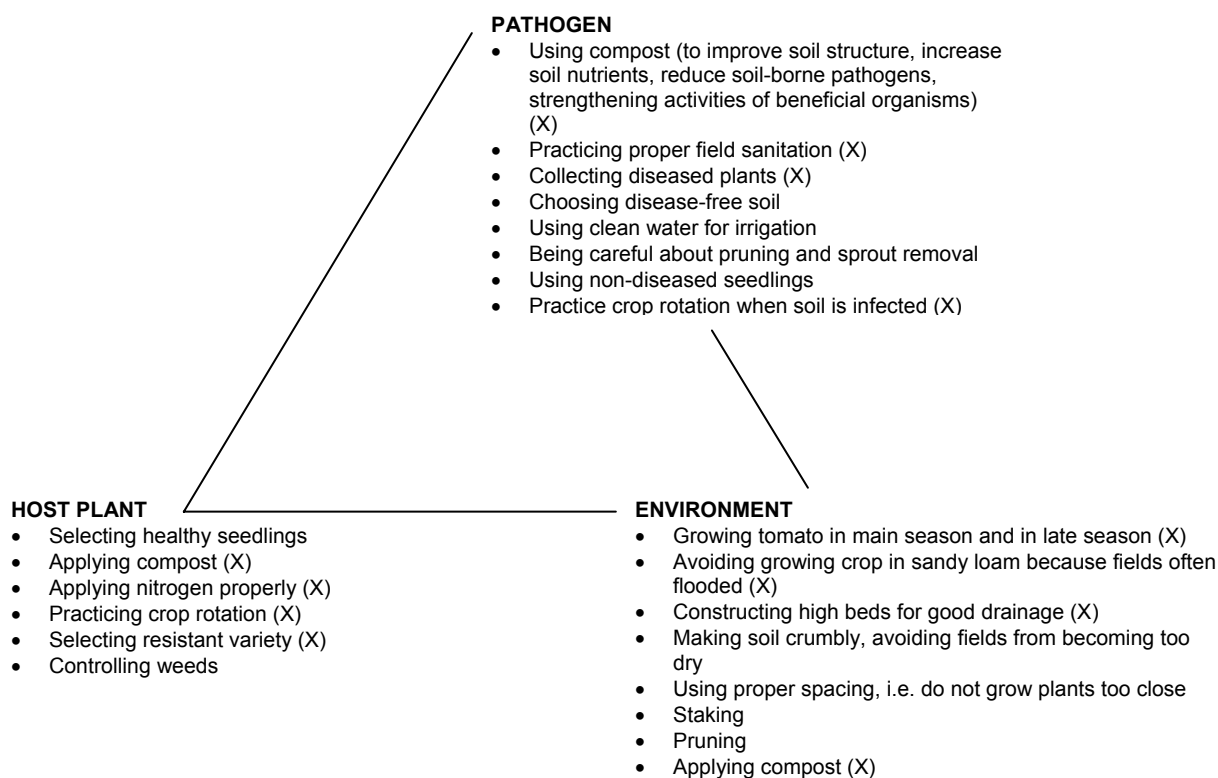
Changing the presence of the pathogen can be: removing leaves with the spores of the disease from the field before planting a new crop so that the disease cannot infect the new plants from the leaves that were left in the field after harvest (sanitation).

Changing the environment can be: using furrow irrigation rather than overhead irrigation so that the leaves will not get wet. Humidity stimulates spore formation (e.g. early blight) and spread of the disease.

Creation of a disease triangle in a workshop on management of soil-borne diseases, Hai Phong, Vietnam (1999).

Participants of this workshop, mainly IPM trainers, discussed about disease development, with the objective to develop studies (Participatory Action Research) with IPM farmers on disease management. One of the diseases selected to prepare a disease triangle was bacterial wilt in tomato.

The following management methods for bacterial wilt resulted from the discussions:



(X) = done by all Vietnamese farmers (according to workshop participants).
(from: FAO Workshop on PAR on management of soil-borne diseases, 1999)

7.6 A disease or not a disease...? How to find out!

Very often, it is difficult to tell if a brown or black spot on the leaf or a piece of dead leaf is actually a disease or just a little insect damage or mechanical damage. Sometimes the symptoms of diseases are not very clear, or a different environment or climate makes a symptom look slightly different from the "theoretical" symptoms.

It is important to find out because if a spot or a discoloration is actually a disease, you may still be able to do something to prevent it from spreading into the rest of the field. This can be uprooting the diseased plants. For some diseases you may have to spray a fungicide to stop the spread. It is important to train yourself in recognizing early symptoms of a disease. If you can see the first symptoms of a disease early, there may still be time to prevent it from reaching a damaging level of infestation.



Often with some common sense and a thorough knowledge of a field's recent history, it is possible to find the cause for specific plant symptoms. The following are guidelines that may be useful in diagnosing vegetable problems (modified from www6).

Guidelines for diagnosing vegetable problems:

1. Identify the symptoms. Do the leaves have a different color? Do leaves or the whole plant have a different appearance, e.g. smaller size leaves or bushy plants? Are there any leaf spots or spots on the stems or fruits? Wilting of shoots or of the whole plant? Holes in the leaves or in the stem? Root abnormalities? Fruit rot?
2. Are all plants in the field affected? Are small areas in a field affected? Or individual plants?
3. Determine if there is a pattern to the symptoms. Are affected plants growing in a low spot of the field, poor drainage area, or an area with obviously compacted soil? Does the pattern correlate with current field operations?
4. Trace the problem's history.
 - When were symptoms first noticed?
 - What rates of fertilizer and lime were used?
 - What pesticides were used?
 - What were the weather conditions like before you noticed the problems - cool or warm, wet or dry, windy, cloudy, sunny?
5. Examine the plant carefully to determine if the problem may be caused by insects, diseases or management practices.

Insects: look for their presence or feeding signs on leaves, stems and roots. Sometimes it's easier to find insects early in the morning or towards evening.

Diseases: look for dead areas on roots, leaves, stems and flowers. Are the plants wilting even though soil moisture is plentiful? Then check the roots for root rot symptoms or root deformations. Are the leaves spotted or yellowed? Are there any signs of bacterial or fungal growth (soft rots, mildew, spores, etc.)? Look for virus symptoms: are the plants stunted or do they have obvious growth malformations? Are all the plants showing symptoms, or are just a few scattered around the field?

6. Could there be nutritional problems? The box below lists a number of characteristic deficiency symptoms for the major and minor nutrients.
7. Could there be a nutrient toxicity? Boron, zinc, and manganese may be a problem here. Soluble salt injury may be seen as wilting of the plant even when the soil is wet. Burning of the leaf margins is usually from excessive fertilizer.
8. Could soil problems be to blame? Soil problems such as compaction and poor drainage can severely stunt plants.
9. Could pesticide injury be at fault? Pesticide injury is usually uniform in the area or shows definite patterns. Insecticides cause burning or stunting. Herbicides cause burning or abnormal growth.
10. Could the damage be caused by environmental conditions? High or low temperatures, excessively wet or dry, frost or wind damage, or even air pollution? Ozone levels may rise as hot, humid weather settles in for long stretches. Look for irregularly shaped spots which may look similar to feeding of mites and certain leafhoppers. Ozone flecks are usually concentrated in specific areas of the leaf, while feeding damage from insects is spread uniformly across the leaf.

Deficiency symptoms for major and minor nutrients:

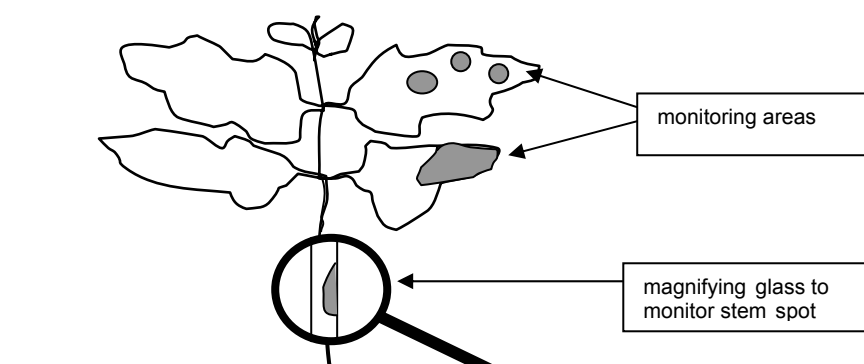
- Nitrogen: Light green or yellow older foliage.
- Phosphorus: Stunted plants and purplish leaves.
- Potassium: Brown leaf margins and leaf curling.
- Calcium: Stunted plants, stubby roots. (Causes blossom end rot of tomatoes, tip burn of cabbage, celery blackheart, and carrot cavity spot).
- Magnesium: Yellowing between veins of older leaves.
- Sulphur: Yellowing of new leaves, stunted plants.
- Boron: Growing points die back and leaves are distorted.
- Copper: Yellowing of leaves which become thin and elongated, causes soft onion bulb with thin scales.
- Iron: Light green or yellow foliage on youngest leaves.
- Zinc: Rust-colored spots on seed leaves of beans, green and yellow striping of corn, yellowing of beet leaves.
- Manganese: Mottled yellow area appearing on younger leaves first. In beets, foliage becomes deeply red.
- Molybdenum: Distorted, narrow leaves, some yellowing of older leaves; whiptail leaf symptoms in cauliflower.

7.7 Studying diseases

If despite checking the guiding questions from the section above, it is still unclear if something is a disease, an option would be to observe the symptoms in the field or in a 'classroom', or house over a period of time. In some TOTs, this is an experiment called *disease zoo*, *disease observatorium* or *disease culture*. An example for leaf or stem spots is given below.

Studying a disease

Select one or a few plants in the field that have disease-like symptoms. Mark the plants with a stick and label the leaves that show the symptoms (you can put a tag on the leaf or draw a big circle with a waterproof markerpen around the spot you want to study). Draw the plant and the stem or the leaves with symptoms in detail (use hand lens) using color pencils (what color is the symptom, where is it located, do you see structures inside the symptom (e.g. black specks), how does the plant tissue look around the symptom, etc.). Measure the size of the symptom and note it down with your drawing.



Come back after a few days and repeat the above: draw and measure the symptoms. If you find that the symptoms are growing, becoming bigger in size and maybe even have spores (you can sometimes find them as dusty powder or in small black pustules on the spot) it is very likely that you are looking at a disease. Check the symptoms found with details on some of the major diseases of eggplant (chapter 8) to confirm diagnosis.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

- 3.1. Description of disease symptoms
- 3.2. Identification of disease symptoms
- 3.3. Disease collection
- 3.4. Pathogen groups
- 3.8. Pathogen groups name game
- 3.9. Cultivating a fungus

7.8 Control or management?

It is important to realize that diseases require another way of thinking in order to have long-term control. Diseases must be *managed*, not controlled. But what is the difference and why is that important to know?

Management means a range of activities that support each other. Many of these activities should be done before transplanting of the crop, some even before sowing the seeds. Disease management is a long-term activity, sometimes it is a planning for several years. It is mainly focused on *preventing* the disease from coming into a field. It also aims at keeping disease pressure low in case a disease is present. Management usually needs the cooperation of several farmers working together to reduce overall diseases in an area.

Control is a short-term activity, focused on killing a disease or stopping the spread of it. The trouble with diseases is that you only see them when you see the symptoms. That means infection has already occurred at least a few days before. It also means that plants that look healthy today, may have disease symptoms tomorrow. Once a plant is infected, it is difficult to actually kill the pathogen. Especially when pathogens live in the soil and attack plants through the root system, they can only be *controlled* by proper *management* techniques like crop rotation or cultural methods. And those kind of methods usually have to be done before transplanting the crop!

Spraying fungicides, a typical short-term activity, may be a control option but only for a limited number of diseases and usually only partially. So a combination with cultural practices like sanitation is essential! It should be noted that some fungicides can kill natural enemies, including predators and parasitoids (see box in section 4.9).

In order to make a good disease management decision, you have to know a few basic things about the disease. Things like: where does it come from, how does it spread? Knowing this will give you a clue how to manage it. Soil-borne diseases are managed differently from wind-borne diseases!

But before talking about *control*, think about: how important is this disease, what damage does it do to my overall yield at the end of the season? What would be the effect of this disease to the crop in the next season? A few spots here and there may not reduce your yield. At what growth stage does the disease appear? What are the weather conditions, are they favorable for a quick spread of the disease? Yes, you may be able to temporarily stop the spread of this disease by applying fungicides. But what are the costs of those fungicides? What are the negative side-effects of fungicides to the natural enemy population? How much *extra* income do you estimate you can win by applying pesticides? That is what counts in the end!

***Diseases can never be completely eradicated but
populations can be reduced to low levels!***

7.9 Disease management: where to start?

Disease management starts with the identification of the problem. Once you have found the cause of the problem, and it is a disease, the easiest first step is to check if there are any resistant crop varieties available (see section 3.2.2). Also, if you know that the disease is giving a lot of problems in one season but not in another, it may be worth considering not to grow the crop in the susceptible season. Not growing the crop at all for a few years (crop rotation) is another often recommended practice in disease management, especially for soil-borne diseases (see section 3.17).

When resistant varieties are not available, find out some more details on the disease. Start for example with: where does the disease come from? How does it spread?

Knowing characteristics of a disease will give you clues on how to manage it!

The table below summarizes some sources and carriers for a number of important eggplant diseases.

DISEASE	SOURCE(S) and/or CARRIER(S)							
	seeds	other infected plants and weeds	diseased crop residues	soil	contaminated (ground) water	carried by wind	tools, people, animals	insect vectors
damping-off	-	-	+	+	+	-	+	-
root rot	-	-	-	+	+	-	+	-
rootknot nematodes	-	+	+	+	+	-	+	-
<i>Phomopsis</i> rot	+	+	+	-	-	+	+	-
early blight	+	+	+	-	-	+	+	-
little leaf	-	+	-	-	-	-	-	+
bacterial wilt	+	+	+	+	+	-	+	-
stem rot	-/+	+	+	+	-	-	+	-

By checking the “+” symbols, you can see what the important sources and carriers for a disease may be. Next thing is to see if these sources/carriers can be modified. By eliminating or reducing a source or a carrier of pathogens, disease may be reduced! Some examples of management practices are listed below. This list is not exhaustive, check sections on individual diseases for a complete set of management practices.

<u>contaminated seeds:</u>	sterilize seeds before sowing (section 3.6),
<u>other infected plants:</u>	uprooting diseased plants, pruning infected leaves, increasing plant spacing,
<u>diseased crop residues:</u>	sanitation – removing all left-overs from previous crop from field,
<u>soil:</u>	crop rotation, for small areas, soil sterilization may be an option (section 3.10.1)
<u>contaminated water:</u>	avoid planting down-hill of an infected field,
<u>carried by wind:</u>	cooperation with other farmers for sanitation practices, covering compost piles, windbreaks (though usually of limited value),
<u>contaminated tools, people, animals, insects:</u>	clean tools, shoes, etc. when used in field, avoid working in the field when plants are wet, control vector insects.

Another factor to influence disease is the environment (see disease triangle, section 7.5). When you know what environmental factors stimulate or inhibit the disease, you can sometimes influence these. Soil temperature may be influenced by mulching; humidity can be influenced by proper drainage of the field, using furrow irrigation instead of overhead irrigation, etc.

Even with all the knowledge, it remains a difficult task to manage diseases. When all preventive activities fail, there may not be another option but to use a fungicide. However, from an ecological and an economical point of view, there is a lot to gain by setting up small experiments to test when and how to apply fungicides, to control diseases in your field, this season. Remember that natural enemies of insect pest and antagonistic organisms may also be harmed by fungicide sprays.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

- 1.4. Effect of pesticides on spiders and other natural enemies
- 3.6. Disease triangle to explain disease management
- 3.7. Demonstration of spread of pathogens
- 3.11. Simulating pathogen spread

7.10 Antagonists: the Natural Enemies of pathogens

Not only insects, but also plant pathogens have natural enemies. These are usually also fungi, bacteria, nematodes or viruses which can kill plant pathogens, reduce populations, or compete for nutrients or attachment to a host plant. Such micro-organisms are called *antagonists*. Sometimes, the term “biofungicide” is used for antagonists if they are used to control a disease.

Antagonists of pathogens are not yet well understood. However, the research that has been done has given promising results, and the study of antagonists has become a rapidly expanding field in plant pathology. The most “famous” antagonist in vegetable production is probably *Trichoderma* (see below) but others may be interesting as well. In Philippines for example, a fungus called Bioact strain 251, was isolated from the soil which controls nematodes. Spore solutions of this fungus are now commercially available as “Bioact” (FAO Dalat report (V.Justo), 1998).

Antagonists: how do they work...? Some examples:

The fungus *Gliocladium virens* reduces a number of soil-borne diseases in three ways: it produces a toxin (gliotoxin) that kill plant pathogens, it also parasitizes them in addition to competing for nutrients.

The biocontrol capacity of the fungus *Trichoderma harzianum*, recommended for control of several soil-borne pathogens, competes in the soil for nutrients with pathogens. *Trichoderma* fungi outcompete pathogens for nutrients and rhizosphere dominance (=area for a fungus to grow around the plant roots), thereby preventing or reducing the impact of pathogens.

Others may compete for the entry place to the host plant, such as pathogenic and non-pathogenic *Fusarium* sp. When a non-pathogenic organism blocks the entry, the pathogen cannot infect the plant.

(Copping, 1998)

Antagonists have been applied to the above-ground parts of plants, to the soil (and roots), and to seeds. Under constant conditions, such as in greenhouses, antagonists can completely protect plants from pathogens. In the field, disease control is likely to be more variable due to the varying environmental conditions (mainly temperature, moisture, nutrient availability and pH).

Proper methods for the multiplication of antagonists as well as ways to formulate them need to be further studied. However, some examples of successful field use of an antagonist are described below.

7.10.1 *Trichoderma* species

An example of an antagonist that is widely available in Southeast Asia is *Trichoderma* sp. *Trichoderma* sp. can suppress soil-borne plant pathogens, including those causing damping-off (*Pythium* sp.), root rot (*Rhizoctonia solani*), stem rot (*Sclerotium rolfsii*), and wilt (*Verticillium dahlia*) in vegetables. *Trichoderma* fungi often promote plant growth, maybe due to their role as decomposers. They may also aid in promoting soil fertility. In addition, *Trichoderma* sp. stimulates tissue development, for example, in pruned trees, through the enhancement of natural auxin release. Specific formulations containing *Trichoderma* are available to treat pruning wounds of fruit trees.

Some *Trichoderma* species are:

- *Trichoderma harzianum* – suitable for warm, tropical climates
- *Trichoderma parceramosum* – suitable for warm, tropical climates
- *Trichoderma polysporum* – suitable for cool climates
- *Trichoderma viride* – suitable for cool climates and acid soils
- *Trichoderma hamatum* – tolerant to excessive moisture
- *Trichoderma pseudokoningii* – tolerant to excessive moisture

Trichoderma harzianum and some others occur widely in nature. Isolates of e.g. *Trichoderma harzianum* were selected for commercialization because of its ability to compete with plant pathogenic fungi. The beneficial fungi outcompete the pathogens for nutrients and for a place to grow around roots or in pruning wounds, thereby preventing or reducing the impact of pathogens.

Gliocladium virens (previously known as *Trichoderma virens*) was the first antagonistic fungus to get approval of the Environmental Protection Agency (EPA) in the USA for registration. *Trichoderma* is often used as a spore suspension on carrier material such as rice bran. It can be used both as a preventive and curative. However, application before pathogens are visible, as a prevention, always gives the best control.

Trichoderma species are successfully used and multiplied in several countries in Asia, including Thailand, Philippines, Vietnam and Indonesia (FAO-ICP Progress report '96 – '99).

Trichoderma sp. should be mixed into the soil a few days before (trans)planting.



A negative effect of *Trichoderma* has been reported on mushrooms. *Trichoderma* can negatively influence mushroom cultivation, possibly due to killing or inhibiting the mushroom fungi. More research is needed to study these effects, but in the meantime it is advisable not to use *Trichoderma* close to a mushroom production area (Harman, 1998).

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

3.5. Beneficials among the pathogen groups

7.11 What about fungicides?

Available fungicides and bactericides are often not effective enough to stop any of the major eggplant diseases, especially during prolonged periods of wet weather. They can however, delay infection of diseases. Fungicides (if necessary) should always be combined with structural management methods like crop rotation, sanitation, etc. (see section 7.8).

7.11.1 Chemical fungicides

There are several ways of classifying fungicides. An often used classification is the following:

- **Preventive** fungicides: those should be applied before the disease actually occurs. The fungicide will form a protective layer around the plant which prevents spores from germinating on the plant. Timing of fungicide application is very difficult to predict. Also, when it rains, the fungicide will be washed off the leaves and there is no protection anymore, just environmental pollution. There are products that can be added to the fungicide that help it stick better to the plants, these are called *stickers*. Results in practice however vary.
- **Curative** fungicides: products that you can spray when symptoms of a disease occur. Some of these form a layer around the plant (contact products), others are uptaken by the plants and transported through the veins to other plant parts (systemic products).

Good to know about fungicides:

- There are few effective sprays against bacterial diseases!
- There are no sprays against virus diseases! (usually insect vectors should be prevented from entering the crop in areas where virus diseases are a problem).
- Control of soil-borne diseases with fungicides is usually not effective: it depends on the pathogen how deep below soil surface it can live and it is unclear how deep the fungicide will go. Some pathogens live inside plant left-overs in the soil, where they are protected from fungicides. From an environmental point of view, it is dangerous to apply fungicides to soil. What is the effect on the beneficial micro-organisms that decompose plant rests? Will the pesticide contaminate the ground water? How long will the pesticide persist in the soil?
- Frequent use of fungicides may lead to fungus resistance to that type of fungicide. That means the fungus is no longer susceptible to the fungicide. For example, there are different "strains" of *Fusarium* wilt in tomato (*Fusarium oxysporum*). All of these *Fusarium* strains cause tomato wilt but the genetic characteristics of a strain are slightly different. This is comparable with different varieties of tomato: all of them are tomato but they differ in e.g. fruit size, color and maturity. Strains may differ in susceptibility to fungicides.
- Many fungicides can actually kill natural enemies of insect pests! For a study example, see box in section 4.9.

No recommendations for the use of specific fungicides are given in this guide. The types, brands, doses of fungicides differ per country and local extension agencies or departments of agriculture may have national recommendation schedules.

1 Calendar spraying

The application of pesticides at regular or fixed intervals during the season is known as calendar spraying. This practice can be effective in disease control, but may lead to excessive fungicide use or poorly timed applications over the duration of the growing season, resulting in a loss of money for the farmer and environmental pollution. More important, calendar spraying is not based on what is actually happening in the field, on agro-ecosystem analysis. It does not account for presence of natural enemies, growth stage, weather conditions etc. Therefore, from an ecological point of view, calendar spraying should be discouraged.

7.11.2 Botanical fungicides

Not much “scientific” information is available on the use of botanicals against fungal diseases. However, in practice, farmers may use several botanical extracts to control diseases.

Garlic is one the more commonly used botanicals, effective both as seed treatment for disease control (see section 3.6.3.), and in a spray solution against fungal and bacterial diseases and insects. There are many methods to prepare garlic sprays. One of them is listed below.



Garlic spray: the recipe

Crush many garlic cloves with a little water, then strain this and mix with water, 1 teaspoon of baking soda, and 2 or 3 drops of liquid soap. Test its effect as a preventive spray against fungal and bacterial diseases and insects.

Ginger (*Zingiber officinale*) can be used at a concentration of 20 g/l water and sprayed 3 times in intervals of 15 days. Recommended against *Rhizoctonia solani*, and *Sclerotium rolfsii* (Stoll, 2000).

Onion extract is recommended against several fungi including *Fusarium oxysporum*. The extract is prepared as cold water extract using distilled water with 50 g onions per liter water. The plant material is crushed in the water and then homogenized. Then it is filtered through a fine cloth and ready to be applied (Stoll, 2000).

8 MAJOR DISEASES OF EGGPLANT



SUMMARY

Eggplant can be affected by many pathogens. Major diseases of eggplant in Asia are early blight, root diseases and wilt.

It seems obvious, but in practice it is often hard to properly diagnose plant diseases. The right identification of a disease, an understanding of the disease ecology, including knowledge of the factors influencing the disease (disease triangle), are essential elements of successful disease management. See chapter 7.

Some general disease management practices are given here. Specific practices are listed under individual disease sections.

- Use of disease-resistant varieties. Setting up variety trials to test how particular varieties perform locally is recommended.
- Increasing soil organic matter. This can increase soil micro-organism activity, which lowers population densities of pathogenic, soil-borne fungi. In addition, it increases nutrient availability, which results in better plant growth.
- Clean planting material. This includes use of clean seed (see section 3.6) and healthy, disease-free transplants.
- Proper fertilizer use. Using too much may result in salt damage to roots, opening the way for secondary infections. Balancing watering and fertilizer is also important. The succulent growth of plants given too much water and nitrogen encourages certain pathogens. On the other hand, stressed plants, especially those low in potassium and calcium, are more vulnerable to diseases.
- Water management. The most important practice is providing drainage to keep soil around roots from becoming waterlogged to prevent rotting. It is also important that foliage stay dry. Infectious material or inoculum of water-borne pathogens spreads from infected to healthy leaves by water droplets, and fungal pathogens need water to germinate and enter the leaf (see section 3.14).
- Sanitation. Removing diseased plants (or parts) helps prevent the spread of pathogens to healthy plants. Crop left-overs can be used to make compost. Sanitation also includes weed control and, in some cases, insect control because many pathogens persist in weed hosts or are spread by insects.
- Crop rotation. Rotation to an entirely different plant family is most effective against diseases that attack only one crop. However, some pathogens, such as those causing wilts and root rots, attack many families and in this case rotation is unlikely to reduce disease.
- Use of biocontrol agents. Good results have been obtained with use of *Trichoderma* sp. for control of soil-borne diseases, including damping-off and root rots. Several other biocontrol products may become available in Asia in the future.

8.1 Root rot and root deformation

8.1.1 Damping-off (*Fusarium*, *Rhizoctonia*, *Pythium* and *Phytophthora* sp.)

See photo 18 (page 177).

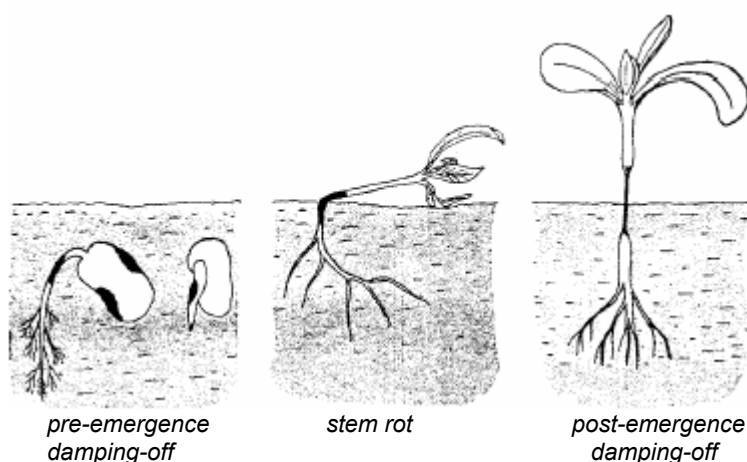
Causal organism: fungi - *Fusarium*, *Rhizoctonia*, *Pythium* and *Phytophthora* sp.

These soil-dwelling fungi infect vegetables, especially legumes, crucifers and solanaceous crops. Species of *Pythium* are more common than the others. If the infection occurs either before (pre-emergence) or just after emergence (post-emergence), and development of a spot (lesion) at the soil line results in collapse and shriveling of the plant, the disease is called 'damping-off'.

Signs and symptoms

Infection occurs just around the soil line in young seedlings. Damping-off fungi rarely attack transplants in the field or established seedlings.

The symptoms of this disease are brown, water-soaked areas around the lesion that shrivel and pinch the seedling off at the base. The dry rot is usually limited to the outer part of the stem and infected plants may fall down or may remain more or less upright. Infected plants remain under-developed and usually die.



(from: Kerruish et al, 1994)

Source and spread

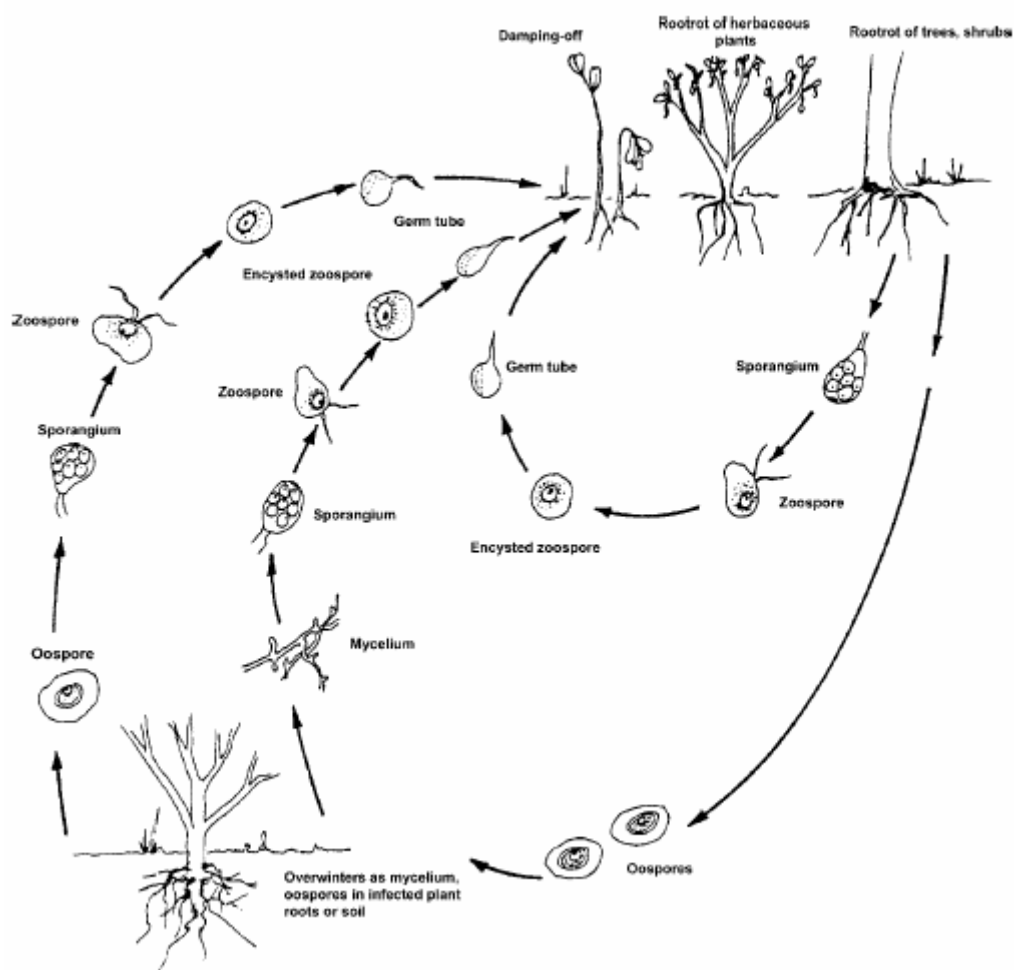
The fungi are natural soil inhabitants but when circumstances are favorable and when susceptible host plants are present, the population can increase to damaging levels. It is difficult to predict when that will occur: it depends on temperature and humidity but also on the population of micro-organisms in the soil. Sometimes, there are micro-organisms (*antagonists*) that serve as natural enemies of the pathogens: they can keep the population of the pathogen under control. This can occur especially when the soil contains a lot of organic material such as compost.

Infection occurs through wounds or natural openings but *Pythium* can also actively penetrate the tender tissue near root tips.

In case of *Pythium* infection, dying seedlings contain the spore-carrying structures of the fungus. The spores can drop to the soil (and attack seed or young seedling roots), or be carried by wind or spread to another location by surface water or irrigation water. *Pythium* can be transported in soil attached to seedling roots during transplanting. And *Pythium* can form thick-walled spores (called *oospores*) that can survive during adverse conditions and persist for several years in the soil.

Role of environmental factors

Damping-off occurs in areas with poor drainage or areas with a previous history of the disease. Damping-off is often associated with high humidity and high temperature. The temperature range in which these fungi can live is quite broad, from about 12 to 35°C with an optimum (the temperature at which damping-off develops fastest) of 32°C. That is why you can find damping-off disease both in highlands with a temperate climate and in (sub)tropical lowlands.



Disease cycle of *Phytophthora* damping-off and root rot
(from: Kerruish et al, 1994)

Natural enemies/antagonists

Many successes have been reported with the use of *Trichoderma* sp. to prevent damping-off. *Trichoderma* outcompetes fungi that cause damping-off for nutrients and a place to grow around the roots ("rhizosphere dominance"). There are several species of *Trichoderma*. The species *Trichoderma harzianum* has been used successfully in tropical climates but *Trichoderma parceramosum* also gave good results in field trials in the Philippines (FAO-ICP progress report '96 – '99). *Trichoderma* sp. are now available for use by farmers in, for example, Indonesia and Thailand. More details on *Trichoderma* in section 7.10.1.

There are several other antagonistic organisms that control damping-off fungi, such as *Bacillus subtilis*, *Burkholderia cepacia*, *Pseudomonas fluorescens*, *Streptomyces griseoviridis*, and *Gliocladium catenulatum*. Different strains of these antagonistic organisms have been registered in the United States as biocontrol products to control damping-off and some other soil-borne plant diseases. In the future these biocontrol agents might become available in Asia.

Damping-off can also be reduced in soils rich in compost. Compost contains many different micro-organisms that either compete with pathogens for nutrients and/or produce certain substances (called *antibiotics*) that reduce pathogen survival and growth. Thus an active population of micro-organisms in the soil or compost outcompetes pathogens and will often prevent disease. Researchers have found that compost of almost any source can already reduce damping-off disease. The effect of compost on plant pathogens can be increased by adding antagonists such as the fungi *Trichoderma* and *Gliocladium* species. Such compost is called *fortified* compost. See section 3.8.3.1 on compost.

Management and control practices

Prevention activities:

- Location: avoid placing the nursery in a densely shaded or humid place.
- Disease chances will be reduced if fields are deeply plowed at least 30 days before planting to allow time for old crop and weed residues to decompose.
- Remove and destroy crop left-overs as these may contain spores of damping-off fungi (and other pathogens).
- Make sure the nursery is well drained and the soil is soft and crumbly.
- Do not apply high doses of nitrogen. This may result in weaker seedlings which are more susceptible to damping-off. Usually, when organic material has been incorporated in the soil before sowing, there is no need to apply additional fertilizer.
- Add lots of compost or other decomposed organic material (15 to 20 tons/ha). Compost contains micro-organisms and it feeds micro-organisms already in the soil. An active population of micro-organisms in the soil may outcompete pathogens and will often prevent disease.
- Crop rotation: If you are raising eggplant seedlings every season, use fresh soil that has not been used for eggplant or other solanaceous crops for at least 2 years. Plant another crop (not a solanaceous crop) in the 'old' eggplant nursery.
- Use vigorous seed or seedlings. Slowly emerging seedlings are the most susceptible.
- Good results have been obtained with use of the antagonist *Trichoderma* sp. For example, application of *Trichoderma harzianum* is recommended by the Dept. of Agr. Extension in Thailand to prevent damping-off. The *Trichoderma* should be mixed into the soil before transplanting.
- An interesting option is the use of fortified compost. This is compost that contains the antagonistic fungus *Trichoderma*. *Trichoderma* is added to the compost after the primary heating period of composting is complete. The *Trichoderma* fungus increases to high levels in the compost and when added to the soil, they are as effective as, or in many cases more effective than chemical fungicides for control of a number of soil-borne diseases, such as damping-off. See section 3.8.3.1 on compost.
- Use seed that is coated with a fungicide layer or with a layer of biological agents. See section 3.6.
- Soil sterilization is practiced in many countries, often as a preventive measure before sowing. There are many methods to sterilize small areas of soil. See details in section 3.10.1.
- Consider using a layer of sub-soil (taken from a layer of soil below 30 cm) to prepare raised nursery beds. See section 3.10.1.3 for details.

Once disease symptoms are found in the nursery:

- Unfortunately, the seedlings that are affected by damping-off cannot be saved. To prevent the disease from destroying all plants in the nursery, you may consider uprooting the healthy seedlings if they are large enough to survive in the field. Chances of success, however, may not be too great and many seedlings may still die. If the seedlings are still small, they cannot be transplanted.
- Uproot and destroy diseased seedlings to avoid build-up of the pathogen population.
- When the nursery soil is wet or waterlogged, dig a trench around the beds to help drain them. It may slow disease spread to other parts of the nursery.
- If soil sterilization is not an option or is impractical, do not use the infected area for nurseries for at least 2 seasons.
- In some areas, fungicides are being used to control damping-off. Results vary however. In this guide fungicide use is not recommended for control of damping-off.



Points to remember about damping-off:

1. Damping-off is a serious nursery problem, caused by several soil-borne pathogens.
2. Damping-off occurs in areas with poor drainage or areas with a previous history of the disease.
3. Crop rotation (including nursery site), proper drainage and sanitation practices (removing crop left-overs) are ways to prevent disease problems.
4. Good prevention of damping-off can be achieved by adding compost or other decomposed organic material (15 to 20 tons/ha) to the soil regularly and before sowing or transplanting.
5. Additional prevention can be obtained with use of antagonistic fungi, such as *Trichoderma* sp.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

- 3-B.1. Seed drenching/coating to manage damping-off
- 3-B.2. Use of subsoil to manage damping-off in the nursery
- 3-B.3. Soil solarization to manage damping-off in the nursery
- 3-B.4. Steam sterilization to manage damping-off in the nursery

8.1.2 Root rot – *Phytophthora* sp.

Causal organism: fungi – *Phytophthora* sp.

If part or all of the roots are destroyed by a pathogen, the plant has a root rot. If the rot progresses so that the entire root system is destroyed, the shoot then collapses as well. Root rots can attack many vegetables. In eggplant, root rot is caused by *Phytophthora capsici* and in tomato it is caused by the fungi *Phytophthora parasitica* and *Phytophthora capsici*.

Root rots in other vegetables may be caused by a complex of other soil fungi, including those that cause damping-off disease, like *Fusarium solani*, *Rhizoctonia solani*, and *Pythium* sp.



Roots affected by
Phytophthora sp.
(from: Blancard, 1992)

Signs and symptoms

Part or all of the root system of the plant is destroyed. At soil level, dark-greenish, water-soaked spots occur which often girdle the stem, causing the plants to wilt and die. Diseased plants appear in patches in the field, with the location and size depending on weather and soil conditions.

Leaf spots may develop, which are often water-soaked and irregular in shape, later becoming a light-brown shade. The fruit shows similar spots often enlarging to cover the entire fruit, which later dries and becomes mummified.

Source and spread

Fungi causing root rots are soil inhabitants. They can spread by soil particles attached to transplants, field tools, slippers or shoes, etc. or with ground water.

Role of environmental factors

The fungus causing root rot in eggplant is most active in moist, warm weather. Both damping-off and root rots occur in areas with poor drainage (=high soil humidity) and/or areas with a previous history of the disease.

Root damage from salts (for example caused by too much fertilization) and soil compaction can also lead to increased loss due to root rots. If a field has symptoms of root rot, the plants that survive are probably also damaged and may have lower yield or show disease symptoms when stressed later in the season.

Natural enemies/antagonists

Trichoderma sp. is an effective antagonistic fungus that can reduce root rot. See section on damping-off above and section 7.10 for more information on *Trichoderma*.

Management and control practices

Same as for damping-off disease. See section above.

Deep planting, planting into cold, wet, or poorly prepared soils, low soil fertility and use of old or poor quality seeds can all increase the incidence of damping-off and root rot disease.

Points to remember about root rot:

1. Root rot is caused by soil-borne pathogens.
2. Root rot occurs in areas with poor drainage or areas with a previous history of the disease.
3. Optimizing drainage and growing conditions, using vigorous seed, rotation of the nursery site and sanitation practices (removing crop left-overs) are ways to prevent disease problems.
4. Good prevention of damping-off can be achieved by adding compost or other decomposed organic material (15 to 20 tons/ha) to the soil regularly and before sowing or transplanting.
5. Additional prevention can be obtained with application of the antagonistic fungi *Trichoderma* sp.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

- 3-D.1. Pot experiment to test whether root diseases are soil-borne
- 3-D.2. Use of subsoil to manage root disorders in the nursery
- 3-D.3. Steam sterilization of soil for the nursery
- 3-D.4. Soil solarization to manage root diseases in the nursery
- 3-D.5. Test effect of soil solarization in the field

8.1.3 Rootknot nematode - *Meloidogyne* sp.

See photo 17 (page 177).

Species belonging to the rootknot nematode family include *Meloidogyne incognita*, *Meloidogyne javanica* and *Meloidogyne arenaria*. They are all very small worm-like creatures living in the soil and feeding on plant roots. The rootknot nematodes have a very wide host range including most of the commonly grown vegetables and many common weeds.

Signs and symptoms

Plants affected by nematodes may wilt during warm weather, or in the middle of the day, but recover afterwards. The rootknot nematode sucks on the roots of many plant species. This feeding activity causes enlargement of the roots and the production of the *root galls*. Root galls are a typical symptom of rootknot nematode infection. A large number of (female) nematodes can be present inside a gall. One female can lay up to 600 eggs. The egg masses (or egg sacs) are usually placed outside the gall. The egg sacs can be seen with the bare eye as yellow-whitish round sacs, but it takes some experience to note them. The nematodes live in the upper 60 cm of the soil.

Source and spread

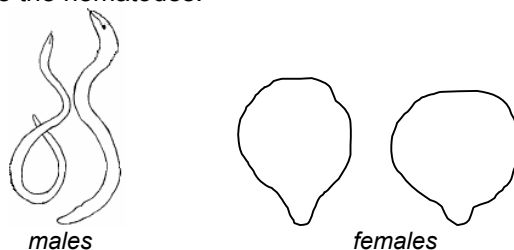
Nematodes are small worms that can travel small distances through the soil. The most important method of spread, however, is in soil attached to feet of field workers/visitors and animals, tools and implements, etc. Soil particles spread by wind or in ground or irrigation water is another way of spreading the nematode. Nematodes can also be transported in soil which is carried on the roots of transplants.

Role of environmental factors

A soil temperature of 26-28°C is highly favorable for the development of rootknot nematode, particularly on light, sandy soils. High temperatures of 40-50°C kill the nematodes. In infested nursery fields, it may be worth trying solarization or other soil sterilization methods mentioned in section 3.10.1.

**Rootknot nematodes: how to see them!**

It is important to recognize the symptoms of rootknot nematodes, especially the early symptoms. There may still be time to take some action to prevent population build-up and severe crop damage. Root galls are typical symptoms of rootknot nematodes. At an early stage however, or in case of a single gall only, it can be difficult to identify if the symptoms are actually caused by rootknot nematodes. This test can be done to help early identification and to confirm diagnosis. It is also a way to actually see the nematodes.

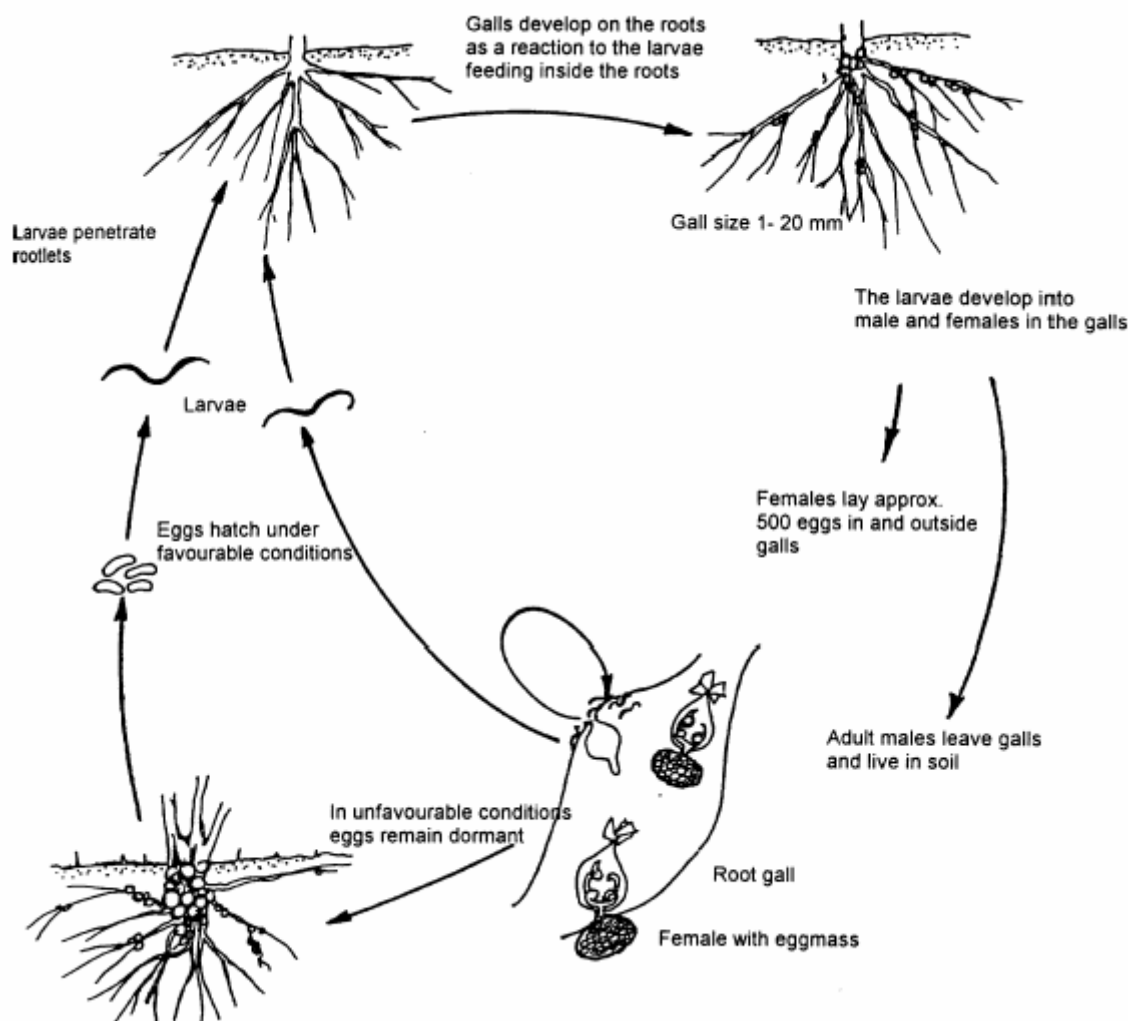


rootknot nematodes:

males

females

It should be noted that it takes some experience to recognize the nematodes (needs experienced facilitator). Also not all galls contain living nematodes, so some trial and error may be necessary. Collect fresh root galls from the field, wash the roots with water to remove soil particles. Put a small layer of clean water on a dark-colored plate. Place the root gall in the water, and crush it thoroughly using pocket knives or needles. Nematodes will be released from the gall and float to the water surface. Female nematodes can be seen as very small, whitish colored, round to pear-shaped structures. Males are smaller and cannot usually be seen with the eyes. Males are not round but long (worm-like) in shape.



Life cycle of *Meloidogyne* rootknot nematodes
(from: Kerruish et al, 1994)

Importance - plant compensation - physiological impact

Given the very broad host plant range and the fact that these nematodes live in the soil, they are very difficult to control once present in the field. When temperature and humidity are favorable, nematode populations can build up in time and this may increasingly result in crop damage.

As a result of nematode infestation, the plants secondary root production is reduced which means that the uptake of water and nutrients will be interrupted. This reduces growth and production capacity of plants. Plants can compensate for some injury by producing new roots but it depends on how much injury occurs if this will result in yield loss.

Natural enemies/antagonists

The action of certain species of fungi that attack nematodes has been studied for many years. One fungus, *Arthrobotrys irregularis*, has proven successful in the control of rootknot nematode. The success of using this fungus depends largely on how well the fungus is able to establish itself within the soil. Another fungus, *P. lilacinus*, has been reported to control rootknot nematode. This fungus also controls the potato cyst nematode in the Philippines. In the Philippines a fungus was isolated from the soil known as "Bioact strain 251". A commercial formulation called "Bioact" containing spores of this fungus was developed. Bioact is very effective against all stages of plant parasitic nematodes, including rootknot (FAO – Dalat report (V. Justo), 1998).

Another fungus, *Myrothecium verrucaria*, is an antagonist that occurs naturally in soils. A commercial strain has been isolated in the USA and it is sold as "DiTera", a powder formulation containing spores of

this fungus. Also from USA: the product “Deny” containing the bacterium *Burkholderia cepacia* (*Ralstonia cepacia*) type Wisconsin that works against *Rhizoctonia*, *Pythium*, *Fusarium*, and disease caused by lesion, spiral, lance, and sting nematodes.

Studies in Australia and the Philippines are evaluating biofumigation as a means of controlling rootknot nematode. See section 3.10.1.4.

Management and control practices

Prevention activities:

- Resistant varieties against rootknot nematodes may be available. Check with local supplier. Under high temperatures, there is a chance of the nematodes breaking through this resistance. However, in areas invaded with rootknot nematodes, resistant varieties should have preference over non-resistant ones as some resistance is maintained.
- Use only healthy seedlings for transplanting. Seedlings with any signs of root galls (or any other signs of diseases) should not be transplanted in the field. In fact, if there are galls found on the roots of seedlings, the whole seedbed should be discarded as the other seedlings are probably infected as well but just do not yet show symptoms.
- Given the very broad host plant range of the rootknot nematode, crop rotation is of limited value. Onion is probably one of the few crops that has little trouble from the nematodes. Using a resistant eggplant variety in rotation with onion may help reduce the population of rootknot nematodes in the soil. Proper weed control should be applied in addition, as the nematodes may survive on some weeds.
- Flooding the cultivated land, such as may occur when vegetables are grown in rotation with rice, will reduce population of the rootknot nematode.
- Bare fallowing of the field during the dry season, provided that all weeds are eradicated as soon as they germinate, may also reduce the population of the rootknot nematode.
- Certain plant species such as groundnut may act as a trap-crop: after penetrating into the roots of these plants, the nematodes die due to abnormal development. This leads to a reduction in the nematode population.
- The incorporation of well-composted organic manure into the soil is said to stimulate the plant and possibly change the balance of micro-organisms in the soil to the detriment of the rootknot nematode. There are also reports of control of the rootknot nematode in tomato by adding fresh organic matter such as poultry manure, cattle manure and different kinds of green manure to the soil. See box below. The fresh organic material should be incorporated into the soil before the seedlings are transplanted. In Dhaka region, Bangladesh, good results have been obtained with incorporation of mustard oil cakes or with poultry refuse in both seedbeds and main field (pers. comm. Md. Atiur Rahman, 2001). In areas where rootknot nematodes cause problems, some trials could be set up testing these options.

Chicken manure to control nematodes?

The incorporation of fresh chicken manure into the soil before transplanting seedlings, has been found to reduce nematode attacks. The reason for this is not clearly understood. It may be that the ammonia gas released during decomposing of the manure kills nematodes. Or it may be that plants compensate for the nematode attack by more vigorous growth due to more nutrients available from the manure (pers. comm. Dr. J. Vos, 2000).



No matter what the reason is, in areas where rootknot nematodes cause problems, it can be worth setting up a field study to test this method.

- Use of botanicals: incorporation of fresh leaves of *Lantana camera* into the soil before the seedlings were transplanted was reported to be effective preventing rootknot nematode infestation in tomato fields in Sri Lanka. Other botanicals such as oilcakes of mahua (*Madhuca indica*), castor (*Ricinus communis*), mustard (*Brassica campestris*), neem (*Azadirachta indica*) and groundnut (*Arachis hypogaea*) and marigold are also mentioned as potentially active against rootknot nematodes (Alam, 1980). It is recommended to study this in a field trial.

Once disease symptoms are found:

- Infected plants, including all roots, should be removed and burnt outside the field. This will not eliminate the nematodes from the field but it will reduce population growth.
- Antagonistic fungi may be available for control of rootknot nematodes. See section on natural enemies above. Check with local extension service for details.
- Grafting is sometimes practiced to overcome rootknot and other soil-borne diseases such as bacterial wilt. The eggplant variety can be placed on a rootstock of the “wild” eggplant variety *Solanum torvum*, which is resistant against rootknot nematodes and bacterial wilt. See section 3.13.
- There are pesticides that can kill nematodes. These are called nematicides. Efficacy of these pesticides is doubtful as the nematodes can be present in deeper layers of the soil and they can be protected by plant roots, reducing the effect of nematicides.

 Points to remember about rootknot nematodes:

1. Rootknot nematodes cause problems in many (vegetable) crops due to their broad host range.
2. A number of cultural practices are effectively preventing or reducing infestation, the main ones being use of resistant varieties, and the incorporation into the soil of fresh organic matter.
3. There are several antagonistic fungi that work against rootknot nematodes. These may become available over the next years.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

- 3-D.1. Pot experiment to test whether root diseases are soil-borne
 3-D.2. Use of subsoil to manage root disorders in the nursery
 3-D.3. Steam sterilization of soil for the nursery
 3-D.4. Soil solarization to manage root diseases in the nursery
 3-D.5. Test effect of soil solarization in the field
 3-B.12. Test different cultivars for resistance to wilt diseases

8.2 Leaf spot, blight, leaf deformation and fruit rot**The cause of blight, spots, leaf malformations, and discoloration....**

“Blight” implies sudden and extensive damage to the leaves. In many leaf diseases however, the affected area is limited which gives the appearance of spots. These spots may be big or small depending upon the organism responsible for causing them, and the environmental conditions. Blight and leaf spots can be caused by different pathogens such as fungi, bacteria, and viruses. Leaf spots can also be caused by unfavorable water relationships or temperatures, mineral deficiencies or excesses, insects or pesticides.

In the field, the difference between the various causes for blights and leaf spots is not always easy to make, especially with early symptoms. It is stressed that for a proper decision on the management of leaf spot caused by pathogens, it is not always necessary to be able to distinguish the different causal organisms. Most fungal and viral leaf spots will need similar management practices, mainly reduction of the source of infection by sanitation. See sections on individual diseases and check the key table in chapter 10.

It is necessary, however, to distinguish between spots and blight caused by pathogens and those caused by other factors such as unfavorable water relationships or temperatures, mineral deficiencies or excesses, insect damage or pesticide injury to the plant. See section 7.6 for a list of questions that may help finding the cause of the “blight”.



8.2.1 *Phomopsis rot - Phomopsis vexans*

See photos 21 and 22 (page 177).

Causal organism: fungus - *Phomopsis vexans*

Other common names: *Phomopsis* fruit rot, *Phomopsis* blight, and foot rot

Signs and symptoms

All above-ground parts can be affected at all stages of development. Spots generally appear first on seedling stems or leaves. Spots may girdle seedling stems and kill the seedlings.

Leafspots are gray-brown, clearly defined, circular spots with a narrow dark brown margin. In time the center of the spot becomes gray, and black pycnidia (fungus reproductive structures that appear as small specks) develop in this area. Affected leaves may turn yellow and die.

Stems can also be affected: lesions are circular and may also contain pycnidia.

Fruit spots are similar to those on the leaves but are much larger: large, circular, sunken tan or black areas on the fruit. Affected fruits are first soft and watery but later may become black and shriveled. Pycnidia also appear on fruit spots, usually in circular forms.

Source and spread

Phomopsis persists in and on seeds and survives in residue from diseased plants. In addition, it is spread through splashing water.

Role of environmental factors

Disease is promoted by wet weather and high temperatures.

Natural enemies/antagonists

Unknown.

Management and control practices

Prevention activities:

- Planting resistant varieties is the most effective prevention. Resistant varieties from the USA are Florida market, Black pride, and Special Hibush (Peet, www1). See table in section 3.2.2.
- Use certified seed.
- Use a three year crop rotation. See section 3.17.
- Sanitation: clean up plant debris where the pathogen can survive and spread to new (solanaceous) crops.

Once disease symptoms are found:

- There are fungicides that may be able to kill the fungus and stop the spread. Note that some beneficials and natural enemies of insect pests may be killed by fungicide sprays as well!

Points to remember about *Phomopsis rot*:

1. *Phomopsis* rot can affect seedlings, leaves, stems, and fruits. Circular spots containing pycnidia (tiny black specks) are typical for this fungal disease.
2. *Phomopsis* rot persists in and on seed, and survives in residue from diseased plants.
3. Resistant varieties exist. Check with local seed supplier.
4. Good crop sanitation, use of clean seed, and a three-year crop rotation schedule may help prevent disease.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

- 3-A.1. Study of symptom development of leaf spots: classroom exercise
- 3-A.2. Study of symptom development of leaf spots: field exercise
- 3-A.3. Effect of infection of the seed bed
- 3-A.4. Effect of the use of infected planting material
- 3-A.5. Test effect of hot water seed treatment
- 3-A.6. Use of subsoil to manage leaf spot diseases in the nursery
- 3-A.7. Soil solarization to manage leaf spot diseases in the nursery

- 3-A.8. Steam sterilization to manage leaf spot diseases in the nursery
- 3-A.9. Test effect of infected crop debris in the field
- 3-A.10. Effect of rain on the spread of leaf spot
- 3-A.12. Test different cultivars for resistance to leaf spot
- 3-A.13. Pruning and plant compensation study
- 3-A.14. Restricted fungicide use to manage leaf spots
- 3-C.1. Symptom development of fruit diseases: classroom exercise
- 3-C.2. Symptom development of fruit diseases: field exercise
- 3-C.3. Use of healthy seed
- 3-C.4. Test of seed health

8.2.2 Early Blight - *Alternaria solani*

See photos 23 and 24 (page 177).

Causal organism: fungus - *Alternaria solani*

This disease can infect many species of the solanaceous family such as tomato, potato, eggplant, green pepper, and hot pepper.



How early is early blight?

The “early” in early blight was used in the U.S.A. to distinguish *Alternaria* blight from *Phytophthora* late blight; it refers to the time of disease appearance relative to plant age. In other countries, early or late disease appearance may have nothing to do with the causal fungus: early blight may appear late in the season and late blight may be found at an early growth stage!

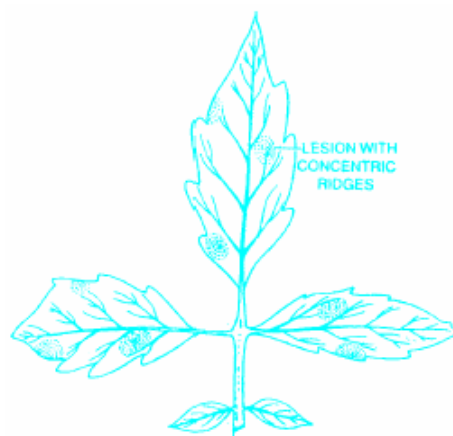
Signs and symptoms

This disease can be destructive on eggplant at any time in the life of the plant. It can affect seedlings but is generally observed on older plants. All aboveground parts of the plant can be affected.

Seedlings may be affected just before or after emergence. On seedlings, dark spots develop on the seed leaves (cotyledons), stem and true leaves. This seedling dieback is known as collar rot. Spotted cotyledons may be killed, and spotted stems may be girdled at the base of the plant. Affected seedlings are stunted and may wilt and die. When older seedlings are infected, stem spots usually are restricted to one side of a stem.

On established plants, dark brown spots with dark concentric rings develop first on oldest leaves. The concentric rings give the spot a target appearance. Leaf spots are characteristic for early blight. The spots are circular and up to about 1,5 cm in diameter. The spots may occur singly or in large numbers on each leaf. Yellowish area may develop on affected leaves and eventually, the leaves turn brown and usually drop from the plant. Leaf spotting first appears on the oldest leaves and progresses upward on the plant. It is possible for entire plants to be defoliated and killed.

In tomato plants, the leaves seem to become susceptible to disease attack in the field when the first fruits begin to ripen. It is also common to see disease symptoms appear when the plants are loaded with fruits. It is not clear if this is also true for eggplant. Plants that are well fertilized and irrigated are not as susceptible.



Early blight leaf spots on tomato leaf
(from: Pandey, 1997)



Early blight fruit spots with fungus spores in concentric rings
(from: Pandey, 1997)

Symptoms may also appear on fruits. Infection of the fruit pedicels may cause a premature fruit drop. On fruit, spots develop into brown to black leathery sunken area, often with dark concentric rings. The concentric rings contain the spores of the early blight fungus.

Source and spread

The fungus can survive in soil and in infested crop and weed residues. It may be seed-borne and carried by wind, water, insects, workers and farm equipment. It can persist for at least one year, possibly several years without a host plant. The spores that land on eggplant will germinate and infect the leaves when they are wet. Spores can enter the leaf, stem or fruit. When infected seeds germinate, the fungus can infect the seedling before or after emergence.

Role of environmental factors

The fungus is most active during mild to warm temperatures (24 to 28°C) and wet weather. The disease is worse during the rainy season. Disease is severe on plants of poor vigor such as old transplants and transplants that are wilted during a long period between pulling and planting. Early blight disease can also be severe on plants stressed by a heavy fruit load, nematode attack, or low nitrogen fertility.

Spores of this fungus are like plant seeds: they need water for germination. Spores of early blight germinate on plant leaves. The spores penetrate the leaves through natural openings in the leaves or directly through the leaf skin when humidity is high and temperatures are between 10 and 25°C. Generally, the higher the temperature, the quicker the infection can occur. The outside of the plant still looks normal but inside the leaf, the fungus starts growing and killing plant tissue. Under field conditions, leaf spots may become visible 2 or 3 days after the infection. The minimum time from first infection to production of new spores is about 5 to 7 days. This relative short disease cycle allows for numerous cycles when conditions are favorable.

Importance - plant compensation - physiological impact

There is a loss of young plants in seedbed, plus the danger of spreading disease on transplants. Leaf infection may result in defoliation starting at the base of the plant. Early blight can lead to complete defoliation during humid weather at temperatures near 24°C. This weakens the plant and may reduce the yield. In addition, losses may occur as a result of fruit infection.

Natural enemies/antagonists

In USA, the biocontrol agent *Bacillus subtilis*, sold as "Serenade" is available for control of several pathogens including early and late blight of vegetables. It can be applied as a spray. Biocontrol products can be found in "The BioPesticide Manual" (Copping, editor) or at several sites on the internet, for example, [www14](#) and [www15](#) (see reference list in chapter 11).

Management and control practices

The best way to manage the disease is on a preventive basis. Once early blight is established in the crop, it is very difficult to control. Inspect the crop twice a week for plants with disease symptoms.

Prevention activities:

- **Planting season:** In areas with high early blight incidence it may be advisable to plant eggplant or other solanaceous crops in the dry season when the incidence of early blight (and other leaf diseases) is lower.
- **Plot location:** It is better not to have multiple plantings in the same area because old crops will serve as inoculum of early blight for the new plantings. Select plots surrounded by e.g. grasslands because they are not a host of this disease.
- **Resistant and tolerant varieties** against early blight may be available. It would be advisable to test some varieties to check the resistance against early blight (and other diseases and insect pests) under local conditions.
- **Use of disease-free seed and plant material.** Presence of initial disease spores attached to seed, soil or transplants should be reduced or avoided. When transplants have leafspots or other signs of infection, they should not be transplanted to the field. Seed should be used only from disease-free plants. Hot-water or chemical treatment of seed is of limited value.
- **Nursery beds should be distant from old plantings.** It is important to use new deep soil that has good drainage properties for the nursery. Sterilize the soil (see section 3.10.1) to reduce soil-borne pathogens. Inspect seedlings for any sign of disease and discard and destroy any that are suspected of infection.

- **Crop rotation:** Eggplant should be rotated with plants other than tomato, potato, pepper, and other solanaceous crops in a schedule of at least two, and preferably three, years.
- **Crop remains should be removed and destroyed immediately after harvest.** Make a compost pile and cover it with a layer of soil. Do not use this compost on eggplant or any susceptible crops unless it is completely decomposed. Infected crop left-overs is a very important source of new infection!
- When possible, **avoid planting solanaceous crops adjacent to the eggplant field** if they will mature before the eggplants. Such plantings can be a massive source of spores for the planting that will mature later.
- Infection rate can be reduced by **maintaining good plant vigor and minimizing injury to plants.** Plant vigor is influenced by several factors including adequate fertilization and proper moisture contents of the soil during transplanting and growing. Increase the organic matter in the soil as much as possible, especially by using well decomposed manure. This will increase fertility. The use of nitrogen fixing legumes in the crop rotation scheme can also increase the fertility of the land and eliminate some of the inoculum.
- When possible, **limit leaf wetness period**, which promotes sporulation and infection, by not using overhead irrigation or irrigating early in the morning to allow quick drying of the leaves. Also avoid growing eggplant in shady areas or areas with little wind as this will increase leaf wetness period.

Once disease symptoms are found:

- **Fungicides** can reduce the rate of infection. The need for fungicides depends on the time of disease appearance and the rate of disease spread. Sometimes, pruning of the older leaves (and removing these from the field!) may already reduce a good portion of the infection. Usually, fungicide applications should begin when early symptoms of early blight are detected. Most fungicides will provide a layer on the leaves to prevent spores from germinating. As new leaves form regularly and rain may wash the protective fungicide coating off the leaves, the fungicide need to be applied regularly. How often depends on disease incidence, growth stage and weather conditions. Sometimes, 7- day intervals are used when the weather is cool and damp, and up to 10-day intervals when the weather is dry. Regular monitoring of the field is very important to establish such a schedule! Trials can be set up to check the importance of early blight and the efficiency of such a spraying schedule. It might be worth trying to establish some kind of spraying threshold: e.g. when a certain number of lesions appear, then a spraying schedule of different interval can be tested. **Disease-forecasting programs** have been developed to predict the rate of early blight development based on weather patterns. Such programs could enable farmers to better time their fungicide applications but the success of forecasting programs varies.
- **Ratoon crop:** cutting the plants back and allowing regrowth may also be worth trying when blight infestation is severe. See section 3.12. It is important to remove all plant material from the field and destroy it. Old leaves may still be a massive source of infection for the new shoots.

Points to remember about early blight:

1. Early blight is a serious disease that can cause death of plants and severe loss of fruits.
2. Most management practices focus on prevention or delay of infection.
3. Sanitation, such as pruning infected leaves is a good control method and it prevents spread of the fungus. However, too much pruning results in lower yields.
4. Once early blight infection occurs and environmental conditions are favorable for its spread, the disease is hard to control by just sanitation. Fungicide application may be needed. However, the timing and number of fungicides applications can be changed by studying the disease in the field.
5. When severe infection reduces yield, it may be worth cutting the whole plant back and allow regrowth (ratooning).

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

- 3-A.1. Study of symptom development of leaf spots: classroom exercise
- 3-A.2. Study of symptom development of leaf spots: field exercise
- 3-A.3. Effect of infection of the seed bed
- 3-A.4. Effect of the use of infected planting material
- 3-A.5. Test effect of hot water seed treatment

- 3-A.6. Use of subsoil to manage leaf spot diseases in the nursery
- 3-A.7. Soil solarization to manage leaf spot diseases in the nursery
- 3-A.8. Steam sterilization to manage leaf spot diseases in the nursery
- 3-A.9. Test effect of infected crop debris in the field
- 3-A.10. Effect of rain on the spread of leaf spot
- 3-A.12. Test different cultivars for resistance to leaf spot
- 3-A.13. Pruning and plant compensation study
- 3-A.14. Restricted fungicide use to manage leaf spots
- 3-C.1. Symptom development of fruit diseases: classroom exercise
- 3-C.2. Symptom development of fruit diseases: field exercise
- 3-C.3. Use of healthy seed
- 3-C.4. Test of seed health

8.2.3 Little leaf

Causal organism: a mycoplasma-like organism (phytoplasma)

Signs and symptoms

The main symptom of this disease is the production of very short leaves. The petioles (leaf stems) are so reduced in size that the leaves appear sticking to the stem. Leaves are very small, thin and pale green. Newly formed leaves are further reduced in size. Shoots of affected eggplant are shorter than normal. A large number of buds are stimulated to grow into short branches with small leaves. This gives the whole plant a bushy appearance. Especially when infection occurs during the early growth stages, plant development is very much reduced. Usually affected plants do not form flowers.

When infection occurs later in the season, the growth of the fruits after infection is restricted or stopped and the fruits become hard and fail to mature. Seed production is negligible.

Source and spread

Little leaf disease of eggplants is caused by a phytoplasma, a mycoplasma-like organism. This is a tiny organism that lives inside a plant and cannot be seen with the naked eyes.

The organism is transmitted by a jassid called *Cestius phycitis* (previously called *Hishimonus phycitis*). This jassid is called a *vector* for this reason. Probably, during the off-season of eggplant, the mycoplasma survives on weed hosts and from there it is transmitted to a new eggplant crop by insect vectors.



In pot tests the vector showed a preference for mycoplasma-diseased leaves, which contained higher amounts of moisture, total carbohydrates, sugars and organic acids than healthy ones. The structure and arrangement of cells in infected leaves apparently favor vector feeding. Also, the bushy growth of infected plants favor vector survival and reproduction.

Role of environmental factors

Unknown. The disease seems to appear especially late in the season. Probably related to seasonal behavior of insect vectors.

Importance, physiological impact, plant compensation

This disease can be very destructive, affecting large portions of a field.

Mycoplasma-diseased leaves contain higher amounts of moisture, carbohydrates, sugars and organic acids (e.g. auxin IAA and cytokinin) than healthy ones. More P and K but less Ca, Mg, total chlorophyll and phenols were present in diseased leaves.

Root development is also reduced in infected plants. The extent of reduction varies with the eggplant variety.

Natural enemies/antagonists

Unknown.

Management and control practices

Prevention activities:

- Some varietal resistance has been reported. See table in section 3.2.2. Research is ongoing to select genotypes with resistance to little leaf disease. Field studies done in New Delhi, India (Das,

1999) for example, showed that 8 out of 66 genotypes of eggplant were resistant. It will take probably some years before such lines will become available varieties. It is advised to test varieties for resistance or tolerance to pests and diseases in a varietal trial.

- Eradication of solanaceous weeds that may serve as hosts.
- Control of jassids, which may carry this disease into the field.
- Planting time: In Madhya Pradesh, India, early sown eggplant crops (third week of June) became less diseased than those sown in July or August, due to differences in leafhopper vector populations. Continuous cropping of the same cultivar increased disease incidence, as did the presence of weeds, sweet potato or tomato crops nearby which helped to increase vector populations (Keshwal, 1986).

Once disease symptoms are found:

- Uproot diseased plants as soon as they are detected. These plants serve as a source of infection!
- In field trials from India under natural infection, little leaf disease was controlled best by dipping seedlings in tetracycline followed by a soil application of phorate (Maheshwari, 1988). Other studies suggest that spraying and root immersion were efficient ways of treating the plants as was evidenced by the amount of tetracycline uptake (Verma, 1978).
- Research from India reported tetracycline therapy to be effective in controlling this disease. The symptoms are suppressed. However, if the disease occurs only at a few plants in the field, it is probably easier and cheaper to rogue these plants and burn them outside the field or use them for composting. See section 3.8.3.1 for proper composting methods.



Points to remember about little leaf:

1. Little leaf is a disease that results in bushy plants without fruits.
2. Little leaf is caused by a mycoplasma (phytoplasma), transmitted by jassids.
3. Growing resistant or tolerant varieties where available, control of jassids, and removing infected plants from the field (sanitation) are ways to prevent and reduce disease incidence.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

- 3-F.7. Role play on effects of pesticides on virus transmission by insect vectors
2-C.4. Testing of cultivars

8.2.4 Anthracnose Fruit Rot

Causal organism: fungi, several species.

Fungi causing anthracnose of eggplant fruits include *Colletotrichum melongenae* and *Gloeosporium* sp. The anthracnose fungi can attack several solanaceous crops including eggplant, tomato and pepper.

Signs and symptoms

Small, water soaked, circular spots develop under the skin of fruit as it ripens. Those spots can appear on both unripe and ripe fruits. The spots become sunken and dark. Numerous dark specks, the fruiting bodies of the fungus, develop in the lesions often in radiating circles around the center. In moist, warm weather, these black bodies ooze gelatinous pink spore masses. Spots vary from one to several on the fruit surface. In warm weather the fungus and soft rot bacteria which enter the split skin over the lesions spread internally forming a semisoft decay which makes the fruit worthless.

Severely infected fruits drop to the ground with the pedicel still attached to the plant. The eggplant seed may be infected and often seedlings have the disease, which later moves into the developing foliage. Such infections are often unnoticed until the fruits start to grow, at which time the fruit rot phase may become serious.

Source and spread

Anthracnose causing fungi survive between crops on infested plant debris in the soil. Early in the growing season, spores from the soil splash on lower leaves of the eggplant. Few symptoms develop on infected leaves, but the spores produced on foliage can be carried by splashing rain to developing fruit. Infected unripe fruits will not develop symptoms of anthracnose until they begin to ripen. Ripe fruit is very

susceptible to these fungi. Seeds from infected fruits are another source of infection. Transplants also serve as a source of inoculum.

Role of environmental factors

Disease incidence increases as humidity and temperature rise.

Most anthracnose fungi grow at temperatures of 13 to 35°C with optimum growth at around 27°C. Anthracnose needs a lot of water to develop (a humidity is 93% or above). That is why rainfall (and overhead irrigation!) favors disease development.

Importance - plant compensation - physiological impact

Anthracnose can reduce a bountiful harvest into rotted fruit in a few days in warm, moist weather.

If fruits drop off the plant early in the season, the plant may be able to produce new ones. However, this is unlikely as anthracnose usually affects ripe fruits.

Natural enemies/antagonists

Unknown.

Management and control practices

Prevention activities:

- A 3-year crop rotation schedule with other solanaceous crops is advised to lower field incidence of anthracnose. See section 3.17.
- No anthracnose-resistant eggplant varieties have been reported.
- Use disease-free seeds (check “certified” seeds, or use a coating before sowing – see section 3.6) and/or use healthy transplants.
- Sanitation: remove all infested plant debris from the field and drop it onto a compost pile outside the main field or feed it to farm animals.
- Plant in well-drained fields to avoid excess soil moisture as fruit ripens.
- Prefer furrow to overhead irrigation. If overhead irrigation is used, apply it during the early part of the day so that plants dry before sundown.
- Harvest and use fruit before it fully ripens.

Sanitation: remove plant parts....to where?

☺ It was noted that some farmers practice field sanitation very properly by removing all crop residues from the field after the final harvest.

☹ However, after collecting all plant debris, they threw it to the sides of the field. From there, spores of many fungi can easily infect the next crop or a neighboring crop.

☺ Take crop debris away from the main field for decomposing or as food for farm animals.

Once disease symptoms are found:

- In areas where anthracnose is a frequent and serious problem, the use of fungicides can be considered. Many fungicides need to be applied preventively, that means before disease symptoms are found. It is however dangerous to spray during the fruiting stage as residues of the pesticide may remain on the harvested fruits! Note that some natural enemies of insect pests may be killed by fungicide sprays as well!

☑ Points to remember about anthracnose fruit rot:

1. Anthracnose-causing fungi can affect both fruits and leaves. Fruit infection is most severe as it results in unmarketable fruits.
2. Anthracnose-fungi survive in infested plant debris in the soil and on seeds of infected fruits.
3. Use of clean seed and healthy transplants, good sanitation practices, and using furrow rather than overhead irrigation are ways to prevent anthracnose infection.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

- 3-A.1. Study of symptom development of leaf spots: classroom exercise
- 3-A.2. Study of symptom development of leaf spots: field exercise
- 3-A.3. Effect of infection of the seed bed
- 3-A.4. Effect of the use of infected planting material
- 3-A.9. Test effect of infected crop debris in the field
- 3-A.10. Effect of rain on the spread of leaf spot
- 3-A.14. Restricted fungicide use to manage leaf spots
- 3-C.1. Symptom development of fruit diseases: classroom exercise
- 3-C.2. Symptom development of fruit diseases: field exercise
- 3-C.3. Use of healthy seed
- 3-C.4. Test of seed health
- 3-C.5. Test effect of hot water seed treatment
- 3-C.6. Transfer of a fungal fruit disease
- 3-C.7. Transfer of a secondary bacterial fruit disease
- 3-C.8. Test different cultivars for resistance to fruit diseases

8.3 Wilt**8.3.1 Bacterial wilt - *Ralstonia solanacearum***

See photo 19 (page 177).

Causal organism: bacterium – *Ralstonia solanacearum* also called *Pseudomonas solanacearum*.

Other names for this bacterial disease are southern bacterial wilt, brown rot and blight.

The disease affects several plant species, mainly family of the Solanaceae (tomatoes, potatoes, eggplants, tobacco, peppers) and peanuts. There are also several weeds that can be affected by bacterial wilt.

Signs and symptoms

The disease is characterized by sudden plant wilting without leaf yellowing. Stem centers and roots become water-soaked and later turn brown. Sometimes, the stem centers become hollow. Also roots are formed on the stem. As the browning and root decomposition progress, the amount of wilting and dying of the leaves increases until the plant is killed. This process may go very quickly. When recently infected stems or roots are cut crosswise and squeezed tightly, a dingy gray to yellowish fluid appears. This fluid is called ooze and contains many bacteria. Woody stem tissue turns brown and roots may start to form on the stem. Soft rot bacteria may enter affected plant parts.

Tolerant plants may show only dwarfing or slow decay of the roots.

Source and spread

The bacterium is soil-borne. It can survive for a long time in the soil. The bacteria can also survive in crop residues, some weeds, and in water. The bacteria can be spread by infected seed, transplants and cutting knives or other field tools. It can also spread from infected higher level fields to lower level field in irrigation or ground water. Nematode infections increase the severity of wilt.

The bacteria enter plants through wounds made by tools, soil insects, broken roots on transplants and through natural openings where secondary roots emerge. Several nematode species that suck on the roots of plants such as the rootknot nematode (see section 8.1.3) can increase the incidence of wilt because they create entry points for the bacteria. Symptoms appear within 2 to 8 days after infection, depending on temperature, plant age and susceptibility of the variety. The bacteria reach the vessels and

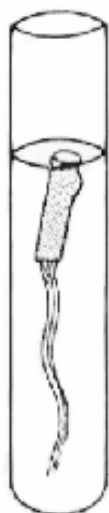


Bacterial wilt: the arrows show two possible entry sites for bacteria in tomato
(from: Blancard, 1992)

spread throughout the plant. As they move, they damage the plant tissue which becomes filled with slimy masses of bacteria. The plant vessels are blocked and this results in the wilting of the plant. If moisture is present on leaves, the bacteria can enter aboveground but infection is more likely when inoculum is present just below the soil surface.

When diseased plant parts decay, bacteria are released in great numbers into the soil where they are disseminated in water.

Diagnostic method for bacterial wilt



To distinguish bacterial wilt from other wilts, select a recently infected plant that is not yet completely dry and dead. Take a stem cutting at soil level up till a few cm above the soil level and place it in a glass of water above the glass bottom. Support the stem piece with toothpicks so that it doesn't slide away. If bacterial wilt is present, a milky stream flows from the lower cut surface of the sliver within a few minutes. This milky stream is called ooze and contains many thousands of bacteria. See photo 20, page 177.

Glass jar with tomato stem piece.
Milky bacterial threads flow from stem.

Role of environmental factors

Wet and warm soil is good for this bacterium. The wilt bacterium is sensitive to high soil pH, low soil temperature, low soil moisture and low fertility levels. Although the bacteria are able to reproduce and cause infection over a wide temperature range, the most favorable temperature is 29 to 35°C.

Importance - plant compensation

Bacterial wilt is a very serious disease that can cause dying of plants in large parts of a field. Once present in the field, it is very difficult to control. Usually, plants will die quickly and no compensation occurs.

Natural enemies/antagonists

- The antagonist *Trichoderma* species may be tried, preferably in combination with compost (see section 3.8.3.1).
- In USA, a non-pathogenic strain of *Pseudomonas solanacearum* is available as biocontrol agent. (ref. www15)
- Several other antagonistic micro-organisms have been studied against bacterial wilt, such as *Bacillus* sp. (Silveira, 1995) and *Streptomyces* sp. (El-Raheem, 1995). Most of these studies were done in laboratories so results are not yet applicable to field situations.

Management and control practices

Prevention activities:

- Resistant eggplant varieties have been reported. For example Arka Kasev and Arka Neelkanth from India. See table in section 3.2.2. However, there are different strains of the bacterium so eggplant varieties may give differences in actual tolerance. Set up a varietal trial to experiment.
- Hot water treatment of seeds at 50°C for 25 minutes effectively reduces the bacteria that stick to seeds. See section 3.6.1.
- Eradication of weeds help reduce the bacterial wilt population.
- Use healthy seedlings grown in wilt-free soil.

- Grow seedlings in pots to avoid injury to roots while transplanting.
- Use of compost may reduce bacterial wilt. This may be due to sanitation (removing all crop residues from the field for composting – including all diseased materials and weeds) and due to improving the soil structure and fertilization. High organic matter in the soil improves conditions for micro-organisms including antagonistic organisms that may work against *Ralstonia* bacteria. In USA, experiments at two sites in Florida showed that (amongst other treatments) mushroom compost also reduced bacterial wilt disease incidence of tomato compared to controls (Peet, www1).

Effects of compost on bacterial wilt: experiments from Vietnam

In Vietnam, farmers found that adding compost (19 tons/ha) to the planting hole of *cucumber* reduced wilt incidence and increased yield by 80%! Pesticide applications were reduced from 9 to 5 per

season. This resulted in an astronomical increase in profits! 😊

Potting experiments on the effect of compost on bacterial wilt in tomato, showed that compost could suppress disease development and spread. 😊

(FAO – PAR on soil-borne diseases in tomato, March 2000)

- Soil amendments: The effect of adding dry powders and crop residues of onion, and garlic crop residues as soil amendments for the control of bacterial wilt has been studied by the AVRDC, Taiwan. They found that adding 1% dry Welsh onion powder (not including roots) to the soil of potted tomato plants significantly reduced bacterial wilt. The effect in field trials, however, was no so distinct. It may be an interesting option for testing in your own field. Effect of crop residues of onion or garlic may also be tried.

Good suppression of bacterial wilt has been achieved by incorporation of mustard green manure in the soil (see section on biofumigation 3.10.1.4). In Dhaka region, Bangladesh, good results have been obtained with incorporation of mustard oil cakes and with poultry refuse in both seedbeds and main field (pers. comm. Md. Atiur Rahman, 2001).

Once disease symptoms are found:

- Control of bacterial wilt is extremely difficult because the pathogen can remain viable in the soil for many years. In some areas, soils could not be used for solanaceous crops due to heavy bacterial wilt infection.
- Pull out infected plants including roots and attaching soil, remove them from the field and destroy them. This may reduce further spread of the bacteria.
- Crop rotation may be useful for soils with bacterial wilt. However, the wide host range of bacterial wilt includes all solanaceous crops and peanuts which severely limits crops that can be used in rotations. In Sri Lanka, crop rotation of tomato with paddy rice effectively controlled the bacterial wilt because the wilt is unable to survive in a field that has been flooded. In India, the following rotations reduced bacterial wilt incidence in eggplant: maize-okra-radish; maize-*Vigna* sp.-maize; okra-*Vigna* sp.-maize; or *Eleusine coracana*-eggplant (wilt-resistant cv. Pusa Purple Cluster)-*Phaseolus vulgaris*. (Sohi, 1981)

Effect of crop rotation on bacterial wilt infection of tomato: a demonstration from Vietnam

In Tan Tien village, Hai Phong province, a demonstration plot was established to show the effect of crop rotation in a bacterial wilt infested field. The crop grown previously was potato and it had been affected by bacterial wilt. The field was split into two: one half was planted with sweet potato (not a solanaceous crop), the other half with tomato. The sweet potato plot looked very healthy. The tomato plot was severely affected with about 40% (visual estimation) of the plants lost due to bacterial wilt.

This demo-plot clearly showed why it is necessary to rotate crops of different families!
(pers. observation F.Praasterink, April 2000)

- A fallow period of several months, including weed control, was reported to be effective in some countries.

- Use of lime is often recommended for control of soil-borne pathogens. The effects of lime are not clear. It may have an effect on micro-climate in the soil, stimulating antagonistic micro-organisms. It may have an effect on nutrient availability, “boosting” the crop through adverse conditions.
- Grafting: where soil is infested with bacterial or fungal wilt organisms, there is an option to graft eggplant seedlings on resistant rootstocks (usually wild eggplant varieties, e.g. *Solanum torvum*). This means that initially both the rootstock and the eggplant seedling are grown. When they reach a certain stage, the stems of both the seedling and the rootstock are cut and the stem of the seedling is placed on the rootstock stem and tied together. The two will merge and continue growth. This way the rootstock (resistant) is not affected by wilt diseases and the seedling will produce normal fruits. See section 3.13.
- Chemical control of bacterial wilt is not recommended!

Points to remember about bacterial wilt:

1. Bacterial wilt is a serious soil-borne disease that can cause total loss of plants in large parts of a field.
2. Some general management practices such as crop rotation, and sanitation of the field help to prevent and reduce disease.
3. Interesting results have been obtained with adding organic matter such as compost into the soil. This is possibly due to stimulation of antagonistic fungi in the soil and better nutrition for the eggplants.
4. Chemical control of bacterial wilt is usually not effective.
5. Biological control agents such as non-pathogenic *Pseudomonas* sp. may become available in Asia in the future.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

- 3-B.5. Identification of bacterial wilt
- 3-B.6. Study of symptom development of bacterial wilt
- 3-B.9. Test effect of liming on bacterial wilt development
- 3-B.12. Test different cultivars for resistance to wilt diseases
- 3-B.13. Raised plants beds to reduce wilt incidence
- 3-B.14. Effects of inundation of fields on incidence of wilt diseases
- 3-B.15. Grafting to overcome bacterial wilt in tomato or eggplant

8.3.2 *Verticillium* and *Fusarium* wilt

See photo 20 (page 177).

Causal organisms: fungi - *Verticillium* sp., *Fusarium oxysporum*

Fusarium wilt in solanaceous crops is caused by several different strains of the fungus *Fusarium oxysporum*. These are: *F. oxysporum* f. sp. *melongenae* (eggplant), *F. oxysporum* f. sp. *lycopersici* (tomato), and *F. oxysporum* var. *vasinfectum* (pepper). *Fusarium* wilt in potato is caused by a complex of up to four different *Fusarium* sp. All of the *Fusarium* wilt pathogens are generally specific to their hosts. Weeds of the solanaceous family can be colonized too.

Although *Verticillium* and *Fusarium* are very different fungi, the symptoms caused in eggplant are similar in appearance and the difference between the two diseases is very hard to tell in the field. Given the soil-borne nature of both fungi, and the similarities in the disease management of these wilts, they will be described in this section together. However, it should be emphasized that although disease symptoms look similar, there may be differences in other aspects and some of those will be listed below.

Both fungi attack a wide range of plant species, including many cultivated crops and weeds. Solanaceous crop plants like tomato, potato, pepper, and eggplant can all be infected.

Signs and symptoms

Plants may be infected at any age by the fungi that cause *Fusarium* wilt and *Verticillium* wilt. Symptoms of this disease are leaf yellowing of the lower leaves. The yellowing progresses upward from the base of the plant. Wilting or yellowing may occur on only one side of a leaf or a branch, or on one side of the plant. Often, the area between leaf veins turns yellow first, resulting in V-shaped areas (typical for *Verticillium*, but may also occur for *Fusarium*). Yellow leaves wilt noticeably before they die. Separate shoots, and later entire plants, finally wilt permanently and die. In fields, the affected leaves may dry up before wilting is detected. Woody stem tissue often becomes brown in affected stems. This discoloration can be detected by cutting affected stems diagonally. The brown discoloration may extend into the roots and lower part of the stem.

Young plants appear normal, but become stunted as they develop. Often no symptoms are seen until the plant is bearing heavily or a dry period occurs. Wilting may occur at midday, when sunlight is bright and temperature is high. Infected plants may survive the season but are stunted and both yield and fruits may be small depending on severity of attack.

Source and spread

Both *Fusarium* and *Verticillium* wilt are caused by soil-borne fungi that can persist in the soil for many years. The fungi produce a very strong type of spores that can survive indefinitely in most fields. Survival is aided by weeds which are susceptible to the fungus. The fungus can be introduced and spread with soil that is attached to transplants. Within each cropping season, most disease originates from inoculum surviving from previous cropping seasons.

Wilt disease can also be spread with seed. Long-distance dissemination probably occurs on seed. When fungal spores germinate close to roots of a susceptible plant, the fungus penetrated the fine root hairs of the root system. Penetration is enhanced by root wounds. The fungus grows inside the root and eventually reaches the vessels. It may move slightly inside the plant vessels but is largely confined. In susceptible varieties the fungus moves through the vessels from the roots both to and through the stem. The vessel are blocked by the fungus and water cannot (or very limited) be transported from the roots to the leaves and above ground plant parts. These wilt as a result.

Role of environmental factors

Environmental conditions that affect disease development include temperature, moisture and soil pH. The optimum air and soil temperature for disease development is about 28°C. No disease develops if the soil temperature is too cool (15°C and below) or too warm (35°C and above), though differences between the fungi species may be found. Generally, *Verticillium* wilt is retarded by the higher temperatures that favor *Fusarium* wilt. That is why in tropical lowland areas, usually *Fusarium* wilt is found.

When the soil temperature favors disease development, root infection can occur. Root infection can be extensive and the fungus grows up into the lower portion of the stem. If the air temperature is too cool for disease development, the plants grow well without external symptoms of the disease. Once the temperature rises, the wilting process may develop quickly.

Importance - plant compensation - physiological impact

The wilt fungi usually enter the plant through young roots and then grow into and up the water transporting vessels of the roots and stem. As the vessels are plugged and collapse, the water supply to the leaves is blocked. With a limited water supply, leaves begin to wilt on sunny days and recover at night. Wilting may first appear in the top of the plant or in the lower leaves. The process may continue until the entire plant is wilted, stunted, or dead. Plants may recover somewhat but are usually weak, and produce fruit of low quality.

When disease development is stopped or inhibited due to unfavorable environmental conditions (e.g. when the soil is very dry) the plant may form additional shoots to compensate for some of the wilted shoots. However, the conditions unfavorable for the disease are usually also unfavorable for vigorous plant development. Once infected, the plant usually cannot recover completely.

Natural enemies/antagonists

When it comes to biocontrol, the different fungi usually have different antagonists (natural enemies). Most antagonistic fungi are very specific in host selection. However, the antagonist *Trichoderma* sp. has given good results in control of many soil-borne pathogens, including *Fusarium* and *Verticillium*. *Trichoderma* is available commercially or from extension agencies in many countries in Asia. *Fusarium* can be controlled by a non-pathogenic strain of *Fusarium oxysporum*. See box below.

Control of Fusarium BY Fusarium.....! Family feud at micro level...!

There are many strains of *Fusarium oxysporum* fungi that cause wilting of plants. A specific strain of *Fusarium oxysporum* is actually highly effective at controlling *Fusarium* wilt of tomato and other crops. They work against their own "family members"! These isolates consistently provide 50-80% reduction of disease incidence in repeated greenhouse tests. They work against the pathogenic strain because they "block the entry" so the pathogen cannot enter the plant.

Commercial products such as "Biofox C" and "Fusaclean" are now available in the USA containing the non-pathogenic *Fusarium oxysporum*. The product is used as seed treatment (dust formulation) or incorporated into the soil (granule formulation).

For details on commercial biocontrol products check "The BioPesticide Manual" (Copping, 1998), or several internet sites such as www14 and www15 (see reference list, chapter 11).

There are several other antagonistic organisms that control *Fusarium* and/or *Verticillium*, such as *Bacillus subtilis*, *Burkholderia cepacia*, and *Streptomyces griseoviridis*. Different strains of these antagonistic organisms have been registered as biocontrol products to control fungal wilt and some other (soil-borne) plant diseases in the United States (refs. www14, www15)

Management and control practices**Prevention activities:**

- Using resistant or tolerant varieties is the best prevention of wilt disease. Some resistance to both *Verticillium* and *Fusarium* wilt is found in eggplant varieties. See examples in table in section 3.2.2.
- Locally produced seeds should be used only from plants free of any signs of wilt disease. Locally produced seeds should be hot-water treated or coated with a fungicide or an antagonistic fungus (when available). See sections 3.3 and 3.6.
- Healthy planting material: seedlings that are suspected of having wilt disease (or any other diseases) should not be transplanted into the main field.
- Maintain a high level of plant vigor with appropriate fertilization (especially not too much nitrogen should be applied) and irrigation.
- Plant in well-drained soil.
- Keep rotational crops weed-free (many weeds are hosts of *Verticillium* and *Fusarium*).
- Preventive application of *Trichoderma* sp. where available may be tested. This may be only economic in fields with a history of soil-borne diseases.

Once disease symptoms are found:

- Infected plants should be removed carefully and burned or composted outside the field. The soil from which that plant was pulled however, is still infected. Removal of infected plants will at least reduce the increase of the fungal population. After the final harvest, remove and destroy all infested plant material including the roots.
- The wilt disease is increased by cultivation of the land, such as weeding. This is possibly because of root disturbance and thus increased root damage which form entry points for the fungus.
- Application of biocontrol products such as *Trichoderma* sp. or others where available may be a good option for control of soil-borne pathogens. See section on antagonists above.
- Grafting: where soils are infested with fungal wilt organisms, there is an option to graft eggplant seedlings on resistant rootstock (can be wild eggplant varieties). This means that initially both the rootstock and the eggplant seedling are grown. When they reach a certain vegetative stage, the stems of both the seedling and the rootstock are cut and the stem of the seedling is placed on the rootstock stem and tied together. The two will merge and continue growth. This way the rootstock



Grafting tomato on resistant rootstock
(from: Messiaen, 1992)

(resistant) is not affected by wilt diseases and the seedling will produce normal fruits.

- A soil pH of about 7 seems to be optimal to suppress this disease. See section 3.7.5. Liming can increase the pH of the soil.
- Long rotation: wilt disease is controlled (or reduced) by long term rotations with non-related crops that are not susceptible to wilt. Because *Fusarium* and *Verticillium* fungi are widespread and persist several years in soil, a long crop rotation (4 to 6 years) is necessary to reduce populations of these fungi. Avoid using any solanaceous crop (potato, tomato, pepper, eggplant) in the rotation, and if *Verticillium* wilt is a problem, also avoid the use of strawberries and raspberries, which are highly susceptible. Rotate with cereals and grasses wherever possible. A 3 or 4 year rotation is usually sufficient to reduce disease incidence although special fungus spores (so called *microsclerotia*) persist in the soil for 10 years or more. Reducing root lesion nematode populations helps control wilt because the wilt fungi often infect nematode-damaged root systems.
- If soils are severely infested, production of solanaceous crops may not be possible. Soil solarization and use of plastic mulch are other options described for control. However, soil disinfection is very difficult because soil can be infested to at least 90 cm depth!

Points to remember about fungal wilt:

1. *Verticillium* and *Fusarium* wilt are caused by soil-borne fungi that can persist in the soil for many years.
2. Use of resistant varieties, where available, is probably the best prevention.
3. Several antagonistic organisms are available as biocontrol agents for control of fungal wilt but not all of these may be available in Asia. *Trichoderma* sp. may be tried as a preventive measure.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

- 3-B.10. Symptom development study of fungal wilts
- 3-B.11. Effect of sanitation on fungal wilts
- 3-B.12. Test different cultivars for resistance to wilt diseases
- 3-B.13. Raised plants beds to reduce wilt incidence
- 3-B.14. Effects of inundation of fields on incidence of wilt diseases

8.4 Stem rot

There are several organisms that cause stem rot to eggplant. Some are listed below, others are described in other sections because the main symptoms are other than the rotting of stems. For example, early blight can cause a “collar rot” of seedlings near the soil line but major symptoms are leaf spots and this disease has therefore been grouped in the leaf spot section. See key table in chapter 10.

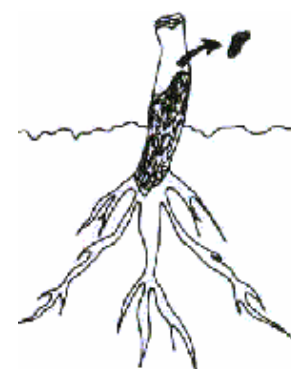
8.4.1 *Sclerotinia* stem rot – *Sclerotinia sclerotiorum*

Causal organism: fungus - *Sclerotinia sclerotiorum*

The disease attacks over 170 species of plants. It causes white mold on beans, cottony soft rot of carrot, watery soft rot of cole crops, root rot of pea, among others. Symptoms vary with host plant.

Signs and symptoms

The disease can be recognized by a soft, watery rot with white, moldy growth on stems, petioles, and leaves of plants. Often initial infection occurs in the axes of branches or where a supporting string may be tied to the base of the plant. These points accumulate nutrients, plant refuse, and moisture on which the fungus can grow. Infection may start on leaves in contact with the soil and gradually grow through the petiole to the stem and eventually girdle it. If conditions remain moist, a large amount of cottony, moldy growth can be seen on the dead tissue. As this growth progresses,



Black sclerotia present mainly in the pith (from: Blancard, 1992)

hard black, irregularly shaped bodies called *sclerotia* form on the surface or in the pith of the stem; they are diagnostic for the disease.

Sclerotia are the resting structures of the fungus. They are actually a very dense mass of hyphae (fungus “threads”). The fungus can survive adverse conditions through sclerotia. Sclerotia range from 2 to 10 mm in length and tend to be about 2 to 3 times longer than thick. They are white to pinkish inside. After the infection has apparently dried up, the line of demarcation between healthy and diseased tissue is very sharp. Often the diseased tissue is a light, straw color.

Source and spread

The fungus survives as sclerotia in the soil and may survive up to 7 years in dry soil. However, if the soil is maintained warm and moist, tiny spore carrying structures (called *apothecia*) start to grow on the sclerotia. These produce enormous numbers of spores that are blown about and cause infections. Once the fungus is established it continues vegetative growth as long as there is sufficient moisture. Sclerotia may be carried with seed or transmitted with soil (e.g. attached to transplants) from field to field.

Role of environmental factors

This disease is dependent on high moisture and cool temperatures. That is why this disease is more common in higher altitude areas of the tropics. It is infectious over a wide temperature range (10 - 30°C), but requires high moisture to germinate and infect.

Importance - plant compensation - physiological impact

Plants of all growth stages are susceptible. The disease is important because a number of fruit bearing plants may be killed and the fungus can survive several years in the soil. Seldomly, all plants in a field are affected.

Natural enemies/antagonists

- *Trichoderma virens* (formerly *Gliocladium virens*) is a beneficial fungus that can reduce *Sclerotinia* stem rot. *Trichoderma* is naturally present in soils all over the world. It is available for field application in some countries such as Thailand and USA. More details on *Trichoderma* in section 7.10.1.
- The biocontrol organism *Coniothyrium minitans* is commercially available in the USA for control of *Sclerotinia sclerotiorum* and *S. minor*.
- Another biocontrol agent is *Bacillus subtilis*, available in Thailand for control of several soil-borne pathogens including *Rhizoctonia solani*, *Fusarium* sp., *Alternaria* sp., *Sclerotinia*, *Verticillium*, *Streptomyces scabies*. It can be applied as a suspension for seed treatment, soil drench, dip, and addition to nutrient solutions.

More information on commercially available biocontrol products can be found in “The BioPesticide Manual” and on several internet sites such as [www14](#) and [www15](#) (see reference list in chapter 11).

Management and control practices

The control of this disease, as with many soil-borne diseases, requires a continuous good management program all year:

- Rotation with non-susceptible crops (beets, onion, spinach, peanuts, corn, and grasses) have been reported to lower disease incidence.
- Flooding of the field for 23 to 45 days (which can be done in areas where vegetables are grown in rotation with paddy rice) lowers disease incidence.
- Deep plowing will bury the sclerotia. Without light they cannot germinate and cause infection.
- Sanitation: All infected plant parts should be removed and destroyed from the field as they appear on plants. At the end of the season, plants and plant left-overs should be removed and destroyed promptly. The soil should be kept free from weeds as these might harbor the fungus. Immature or uncomposted livestock manure and plant mulches should not be used because this may still contain living fungus.
- Soil disinfection: Solarization of the soil is a good option to reduce disease incidence (see section 3.10.1.2). This may even be a good practice if stem rot is not a problem since other diseases and pests are also controlled.
- Moisture control: Removing lower leaves from the plants will help to keep the plant dry and this may prevent infection through the leaf tips that touch the ground. For the same, planting at a wide plant spacing, and low plant density help reduce disease development. Furrow rather than overhead irrigation also helps to keep plants dryer.

Points to remember about *Sclerotinia* stem rot:

1. *Sclerotinia* stem rot can affect a very wide range of crops. In eggplant, it causes stem rot at soil level.
2. Black, hard structures called *sclerotia*, formed on and in the stem, are diagnostic for this fungal disease. Sclerotia can persist in the soil for many years.
3. Several biocontrol products such as *Trichoderma* sp. can reduce stem rot. Other biocontrol products may become available in the future.
4. Cultural practices, such as sanitation by removing and destroying all infected plant material, and crop rotation, help manage this disease.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

- 2-B.4. Use of clean soil: solarization of the seedbed
- 2-C.2. Testing of cultivars
- 3-E.4. Sanitation measures to manage cabbage soft rot (adapt to stem rot)
- 3-B.14. Effects of inundation of fields on incidence of wilt diseases

8.4.2 Southern stem rot – *Sclerotium rolfsii*

See photo 25 (page 177).

Causal organism: fungus - *Sclerotium rolfsii*

Common names: Southern blight, Southern wilt, Southern stem rot, stem rot, blackleg, collar rot.

Southern stem rot is a serious and widespread soil-borne disease in many parts of the world. It attacks a number of vegetable crops including tomato, eggplant, bean, cantaloupe, carrot, pepper, potato, sweet potato, watermelon, and others. In addition, several field crops such as cotton, peanut, soybean, and tobacco can be affected. The fungus can also decay harvested produce, especially carrots.

Sclerotium rolfsii is often associated with other soil fungi such as *Phytophthora parasitica* and *Rhizoctonia solani*, fungi that cause damping-off disease in seedlings or other root and stem rot diseases.

Signs and symptoms

The disease is recognized by wilting and yellowing of leaves; these are often the first symptoms. When the plant is pulled up, roots are softened. The stem is rotten at the soil line (“collar rot”). A white, moldy growth is evident on affected stem tissues and adjoining surface soil. As the disease develops, tiny, smooth, brown bodies called *sclerotia* (fungus reproductive structures) are produced on the stem near the soil line. The sclerotia are brown in color and look like cabbage seeds while the sclerotia produced by the fungus *Sclerotinia sclerotiorum* (see section 8.4.1 above) are larger and black in color. The sclerotia are diagnostic for the disease.

Source and spread

Sclerotium rolfsii is a soil-borne fungus. It can survive as sclerotia and in host left-overs in the soil. A characteristic of the fungus is that it is generally restricted to the upper 5 to 7 cm of the soil and will not survive at lower levels. In most cases, the fungus does not survive in significant numbers when a host plant is absent for two years or more. However, the sclerotia, which are thick layered, can survive for much more than 2 years. Any crop rotation schedule should therefore be at least a 3 to 4 year one.

The fungus can be spread in running water, in infested soil, on tools and implements, in infected seedlings, and as sclerotia among the seed. Uncomposted crop residue can spread the infection.

Role of environmental factors

Warm weather and high soil moisture, create favorable conditions for the development of this disease. In cooler climates, the disease usually appears in “hot spots” in fields and continues until cooler, dryer weather prevails. The disease is rare in areas with cold winters.

For reasons not yet understood, ammonia use seems to limit disease development. This may be related to slowed fungal growth, altered host susceptibility, or increased populations of antagonistic soil microorganisms. Calcium may also be involved. To the extent that tissue calcium levels are raised, calcium fertilizers may suppress disease by altering host susceptibility. However, normal liming of the soil does not change calcium levels in plant tissue enough to protect against *S. rolfsii* in infected soils.

Importance - plant compensation - physiological impact

Losses may vary from light and sporadic to almost total destruction of the crop.

Sclerotium rolfsii kills host tissue in advance of penetration and then lives on the dead plant tissue.

Natural enemies/antagonists

The antagonistic fungus *Trichoderma* sp. may be an option for control of *Sclerotium rolfsii*. See section 7.10.1. Other biocontrol organisms may be effective. See section 8.4.1 above, on natural enemies.

Management and control practices

- Avoid fields where *Sclerotium rolfsii* occurred before.
- Long crop rotations to grasses, buckwheat or corn, which are not susceptible.
- Soil solarization (see section 3.10.1.2) for 4 to 6 weeks at 38 - 50°C is reported to help reduce disease.
- Prepare the land properly. The previous crop must be well decomposed prior to planting. This may require deep plowing just before planting. Previous crop left-overs should be buried to depths below 10 cm. When crop left-overs are ploughed under to these depths, the fungus cannot survive since it can grow only on or near the soil surface.
- Proper drainage may help reduce disease infection. Preparing plant beds also helps improve drainage.
- Reduce cultivation activities after planting. Cultivation may bring buried plant left-overs back to the soil surface or throw soil with left-overs against plant parts and this may provoke infection.
- Control foliar diseases since dead leaves on the ground may trigger infection. Weeds should also be controlled early in the season for the same reason.
- Botanicals: Ginger (*Zingiber officinale*) is recommended against *Sclerotium rolfsii* at a concentration of 20 g/l water and sprayed 3 times in intervals of 15 days (Stoll, 2000).

Points to remember about *Sclerotium rolfsii*:

1. In eggplant, *Sclerotium rolfsii* causes stem rot at soil level and rot of roots.
2. Tiny, brown, hard structures called *sclerotia*, formed on the stem, are diagnostic for this fungal disease. Sclerotia can persist in the soil for many years.
3. Several biocontrol products such as *Trichoderma* sp. can reduce *S. rolfsii*. Other biocontrol products may become available in Asia in the future.
4. Cultural practices, such as sanitation by removing and destroying all infected plant material, proper drainage, and crop rotation help prevent this disease.

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:

- 2-B.4. Use of clean soil: solarization of the seedbed
- 2-C.2. Testing of cultivars
- 3-E.4. Sanitation measures to manage cabbage soft rot (adapt to stem rot)
- 3-B.14. Effects of inundation of fields on incidence of wilt diseases

9 WEED MANAGEMENT



SUMMARY

The most important time to keep the field free of weeds for eggplant production is generally in the first 4 to 6 weeks. By then, the crop is large enough to shade out late-emerging weed seedlings or is otherwise competitive with weeds. Before and after this weed-free period, weeds can be suppressed by several cultural practices including mulching, and cover crops.

Use of herbicides alone is usually not the most economical method for weed control. Good cultural and crop management practices are the backbone of any weed management program. The most desirable weed management program is one that will control existing weeds economically and prevent a buildup of weed seed or tubers, rhizomes, etc. in the soil. Such a program includes integrated use of several crop management practices which may include any of the prevention practices listed in 9.4.

Biological weed control options, such as weed-controlling fungi, are being studied and may become available in the near future.

9.1 Weeds: good or bad?

**Weeds are normal plants,
but they are “weeds” because they grow where we do not want them.**

👍 Weeds in an eggplant field are usually unwanted because they compete with eggplants for water, nutrients, and sunlight. They may harbor insect pests and diseases or form breeding places for pest insects. In addition, the presence of weeds decreases air circulation between the plants, increasing the humidity inside the crop. This can lead to more diseases, because many (fungal) diseases need humidity to infect a plant. Weeds may also directly reduce profits by hindering harvest operations, lowering crop quality, and produce seed or rootstocks which infest the field and affect future crops.

👎 But there can be some good points of weeds too: many weeds make good compost, several are edible for human use or when fed to farm animals. Weeds have consumed nutrients from the soil and these can be returned to the soil by using weeds as mulch or as “green manure” (see section 3.8.3.2). There are also weeds that have a medicinal use. Under certain circumstances, weeds may have a beneficial effect in preventing soil erosion. Weeds can provide shelter places for predators and other beneficial insects. In addition, some flowering weeds can be food sources for adult parasitoid wasps that feed on the nectar inside the flowers.

Weeds can be indicators of soil fertility. Chan (*Imperata cylindrica*) for example is a common weed in Bangladesh, growing only where soil is very infertile. This gives valuable information on the status of the soil.



Chan

9.2 Types of weed

Weeds can be classified in several ways. The most commonly used classifications are:

Annual or Perennial

1. **Annual weeds:** these are the most common weeds that germinate, flower, produce seed and die within one year. In some cases annual weeds have several generations per year. Most are producing a lot of seed. The seed can remain viable for many years in the cool depths of the soil, ready to germinate when exposed by cultivation to light and moisture.
2. **Perennial weeds:** those weeds that remain in the soil from one year to the next. They often require more than 1 year to complete their life cycle. Typical perennial weeds have deep roots or creeping runners which spread vigorously, or roots which can resprout from small fragments left in the soil.



perennial weed

Broadleaf weeds or grasses

1. **Broadleaf weeds:** germinating seedlings have two leaves. The leaves are usually wider than those of grasses. Broadleaf weeds are basically all weeds except grasses, sedges and bamboo.
2. **Grasses:** seedlings have only one leaf. Next to grasses, other common weeds in this group are sedges and bamboo.



broadleaf weed

The Seedbank

To check if there is weed seed in your soil, this exercise is a useful one. Take a portion of soil from the field (about half a bag full) and bring it to the 'classroom' or any other place near the house. Put the soil on a piece of plastic. Water it and leave it for several days. Keep the soil moist but do not make mud out of it! Seed of weed will germinate in the next days and you can check how many weeds come up and which species they are.



9.3 Control or management?

Similar to disease and insect management, weeds also must be managed. Weed management means a range of activities that support each other. Some of these activities should be done during crop growth, some even before sowing the seeds. Weed management, just like insect and disease management, is a long-term activity, sometimes it needs planning for several years. Control is a short-term activity, focused on killing or removing weeds from the field.

A good weed management program is one that will *control* existing weeds economically and *prevent* a buildup of weed seed or tubers, rhizomes, etc. in the soil. Integrated weed management, like insect and disease IPM, focuses on prevention, beginning with identification of weed species. Such a program includes integrated use of several crop management practices which may include any of prevention practices listed in section 9.4 below.

Is 100% control of all weeds necessary?

The ultimate goal of growing vegetables is to maximize profits in a sustainable way. While it is true that crops are able to tolerate a certain number of weeds without suffering a yield reduction, it is first important to consider weed problems on an individual basis. There are some weeds for which 100% control may be desirable because they are particularly competitive, persistent, or difficult to control. Identification of weed species is therefore a first step in weed management.

Weed management should also be related to growth stage. It may be necessary to go for 100% weed control in the first few weeks after transplanting but when plants are fully grown, some weeds may be tolerated. Such weed-free period is called the *critical weed-free period*, a concept explained in the box below (modified from Peet, www1).



Critical weed-free period

The critical weed-free period is the minimum length of time during which the crop should be practically weed-free to avoid a yield or quality reduction. The critical weed-free period varies with crop, weed species and environment. The critical weed-free period concept is based on the following observations: At the time of field preparation and planting, the field is virtually free of weeds. Soon after, however, weed seeds brought to the surface by field preparation start to germinate.

At some point, crop seedlings and weeds are large enough to compete for light, water and nutrients. Weeds usually win this competition, marking the beginning of the critical weed-free period. Young seedlings that have to compete with weeds for nutrients and light may form weaker plants. Weaker plants are more susceptible to pests and diseases and may eventually give lower yields. Economic losses will occur if weeds are not controlled. The end of the critical weed-free period is generally several weeks later when the crop is large enough to shade late-emerging weed seedlings or is otherwise competitive with weeds (Peet, www1).

The critical weed-free period concept does not mean that weeds can be ignored before or after the critical period, however. If no provisions have been made to reduce weeds (e.g. by use of mulches, see section 9.4 below), weeds may be very difficult to control by the beginning of the critical period, with or without herbicides. Another consideration is that weeds present after the end of the weed-free period may not reduce yield but can make harvest difficult.

For vegetables in general a critical weed-free period is the first 4 to 6 weeks after crops are planted. This also applies to eggplant (Peet, www1).

Cost-effective weed management: an example from Bangladesh

To reduce weed problems in eggplant fields, farmers usually conduct frequent weeding operations, which ultimately increase the cost of cultivation. On-farm trials in Bangladesh have shown that, instead of 3-5 weedings, farmers can save 35 to 50% of weeding costs by applying only two hand weedings at 15 – 20 and 35 – 40 days after planting of eggplants without losing any yield. This technique will reduce cultivation costs and provide larger economic benefits to farmers (pers.comm. Md. Atiur Rahman, 2001).

9.4 Prevention of weed problems: some tactics

“*The best control is prevention*” is also valid for weed management.

Some tactics for weed prevention:

- Crop rotation is an effective practice for long-term weed control. Crop rotation alone is usually not sufficient to control weeds, but it does introduce conditions and practices that are not favorable for a specific weed species, reducing growth and reproduction of that species. Crop rotation provides the opportunity to plant competitive crops which prevent weed establishment. Rotation to a densely planted crop such as alfalfa or small grains helps prevent most annual weeds from becoming established and producing seed and it helps reducing populations of some perennial weeds.

In addition, some weed problems are more easily managed in some crops than others because different control options may be available. Crop rotation also helps disrupt weed life cycles and prevents any single weed species from becoming firmly established.

- Use uncontaminated vegetable seed and plant material.
- Mulching is a very good and very commonly used method for both weed prevention and weed control. Mulch is any material placed on the surface of the soil, it can be organic matter such as straw or compost or it may be plastic sheets. A thick layer of mulch (5 cm or more) controls 90% of weeds. The mulch prevents sunlight from reaching the ground. Germination of weed seed is reduced because most weeds need light for germination. Even when some seed germinates, young seedlings die when they do not get sufficient light. In addition, a layer of mulch helps to retain the moisture in the soil during dry periods. When organic mulch is used, it gradually rots into the soil giving off nutrients and helping to improve the soil structure. See also section 3.8.3.4.
- Increase planting density to shade weeds: When the crop is sown or transplanted densely, the canopy will close quickly. Shade will prevent many weeds from germinating. In a dense crop however, chances for disease infection are higher because the humidity inside the canopy can be high. Another problem is that if weeds germinate anyway, they will be difficult to control at tight spacing.
- Compost manures to reduce weed seed: animal manures may still contain viable weed seed.
- Using cover crops to smother weeds is another widely used cultural practice. Cover crops can either be planted ahead of the vegetable crop, or they can be seeded at the same time the crop is planted to form a living mulch under the crop as it develops. Grasses or legumes such as soybeans grown in



narrow rows quickly form a complete cover, outcompeting weeds. See section 3.8.3.2 on cover crops.

- **Relay cropping:** this means sowing seeds for the next crop before the standing crop is harvested. In Bangladesh for example, common relay crops are Aman rice and Khesari (pea grass). The Khesari seeds are broadcast a week before the Aman harvest. This does not provide enough time for weeds to grow.
- Weeds, and especially annual weeds, should be prevented from producing seed. When this is done at regularly, the “store” of weed seed populations in the soil will be reduced gradually every year that the field is cultivated. If pulled weeds have gone to seeds, do not use them as mulch because the seeds may be spread. Instead, put them on a compost pile away from the field. If the compost is prepared properly, weed seeds are killed during the heating process of composting. See section 3.8.3.1 on compost.

Botanical weed control....!?

Grasses, such as sorghum-sudan grass, grown as cover crops to provide weed control, may also have another effect. For example, when sorghum-sudangrass decomposes in the soil, a chemical is released that suppresses weed germination. 😊

However, some vegetables may also be sensitive to these residues. ☹️
(Peet, www1).

9.5 How to control weeds

Once there are weeds in the field, and weed control is considered economically justified, there are many ways to get rid of them. A number of options is listed below (Peet, www1; and www12).

9.5.1 Physical control

- **Hand weeding** is the oldest, simplest and most direct way of controlling weeds. Weeding can be done by hand or with some kind of hoe or other tool which will cut off or uproot the weeds. Hoeing is useful where there is a large area to clear of annuals or when weeding is done around very small plants. However, there is a risk of damaging the roots of the crop and, in dry conditions, hoeing breaks the surface layer of the soil and increases moisture loss. Weeding after rain or watering makes it easier to remove the weeds from the ground. *Perennial weeds* can be eliminated by digging them out. This is hard work initially but once it is done, it's done. Remove every piece of root from perennials with easily resprouting roots, or they may form even more weeds than you started with!
- **Ploughing** the field will bury some weeds and cut others. Prepare seedbeds immediately before planting or sowing.
- **Mulching** is an easy and very effective method of controlling weeds and keeping the ground weed-free. See prevention section above and sections 3.8.3.4 and 3.11.4.
- Allowing pigs to spend some time in the field before preparing for planting is another option. Pigs can dig out and eat weeds, especially perennial weed with root stocks.



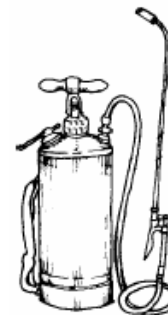
9.5.2 Chemical control

The use of herbicides (in some areas called *weedicides*) to control weeds is increasing over the past years. Main reason for this is that labor costs (for manual weeding) are increasing in many countries. However, compare costs for manual weeding versus costs of applying a herbicide! It is not always cheaper to apply herbicides.

Generally, there are two types of herbicides (according to their mode of action):

1. **Contact herbicides:** these kill plants on which they are sprayed. Contact herbicides are generally most effective against broadleaf weeds and seedlings of perennials. They will usually not kill established perennials.


2. Systemic herbicides: these are chemicals that are taken up by the leaves or roots of plants and will move within the plant to kill portions that were not sprayed. Systemic herbicides can be either sprayed on the leaves or applied to the soil (e.g. as granules).



In addition, herbicides can be selective or nonselective.

1. Selective herbicides kill some plant species but do not damage others,
2. Nonselective herbicides will kill all plants, including eggplants.

When considering chemical weed control, a few things are important to keep in mind:

- Herbicides are unlikely to be used profitably to control weeds unless labor and cultivation costs are high.
- Herbicide performance is strongly related to environmental conditions, so not even the best herbicides are equally effective from year to year. Herbicide performance depends upon the weather, soil conditions, and accurate application.
- Check details of each herbicide brand carefully: do they work selectively? What weed species do they control? What is the best time to apply them? What doses is recommended? How to apply them? Etc., etc. Improper herbicide use may injure plants!
- Some herbicides can be dangerous to animals and humans. For example 2,4-D and Glyphosate (Round-up), commonly used herbicides, are both classified as damaging or irritating when in contact with the human skin!
- Herbicides are used to kill only weeds, however, some may be toxic  to both natural enemies and pest insects! This can be tested in insect zoos. See example in box below.

Effects of herbicides on natural enemies: a study example

1. Prepare hand sprayers with the herbicide to be tested.
 2. Select a few plants in the field. Label plants with name of treatment and spray them with the herbicide. Let leaves dry on the plant.
 3. Pick one or several leaves from each labeled plant and place these in jars (use gloves!).
 4. Collect predators, e.g. spiders or ladybeetles from the field (use a small brush).
 5. Place predators in the jars, close the lid and place a piece of tissue paper between the lid and the jar to avoid condensation inside.
 6. Check condition of predators after 8 and 24 hours.
- Instead of leaves, a piece of cloth can be sprayed with pesticides.

Note: When handling pesticides wear protective clothing and wash with plenty of soap and water afterwards.

- Some herbicides are known to kill or severely limit the germination and growth of beneficial fungi in the soil, for example *Beauveria bassiana*, a fungus that can kill pest insects.
- Some herbicides are very persistent in the soil: they can stay in the soil for a long time. They may even stay active in the soil until after harvest and may cause damage to the next crop.
- Some herbicides can damage the crop, causing “burning” of leaves. This can happen under any conditions, but also when herbicides are applied in the wrong doses (usually too high doses) or at a wrong time of the day. For example, Glyphosate (Round-up) may cause leaf burn when applied at high temperatures, in the middle of a sunny day. This herbicide injury can be easily confused with disease symptoms.
- Some herbicides are washed off during rain and lose their effectiveness.

- The continued use of the same herbicide may lead to tolerance or resistance of weeds against that herbicide. This means such a herbicide does not control those weeds anymore. This results in a buildup of weeds, particularly perennials, which are difficult to control with herbicides. The best way of preventing the buildup of weeds tolerant to herbicides is to regularly remove them by hand and to use several brands of herbicides after each other (do not mix them!).
- Generally, the best time to apply soil herbicides is when soil is moist. Do not apply herbicides on dry soil (particularly the systemic herbicides) because they may become inactive before they can kill the weeds. Not all herbicides should be applied on soil - some are to be applied on the weeds directly. Check labels before applying.

Mixing pesticides: herbicides and insecticides

Mixing herbicides with insecticides are of special concern because they often result in injury to crop plants. Crop injury results because of chemical reactions between the insecticide and the herbicide and the effects of those chemicals on the crop. Symptoms of this injury can include stunting and yellowing.



The severity of injury depends on environmental conditions, the insecticide used, and the method of insecticide application. It seems that rain during or prior to the application of a mixture may increase the severity of injury.

- When applying herbicides, it is recommended to spray infected spots only, not the whole field. This will save an amount of pesticide and may save part of the beneficial population.

Dependence upon herbicides alone seldom provides the most economical weed control.

9.5.3 Biological control

Weeds, just like insects and pathogens, have natural enemies! These include insects, fungi and nematodes. Just like an eggplant can be attacked by an insect, a weed plant can also be attacked. Weeds are normal plants, but they are “weeds” because they grow where we do not want them. There is a lot of research being done on biological control agents for weeds. For example, there are fungi that live on certain weeds and can kill them in a short time. Applying a water solution containing spores of those fungi may be a valuable alternative to chemical herbicides. For example, the fungus *Colletotrichum gloeosporioides* has been effective in controlling northern jointvetch, a plant pest in rice and soybean crops in the USA. Unfortunately, these fungi are often specific to a particular weed species and unlikely to control all the major weeds present.

Insects can control weeds by feeding on seeds, flowers, leaves, stems, roots, or combinations of these, or by transmitting plant pathogens, which will infect plants.

Other natural enemies of weeds include nematodes, and fish (for those weeds growing in canals, fish ponds, etc.).



Although there are very interesting trial data on control of weeds with natural enemies, practical field application under various conditions is still a problem. North American introductions of weed-feeding natural enemies for example, have ranged from very successful, with a 99% reduction of the pest species, to complete failures, with the introduced species unable to become established in the new location. Weed-controlling fungi need a certain amount of humidity and may not work during the dry season.

Therefore, to date, only very few biological weed control agents are commercially available but this may change in the near future (ref. www5).

Related exercises from CABI Bioscience/FAO Vegetable IPM Exercise Manual:
2-C.7. Mulching of plant beds: organic and inorganic mulches

10

Key to some common eggplant problems

Affected plant part	General symptom	Specific symptom(s)	Possible cause	see section
entire plant	stunted growth	Bushy plants with very short leaves	Little leaf	8.2.3
entire plant	stunted growth	Stunted growth	Fungal wilt	8.3.2
entire plant	stunted growth	Poor growth, deformation of leaves and/or shoots	Red spider mite	5.3
entire plant	stunted growth	Poor growth, deformation of leaves and/or shoots	Aphids	5.5
entire plant	stunted growth	Stunted plants with purplish leaves	Phosphorous deficiency	-
entire plant	stunted growth	Stunted plants	Soil compaction	-
entire plant	stunted growth	Stunted plants	Water logging (poor drainage)	-
entire plant	wilting	Sudden plant wilting without leaf yellowing	Bacterial wilt	8.3.1
entire plant	wilting	Wilting of shoots or entire plant	Rootknot nematodes	8.1.3
entire plant	wilting	Plant wilts, stem rot at soil line	Root rot	8.1.2
entire plant	wilting	Plants turn yellow, wilting occurs	Whitefly	5.8
entire plant	wilting	Plants wilt	Too much fertilization	-
fruit	fruit drop	Infection of the fruit pedicels (showing spots or browning) may cause premature fruit drop.	Early blight	8.2.2
fruit	fruit drop	Fruits with many spots drop to the ground with the pedicel still attached to the plant.	Anthracnose fruit rot	8.2.4
fruit	fruit spot	On fruits, spots usually begin at the stem end and develop into black leathery sunken area, often with dark concentric rings.	Early blight	8.2.2
fruit	fruit spot	Fruit spots are initially small, water-soaked circular spots. Later spots become sunken and dark. Dark specks may be present in the spot, often in radiating circles around the center. Sometimes, pink gelatinous spore masses are seen inside the spot.	Anthracnose fruit rot	8.2.4
fruit	fruit spot	Fruit spots: large, circular, sunken tan or black areas on the fruit. Affected fruits are first soft and watery but later may become black and shriveled. Black specks (pycnidia) may also appear on fruit spots, usually in circular forms.	<i>Phomopsis</i> rot	8.2.1
fruit	fruit spot	Fruit spots enlarging to cover entire fruit which dries and becomes mummied.	Root rot	8.1.2
fruit	hole	Hole in the fruit stalk or fruit itself.	Fruit and shoot borer	5.1
fruit	spot	Fruit surface is speckled, with small brown patches	Thrips	5.6
leaf	blight	Brown areas, often on underside of the lower leaves	Thrips	5.6
leaf	blight	Brown leaf margins and leaf curling	Potassium deficiency	-

Affected plant part	General symptom	Specific symptom(s)	Possible cause	section
leaf	blight	Brown areas on leaves, often on leaf margins	Too much fertilization	-
leaf	blight	Brown areas on leaves	Pesticide burning	-
leaf	blight	Leaves turn brown and die, no specific leaf spots visible	Bacterial wilt	8.3.1
leaf	blight	Leaves turn brown and die	Fungal wilt	8.3.2
leaf	deformation	Leaves wrinkle and can remain very small	Aphids	5.5
leaf	dwarfing	Leaves are extremely small	Jassid	5.4
leaf	dwarfing	Leaves are extremely small	Little leaf	8.2.3
leaf	feeding damage	Leaf tissue gone, sometimes only leaf tissue between the veins	<i>Epilachna</i> beetle	5.2
leaf	feeding damage	Leaf tissue has been "scraped"	<i>Epilachna</i> beetle	5.2
leaf	mosaic	Leaves show mosaic pattern of yellow and green patches	Jassid	5.4
leaf	rolled leaf	Leaves are rolled lengthwise, may be brown and dry.	Leafroller	5.7
leaf	rot	Soft, watery rot with white, moldy growth on stems, petioles, and leaves. Often on leaves touching the soil.	<i>Sclerotinia</i> stem rot	8.4.1
leaf	spot	Leaf spots: on established plants, dark brown spots with dark concentric rings develop first on oldest leaves. The concentric rings give the spot a target appearance	Early blight	8.2.2
leaf	spot	Leaf spots are gray-brown, clearly defined, circular. Center of the spot turns gray, and black pycnidia (small pustules, fungus reproductive structures) develop in this area.	<i>Phomopsis</i> rot	8.2.1
leaf	spot	Water-soaked leaf spots, irregular shaped	Root rot	8.1.2
leaf	spot	Brown-black sticky layer on leaves and stems	Aphids	5.5
leaf	wilting	Leaves wilt, sometimes recover or die	Fungal wilt	8.3.2
leaf	window	Soft outer leaf tissue gone, thin layer left like a "window"	<i>Epilachna</i> beetle	5.2
leaf	yellowing	Leaves: Yellowish area may develop on leaves containing leaf spots and eventually, the leaves turn brown and usually drop from the plant.	Early blight	8.2.2
leaf	yellowing	Leaves with dark leaf spots turn yellow and die.	<i>Phomopsis</i> rot	8.2.1
leaf	yellowing	Yellowing and wilting of leaves	Southern stem rot	8.4.2
leaf	yellowing	Yellowing of lower leaves. Leaves wilt and defoliation occurs.	Fungal wilt	8.3.2
leaf	yellowing	Leaves look "silvery" in color, particularly along the veins	Red spider mite	5.3
leaf	yellowing	Leaf edges become yellow	Jassid	5.4
leaf	yellowing	Leaves have a silvery appearance, may be stunted	Thrips	5.6
leaf	yellowing	Leaves turn yellow	Whitefly	5.8
leaf	yellowing	Older leaves are light green or yellow	Nitrogen deficiency	-
root	deformation	Enlargement of the roots (root-galls)	Rootknot nematodes	8.1.3
root	rot	Roots are rotten, plant dies	Root rot	8.1.2
seedling	leaf spot	Dark spots on the seed leaves (cotyledons), and true leaves may kill leaves	Early blight	8.2.2

Affected plant part	General symptom	Specific symptom(s)	Possible cause	section
seedling	stem spot	Dark spots may girdle seedling stems, resulting in rotting of stem, wilting and death of seedling	Early blight	8.2.2
seedling	stem spot	Spots may girdle seedling stems resulting in wilt and death	<i>Phomopsis</i> rot	8.2.1
seedling	stem spot	Brown, water-soaked spots on seedling stems at soil line	Damping-off	8.1.1
seedling	wilting	Stunted growth, wilting	Early blight	8.2.2
seedling	wilting	Shriveling of stem at soil line	Damping-off	8.1.1
shoot	wilting	Wilting of a shoot, rest of plant looks healthy	Fruit and shoot borer	5.1
shoot	wilting	Shoots wilt, leaves are yellowish-brown	Thrips	5.6
shoot	holes	Small holes in growing tips of a shoot	Red ant	5.9
stem	hole	Hole in a stem, shoot above wilts	Fruit and shoot borer	5.1
stem	rot	Soft, watery rot with white, moldy growth on stems, stems can be girdled	<i>Sclerotinia</i> stem rot	8.4.1
stem	rot	Hard black, irregularly shaped bodies (sclerotia) form on the surface or in the pith of the stem	<i>Sclerotinia</i> stem rot	8.4.1
stem	rot	Stem is girdled, becomes rot, plant wilts as a result	<i>Sclerotinia</i> stem rot	8.4.1
stem	rot	Stem is rotten at the soil line. Sometimes white fungus mold and at first white, later brown, tiny sclerotia (fungus reproductive structures) are produced on the stem near the soil line.	Southern stem rot	8.4.2
stem	rot	Stem rot at soil level	Basal stem rot	8.4.3
stem	spot	Brown-black dry rot of lower stem of seedling	Damping-off	8.1.1
stem	spot	Stem spots: circular and may contain pycnidia	<i>Phomopsis</i> rot	8.2.1
stem	spot	Dark-greenish, water-soaked spots at soil level which may girdle stem	Root rot	8.1.2
veins	browning	Stem centers and roots turn water-soaked and later brown	Bacterial wilt	8.3.1
veins	browning	Vascular tissue of stems and roots becomes slightly brown	Fungal wilt	8.3.2

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* Copies of these documents can be made available upon request by the local Country IPM Office and/or the Regional Vegetable IPM Office in Bangkok.

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EGGPLANT VARIETIES



1. Eggplant fruits in many different shapes and colors



2. Freshly harvested eggplant fruits (Bangladesh)



3. Farmer shows eggplant fruit damaged by Fruit and Shoot Borer (India)



4. Lady farmer harvesting eggplant fruits (India)

EGGPLANT INSECT PESTS



5. FSB exit holes in fruit



Eggplant Fruit and Shoot Borer (*Leucinodes orbonalis*), FSB

6. FSB larva inside eggplant fruit



7. FSB shoot damage (note exit hole in stem)



8. Epilachna beetle adult feeding on leaf



9. Epilachna beetle larva



10. Green leafhopper adults



11. Leaf damage



12. Thrips adults feeding along midvein



13. Thrips leaf damage to underside of leaf



14. Leafroller (*Eublemma olivacea*): typical rolled leaf



15. Leafroller larva

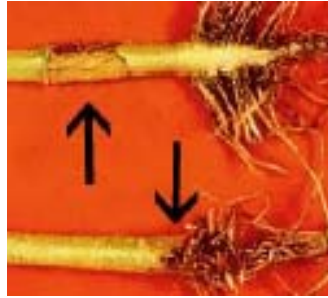


16. Leafroller damage to eggplant

EGGPLANT DISEASES



17. Rootgalls caused by rootknot nematodes (on tomato)



18 Damping-off: stem lesions (on pepper)



19. Bacterial wilt: bacteria oozing from cut stem



20. Verticillium wilt: top: wilting plant, bottom: vascular discoloration



21. *Phomopsis* blight lesion on stem



22. *Phomopsis* rot - close-up of pycnidia



23. Early blight leaf spots (*Alternaria solani*)



24. *Alternaria* fruit rot



25. Southern blight (*Sclerotium rolfsii*): fungus at base of stem

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