

Tomato 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 TOMATO



FAO Inter-Country Programme for the Development and Application of
Integrated Pest Management in Vegetable Growing in South and South-East Asia

December 2000

Why this guide?

About this guide

This ecological guide is developed by the FAO Inter-Country Programme for IPM in vegetables in South and Southeast Asia. It is an updated version of the Tomato IPM Ecological Guide dated June 1996.

The objective of this ecological guide is to provide general technical background information on tomato production, supplemented with field experiences from the National IPM programmes connected to FAO's Vegetable ICP, 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 IPM Exercise book", 1998 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.

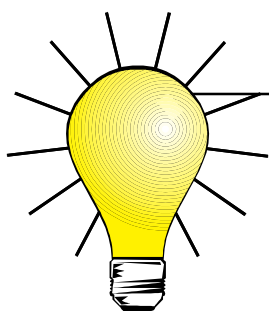
How to use this guide

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 action 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.

IPM cannot be mastered through books or guides: 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 Vegetable ICP hopes that this guide may be an

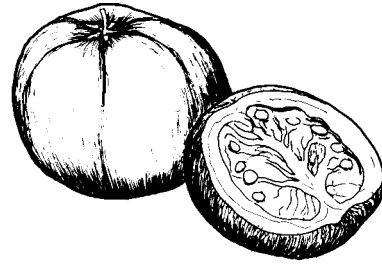
inspirational tool

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 into understanding ecosystems.

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.

In Vietnam for example, the average pesticide use in 103 FFSs in the period autumn-winter 1996 to summer 1999, dropped from 4.41 applications in the Farmer Practice plots to only 1.63 in the IPM plots. Yields of tomato in the same period were on average 9% higher in the IPM fields as compared to the Farmer Practice control.

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 for IPM in Vegetables in South and South-East Asia (Phase I) is a five-year regional program (April 1996 – June 2001) for the development and application of Integrated Pest Management (IPM) in vegetable production. The programme, funded by the Netherlands and Australia, operates through governments and NGOs in Bangladesh, Cambodia, Indonesia, Lao PDR, Philippines, Thailand and Vietnam.

Development objective of the IPM programme is “Sustainable, profitable and environmentally sound production of vegetables in the participating countries through the development, promotion and practice of IPM by farmers and extension staff.”

The vegetable IPM programme aims to empower vegetable farmers by training them to become experts in the production and marketing of their own produce. The IPM Farmer Training is based on the following principles:

- Farmers learn how to grow a healthy crop,
- Farmers learn how to regularly monitor their crop for informed decision making,
- Farmers learn how to conserve, augment and introduce natural enemies,
- Farmers become experts in the production and marketing of their own produce.

The vegetable IPM programme supports Training of Trainers (TOT) courses, Farmer Field Schools (FFS) and field studies (farmer research, or Participatory Action Research (PAR)).



1.3 Developing vegetable IPM based on rice IPM

The FAO Inter-Country Programme for the Development and Application of IPM in Vegetable growing in South and South-East Asia has branched off from the Inter-Country Programme for IPM in rice in South and South-East 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.

However, looking at the ecosystem of rice compared to vegetables, there are major differences. This has important implications for pest management strategies in both crops.

Rice is indigenous to Asia; most vegetables are imported from abroad (even though this may be many years ago). Therefore, rice has a large population of indigenous natural enemies whereas vegetable may not. 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 may well be able to keep pest insect populations low, and rice plant can compensate for some crop injury.

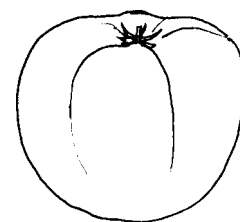
In vegetables, there may not be indigenous natural enemies that are effective enough to keep pest populations low. Pest management strategy is therefore based on “informed intervention”: other pest management strategies need to be applied to keep pest populations low. This important difference is summarized 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 divers	Not as divers
Stability ecosystem	Stable (if not disturbed)	Not as stable
Management strategy	INFORMED NON-INTERVENTION	INFORMED INTERVENTION

1.4 Tomato: a bit of history

The Latin name of tomato is *Lycopersicon esculentum* Mill., member of the family Solanaceae. Tomato has become a major world food crop in less than a century. The tomato, considered a vegetable but actually a fruit, is native to the Americas. It is believed to have been domesticated in Mexico, where a variant of the wild cherry tomato was brought into cultivation as early as 700 AD. The name tomato is in fact derived from the Mayan word “xtomatl”.



When the Spanish Conquistadors first introduced the tomato to Europe, in the mid-sixteenth century, it was grown as an ornamental plant. Once discovered to be edible, however, it was soon adopted into European cuisines. The British were slower to accept it as a food, fearing it was poisonous because of its membership in the Solanaceae family, which included poisonous species such as the deadly nightshade. The same fear persisted among the colonists in the United States until the early nineteenth century.

The tomato has come a long way, not only in distance from its centre of origin, but also in terms of varietal improvement, enhanced storage qualities and processing techniques. Today, numerous varieties, some transgenic, are cultivated in all regions of the world. Very large quantities are processed and preserved in a variety of forms. Much of the volume of processed tomatoes is packaged as bulk tomato paste and used to make products such as juice, sauces and soups. (FAO, 2000)

Such versatility coupled with a growing demand for the fresh fruits, has pushed the development of tomato as one of the main crops of the century. Breeding which intensified in the US in the 1930's and Europe in the 1960's, has been based on hybridization (ref. www34).



2

TOMATO CROP DEVELOPMENT



SUMMARY

This chapter describes general growth stages for tomato. 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 tomato plant 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.



Presently there is no standard terminology for describing tomato growth stages or crop stages like there is for rice. Although terms such as “flowering” and “fruit set” do exist, this terminology is often regional and can vary among farmers and others involved in agriculture. Moreover, tomato will bear flowers and fruits and produce new shoots at the same time so growth stages are not clear-cut but overlapping.

Accurate growth stage descriptions are very useful in pest management since plant susceptibility to pests varies with the growth stage. And more important, some growth stages can tolerate damage by certain insect pests or diseases whereas in other stages crop damage may result in yield loss. For example, the tomato fruitworm (*Heliothis armigera*) may cause leaf or shoot damage in young plants but this may not result in yield loss because the plant compensates the damage by producing new shoots. However, fruitworms attacking fruit cause direct quality loss of fruits and thus reduction of income.

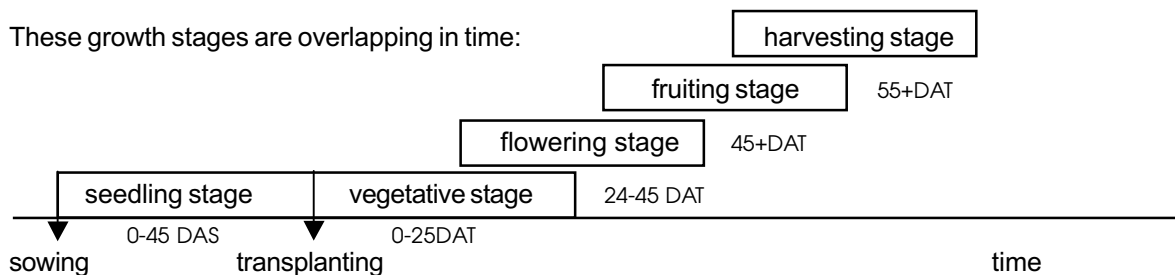
2.1 Tomato growth stages

Tomato completes a life cycle, from seed to seed, in one season. Tomatoes are usually grown for a few months, although they can be cropped for 24 months or longer when growing conditions (water, fertilization, etc.) are optimal and plants are not exhausted by diseases or insect pests.

General growth stages for tomato are:

- Seed.
- Seedling stage: usually the period from emerging seed to transplanting to the main field.
- Vegetative stage: from transplanting until first flower buds develop.
- 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.

These growth stages are overlapping in time:



DAS = Days after sowing

DAT = Days after transplanting

2.2 Susceptibility of growth stages to tomato pests

Whether various pest and disease species that attack tomato 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. Tomato plants 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.




Some pests are present throughout the season and can affect tomato at any growth stage. They will only affect the quality or yield at susceptible growth stages. Damage will also depend on the tomato 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 tomato pests and diseases may occur at specific growth stages. Please note that these are general values. There may be considerable differences in each region!

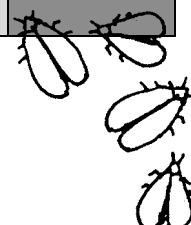
Always look at all elements of the agro-ecosystem when making crop management decisions!

Table 2.2 Susceptibility of growth stages to tomato pests

pest/disease \ growth stage	seedling	vegetative	flowering	fruiting	harvesting
Damping-off (<i>Pythium</i> sp.)	Dark Gray				
Tomato fruitworm (<i>Heliothis armigera</i>)		Light Gray	Dark Gray	Dark Gray	Dark Gray
Whiteflies (<i>Bemisia</i> sp.)		Light Gray	Dark Gray	Light Gray	Light Gray
Cutworm (<i>Agrotis</i> sp.)	Dark Gray	Light Gray			
Armyworm (<i>Spodoptera</i> sp.)	Light Gray	Light Gray			
Leafminer (<i>Liriomyza</i> sp.)		Dark Gray	Dark Gray	Dark Gray	Dark Gray
Root rot/Fruit rot (<i>Phytophthora</i> sp.)		Dark Gray	Dark Gray	Dark Gray	Dark Gray
Rootknot nematode (<i>Meloidogyne</i> sp.)		Light Gray	Light Gray	Light Gray	Light Gray
Early Blight (<i>Alternaria solani</i>)	Dark Gray	Dark Gray	Dark Gray	Dark Gray	Dark Gray
Late blight (<i>Phytophthora infestans</i>)	Light Gray	Dark Gray	Dark Gray	Dark Gray	Dark Gray
Mosaic virus (TMV)		Dark Gray	Dark Gray	Dark Gray	Dark Gray
Leaf curl virus (TYLCV)		Light Gray	Dark Gray	Dark Gray	Dark Gray
Bacterial wilt (<i>Ralstonia solanacearum</i>)		Dark Gray	Dark Gray	Dark Gray	Dark Gray
<i>Verticillium</i> and <i>Fusarium</i> wilt	Light Gray	Dark Gray	Dark Gray	Dark Gray	Dark Gray
Sclerotinia stem rot (<i>Sclerotinia sclerotiorum</i>)		Dark Gray	Dark Gray	Light Gray	
Southern stem rot (<i>Sclerotium rolfsii</i>)	Light Gray	Dark Gray	Dark Gray	Dark Gray	Dark Gray
Blossom-end rot				Light Gray	Dark Gray

 dark gray area: main pest occurrence

 light gray area: pest occurs to lesser extent





Related exercises from CABI Bioscience/FAO 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 used, use low amounts of chemical fertilizers.
- 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 tomato 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 tomato 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 Tomato botany and morphology

The Latin name of tomato is *Lycopersicon esculentum* Mill., member of the family *Solanaceae*.

Tomatoes are usually grown for a few months, although they can be cropped for 24 months or longer when growing conditions (water, fertilization, temperature etc.) are optimal and plants are not exhausted by diseases or insect pests.

By *growth habit*, the common tomato is often characterized into two types:

1. **Determinate type:** the side shoot above the first flower cluster produces up to 2 leaves and a flower cluster but no further vegetative shoots. This ends the upward growth of the plant. Many side shoots arise from the primary shoot, giving the plant a *bushy appearance*, but each eventually terminates in a flower cluster. Determinate tomatoes usually have a quite bushy appearance and may need some pruning of leaves to obtain good quality fruits.
2. **Indeterminate type:** this type of plant continues growing almost indefinitely and flower clusters develop to the side of a main shoot or main stem. This type of tomato usually needs staking and pruning of the side branches (called suckers) to obtain good quality fruits.

Most commercially grown processing and fresh market tomatoes have a determinate growth habit, because their shorter stature makes them easier to stake and the concentrated maturity reduces the harvest period, which generally reduces labor costs. Indeterminates are used in greenhouse production and by home gardeners because of the longer, less concentrated harvest period (Peet, www37).

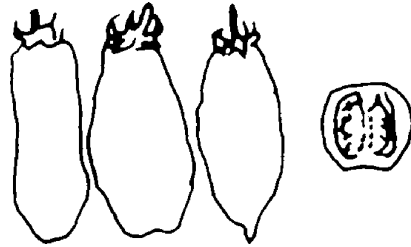
Fruit Characteristics

The tomato fruit is classified botanically as a berry. Fruit can be yellow, orange, pink, red, or even white in color. Size varies from small cherry types with only two divisions of the ovary (locules) to large multi-locular beefsteak types.

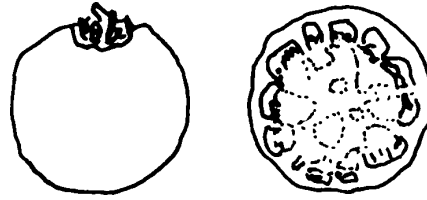
Two-locule wild types: Examples are cherry tomatoes and processing (plum or pear) types. Cherry tomatoes are small and round and grown only for fresh market. Processing types are usually somewhat larger and can be pear, plum or ‘square-round’ in shape. Although most processing tomatoes are canned or processed into sauces and condiments, small percentages are also sold fresh.



**Round fruits from indeterminate plants
(often greenhouse varieties)**



Elongated fruits, determinate varieties for processing



Late "beefsteak" varieties with large fruits, usually for fresh consumption
(picture from : Messiaen, 1992)

Four to six locules: Examples are most commercial cultivars for fresh market. **More than six locules:** Examples are the large 'beefsteak' types. Although the eating quality is very good, beefsteak tomatoes are now grown mainly in greenhouses or by home gardeners because they do not ship well and are more likely to crack and to be irregularly shaped.

3.2 Climate and site selection

Tomatoes can be grown in a wide altitude range: from the sub-tropical plains through to the high hills, depending on the variety and sowing dates. Despite this wide range, tomatoes are very sensitive to low light and adverse temperatures. Tomatoes need at least 6 hours of direct sunlight per day to flower.

Although tomatoes grow well over a wide range of temperatures (18 to 30°C), fruit set is very sensitive to high and low temperatures. A temperature range of 20 - 25°C is considered optimum for the growth of tomato. At higher altitudes, when daytime temperatures are warm but nights drop below 12°C, many varieties will not set fruit. In summer, when day temperature is above 35°C and nights are above 25°C, flowers may produce oddly-shaped (rough) fruit or flowers may fall off without setting fruit at all. Adverse effects seem to be worst when both day and night temperatures are high or when both are low.

Proper coloring of the fruit is also temperature dependent. Lycopene and carotenes, components that determine color, are not synthesized above 29°C and lycopene is not synthesized below 10°C, precluding normal color development in ripening fruit (Peet, www37).

Avoid very windy areas for tomato cultivation as pollination and fruit set may be impaired due to strong winds. Dry winds in addition, results in dropping of blossom. Bamboo mats or trees can be used as windbreaks in windy areas. See section 3.14 on windbreaks.

3.3 Selecting a variety

A large number of tomato varieties are available. Choice of variety will depend on factors such as availability, climatic conditions (lowlands or highlands), time of planting (early or late maturing varieties), insect or disease resistance or tolerance, market requirements (demand, fresh consumption or processing). In Asia, some farmers use their own tomato seed; others buy new seed in local shops.

3.3.1 Hybrids and OPs

Many tomato 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.



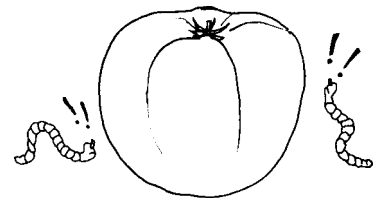
Hybrid variety: seed resulting from the cross-fertilization of two carefully selected lines, to produce plants of exceptional vigor and uniformity. Often called F1 hybrids; “F1” means that these are hybrid varieties of the first generation after crossing. There can also be F2 hybrids. Many varieties 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 are usually (much) more expensive. In most cases, they are worth the extra price. Seed should normally not be saved from F1 hybrids because this seed (=next generation) produces inferior quality in the next crop. Hybrid seed therefore need 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. Depending on the breeding process and the crop, *commercial* OPs can be very homogenous.

3.3.2 Resistant varieties

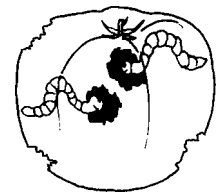
Another important aspect to consider when selecting a variety, is if the variety is tolerant or resistant against certain insect pests or diseases. Growing a resistant variety is one of the best and most environmental safe methods of crop protection! Unfortunately, resistant varieties are not always available. Also, resistant varieties are usually not resistant to all pests and diseases that may occur. Most of the tomato varieties from seed companies have a certain level of bacterial wilt tolerance and are resistant to at least one strain of *Fusarium* wilt.

Resistant variety: an insect pest or disease cannot live on the plant. This can be due to long or sticky hairs on a plant that hinder an insect to walk and feed on a plant, or the excretion of toxic chemicals by the plant, or the chemical 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.



✓ Test tomatoes in a varietal trial

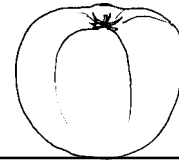
Many seed companies are willing to support demonstration plots of different varieties. For the seed company, the demonstration plot may be a promotion and they will often provide the seed for free. For farmer groups it may be worth the effort contacting a few companies and testing a number of varieties 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.



“Long shelf-life” varieties

New breeding methods have resulted in the development of tomato varieties that produce “long shelf-life” fruits in 1990. These tomatoes are slow to soften once they reach the red-ripe stage. Long shelf-life varieties are harvested red (with good flavor) from the plant, and are still strong enough to reach the end consumer. The extra shelf life (in US conditions) is about 10-20 days. Long shelf-life varieties (e.g. Elanor, and Lenor) are available in Europe and USA.

A common practice is to harvest tomato fruits when they are still green. Green fruits can be harvested, transported and stored better than red fruits. To obtain a red color, ethylene, a gas that plants normally produce to initiate ripening, is used. However, this results in tomatoes which do not have much flavor. Long shelf-life varieties were developed both to increase shelf-life and flavor, because fruits are harvested red from the plant.



3.4 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 tomato crop. Few farmers however, actually produce quality tomato seed. Some issues that are important for the selection of good quality tomato 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 tomato diseases are for example early blight, Tomato Mosaic Virus (TMV), and fungal wilt (*Fusarium* sp. and *Verticillium* sp.). Early in the harvest stage, usually less 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 contain usually 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 only large seed.
These will usually give strong plants.
- Discard seed that is spotted, or has black areas.
This might be a fungal or bacterial infection. Unfortunately, also healthy looking seed may be infected with pathogens so removing spotted seed does not guarantee a disease-free seed lot 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 tomato seed is put into water, it is noted that 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).

3.5 Seed extraction

To extract tomato seed, fruits are cut in two and pressed to extract the pulp. The pulp, containing the seed, is collected in a container and left to ferment. A white fungus will form on the surface and after about 24 hours, depending on temperature, the mould that covers each seed will be gone. Fermentation can also be done by placing seed in water for several hours. 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).

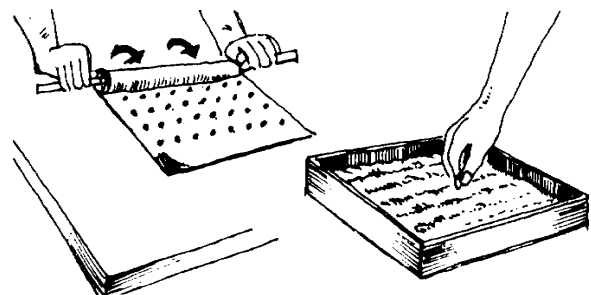
Related exercises from CABI Bioscience/FAO manual:

2-A.9. Seed multiplication methods

3.6 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. For example, an international seed company based in Thailand states that germination of their hybrid tomato varieties is over 80%. 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

Related exercises from CABI Bioscience/FAO manual:

2-C.4. Testing of cultivars

2-A.10 Test for seed germination



3.7 Seed treatments

There are two reasons to treat seed:

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 tomato are early blight (*Alternaria solani*), Tobacco Mosaic Virus (TMV) and fungal wilt (*Fusarium* and *Verticillium*).

Most seed companies do not normally treat tomato seed. Only when a seed-borne infection such as TMV 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. Fungi or bacteria living in the soil may attack the seed and cause death of the seed or the emerging roots even before the seedling has emerged above the soil (soil-borne diseases). 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 3.11.1 and 3.20) 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 tomato or other solanaceous crops for at least 2 years) and the use of resistant or tolerant tomato varieties. See also sections 3.3 on variety selection, 3.8 on soil, 3.11 on nursery management, 3.20 on crop rotation, and box in section 3.8.3.

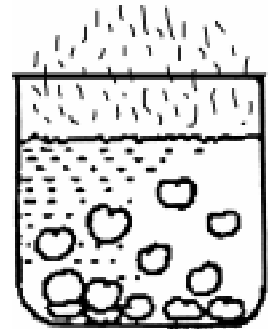


3.7.1 Hot water seed treatment

To kill fungal spores or bacteria attached to or within the seed, seed 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 strongly reduced.

The easiest way to treat seed is to prepare water of 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 seed. It may be easy to wrap the seed in a cloth to keep them together. Leave the seed in the flask for 30 minutes. After soaking in hot water, the seed is placed in clean, boiled, cold water to cool down. Dry by spreading the seed in a thin layer on paper or on cloth.



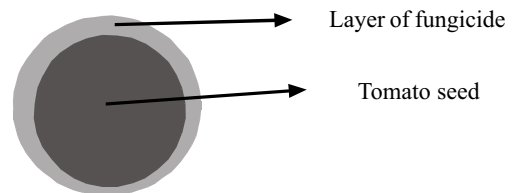
In some cases, a fungicide coating is applied after hot-water treatment. See section 3.7.2 below.



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

3.7.2 Chemical seed treatment

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 will 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. 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.



Seed coated with a fungicide



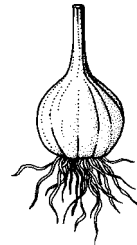
Use protective gloves when planting coated seed !

Unfortunately, chemical seed sterilization cannot guarantee that the seed are *completely* disease free. This is because some pathogens are present inside the seed. An example is TMV: virus can be present both on and in the seedcoat. Chemicals only sterilize the surface of the seed and do not reach infections inside the seed. Hot water treatment may sometimes be more effective to control pathogens inside seed. (ref. www24)



3.7.3 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).



3.7.4 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 are the antagonist 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 [www25](#) and [www29](#) (see reference list, chapter 12) 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 disease.

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 et al, 1998).

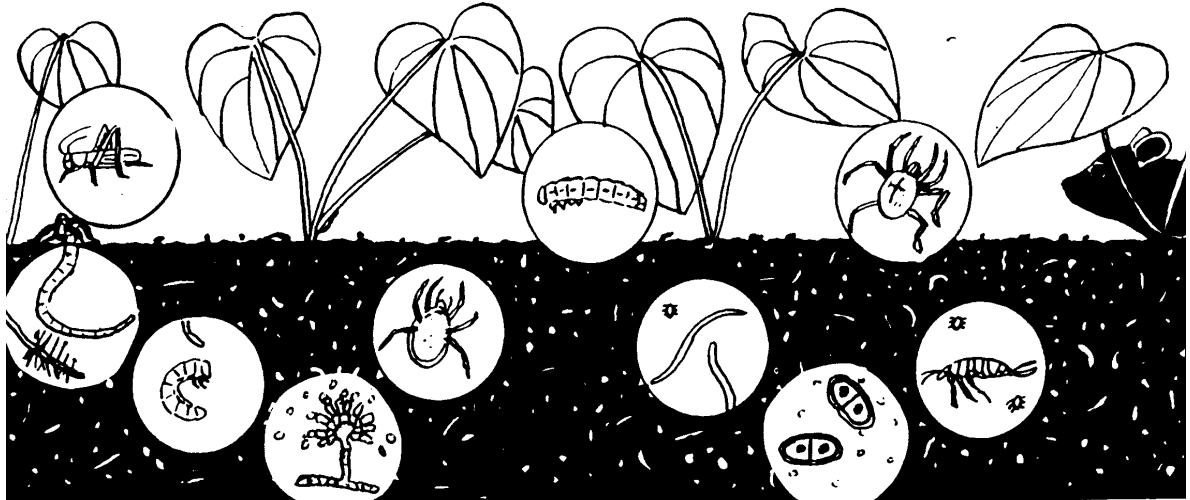
Related exercises from CABI Bioscience/FAO manual:

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

3.8 Soil

3.8.1 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 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. See also section 3.9.3 on role of micro-organisms.



The Living Soil: soil contains many small organisms like nematodes, fungi, and small insects.

(Picture from Schoubroeck et al, 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 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 manual:

2-A.4. The living soil

For more exercises on living soil, see B. Settles' manual on the website of Community IPM!

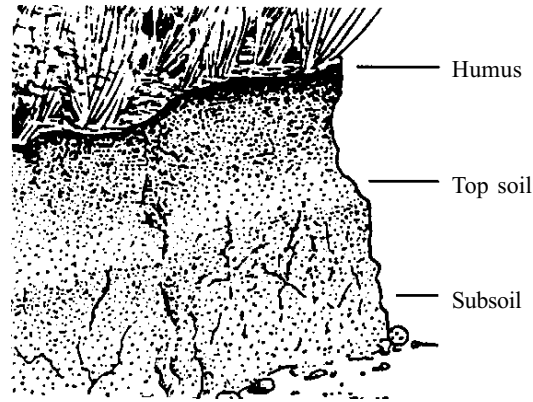
3.8.2 Soil type

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 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 air and water holding pores are formed. 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).



Tomatoes grow on many soil types but all good tomato soils must be well-drained. On sandy soils, tomatoes mature early, but silt or clay loam soils are generally considered the most productive.

Related exercises from CABI Bioscience/FAO manual:

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

3.8.3 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 (PAR), 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, www26).

Pathogens are so small that they cannot be seen with the naked eye. Only when they affect the plants 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 3.20).
2. Use of clean seed (see section 3.7).
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 3.9.3).
6. Proper water management: mainly providing drainage to keep soil around roots from becoming waterlogged (see section 3.16).
7. Application of antagonistic fungi such as *Trichoderma* sp. into the soil. See section 7.10.



Related exercises from CABI Bioscience/FAO manual:

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

3.8.4 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 3.11 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” (or control of a soil-borne pathogen) 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 tomato) by mustard green manures was obtained in field studies. See section 3.11.1.4 for details on biofumigation and other options for biological soil sterilization.



3.8.5 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 break-down 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, tomato performs best in soil with a pH range of about 6.0 to 7.0.

3.8.6 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.

Soils tend to 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.

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 3.8.6

Table 3.8.6 Some indicators of lime required to raise pH 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 “scientifically proven” in case of 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 seven 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, www26).

3.8.7 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 a mulch (such as rice straw) or a “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 3.9.3.2.

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 it stimulates activity of micro-organisms in the soil. Micro-organisms help releasing nutrients from organic material in the soil. See section 3.9.3 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 hover flies, and provide shelter for natural enemies such as spiders.

4. No use of pesticides on soil.

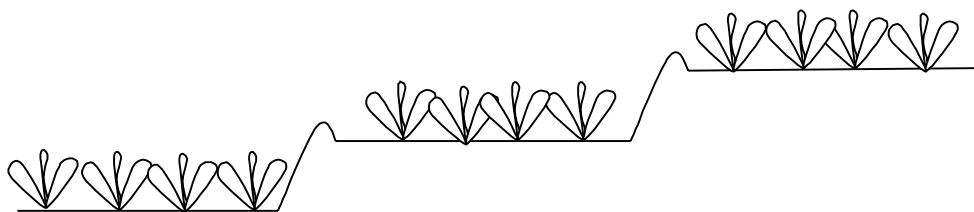
Pesticides disturb the activity of micro-organisms in the soil and may create imbalances in soil fertility.

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 to 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 has been known to cause disease problems in plants. In some cases it can be good to use a small amount of e.g. nitrogen to push plants through a stressful period such as downy mildew attack in the nursery.

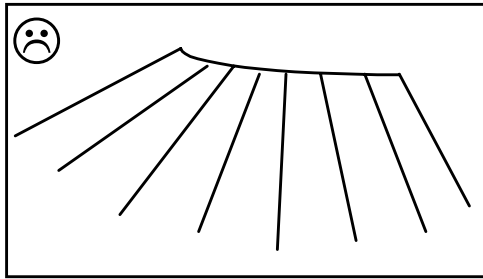
6. Building terraces on steep slopes.

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:

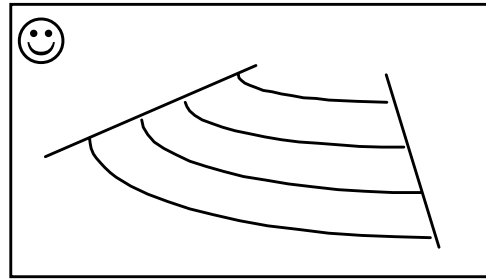


7. Plant along gradient of the slope.

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 can easily spread into the lower parts of the field.



Top down planting stimulates erosion....



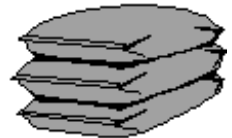
... plant along the gradient of the slope!

Related exercises from CABI Bioscience/FAO manual:

2-A.2. Soil conservation: why?

3.9 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 by adding fertilizers. This can be 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.

3.9.1 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 micro nutrients are lumped together under *micro nutrients*, also called *trace elements*. Addition of micro nutrients should be made only when a clear deficiency is indicated, preferably by a soil test analysis.

NPK

Some of the micronutrients are found in the mineral particles of the soil but most come from *humus*. Humus comes from the break down of organic matter. The micro nutrients 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 break-down of leaves in the soil: slowly they will become soft, fall apart into very small pieces and eventually disappear. This break-down 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 matter.

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

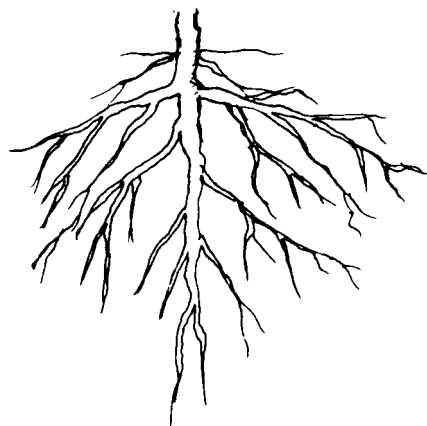
3.9.2 Soil testing

The amount of fertilization 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 how much nutrients needs to be added. 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 underpredict the amount of soil nutrients actually available to plants over the course of the entire season (ref. www2).

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, seem to be searching for something but grow vertically, they 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.



3.9.3 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 which 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.



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 3.8.5 on soil pH.

Soil health: micro-organisms in the soil promote soil health. Species of those 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 more examples 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.

3.9.3.1 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 3.9.3 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.

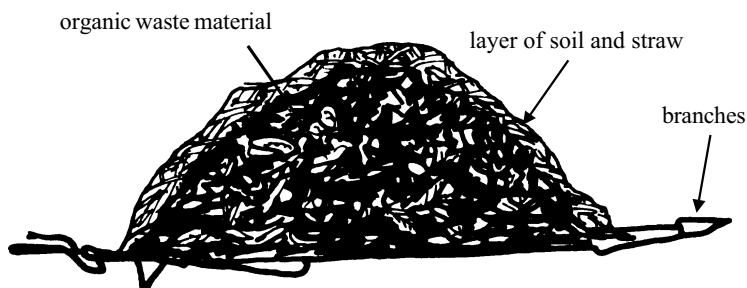
Disadvantages of compost:

- 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 is 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 www11).

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



A simple compost pile



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.

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.

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.

Cover the pile during rainy periods so it will not get too wet.

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 more moist 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: www30; www31; www32)

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.

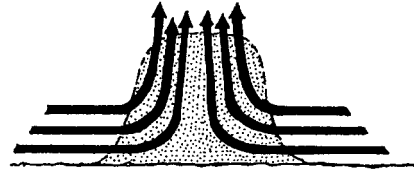
Pathologists describe two different types of disease suppression in compost and soil.

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.



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



Temperature rising in a free standing compost heap



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. www33).

Other biocontrol agents (or antagonists, *For more information on antagonists see section 7.10*) that colonize composts include bacteria like *Bacillus*, *Enterobacter*, *Flavobacterium balustinum*, 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.

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. There are specialized compost companies that produce consistently suppressive composts, especially for the nursery industry.

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.

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.

Other researchers report less disease incidence (even foliar disease such as early blight in tomato), 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 below.

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 method to restore or enhance the population of micro-organisms in the soil.

A number of researcher 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. www34).

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

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.





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.

The tomato field 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 the 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 www26)



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, www5).

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. tomato, 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
- soybean, mung bean, velvet bean

These are all 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 3.11.1.4 and 3.11.1.4.

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 3.9.3.3 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 tomato diseases, particularly weeds that belong to the family of Solanaceae. ☹ (modified from www11)

Related exercises from CABI Bioscience/FAO manual:

2-A.5. Use of green manure



3.9.3.3 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, www11). Average nutrients available in manure from different sources, and from ashes are listed below .

Table 3.9.3.3 : Average nutrients available in manure

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 tomato plants. 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 tomato 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 3.11.1.5 on soil sterilization of nurseries.
- Decomposition process produces methane, a gas harmful to plant roots. Also see section 3.11.1 on soil sterilization of nurseries.
- Regular supply of fresh manure leads to lower soil pH.

3.9.3.4 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.

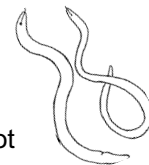
Leguminous crops, such as clovers, can also be grown as a “living mulch”, grown together with the main crop. Such living mulch is an effective soil protection and it provides nitrogen to the main crop. See section 3.9.3.2 above.

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 (NH_3) 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.



3.9.4 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.



3.9.5 Comparing organic and chemical fertilizers

When comparing organic and chemical fertilizers on the amount of nutrients they contain, the following points must be borne in mind:

- Organic fertilizers such as compost vary widely in composition depending on the raw material used in their preparation,
- Organic fertilizers usually provide (part of) the major plant nutrients N, P and K , and a wide range of micronutrients, whereas chemical fertilizers do not,
- Nutrients are normally more slowly released from composts than from very water-soluble chemical fertilizers. This means the crop will profit longer from organic compost, especially during the rainy season. Some nutrients in compost are held in humus-like compounds which decompose very slowly so that their effects on soil continue for years after application.

In table 3.9.5 a summary comparison of the advantages and disadvantages of both fertilizers is listed.

Table 3.9.5 Comparing organic and chemical fertilizers

	Organic fertilizers	Chemical fertilizers
Advantage	<ul style="list-style-type: none"> • rich in nutrients • usually provide (part of) the micronutrients N, P & K, and wide range of micronutrients • improves soil structure • increases water holding capacity soil • gradual release of nutrients • 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 per volume unit (kg) • fast release of nutrients • easy to determine dosage • easy to apply, not labour intensive
Disadvantage	<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/drained off quickly during wet season • expensive

3.9.6 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. Some researchers promote the use of foliar application of urea on tomato. Trials done show that urea applications result in increased vegetative growth but delayed maturity of the fruits. Yield eventually may be higher.

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



3.9.7 Fertilization needs of tomato

Tomatoes are considered 'heavy consumers' because of their rapid growth and long production season. Production of one ton (1000kg) of tomato fruit removes 1.4 – 3.6 kg nitrogen, 0.2 – 1.4 kg phosphorous, and 2.2 – 5.4 kg potassium from the soil (Peet, www38).

The table below lists general tomato 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!

In addition, you can set up a small trial 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 probably 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).

General recommendation for total application of fertilizers for tomato is:

Compost 15 – 20 tons/ha
 N 70 – 100 kg/ha
 P₂O₅ 70 – 100 kg/ha
 K₂O 140 – 200 kg/ha

This can be split into the following applications for example. See an example from Vietnam in table 3.9.7

Table 3.9.7 An example of a fertilizer recommendation for tomato

Timing	Fertilizer	Quantity	Application method
2 – 4 weeks before transplanting	Compost	15-20 tons/ha	mixed into soil
At transplanting	20% of total N 20% of total P ₂ O ₅ 20% of total K ₂ O	14 – 20 kg/ha 14 – 20 kg/ha 28 – 40 kg/ha	Side-dressing
15 DAT	20% of total N 20% of total P ₂ O ₅ 20% of total K ₂ O	14 – 20 kg/ha 14 – 20 kg/ha 28 – 40 kg/ha	Side-dressing
35 DAT	20% of total N 20% of total P ₂ O ₅ 20% of total K ₂ O	14 – 20 kg/ha 14 – 20 kg/ha 28 – 40 kg/ha	Side-dressing
55 DAT	20% of total N 20% of total P ₂ O ₅ 20% of total K ₂ O	14 – 20 kg/ha 14 – 20 kg/ha 28 – 40 kg/ha	Side-dressing
75 DAT (if applicable)	20% of total N 20% of total P ₂ O ₅ 20% of total K ₂ O	14 – 20 kg/ha 14 – 20 kg/ha 28 – 40 kg/ha	Side-dressing

(modified from FAO, 1988; Peet, www5; and pers. comm. IPM trainers Hanoi, Vietnam, 2000)

DAT = Days After Transplanting.



Part of the recommended nutrients can have organic sources, such as compost or green manure. See section 3.9.3.

Every person, every book or guide will give another recommendation for tomato 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, calcium and boron in tomato

Nitrogen (N) promotes vegetative growth, but it is easy to apply too much before fruit set. The resulting plants are thick stemmed and dark green. New leaves sometimes ball up rather than expand. The ratio carbohydrates (available from photosynthesis) - nitrogen (supplied through fertilizers) – (C/N ratio) is critical. If nitrogen and sunlight for photosynthesis are both adequate, then plants will grow and yield well. If N is high and plants are crowded or light is low, set will be poor because vegetative growth consumes all available carbohydrates (that are produced by photosynthesis). Such plants are sometimes described as ‘viney’. The best solution is to provide as much light as possible and enough nitrogen to keep the plant growing steadily. Too little N is, of course, also bad because it stunts plant growth. Blossom end rot (see section 8.5.1) appears to be increasing with increasing levels of nitrogen.



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

High level of **phosphorus** (P) throughout root zone is essential for rapid 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 tomato. Soft fruit and poor condition of skin are associated with low K.

Be aware that both P and K are being released slowly, and that particularly P is needed for root development, therefore basal application of P and K is crucial for healthy crop development. Topdressing P and K is often not efficient.

Low **calcium** availability increases blossom-end rot and may also cause fruit cracking.

Fruit russetting (fruit cracking), brittle stems, reduced root growth and tip dieback are associated with low **boron** levels.

See section 8.5 on symptoms of fertilizer excess of deficiency.

Related exercises from CABI Bioscience/FAO manual:

2-C.5. Fertilizing experiments

2-C.6. Use of foliar fertilizers

2-A.6. Composting

2-A.7. Use of compost



3.10 Planting time and pest occurrence

The type and number of pest and diseases can vary in different times during the year. During the dry season for example, late 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.

Planting time can be a tool to break the continuity of insect breeding by creating periods without food plants for pests. See also crop rotation section 3.20.

Related exercises from CABI Bioscience/FAO manual:

2-A.12. Weather conditions and planting time

3.11 Nursery management

3.11.1 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!

3.11.1.1 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 shortly 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, root-knot 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.

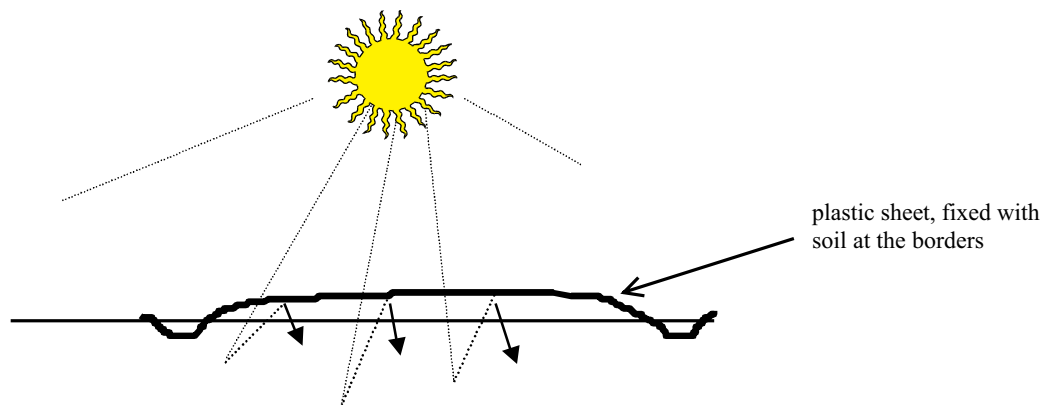
(pers. comm. farmer Chittagong, Bangladesh, 1998)



3.11.1.2 Solarization

Another soil sterilization method is *solarization* - with help of the sun. 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 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 it for about 2 weeks. Then, he used the soil to prepare a raised nursery bed in which the seed were sown. He reported no trouble with damping-off!

(Pers. comm. Mr. Yousuf, Jessore, Bangladesh, 1998)

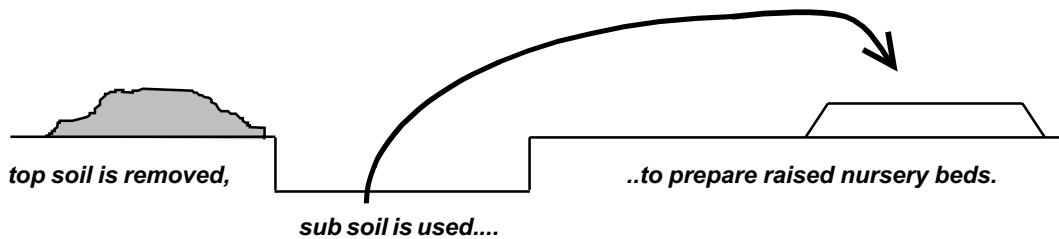
Solarization can be combined with another soil sterilization method described in section 3.11.1.5. With this method a large amount of organic material (e.g. a green manure crop like grass (40 tons/ha) is incorporated into the soil before applying the plastic sheets. A better sterilization effect may be obtained and organic material is added to the soil, which improves soil structure and fertilization. See section 3.11.1.5 for details.

3.11.1.3 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 damping-off causing organisms 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.



3.11.1.4 Biofumigation

Soil-borne pests and pathogens can be suppressed by chemical compounds that are released during decomposition of certain crops. This is called *biofumigation*. The chemical compounds that are able to kill or suppress pathogens are principally isothiocyanates. Those crops with biofumigation potential are used as a rotation crop, a companion or a green manure crop. In Australia, research is ongoing to test which crops can be used for suppression of certain pests and pathogens (pers. comm. Dr. John Kirkegaard, 1999).

The process of biofumigation is studied in two contexts:

1. Rotation crops: broad acre harvested rotation crops such as the canola/wheat sequence.

Here only root material would be active and opportunities are studied to enhance the biofumigation effects, focussed on suppression of pathogens for which chemical control is uneconomic and crop rotation is the only current control measure.

The Australian group have identified a chemical component (aromatic glucosinolate) in the roots of canola which hydrolyses in soil as the roots decay to release an isothiocyanate which is highly toxic to fungal pathogens. Further research is now in progress to test different pathogens as well as beneficial organisms.

2. Green manures for horticultural/intensive agriculture

Here the Australian group are considering a green manure situation in which a variety of different brassicas can be selected, and both root and shoot tissue can be incorporated (if desired). This means 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 research of the Australian group aimed to identify the range of different glucosinolates and their concentrations in different Brassica species, varieties and plant parts. They also determined how growing conditions influenced their concentrations. Having established the major types, they then tested the toxicity to a range of fungal pathogens, and to insects, nematodes and bacteria.

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.

At present excellent suppression of bacterial wilt of solanaceous crops (tomato, eggplant, etc.) by mustard green manures has been achieved while for other pathogens (e.g. *Pythium* sp. causing



damping-off disease) the effectiveness is poor. The good results with bacterial wilt suppression may be a good starting point for setting up experiments in training programmes, possibly with assistance of staff from the Australian research group.

3.11.1.5 Biological soil sterilization

Another relatively new 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 homogenous. 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 used 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 *Pratylenchus*).

This soil sterilization method can be combined with solarization (see section 3.11.1.2). 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, W., PAGV Jaarverslag 1998; pers. comm. Dr. W. Blok, Wageningen Agr.Univ., 1999).

3.11.1.6 Boiled water

Although not “scientifically 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 a trial to compare the method against the common practice!

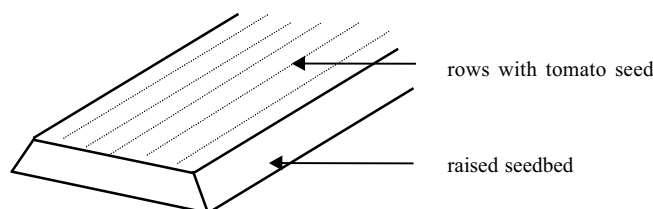
3.11.2 Sowing

Tomatoes can be sown directly in the field or sown in a nursery or in pots and transplanted later. Usually, transplanted tomatoes show earlier ripening and give higher yields than directly seeded tomatoes. Therefore, most commonly, tomatoes are 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 for 3 years or more. This is a prevention for the occurrence of (soil-borne) diseases.

3.11.2.1 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.



Seed is 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. Seed is either broadcast in the rows and thinned out later or placed individually every 3 cm. If the seed is planted deeper, it will take more time to germinate, so you will have to wait longer before transplanting. When seed is sown less than about 1 cm deep, it will be more susceptible to drought, and will form weaker seedlings.

Broadcasting the whole seedbed usually costs 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. In Vietnam for example, 150 g/100 m² is used when broadcast (pers. comm. IPM trainers Hanoi, April 2000).

The optimum soil temperature for germination is 29°C (minimum = 10, maximum = 35°C). On the average, 6 to 14 days are required for germination.



✓ **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.

3.11.2.2 Sowing in pots

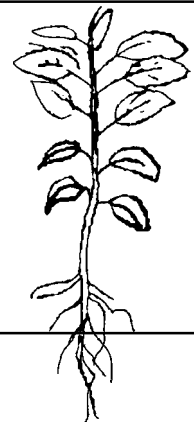
In areas with heavy soil-borne disease infestation, or with unsuitable soil for a nursery site, it is possible to raise seedlings in pots. Pots made out of banana leaf can be used, polybags, jars or other materials. The advantage of using organic material such as banana leaves is that these can be left 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 3.11.1.3).

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, experiences from Asia:

Experiences are reported from Lao PDR, where cabbage seedlings raised in polybags are 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)





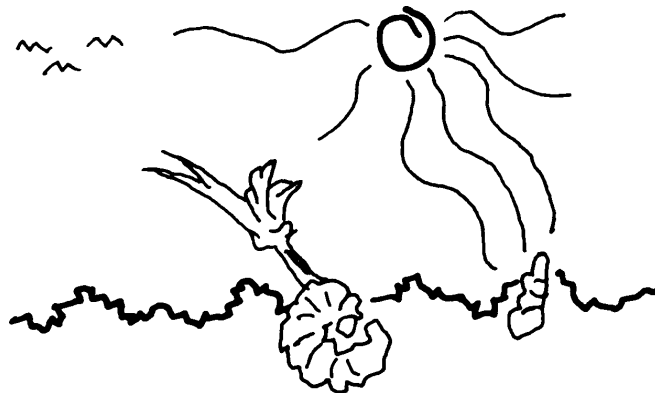
Related exercises from CABI Bioscience/FAO manual:

- 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

3.12 Field preparation

3.12.1 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.



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

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 focussed 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 3.9.3.2 and 3.9.3.4, 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. This 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.



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.

Advantages

- Crops use water more efficiently
- Water-holding capacity of soil increases
- Water losses from runoff and evaporation are reduced
- Soil organic matter and population of beneficial micro-organisms are maintained
- Soil and nutrients are less likely to be lost from the field
- Less time and labor is required to prepare field for planting

Disadvantages

- Compaction of the soil may occur
- Flooding or poor drainage may occur
- Delays in planting when field is too wet or too cold
- Carryover of diseases and pests in crop residue
- Transplanting in stubble is more difficult and may take longer resulting in delayed or less uniform crop maturity

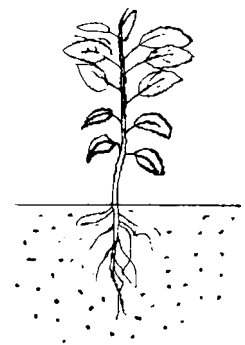
(Peet, www4)

3.12.2 Transplanting

Tomato seedlings can be transplanted when they are about 15 cm long and have 4 or 5 true leaves, usually 4 to 8 weeks after sowing. Thoroughly water plants 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 and exposed to sun or drying wind.

Some nurseries harden seedlings before they are sold for transplanting. Seedlings are hardened by the withholding of water and nutrients for a certain period of time. This results in seedlings that can survive adverse conditions and are therefore 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 tomato 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).



3.12.3 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. Tomato fruit numbers and fruit weight per plant increase 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 armyworm caterpillars (*Spodoptera sp.*) can easily walk from one plant to the next when leaves of adjacent plants touch.

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

Table 3.12.3 Some factors related to plant spacing

Narrow spacing	Wide spacing
more plants per area = higher initial costs	fewer plants per area = lower initial costs
small 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

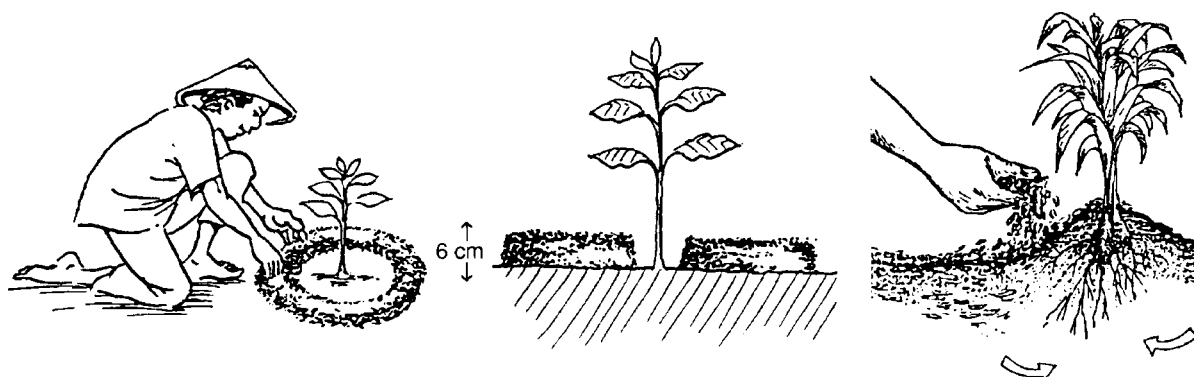
Spacing depends on type and variety of tomato grown, pruning system and local tradition. Within-row spacing will depend on the vigor of the variety and on how severely it will be pruned. Some farmers space plants widely (65 – 90cm) in the row and prune very lightly or not at all.

An indication for spacing can be:

- Bush type (determinate) tomatoes:
 - 50 - 100 cm (between rows)
 - 40 - 60 cm (between plants)
- Staking type (indeterminate) tomatoes:
 - 50 - 180 cm (between rows)
 - 30 - 75 cm (between plants)

3.12.4 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.



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.

Mulching may have a role in reducing pests and diseases. Plastic mulches with aluminium film have been shown to reduce aphid attacks. The shiny aluminium reflects light and deters aphids. 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. See box below.

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 3.9.3.4 on organic mulch.

Plastic mulch, thrips and virus

In field trials in Indonesia, white and silvery plastic mulch reduced thrips injury and delayed virus epidemics in hot pepper. The overall positive effect of plastic mulch on crop health contributed to improved crop production. ☺

However, plastic waste materials may have a negative side-effect on the environment. ☹
(Vos, 1994).

Research is ongoing to develop biodegradable plastic ("bioplastic") which can be placed, together with crop left-overs, on a compost pile.

Related exercises from CABI Bioscience/FAO 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

3.13 Pruning and staking

Pruning of suckers is usually done for staking type (indeterminate) tomatoes. Bush type (determinate) tomatoes will only need pruning to remove large numbers of small fruits and some leaves (see section 3.1). Pruning of excessive leaves ensures proper fruit color as it allows the sun to reach the fruits. Care should be taken to leave enough of foliage to shade the fruit and protect it against sunscald.

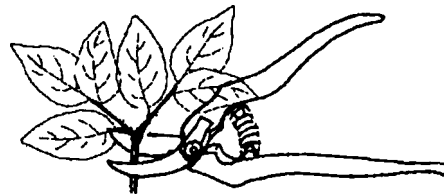


Pruning should be done regularly, starting at an early stage because when done later in the season, it becomes difficult to distinguish between the main stem and the suckers. The positive effect of pruning also becomes less profound if suckers are allowed to become stems and even to flower.

When aiming for the early market and quality rather than quantity, tomato plants should be pruned to a single stem, removing all suckers. This shortens the growing season and ripens fruit uniformly. Another way to achieve early fruit production and later sun protection is to take out all suckers on the lower 50 cm of the stem, then let the plant bush out with the branches tied to a support.

The single stem system can be modified by allowing one sucker to grow from near the base to form a two-stemmed plant, later removing the rest of the suckers on both stems. More fruits can be harvested over a longer period with this system.

It depends on local traditions, varieties used and market requirements what pruning method would have the preference. In small trials, the different pruning systems could be tested and yields and quality of the fruits can be compared.



Below, three common staking systems are described that are commonly used in Western countries

Trellising: In fresh market tomato production systems, plants are usually held off the ground with individual stakes or by a trellis strung along a row of stakes. In commercial fresh market tomato production, plants are usually trellised with two plants between each stake. With this system, they are pruned to remove all suckers except the one immediately below the first flower cluster. Then sturdy 120 cm stakes are placed between every two plants. Extra stakes brace the stake at the end of the row. Nylon twine is strung horizontally along the line of stakes, wrapping the stakes tightly and encircling the plants. Typically, the first stringing takes place 2 to 4 weeks after transplanting or when transplants are 30 to 40 cm tall. The first string is placed about 25 cm above the ground and is sometimes crossed between the plants to provide additional support. As the plants grow, additional strings are added at intervals of 15 to 25 cm up the stake. These additional strings are not usually crossed between the plants. Shorter determinate cultivars are used so only four strings are necessary. This system is variously referred to as the stake or trellis system and is widely used in commercial tomato production. Once the trellises are strung, the plants are generally not pruned again except to remove shoots growing from the base of the plant (ground suckers). Disadvantages are that trellises will sometimes fall over in high winds on wet fields and trellises and strings must be removed at the end of the season (Peet, www38).

EXAMPLE

In southern Philippines (Mindanao) the use of trellises for staking in tomato cultivation is very extensive for the following reasons:

1. to protect the fruits from infection with soil-borne pathogens,
2. to ensure good quality fruits,
3. to provide suitable space for aeration and crop protection activities.

(Sivanaser et al, 1991)

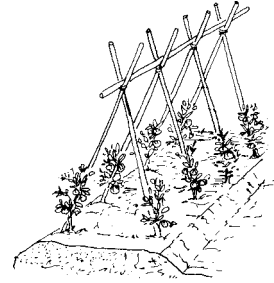
Tying to poles: Individually tying each plant to its own pole or stake was once common, but this method is now mostly used in home gardens because it is labor intensive and expensive. In pole production, indeterminate cultivars are pruned to a single stem which is tied or clipped to a 150-180 cm pole. As the plant grows, tying and removing





side shoots from the main stem must be repeated every 7 to 10 days. To speed ripening, the main stem is usually cut off when it reaches the top of the stake.

The advantages of this system include easy harvest, large, clean fruit, and little soft rot. In hot weather, however, the foliage offers little protection from the sun, resulting in sunscald and fruit cracking. It is also more expensive and labor-intensive than trellising (Peet, www38).



Sprawling on ground: This method is used to grow mechanically harvested tomatoes such as those for processing and some mature green fresh market tomatoes. Generally plants are seeded rather than transplanted. There is little requirement for labor or materials but in wet weather, fruit rots on the ground even when grown on black plastic. Vines are more susceptible to foliar diseases because of poor air circulation. However, research is underway to develop varieties with a growth habit which will hold fruit off the ground without staking (Peet, www38).

Tomato FFS in Ban Nongkeo, Lao PDR

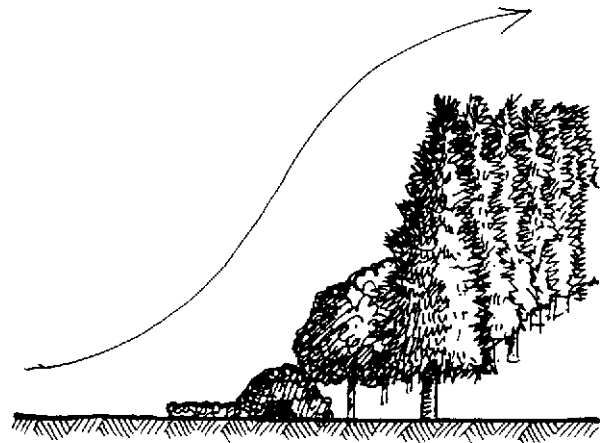
During a field study on fertilizer management on tomato, the FFS group did not stake their tomato plants because they felt it was “too much work for only a little income”. However, the group found that at the end of the study, losses due to fruit rotting after touching the soil were high: 30%! ☹

(FAO – FFS report, Ban Nongkeo, Lao PDR, 1998)

3.14 Windbreaks

In areas with a lot of wind, the use of windbreaks is recommended. Strong winds may impair fruit set and result in lower yield and lower fruit quality.

Many crops and trees can be used as windbreaks. Some of the common annual crops include maize or (in cooler areas) grain crops. Grain windbreaks have been found effective when grain rows are used for each tomato row. Trees suitable for use as windbreaks are for example cashew (*Anacardium occidentale*), neem (*Azadiracta indica*), and *Eucalyptus* sp. (for boundaries).



3.15 Pollination and fruit setting

Tomato flowers have both male and female parts within every flower. Pollination of the female flower part must occur before fruit will set. Poor pollination results in off-shaped fruits if seeds do not develop uniformly throughout the fruit, smaller fruits, and fruits that are rough (ridged) along the tops. Pollination can be prevented by various stresses such as cold or hot temperatures, drought, high humidity, nutrient deficiencies, nutrient toxicities, as well as lack of pollen transfer.

Field tomatoes are mainly pollinated by wind rather than by bees, which pollinate many other types of vegetables. Tomato flowers do not produce nectar, attractive to honey bees.



Tomato is mainly a self-pollinating crop: most of a flower's pollen fertilizes the ovary within the same flower, although some of the pollen reach surrounding flowers. Wind shakes the flower so that pollen leave the anther and travel to the stigma.

3.16 Water management

3.16.1 Drainage

The most important water management practice is providing drainage to keep soil around roots from becoming waterlogged. This is especially important when tomato (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 head 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 dewatering. 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... ☹

3.16.2 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 and late blight in tomato 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 3.20 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.

Water requirements of tomato

Tomatoes have a high water requirement but also have an extensive root system. With good growing conditions, plants should be given as much water as possible during vegetative growth.

Probably the most important consideration in watering tomatoes is consistency. When water availability fluctuates or when it is too high or too low at critical stages, fruit disorders such as blossom-end rot develop. (See section 8.5 on physiological disorders.) Watering extensively after a dry period may cause a sudden growth burst resulting in cracking of the fruits.

For maximum yield, adequate water levels need to be maintained throughout fruit development. For maximal flavor, however, a slight water stress during fruit development (60 to 80 percent of the estimated requirement) is sometimes recommended. This would avoid a “watery” taste of the fruits. Water stress is quite difficult to dose as too much water stress results in dropping of the fruits and flowers and fruits that remain on the plant may not recover fully (Peet, www38).

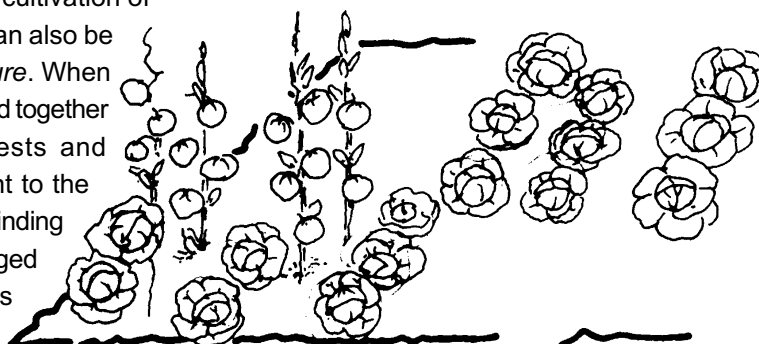
Related exercises from CABI Bioscience/FAO manual:

2-C.8. Flooding and overhead irrigation

3.17 Intercropping and trap crops

3.17.1 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 get a chance to hide in the other crop. When the intercrop is taller than the tomato plants they can form a “barrier” thus reducing spread of insect pests and diseases.

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. Intercropped tomatoes with onion or garlic reduced levels of whiteflies and aphids on tomatoes (Tumwine, 1999).

Other plants may have nematocidal 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. which can be effectively controlling nematodes on tomato (Tumwine, 1999). According to AVRDC (1994), intercropping tomato with cowpea could be used in IPM in the tropics to control bacterial wilt.

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 tomato (e.g. sunflower or sorghum), or grown very close to the tomato plants, it may cause yield reduction due to competition for light, space and nutrients (Tumwine, 1999). See box below.

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

Effects of intercropping on tomato late blight disease: a study from Uganda

Experiments were conducted in Uganda to identify crops which could be grown with tomato and which reduced late blight disease (*Phytophthora infestans*). Tall and short crops were intercropped with tomato and sanitation (removal of infected leaves, shoots and flowers) was practiced. Some conclusions from these studies were:

- Late blight incidence in intercropped plots was lower than in control plot (although also because of sanitation practices).
- Soybean and sesame are compatible for intercropping with tomatoes at 60cm between row spacing.
- Tall plants such as sorghum and sunflower have a suppressive effect on tomato growth and productivity when intercropped, presumably because of shading.
- Sanitation alone had a negative effect on tomato growth and production.
- Row spacing between intercrops is crucial to minimize side effects such as shading and competition for nutrients.

(Tumwine, 1999)

3.17.2 Trap crops

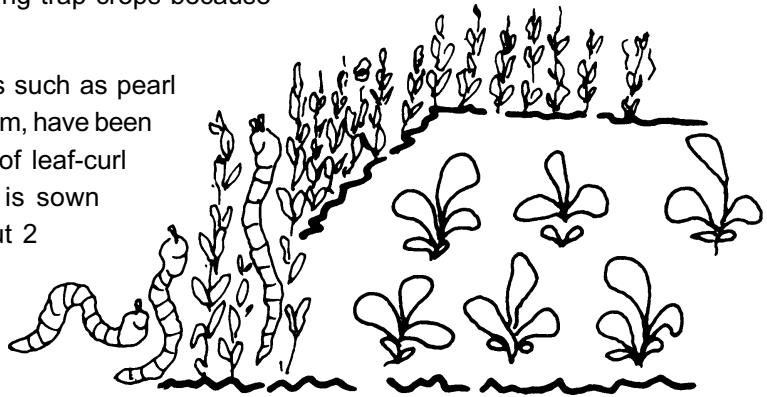
A trap crop is a crop other than tomato that attracts insect pests so that these pests will not harm the tomato plants. Usually, trap crops are also members of the solanaceous family because they have to



attract the same insects that will attack tomato. Some people find this is a disadvantage of planting trap crops because pests are attracted to the field.....!

In India for example, planting crops such as pearl millet, sunflower, sesame and sorghum, have been observed to reduce the incidence of leaf-curl disease in tomato. The trap crop is sown around the main tomato field about 2 months before transplanting tomato seedlings.

Other studies claim that cucumber, intercropped with tomato, attract most whiteflies thus resulting in less leaf-curl disease (Salih, 1983).



Related exercises from CABI Bioscience/FAO manual:

2-C.3. Mixed cropping versus monocropping

3.18 Harvest

The time required to reach maturity depends on variety and climatic conditions. As a general indication early varieties will need 50 - 65 days, mid varieties 65 - 80 days and late varieties 80 - 100 days from transplanting to harvest (Peet, www36).

Tomato yields depend on cultivars, cultural practices, and pest and disease occurrence in the season. In Vietnam for example, average yields in IPM plots of 103 FFSs in the period autumn-winter 1996 to spring-summer 1999 ranged from 17 tons/ha in North Central Vietnam to 42 tons in the Central Highlands.

Ripening stages of tomato are listed in the table below.

Table 3.18 Ripening stages of tomato

Ripening stage	Characteristics
immature	fully green
mature green	Mature greens have a white to yellow 'star' on the blossom end, but the only definitive test of maturity is to cut the tomato in half. If the seeds are cut by the knife, the fruit is still immature. In practice fruit are picked by size and location on the plant.
breaker	The breaker stage occurs within 24 hours of the mature green stage and is easily distinguished because the blossom end is pink. 'Breakers' ripen naturally without gassing and are labeled in supermarkets as 'vine-ripe'.
pink	whole fruit is pink to light-red
red	fully red

(Peet, www36).



Market requirements usually dictate the ripening stage at harvest, although pest and disease pressure may also be a reason. See box below.

Tomatoes harvested at the mature green stage make up the bulk of the commercial fresh market tomato crop because they tolerate rough handling better than the riper stages and hold the longest in storage, transport, and on the store or supermarket shelf. For home consumption, fruits can be left on the plant until fully ripe.

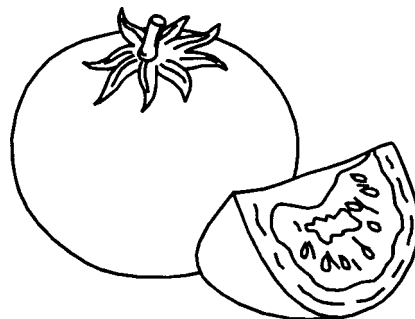
Example harvesting time

In Southern Philippines (Mindanao), fruits are harvested at 75-85 days after transplanting or at mature green stage in order to shorten the “field life” of fruits to minimize the period of exposure to pests (Sivanaser et al, (p.88) 1991).

Tomato is harvested at different pickings. The interval between the pickings depends on the weather. During warm weather, tomatoes can usually be picked at 2-3 day intervals and at weekly intervals when the weather is cool. Pick tomatoes from the plants by twisting them rather than pulling them to avoid damage. Fruits are generally removed from the upper portion of the plant. Vines and fruit should be completely dry when mature green fruit are harvested. Otherwise, fruit may develop sunken, blackened areas during ripening. Vine-ripes must be hand harvested thoroughly and as frequently as every other day.

A common recommendation for fresh market tomatoes is to harvest green matures when about 10 percent of the fruit on the first hand is at the breaker stage of maturity. Tomatoes to be canned or used in processing are harvested red-ripe (Peet, www36).

Green mature tomatoes still develop red color in time. This happens usually due to a gas called ethylene, which ripening fruits release naturally. Ethylene increases the ripening process in fruits (and cutflowers). In some western countries, tomatoes picked at the mature green stage are ripened artificially with ethylene gas in special rooms. See section on post-harvest below.



The taste of tomatoes...

In recent years, the flavor of tomatoes in western countries is frequently criticized by consumers. The problem is determining when the tomato reaches the mature green stage in the field. When immature greens are picked, the eating quality is reduced even though these tomatoes can be gassed to redness with ethylene. But the sugar and acid content, which determine the taste of the tomato, are low, resulting in a flavor-less fruit.

Mature green tomatoes develop flavor to the same extent as fruit left on the plant another 24 hours, until color appears, the ‘breaker’ stage (Peet, www36).

Long shelf-life varieties have been developed to avoid harvesting green tomatoes. These varieties are slow to soften once they reach the red-ripe stage. They take about twice the time to ripen, which may be a disadvantage in areas with high disease pressure. Long shelf-life tomatoes have developed a natural flavor on the plant and are still strong enough to be handled and transported to the end-consumers (ref. www34).



3.19 Post-harvest

In many Asian countries, tomatoes are packed after harvest and send to market.

In some (Western) countries, fresh market tomatoes are dropped into a water tank after harvest to clean the fruit. Improper tank procedures can also spread disease, however, thus increasing storage losses. Disease spread can be minimized by:

- Not allowing fruit to submerge deeply or to float more than one layer deep in the tank. Pressure from deeper submersion forces pathogen-containing water through the stem scar into the fruit.
- Removing fruit after two minutes.
- Slightly chlorinating the water.
- Warming tank temperature to a few degrees C above fruit temperature. Cool water constricts the fruit, pulling in pathogens.

There is a lot of research done on the best storing conditions for tomatoes. Unfortunately, all of these require conditioned storing rooms in which the temperature and humidity can be fixed.

In general, the length of storage depends on the harvest stage. Mature green fruits can be stored up to 30 days at cool temperatures, e.g. 10°C. Ripe fruits will keep for about a week.

More details for storing tomatoes in conditioned environments in the box below.



A story on storing tomato in conditioned rooms

Commercial crops of fresh market tomatoes picked at the mature green stage are ripened artificially with ethylene gas in special rooms. Relative humidity in the gassing rooms is 90 to 95% but the ripening temperatures used depend on how soon the fruit is needed. Mature green tomatoes should start to develop red color in 5 to 7 days at 18 – 20°C. The speed of the process can be changed by raising or lowering the temperature. Tomatoes will not ripen at temperatures above 29°C or below 10°C. Extended exposure of green tomatoes to temperatures of 5°C or lower causes rotting of fruit before they ripen. In a refrigerator of 5,5°C, enzymes necessary for ripening are deactivated and the tomato won't ripen even after it is taken out of the refrigerator. Thus, tomatoes should not be kept in the refrigerator unless they are already fully ripe. Fruit can be kept up to 57 days in controlled environment storage at 12°C, 5% CO₂ and 5% O₂ (Peet, www36).

Related exercises from CABI Bioscience/FAO manual:

2-C.10. Assessment of harvest time

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

3.20 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 has entered a field it is very difficult to get rid off. 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 fertility degradation 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 3.9.3.2) and adding legumes (supplying nitrogen) to the rotation schedule is therefore recommended.

Nutrient consumption is quite different for each crop. In general however, 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. 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	all types of beans, all types of pea, 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 black sclerotia produced by the fungus *Sclerotinia* can survive for years. *Pythium* and *Phytophthora* can also produce long-lived resting spores. Such spores help these fungi to 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:

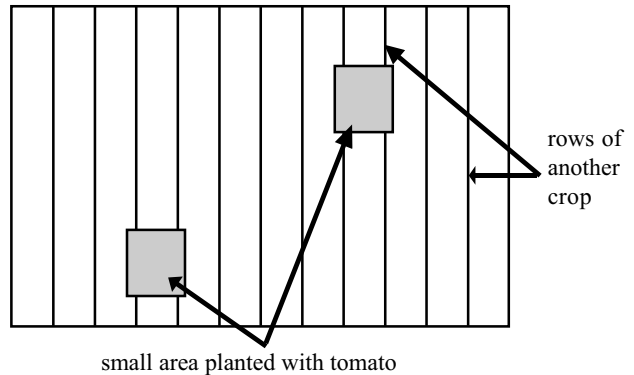
Disease	Can stay alive in soil without solanaceous plant for ..
Early blight (<i>Alternaria solani</i>)	at least 1 year
TMV (mosaic virus)	2 years
Sclerotinia stem rot (<i>Sclerotinia sclerotiorum</i>)	7 years
<i>Fusarium</i> & <i>Verticillium</i> wilt	several years (almost “indefinitely”)

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 tomato 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 tomato. 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 tomato or another solanaceous crop again. Check if there still are old tomato leaves in the neighborhood of your field or in the soil which can be the source of infection. These should be removed and destroyed. When no disease occurs you can try planting tomato again in the whole field next season.



It should be stressed that this test is not 100% 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 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, or by feeding inside the leaves. However, not all insect feeding reduces yield! Tomato plants 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.

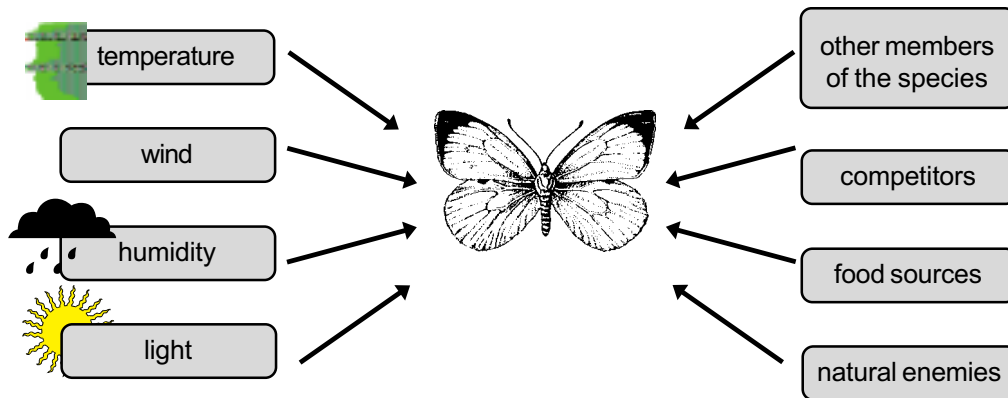
Natural enemies (predators, parasitoids, pathogens and nematodes) reduce pest insect populations. They can be indigenous or reared and released into the field. The latter is becoming more and more important for many vegetable insect pests. For tomato, good pest insect control can be achieved with pathogens such as NPV.

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 are a reason that 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 a tomato 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 possibly the environment and human health. ☺

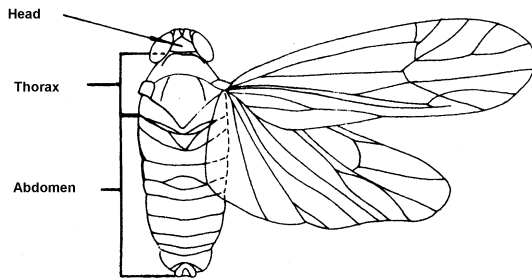
In many areas, the use of pesticides is still a common practice for insect and disease control. Most pesticide sprays are very toxic to natural enemies. The death of natural enemies means that insect pest species can increase in number very rapidly. Normally, natural enemies will remove a large number of the pest insects but 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 et al, 1993; and Weeden et al, www12).



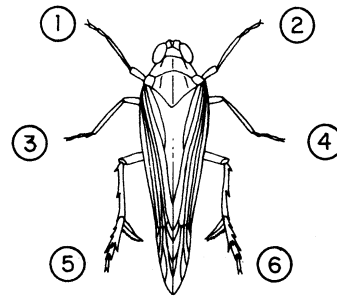
4.2 Insect anatomy

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

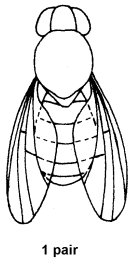
Insects have



Three body regions

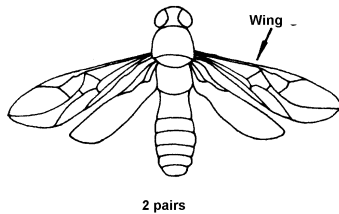


Six legs

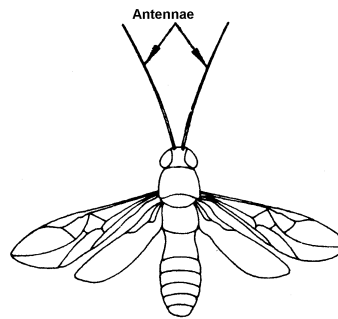


1 pair

One or two pair of wings



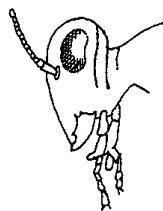
2 pairs



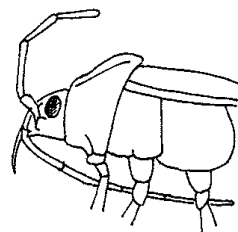
One pair of antennae

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.

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

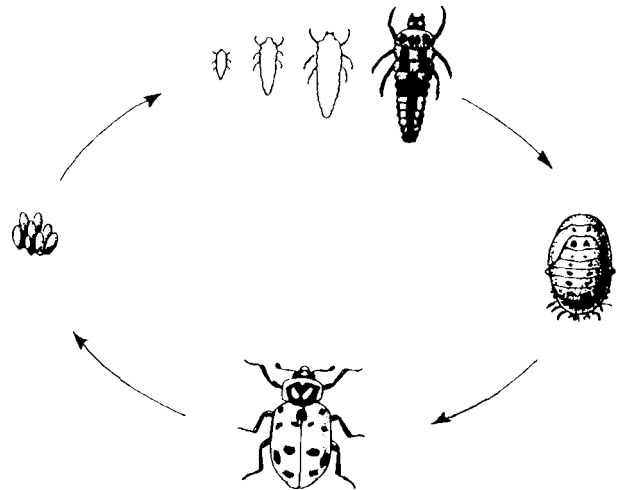


4.3 Insect Life Cycles

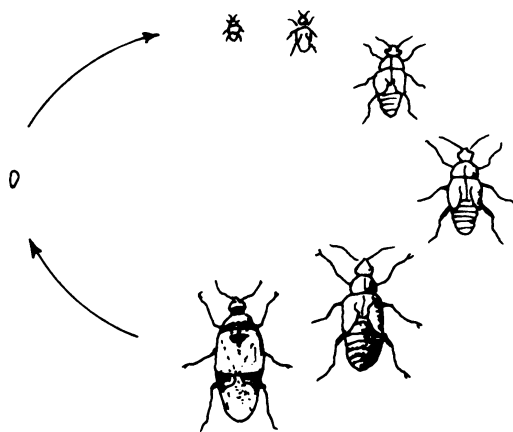
Insect life cycles can be complete or incomplete (gradual). In *complete* life cycles, or better: life cycles with a complete metamorphosis, insects pass through the egg, larval, pupal and adult stage. A larva is a young insect that looks very different from the adult. Larvae may also behave differently 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



Complete metamorphosis: lady beetle: egg, 4 larval stages, pupa, adult
(from: Hoffmann, 1993)



Incomplete metamorphosis : a flower bug : egg, 5 nymphal stages, adult
(from Hoffmann, 1993)

generally several nymphal stages. A nymph is a young insect that resembles the adult except that they lack wings and the nymph may be colored differently than 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 shed 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.

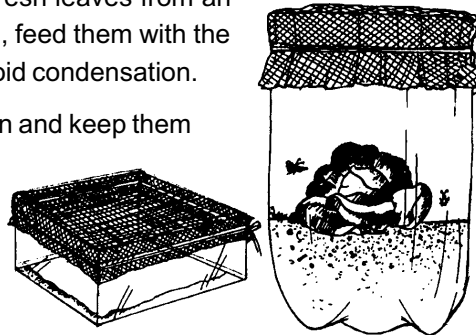


Insect Zoo: studying life cycles of insects

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 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.

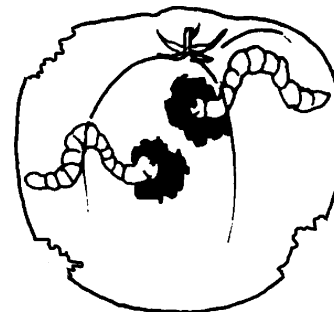
When insects are sucking on the leaves of the plant, like aphids do, they are sucking the sugars out of the plant cells or the veins. This leaves less sugar available for the plant for its growth and development.

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 diseases. These insects are usually sucking insects like aphids, jassids, thrips and whitefly. Whitefly, for example, is an important vector of leaf curl virus disease (see section 8.2.4). A virus infected plant has virus parts in most cells and sometimes inside veins. When an insect feeds on an infected plant, it will suck with the plant juice also some virus 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 virus 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. The tomato plant is able to compensate for feeding because more leaves and roots are produced than actually needed for fruit formation and new shoots are regularly formed (especially in indeterminate varieties). For example, defoliation studies in Vietnam showed that tomato yields were not significantly reduced when up to 50% of the leaves were cut off the plant, at 15, 30 and 50 days after transplanting, as compared to the undefoliated control (FAO - TOT report Vietnam, 1995).

Low levels of insect feeding and minor disease infections on leaves, stems and roots do not significantly reduce yields. However, even a small injury to fruits results in considerable loss of quality and inherent lower product prices. It is also 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 environmental pollution.

Related exercises from CABI Bioscience/FAO 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 a tomato field. Not all of them can be called "pests", in fact, very few insects have the potential to cause yield loss to tomato. 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 tomato. In fact, their presence keeps the population of natural enemies alive so one could almost say at that time they are "beneficial"....!

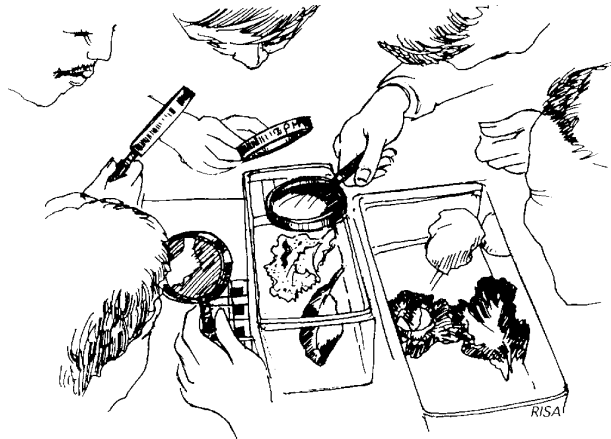
The goal of growing tomato is to produce as much yield as possible without spending a lot of money. If there are no pests to control, do not waste money on pesticides that can damage the natural enemy population, the environment and your personal health!

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.



✓ **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.

If 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 tomato 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 tomato fruitworm 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, fruitworms attacking fruits cause direct quality loss of fruits.

Related exercises from CABI Bioscience/FAO 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

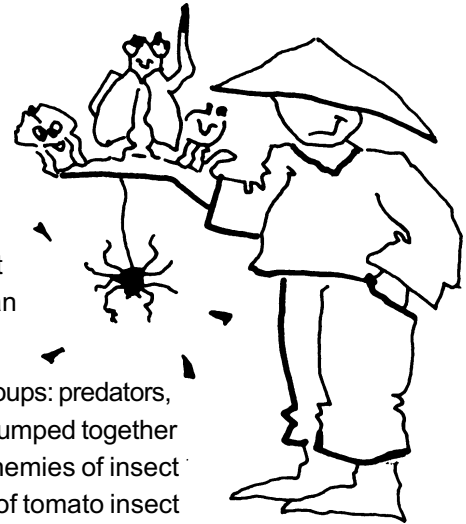


4.7 The Friends of the Farmer

Natural enemies are the friends of the farmer because they help the farmer to control insect pests (herbivores) on tomato plants. Natural enemies are also called *beneficials*, or *biocontrol agents*, and in case of fungi, *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 natural enemies than 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 tomato 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, lady beetles, 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 cabbage 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 *entomopathogenic* nematodes, attack and kill insects.
- Entomopathogenic nematodes are usually only effective against pest in the soil, or in humid conditions.



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 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.

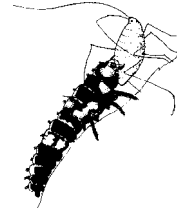
Efficiency of predators, in addition, is determined by their appetite. For example, ladybeetle adults may eat as much as 50 aphids per day. To check the appetite of predators, the following experiment is easy to do.

The Predator Appetite Test...!

Catch a predator, e.g. a ladybeetle or a syrphid 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 or ladybeetle. 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 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 like 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. Tomato plants can compensate for quite some injury and not all insect feeding results in yield loss. Monitor the field regularly!
2. Be extremely careful with 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.

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 lady beetles 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.

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.
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 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, lady beetles, 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 this country regarding registration (Regulatory Affairs).

Numerous examples from Asia exist on the use of reared natural enemies for release in the field. In tomato, this is mainly restricted to the production of NPV (Ha NPV), a virus killing tomato fruitworm (*Heliothis armigera*). NPV viruses can be multiplied on-farm but can also be bought from companies or governmental institutes. See section 6.3.3 on NPV.

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 tomato 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 www25 and www29 (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 often used 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 tomato plants, 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 crops like tomato or hot pepper, net houses on nurseries can provide good initial control against aphids or whiteflies, which may carry virus diseases.

Net houses may also be higher: about 2 - 3 meter. These can be used for both nurseries and production fields. For good insect prevention, they need to be closed properly!



Net house: plants in, pests out!

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.

Unfortunately, some of the studies were not successful because the nets were stolen from the field...! (pers. comm. Prabhat Kumar, 1999, Bangladesh).

Although initial investment for preparing the net houses is high, savings from reduced sprayings can make it interesting. 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 some more disease problems.

Related exercises from CABI Bioscience/FAO 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 the 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

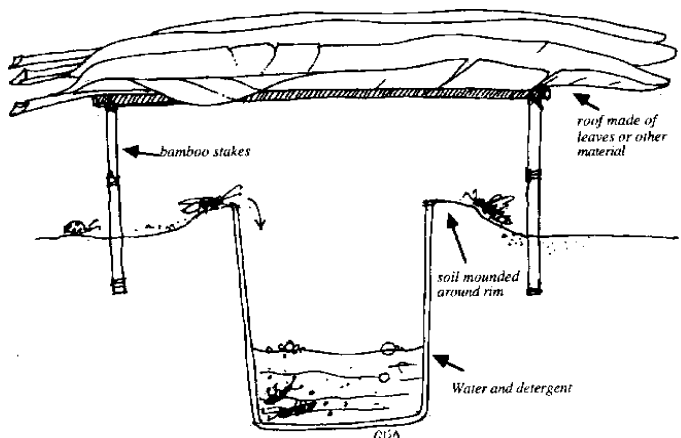
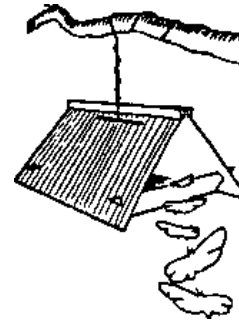


crop cannot be used to predict the number that will occur in other crops, not even when the crop are in adjacent fields.

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'.

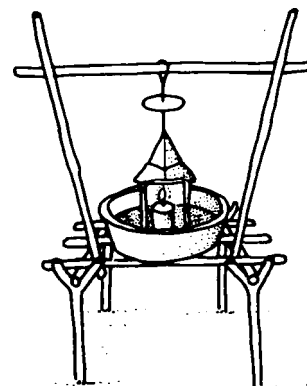
The males will fly to the pheromone trap and are trapped on the sticky plate. Pheromones have been developed for several vegetable pests including armyworms (*Spodoptera* sp.). Pheromones are mainly used for detecting and monitoring pests, to a lesser extent for control of pest populations. One of the reasons is the high cost of pheromones.



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.

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.

Related exercises from CABI Bioscience/FAO 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:

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

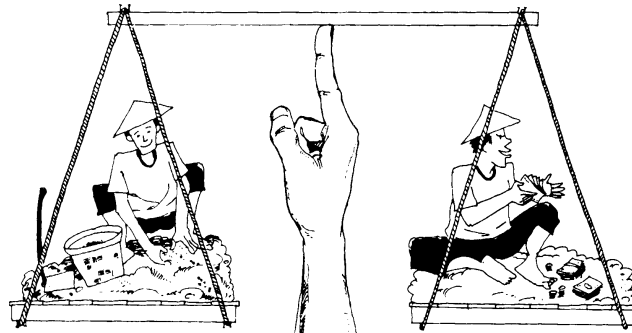
The formula basically says that economic damage (=financial loss) begins at the point where costs of damage (yield loss due to insect/disease damage) are equal to the cost of control (costs of pesticides for example).

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!

However, in practice, most economic threshold levels are based on fixed infestation or damage levels. They do not consider the ability of the crop to compensate for (a large part of the) damage from neither insects nor the natural enemy population that may control the pest insect to an acceptable level. Many other factors like weather conditions, personal health, etc. that are part of IPM agro-ecosystem analysis (AESAs) are not considered in ETL values.

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)

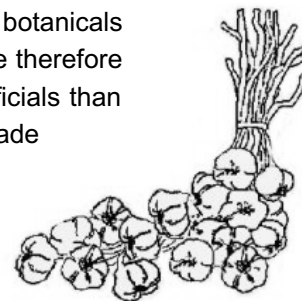
AESA

- 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
- water availability (irrigation, drainage)
- type and amount of weeds
- 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 to mammals (with the exception of nicotine) than non-botanicals.



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.

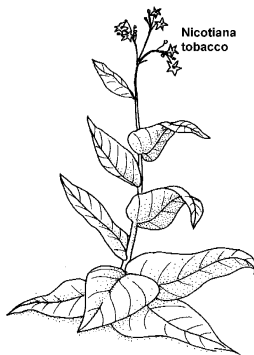
However, in addition to pest insects, some natural enemies may be killed by botanicals!

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.

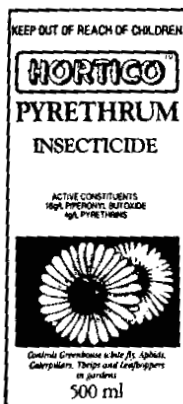
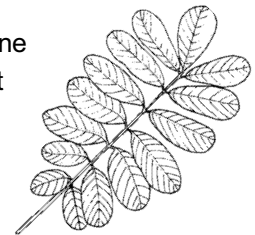
High concentrations can cause burning of plant leaves! Also, natural enemies can be affected by neem applications (Loke et al, 1992).



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 man! 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, and 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.

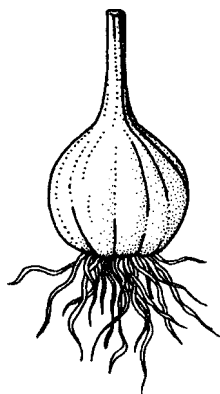


Marigold is often grown in gardens for its attractive flowers. They are cultivated commercially for use as cut flowers. In addition, marigold can have a repellent effect on insects and nematodes.

In Kenya for example, dried marigold when incorporated into the nursery soil was found an effective treatment in terms of overall seedling health. Other experiments showed that fresh marigold tea repels Diamondback moth larvae in cabbage, but for a few hours only (Loevinsohn et al, 1998).

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 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 et al, 1998). This probably applies for a period with low rainfall, as the solution will be easily washed off with rain.



Garlic has been long known for its insecticidal activity. Garlic contains garlic oil and allicine, 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 may 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 3.7.3. 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 3.17.



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!

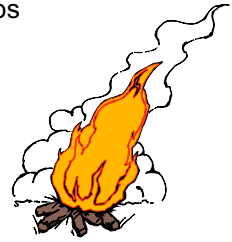


4.11.5 Use of mineral based pesticides

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 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 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 insects 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 tomato 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.



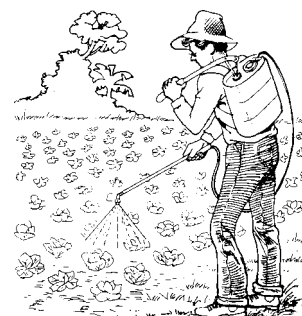
The Rationale of Biorationals....

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

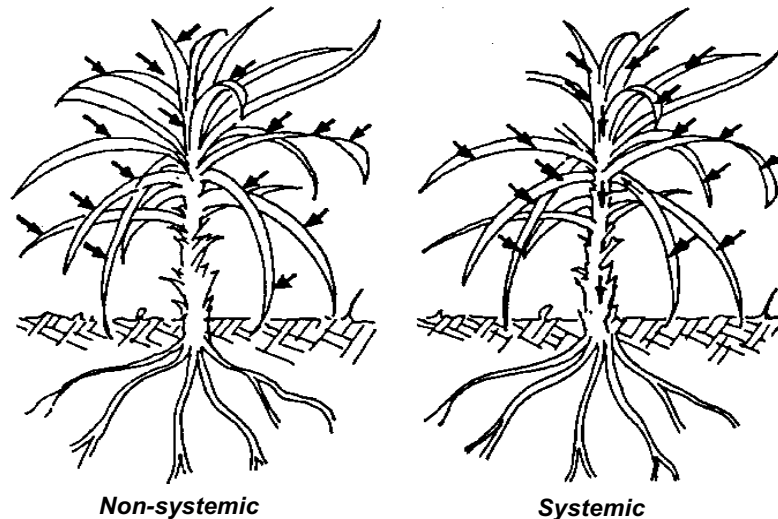
Insecticides are classified in several ways, and it is important to be familiar with these classifications so that the choice of an insecticide is based on more than simply how well it controls the pest.

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.

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.



Table 4.11.9 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)	Methamidophos (Monitor, Tamaron)	Fenitrothion (Ofatox)	Trichlorfon (Dipterex)	Kasugamycin (Kasai)
Mevinphos (Mevinphose)	Edifenphos (Hinosan)	Dimethoate (Bi58)	Dicofol (Kelthane)	Zineb
Alachlor (Lasso)	Dichlorvos (DDVP)	Cypermethrin (Sherpa, Vifenva, Cyrin)		Validamycin A (Validacin)
	Monocrotophos (Azodrim)	Fenvalerate (Sumicidin)		Diafenthiuron (Pegasus)
	Metomil (Lannate)	Deltamethrin (558)		Atrazin (Gesaprim, others)
		Fenobucarb (Bassa)		Benomyl (Benlate)
		Cartap (Padan)		Maneb
		Fipronil (Regent)		
		2,4-D		
		Endosulfan (Thiodan, a.o.)		
		Fluvalinate (Maverik)		
		Paraquat (Gramoxone)		

(Murphy, 1998, 1999 – unpublished)

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 et al, 2000). Up to 20% of all spray operations were associated to witnessed pesticide poisoning among wet shallot farming in Java (Kishi et al, 1995). During a single spray session among Sumatran women (of whom 75% were using a extreme, high or moderately hazardous to human health pesticide), 60% had an observable neurotoxic sign of pesticide poisoning (Murphy, in press). In an IPM farmer conducted survey 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 IPM 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).

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 quick. 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. 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. www41). 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.

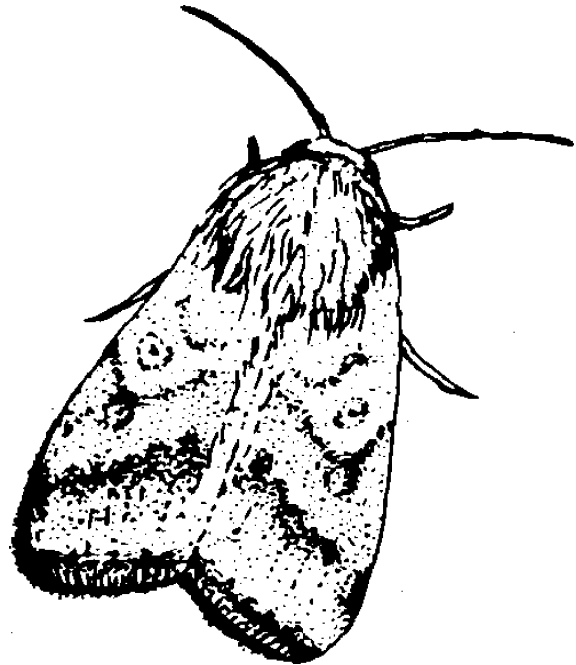
Related exercises from CABI Bioscience/FAO manual:

- 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



5

MAJOR TOMATO INSECT PESTS



SUMMARY

Two major insect pests of tomato in Asia are tomato fruitworm (*Heliothis armigera*) and leafminer (*Liriomyza* sp.). Other pests such as whitefly (transmitting leaf curl virus) and armyworms can locally be important. Strains of the biocontrol agent NPV can provide good control of for example fruitworm and armyworms. Care should be taken with multiplying of NPV on-farm for reasons explained in section 6.3.3. Several cultural practices such as weed removal, removing infested plant material, use of trap crops, and hand-removal of egg-masses and larvae can provide additional insect control. For most tomato insect pests, insecticide use is not effective nor economical and may in some cases (e.g. 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 Tomato fruitworm - *Heliothis armigera*

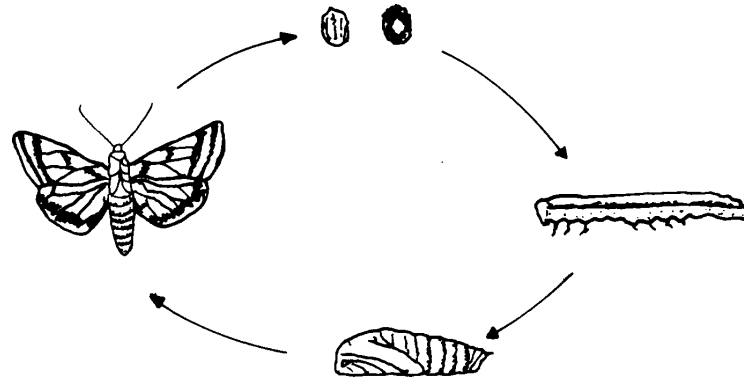
Also called *Helicoverpa armigera*.

English names: corn earworm, cotton bollworm or American bollworm.

The tomato fruitworm has a very broad host plant range including many vegetables, cotton, maize, tobacco, sorghum and a variety of ornamental plants. This pest insect has become highly resistant to chemical pesticides and is therefore causing great damage to cotton, legumes and vegetables.

Description and life cycle

The adult fruitworm is a brown moth with a wingspan of about 30 - 40 mm. The wings are marked with dark-gray, irregular lines. The eyes are light-green in color. Moths are active at dusk and during the night. They are strong fliers and can travel great distances. Each female moth may lay 1000 eggs or more. Female moths are attracted to tomato plants in the flower and fruiting stages.. Once flowering of the tomato plants is complete, female moths will no longer lay eggs.



Life cycle of Heliothis armigera

The eggs are laid singly, usually on the upper surface of the young leaves and near fruits. Eggs are about 0.5 mm in diameter, white to yellow at first, later turning brown in color. Eggs hatch in 2-7 days, depending on temperature. Upon hatching, larvae feed on the young leaves but after about one day they bore into a suitable fruit where they continue their development. They prefer green fruits and usually enter the fruit from the stem end.

The caterpillars vary greatly in color, ranging from light green to pink or dark brown. The color is a result of what the larva eats. The body has long dark and pale bands. Fully grown larvae are 40 mm long. There are five to six larval instars and the total larval period takes 14 - 26 days. Larval development is quicker when the temperature is higher.

Pupation takes place in the soil at about 5 - 10 cm depth. The pupa is shiny brown and about 16 mm long. The pupal development takes 10 - 14 days in the tropics.



Plant damage and plant compensation

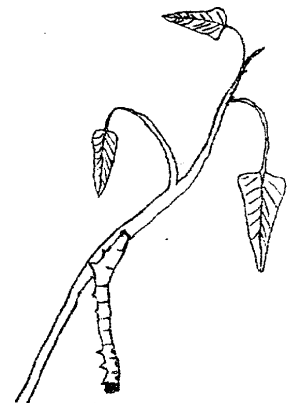
Leaves are damaged by feeding larvae and flower-trusses can be cut off. The most serious damage of the tomato fruitworm is that caused by penetration of the fruits by caterpillars. This may destroy many fruits. Damage to fruit usually appears as deep, watery cavities, contaminated with feces. When fruits are attacked at a very young stage, they usually drop. Older fruits may remain on the plant but in many cases, they develop a soft-rot as a secondary infection. Losses resulting from attacks of the tomato fruitworm can amount to 90% of the fruits.

Minor leaf damage can usually be compensated by the plant but damaged fruits are lost.

Natural enemies

- **NPV**

Heliothis armigera NPV, or Ha NPV, a virus specific to *Heliothis armigera*, has been reported successful in control of *Heliothis*. It is mass produced in several countries, e.g. India, Philippines (though not yet commercially available) and Indonesia. Biological Control Research Centers (part of National Institute of Plant Protection) in Indonesia have developed a method for production and application of NPV by farmers. In Philippines, participants of Farmers' Field Schools learn how to use and produce their own NPVs. Due to problems with mass-rearing the host insects, Thailand now imports the NPV for *Spodoptera exigua* and *Heliothis armigera* from USA (FAO Dalat report, 1998). See section 6.3.3 on NPV, for production and quality matters.



caterpillar wilt

- **other pathogens**

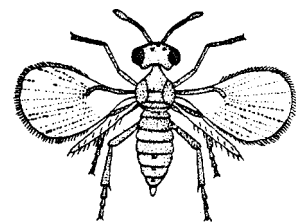
Next to NPV, the tomato fruitworm can also be attacked by other pathogens such as fungi. This may be important in periods of high humidity.



fungi

- **parasitoids**

The egg-parasitoid *Trichogramma* parasitizes tomato fruitworm (and several other insects). When field releases are properly timed *Trichogramma* can greatly reduce *Heliothis*. Regular field monitoring is therefore essential for the success of *Trichogramma*. In field trials in the Philippines, several species of *Trichogramma* were evaluated for fruit and shoot borer of eggplant. *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).

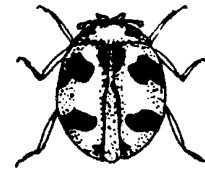


Trichogramma



• **predators**

Predators are probably the most important natural enemies of *Heliothis*, feeding on the eggs and young larvae. Common predators include the bug *Orius* sp., the coccinellid beetle *Coleomegilla* sp., the lacewing *Chrysopa* sp., and several species of syrphid fly larvae. *Chaetocnema* sp., a predatory pentatomid bug, was mass-produced in the Philippines under laboratory conditions for use in the control of several lepidopterous pest species, including tomato fruitworm. However, production of this predator has stopped due to administrative problems (FAO - Dalat report, (V.Justo), 1998).



coccinellid beetle

Management and control practices

Prevention activities:

- Careful monitoring of plants and fruits is needed to detect early infestation of the fruitworm and to reduce yield loss.

Once the tomato fruitworm is present in the field:

- Handpicking of egg masses and larvae at the early stages of the crop is found to be effectively reducing damage. This may be applicable on small scale production only.
- Removing and destroying shoots and fruits attacked by caterpillars may help reducing infestations of fruitworms in tomato.
- The use of nuclear polyhedrosis viruses (NPV) against *Heliothis* is becoming increasingly popular in Asia. Repeated applications at short intervals are necessary for adequate control.
- Biological insecticides containing *Bacillus thuringiensis* (Bt) can be effective.
- Where the possibility exists, trials could be conducted with the release of the egg-parasitoid *Trichogramma*.
- It is probably not effective to spray insecticides against fruitworm. Because many pesticides, particularly pyrethroids, have been widely used to manage *Heliothis* sp. on many crops, the insect has developed resistance to pyrethroids and other insecticides!

When applying an insecticide is still thought necessary the following should be noted.

- Many insecticides reduce the population of natural enemies in the field!
- Timing of insecticide application is critical for the success: insecticides must be present on the tomato plants when the eggs hatch so that newly hatched larvae will be killed. Eggs are not susceptible to most insecticides.
- Applying an insecticide after the caterpillars are inside the fruits is of no value because the damage is already done and control is poor.
- Once flowering of the tomato plants is complete, no treatment is necessary because female moths will no longer lay eggs at this growth stage.



Points to remember about tomato fruitworm:

1. Tomato fruitworm is a serious pest, especially during flowering and fruiting stage. During vegetative stage, plants can probably compensate for injury. Once flowering is complete, moths will no longer lay eggs.
2. Good control can be obtained with use of HaNPV .
3. Most insecticides do not give sufficient control because fruitworm is highly resistant against many insecticides.



Related exercises from CABI Bioscience/FAO manual:

- 4-B.1. Measuring mortality of eggs of boll worm
- 4-B.2. Mixed cropping of tomato with beans
- 4-A.3. Plant compensation study
- 4-A.9. Hand picking of eggs and caterpillars

5.2 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 English names: tobacco whitefly, cotton whitefly or sweet potato whitefly.

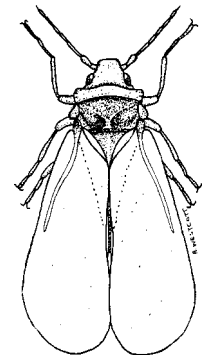
Whitefly species currently are known to attack over 500 species of plants representing 74 plant families.

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.

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.

When a plant containing whiteflies is shaken, a cloud of tiny flies flutter out but rapidly resettle. 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.



adult whitefly

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.

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.



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 harvest 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. In general, the older the plant when infected with virus or the later the onset of plant disorders, the less damage to the crop, so preventative action is critical.

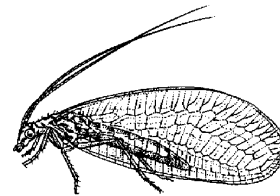
Natural enemies

Whiteflies are controlled by predatory insects such as green lacewing (*Chrysopa* sp.) or lady beetles (Coccinellidae); by parasitic wasps such as *Encarsia* or *Eretmocerus* species; and fungal diseases such as *Beauveria*, *Paecilomyces* or *Verticillium* species.

There may be many more natural enemies of whitefly 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 aphelinids *Eretmocerus serius*, *Eretmocerus* sp. and an unidentified aphelinid. Populations of predators included the coccinellids *Brumoides suturalis*, *Verania vincta*, *Menochilus sexmaculatus*, *Chrysoperla carnea*, and the phytoseiid *Amblyseius* sp. Fungal pathogens found included *Aspergillus* sp., *Paecilomyces* sp. and *Fusarium* sp. (Natarajan, 1990)



Chrysoperla carnea

Parasitic wasps usually are more effective at low pest population densities, whereas predators are more effective at high population densities. 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.

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.

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 greatly 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, other methods such as biological control can be more effective.

Prevention activities:

- Plant resistant tomato varieties where available. 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 control decision.
- 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 some areas 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 and often have to be removed at flowering for proper pollination to take place.
- 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, e.g. with sorghum or cucumber. See box below.

Effects of intercropping on tomato insect pests – some references:

- The incidence of pests and diseases was low in tomato intercropped with maize.
- Intercropping tomato with beans largely reduced the damage of tomatoes by fruitworm (*Heliothis armigera*), armyworm (*Spodoptera* sp.) and leafminer (*Liriomyza sativae*).
- Intercropping tomato with sorghum controlled whiteflies and had the best yields and effects on predators.
- Tomatoes grown with cucumber or Capsicum delayed the build-up of whitefly transmitted leaf curl virus (TYLCV)

(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 can reduce whitefly populations. 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).

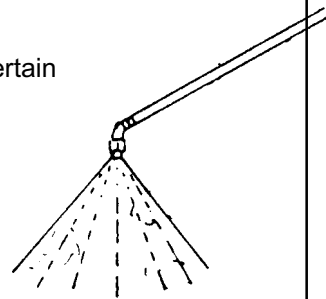
Once whiteflies are present in the field:

- 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.

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. www40).



Points to remember about whitefly:

1. Whitefly can be an important pest in tomato because it transmits leaf curl virus (TYLCV).
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.

Related exercises from CABI Bioscience/FAO 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



5.3 Cutworm - *Agrotis sp.*

The name 'cutworm' is given to caterpillars of various moth species that feed on plants at ground level, usually cutting young plants at soil level. Most cutworms belong to the genus *Agrotis*. Some larvae of *Spodoptera sp.* are also called cutworms although these caterpillars usually defoliate leaves.

The two main species of cutworms are:

- *Agrotis ipsilon* - black cutworm, greasy cutworm
- *Agrotis segetum* - common cutworm, turnip moth

Cutworms can attack many types of vegetables and other crops including rainfed rice. They attack both seedlings and mature crops.

In the field the species are often difficult to distinguish.

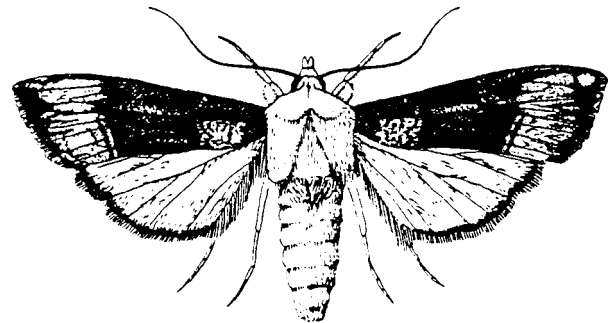


Description

Larvae are usually active during the night and spend the day hiding in the litter or in the soil. They can be found to a depth of up to 12 cm.

The caterpillars have three pairs of true legs just behind the head and five pairs of false legs in the middle and last part of the body. Cutworm caterpillars curl up when disturbed.

The larvae of the black cutworm (*Agrotis ipsilon*) are brown-black in color, with a pale gray band along the mid-line and dark stripes along the sides. The head is very dark with two white spots. The general appearance of the caterpillar is greasy and black in color. A mature caterpillar is 25-35 mm long. The larval development takes 28 - 34 days, depending on the temperature. The first two instars feed in groups on the leaves of plants, the third instar becomes solitary and becomes a real cutworm (sometimes even



(pictures from Stoll, '87)

has cannibalistic habits). The pupa of the black cutworm is dark red-brown and about 20 mm long. Pupation takes 10 - 30 days depending on temperature. Adults are large, dark moths with a wingspan of 40 - 50 mm, with a gray body. Forewings are pale brown in color with a dark brown-black pattern of markings. The hindwings are almost white but with a dark terminal line.

In warm conditions, there can be 5 generations or more, depending on the temperature. Life cycle from egg to adult takes 32 days at 30°C, 41 days at 26°C and 67 days at 20°C.

The caterpillar of the common cutworm (*Agrotis segetum*) is gray-brown and about 30 - 40 mm long when mature. It has faint dark lines along the sides of the body. The larval body is plump and rather greasy in appearance. The pupa is smooth shiny brown to red-brown with two spines at the rear, about 15 - 20 mm long. Pupation takes place in the soil.

Adult moths are usually smaller than the adults of the black cutworm. They measure 30 - 40 mm across the wings, the forewing is gray-brown in color with a dark brown kidney-shaped marking. The hindwings are almost white in the male but darker in the female. The body and head of the adult are brown in color.



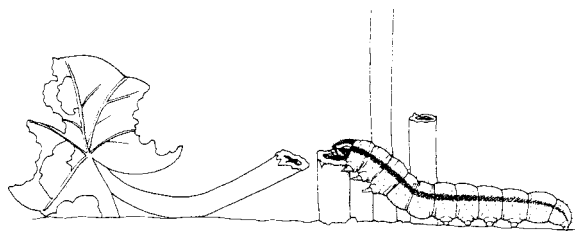
Life cycle

Adult moths fly at night and can cover large distances. Female moths lay many eggs (up to 1200). The eggs are laid singly or in small groups around the base of host plants or on leaves or stems, and on weeds or plant left-overs in the field. Eggs are ribbed, about 0.5 mm in diameter and pale yellow in color at first, later turning cream-colored to brown. The eggs of *Agrotis ipsilon* have reddish-yellow markings. The eggs hatch in 3 to 25 days, depending on the temperature. At 25°C for example, the eggs hatch in 3-4 days. The first instar larvae feed on the leaves of the host plants and when larger, they go down to the soil and adopt typical cutworm feeding habits. There are usually five to six larval instars. Fully grown larvae pupate as deep as 12 cm in the soil. Pupation lasts 10 to 30 days, depending on the temperature.

Cutworms can survive only where the soil is dry. Temperatures above 35°C will kill the insects.

Plant damage

Damage to seedlings and young plants can be very serious. During the day, cutworms hide in the surface layers of the soil, under leaves or stones. At night, the larvae come to the soil surface and feed on plant stems at ground level. The stem may be completely hollowed out just below soil level or cut through at soil level. Typical damage is for the cutworm to move along the row of seedlings cutting each one through the stem at ground level. Cutworm damage is most severe in light, sandy soils where the larvae can burrow easily.



Natural enemies

There are some parasitoids and predators of cutworms recorded, including the fly *Peleteria nigricornis*, the nematode *Hexameris arvalis* and a granulosis virus. The nematode *Steinernema bibionis* is being used on a commercial scale in some (Western) countries like the Netherlands for the biological control of cutworms. The nematode *Steinernema riobravis* may have potential for cutworm control in the tropics.

Management and control practices

Generally, cutworms are very difficult to control because by the time infestation becomes apparent, damage may already be quite serious.

Prevention activities:

- Weed removal: weedy land harbors most cutworms as the adult moths prefer these sites for egg laying. Weeds also serve as food for the first instar larvae. Crops immediately following dense weed cover are therefore more likely to be seriously damaged by cutworms than crops planted in weed-free soil.
- Flooding of the infested field to drown larvae and other soil-inhabiting pests may be an option when irrigation facilities exist. This is an option when the field is known to contain many cutworms and should be applied before preparing the land for a new crop.
- Ploughing the field will bring larvae and pupae to the soil surface for exposure to sunlight or predators like birds.



Once cutworms are present in the field:

- Hand collection of larvae may be possible for small plots. It may not be practical for tomato production on larger scale. The cutworms can be found in the soil near plants attacked. Cutworms may also be trapped under small pieces of wood or pieces of rigid cardboard, placed in the field. When searching for shelter during the day, the cutworms may hide under these things and can be collected more easily.
- Irrigation during dry periods may help to control cutworms because high humidity reduces larval survival.
- Chemical control is usually not effective: the soil-dwelling stages of the cutworms, often under dense and continuous crop foliage make them difficult to “hit” with insecticides. For this reason, sprays are very often not effective against cutworms. Most sprays are targeted against the first instars that feed on the plant leaves, timing is very difficult and often again, the sprays are not effective.
- Cutworms can sometimes be controlled with baits containing an insecticide mixed with moistened bran or vegetable pulp and spread over infested areas or placed under covers to retain moisture. Chopped vegetable leaves mixed with an insecticide can be spread between the tomato rows as bait. Check with local extensionists if there is any experience with using baits for cutworm control and, if so, when and how they should be applied. Set up a small trial in your field to test if the baits are effective.
- Control is rarely needed after tomato plants reach about 30 cm tall.
- Where available, biocontrol agents such as entomopathogenic nematodes may be an option.



Points to remember about cutworms:

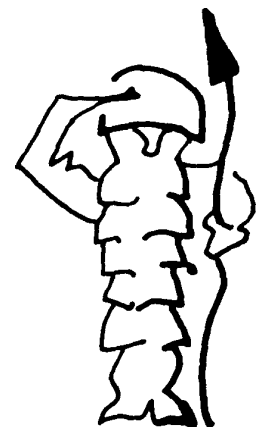
1. Cutworms can be a problem in nurseries, but usually not in the main field.
2. No effective biocontrol agents are available to date although the option of cutworm management with entopathogenic nematodes needs further study
3. Weeding might prevent cutworm infestation.
4. Use of baits can be an effective cutworm control measure.

Related exercises from CABI Bioscience/FAO manual

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

5.4 Armyworm - *Spodoptera* sp.

The name ‘armyworm’ is the common name for a stage in the life cycle of certain moths. Most of them belong to the genus *Spodoptera* but there are other caterpillars that may be classified as armyworms. “Armyworm” is more a behavioral term: when the supply of food for armyworms is running out, they may “march off” over the ground like an army to find new feeding locations. With very large populations, the ground may be completely covered with “marching bands” of caterpillars.





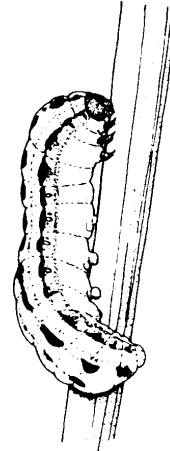
This behavior however, depends on the circumstances. For example, *Spodoptera litura/littoralis* in small numbers feed on the leaves of plants but will sometimes act as a cutworm (in rice) and at other times will swarm in groups and act as a typical armyworm.

Armyworms attack many crops including cotton, tomato, rice, tobacco, maize, legumes and many other crops.

The main species of armyworms of importance for vegetables are:

- *Spodoptera exigua* - lesser armyworm, beet armyworm
- *Spodoptera littoralis* - common cutworm
- *Spodoptera litura* (= *Prodenia litura*) - fall armyworm, cluster caterpillar, rice cutworm, cotton leafworm

Spodoptera littoralis and *Spodoptera litura* have only recently been separated as different species by the genitalia of the adult moths. One needs a very good lens to be able to see the difference. The caterpillars of the two are not really separable as caterpillars of all armyworms can have different colors from green to black, and change this colour according to host plant tissue eaten. However, it is important to be able to separate them into the right species. This is because effective NPV has been developed as biocontrol agent. NPV is very specific to the species and applying the “wrong” NPV will not give effective control.



Description and life cycle

Adults of armyworms are gray to gray-brown in appearance, with a wingspan of about 25 mm. The forewings are yellow-brown with white and black patterns. The hindwings are whitish. They do not usually fly far and lay their eggs close to the place of emergence. Eggs are laid in large masses on the undersides of host plant leaves. Each egg mass has a fuzzy appearance because it is covered in fine hairs and scales from the body of the female. About 500 - 2000 eggs per female are deposited in batches of 50 - 200 over a few days period. The eggs are ribbed, and range in color from green-gray when freshly laid, becoming very dark in color just before

hatching.

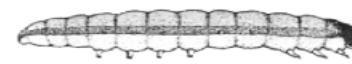
Egg hatch occurs 2 - 6 days after laying. Caterpillars of armyworms feed in groups together for a while but spread out when they become older. They usually feed at night.

Newly hatched caterpillars are light green in color and about 1 mm in length with relatively large heads. They undergo five or six moults and reach a length of 35 - 50 mm before burrowing into the soil for pupation. When fully grown, caterpillars vary in

color from light tan or green to almost black. Larvae of *S. exigua* are often green in color with a white line along the side; *S. littoralis* are often brown to black and can have more black spots/stripes on the body. They are also usually a bit larger than *S. exigua*. Larvae of *S. litura* and *S. littoralis* have a distinct black band on the first abdominal segment. The head is black. They feed together in groups. The pupa is dark red in color, 15 - 20 mm long. The pupal stage takes about 12 days.



Spodoptera exigua caterpillar



Spodoptera littoralis caterpillar

Plant damage

Armyworms skeletonize host plant leaves. Egg batches are laid close together and in a severe year clusters of many caterpillars may rapidly defoliate of plants. Usually however, damage is not severe.



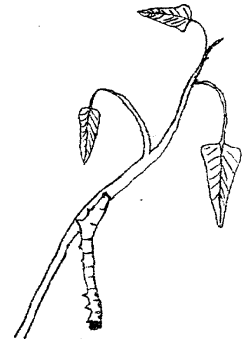
Natural enemies

Good results have been achieved with the use of nuclear polyhedrosis viruses (NPV) for the control of armyworms. These NPVs have become an important biocontrol agent in IPM systems. There are different strains of the NPV:

- SINPV for control of *Spodoptera litura*
 SeNPV for control of *Spodoptera exigua*

NPV is being tested at various locations in Asia, e.g. Vietnam, Philippines and Indonesia. See box below. Some countries are already using it on a large scale.

In Indonesia, the Biological Control Research Center (of the National Institute of Plant Protection, Indonesia) has developed a method of production and application of NPV, which can be done by farmers. Usually, starter cultures of NPV are supplied by institutes such as the National Institute of Plant Protection. See section 6.3.3 for NPV production guidelines and some quality matter.



caterpillar killed by NPV

Other natural enemies:

Preparations of *Bacillus thuringiensis* (Bt) have been found to be effective against armyworms.

In Lao PDR, the larval parasitoid *Microplitis* sp. was found parasitizing *Spodoptera* in cabbage and cauliflower (pers. comm. A. Westendorp, 2000).

Some NPV study data from Vietnam

A vegetable FFS-graduate farmer group in Ha Tay village, near Hanoi, started experiments with the use of NPV against *Heliothis* and *Spodoptera* on cabbage and tomato. The group did both potting experiments and field studies with NPV which was supplied by the National Institute of Plant Protection. Some of the conclusions that were drawn from their potting experiments:

- Larvae that die from NPV change color from green to yellow, they die slowly (several days), the skin breaks easily, then fluid comes out, and the caterpillar may hang down from the leaves.
- Small larvae are more susceptible than larger sized larvae. Mortality rates were 100% for small, 90% for medium and 85,5% for large sized larvae. The group concluded NPV should be applied to the field when larvae are still small.
- NPV did not have any effect on natural enemies in jar experiments.
- Larvae infected with NPV die within 3 to 4 days.
- NPV-infected larvae eat less (area of leaf) than healthy larvae.
- In jars, NPV was still viable after 2 days but this may not be the case in field where there is sunshine, rain, etc.

In a field study, the farmer group found that NPV gave 80% control of armyworm.

The farmers concluded that NPV is better than chemical pesticides because it gives equal or better control of the specific pests. In addition, it may spread through populations in the field. However, they also recognized that the effect of NPV is short (break-down by sunlight) so it needs to be applied more often. On-farm production of NPV has not been tried so far by this group (pers. comm. Ha Tay farmer group, April 2000).



Management and control practices

Prevention activities:

- Burning of crop stubble and removal of weeds help to lower the pest population. The armyworms may survive on crop stubbles and weeds after harvest and infest a newly transplanted crop, causing crop injury.
- Flooding of the infested field to drown pupae and other soil-inhabiting pests may be an option when irrigation facilities exist. This should be done before preparing the land for a new crop.
- Ploughing the field will bring larvae and pupae to the soil surface for exposure to sunlight or predators like birds.
- In some cases, armyworms may be more attracted to trap crops rather than tomatoes. Beans could be used. See box in section 5.2. It might be worth trying a few crops to see if the armyworm population is larger on the trap crop than on the tomato.

Once armyworms are present in the field:

- Hand collection of larvae and egg masses may be possible for small plots. It may not be practical for tomato production on larger scale.
- The biocontrol agent NPV is becoming increasingly available in many countries in Asia. The NPV is quite specific for a host insect and symptoms are easily recognized in the field. In addition, NPV are easily produced, applied and evaluated by farmers. See also section 6.3.3 on NPV. In Indonesia for example, application of SeNPV along with hand picking larvae provided the best control of *S. exigua* in shallot fields. The highest yields were obtained in the treatment where SeNPV was carried out with hand picking (Shepard, 2000). See box in section 6.3.3.
- Availability of biocontrol agents has made insecticides for control of armyworms redundant. Where NPV is not available, and pesticide applications are considered, balance benefits from pesticide application against harm done to natural enemy population. Spraying for armyworm may result in more trouble with for example leafminers because their natural enemies are killed!



Points to remember about armyworms:

1. Yield loss from armyworm damage in tomato is usually not severe.
2. Very effective biocontrol agent NPV is available in many countries.
3. Chemical control of armyworm is usually not necessary.

Related exercises from CABI Bioscience/FAO manual

4-A.3. Plant compensation study

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



5.5 Leafminer - *Liriomyza* sp.

See plate 1, Fig. 1 - 4

In recent years, leafminers have been reported to pose a problem in vegetable cultivation in a number of Asian countries. They have become particularly important in crops such as peas, beans, cucumber, tomato, potato, some crucifers and ornamentals. Damage caused can be quite dramatic with considerable yield loss.

The species of major concern at present is *Liriomyza huidobrensis*, which occurs in highland areas. Considerable damage is caused to a range of vegetable crops (e.g. potato, French bean, cucumber, celery, and spinach) with losses frequently exceeding 70%. However, a second species, *L. sativae* now has a wide range in lowland vegetable growing areas where it is causing problems. A third leafminer species, *L. trifolii*, is established in several countries, for example China, Taiwan, and Lao PDR, and is likely to spread to neighboring countries. *Liriomyza huidobrensis* is believed to be a recent introduction and seems to be spreading fast in the region (FAO - Workshop on leafminers of vegetables in Southeast Asia, 1999).

Another leafminer species common in tomato is *Liriomyza bryoniae*, the tomato leafminer.

All species of leafminers have a very broad host plant range, including many vegetables and ornamental plants.

Leafminer infestation of a crop occurs:

- naturally, as a non-induced seasonal pest.
- after pesticide sprays, because its natural enemies are destroyed,
- when adults build up on other crops or weeds and migrate to a particular plot.

(Minkenberg, 1990).

Description and life cycle

Adult leafminers are very small black flies. They may be observed on leaves, where the females puncture the leaves and feed on the sap. Eggs are inserted into the leaves. A single female can lay up to 250 eggs which hatch in about 3 days, depending on temperature.

The larva is a legless and headless maggot with darkly colored intestinal contents. Larvae of *L. trifolii* are bright yellow in color. Larvae of *L. bryoniae* are creamy white with a yellow front.

The larva feeds between the upper and lower surface of leaves, making the distinctive winding, whitish tunnels or *leafmines*. Inside the mine frass produced by the larva can be seen. It feeds for 1 to 3 weeks, depending on temperature. Larvae emerge from the leafmines and pupate on the leaf surface or, more commonly, in cracks in the soil. The pupa is shiny golden-brown in color.

The entire life cycle can be completed in less than 3 weeks when the weather is warm, giving many generations per year. In areas with a cold winter period, leafminers overwinter as pupae.

Adult flies are weak fliers and movements into fields is often from the direction of prevailing winds.

Plant damage and plant compensation

First symptoms are small white spots on the leaves where the flies feed and lay eggs. Later, white, curling miners occur in the leaves, caused by feeding larvae.

Leafminers directly damage tomatoes by stippling and mining the leaves. Heavily mined leaves will have a reduced energy production (photosynthesis) for the plant. Leaf wounding creates entry points

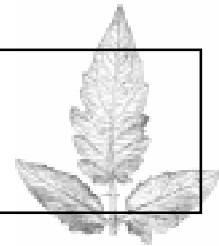


for infection by bacterial and fungal pathogens. Mining of leaves adjacent to fruit during its early stages of development has an effect on the yield. Plant stress, moisture loss or sun scald of fruit due to the absence of leaves may occur as secondary problems. In Indonesia and the Philippines for example, heavy leafminer infestation in potato fields resulted in low yields and very small sized potatoes.

Further, leafminer flies may transmit viruses (Minkenberg, 1990).

However, high levels of leafminer injury are needed to result in actual yield reduction. Tomato plants have many leaves to produce energy for crop growth and fruit production. Loss of part of the leaves will trigger the plant to compensate for that loss by producing new leaves.

☺ Defoliation studies in Vietnam (1995/1996) showed that tomato yields were not significantly reduced when up to 50% of the leaves were cut off the plant, at 15, 30 and 50 days after transplanting, as compared to the undefoliated control (FAO - TOT report cabbage and tomato, 1995)



Natural enemies

Numerous indigenous species of natural enemies have been found throughout Asia and parasitism levels on some crops can be very high. For example, *L. trifolii* and *L. bryoniae* have over 40 parasitoid species in the families Braconidae, Eulophidae and Pteromalidae. Invertebrate predators may also be important.

Parasitoids: Fairly diverse communities of native parasitoids were reported from most of the participating countries, but only a few species are dominant (e.g. *Hemiptarsenus varicornis*, *Neochrysocharis okazakii*, *Neochrysocharis formosa*, others). However, for the most part, the impact of these parasitoids is not known exactly.

- Indonesia: 8 parasitoids are present, of which *Hemiptarsenus varicornis* (Girault) (Hymenoptera: Eulophidae) is most common.
- Malaysia: 9 parasitoids are present. Parasitism level of various parasitoids on leafminers in sugarpea was 41% in field trials.
- Vietnam: 13 parasitoids, Parasitism rates in summer and winter crops varied from 4.5 – 40.9% and 39.9 – 54.7% respectively. Lower rates of parasitism in some places were associated with heavy use of insecticides.

The parasitoids *Dacnusa sibirica*, *Diglyphus isaea* and *Diglyphus begini* are commercially produced in some countries for field/greenhouse releases (Minkenberg, 1990).

Predators may also have a potential role in leafminer control. For example, numerous predatory flies of the genus *Coenosa* (Ephydriidae), which were reported to be natural enemies of leafminers elsewhere (e.g. Indonesia, Israel), were observed at an organic farm in Malaysia, and some were noted to be very active in catching other small flies on cabbage plants. See box below.

Spiders may also be predators of leafminer adults. There have also been reports of ants, mirid bugs and nematodes attacking the leafminers.



A visit to an organic farm in Cameron Highlands, Malaysia

An organic farmer in Cameron Highlands was producing a range of vegetables (many under plastic cover, including crucifers) organically to meet the requirements of an 'organic'

market. During a field visit, the visiting group saw that virtually every cabbage plant was protected by one or more predatory flies (usually one, as if each plant was its territory) of the species *Coenosia exigua* Stein (Diptera: Muscidae) and these predators caught any smaller fly (over half the predators actually had a smaller fly in their mouths). The group suspected that the larvae of these predators had abundant food supply in the rich organic matter in the soil as food. And that this organic matter fueled an abundance of other dipteran (fly) species which was the main diet of the adult stage.

A phenomenal number of spiders were also observed. In contrast, no leafminers were visible on the cabbage. The findings indicate that conservation of indigenous natural enemies may suffice, in some areas and for some crops, for keeping leafminers under control.

The farmer told the group that if he used pesticides, he ended up with a leafminer problem...

(pers. comm. Dr. M.Whitten, 1999; and FAO - Progress report – Feb 1999, p.57)

In West Sumatra, IPM farmers are able to manipulate native parasitoids to levels above 70%. A method of augmentation and release of parasitoids (mainly *Hemiptarsenus* sp. and Braconids) to control leafminer was developed by the IPM group of West Sumatra (Zamzami, 1999. In: FAO – Workshop on Leafminers, 1999).

However, field studies over 2 seasons in potato in Indonesia, revealed that the potency of local natural enemies was not strong enough to control *Liriomyza* sp. The Indonesian group decided to import 5 species of *Liriomyza* parasitoids from Hawaii. See box below for study details.

Study on indigenous natural enemy effectiveness against leafminers in Indonesia:

Studies were conducted on indigenous parasitoids for leafminers on potato in Pangalengan, Indonesia (rainy season 2000 and one season before) by farmers and researchers (Bogor Agricultural University) comparing a Trial Field (without insecticide – use of fungicides only) with Farmer Field (using both insecticides and fungicides). Objective was to get data on the population of *Liriomyza* sp. and its local natural enemies in the field in Pangalengan, and to increase the population and the role of local natural enemies by manipulating the ecosystem and planting time.

The studies showed that population of the leafminer *Liriomyza huidobrensis* at the end of the season was still very high (up to 99%). Parasitism rate by the parasitoid *Hemiptarsenus varicornis* in potato was very low: 6.27 % in the Trial Field, and 3.44% in the Farmer Field.

Parasitism rate in a red bean crop was high (in Trial Field up to 80.85% and in Farmer Field up to 50.85%) and was increasing, but the parasitoid seemed to prefer red bean to potato (although the red bean was multiple cropped with potato).

The predatory fly (probably *Coenosia* sp.) was monitored by using yellow sticky trap. Fly populations increased over time, especially in the Trial Field, which used more compost to support the population of the predatory fly. But, despite the increase in predatory fly population, the leafminer infestation was still too high to be controlled by the predatory fly.

The conclusion was that the potency of local natural enemies is not strong enough to control *Liriomyza*



sp. They have decided to import 5 species of *Liriomyza* parasitoids from Hawaii :

1. *Diglyphus begini* (larvae ectoparasitoid)
2. *Diglyphus intermedius* (larvae ectoparasitoid)
3. *Chrysocaris oscinidus* (larvae-pupa endoparasitoid)
4. *Ganaspidium utilis* (larvae-pupa endoparasitoid)
5. *Halticoptera circulus* (larvae-pupa endoparasitoid)

Several rearing and screening laboratory experiments are being planned, as well as field studies focussing on:

- Inventory of weeds that have potency as “reservoir” for parasitoids.
- Developing simple method for parasitoids rearing in the field.
- Train other farmers on *Liriomyza* and it’s natural enemies.
- Developing simple method for rearing of predatory fly as an alternative or supporting control agents of *Liriomyza* sp.

(FAO – Cahyana, 2000. “Study on *Liriomyza huidobrensis* in Pangalengan second season”)

Management and control practices

Prevention activities:

- There are varieties of tomato that have a certain degree of resistance to leafminers. The mechanism of resistance is non-preference: the curled leaves of resistant varieties seem to be unacceptable to females which feed and lay eggs on flat leaves.
- Destruction of alternative host plants, particularly broad-leaved weeds, near tomato fields at least one month prior to transplanting tomato seedlings, may delay leafminer appearance.
- Liriomyzid leafminers attack a wide variety of vegetable crops. Where possible, avoid planting next to infested fields, especially those near harvest.
- Leafminers and the impact of indigenous natural enemies should be further assessed. If indigenous natural enemies can keep leafminer damage to an acceptable level, there may be no need for importation of exotic natural enemies from elsewhere.
- The field laboratory in West Sumatra has developed a system for augmentative releases of parasitoids of *Liriomyza* leafminers by introducing leaf material from areas where the parasitoids are more abundant. See section above.
- The use of trap crops has been tried, for example in Indonesia. Population of leafminer in potato was reduced by 60 – 70% by using climbing red bean as a trap crop. Red bean was planted at the same time as potato. The leaves attacked by leafminer were removed and destroyed (by deep burying or burning) to reduce population (FAO - Progress report, Feb 1999, Mr. Aliyudin, TP4, Pangalengan, Indonesia).

Once leafminers are present in the field:

- High levels of damage are needed to result in yield reduction of tomato. Monitor fields closely and especially check for parasitism of the leafminer larvae. As mentioned above, many parasitoids can be present in the field to keep the leafminer population low and plants will compensate for leaf injury by producing new leaves.
- On small scale plantings, removing and destroying leaves containing leafminer larvae may keep populations at a manageable level.



- In order to control leafminers, farmers have been using a wide range of chemical insecticides, even though they are not effective (leafminers have developed resistance against many of the major classes of insecticides) nor economical. In addition, pesticides may destroy natural enemies, leaving the field vulnerable to infestation by leafminers, which are not controlled by these pesticides. ☹
- Other non-chemical practices for leafminer control done by farmers include yellow sticky traps (their usefulness appears to be situation-specific), intensive sweeping of the crop (using cloth sheets coated with sticky materials, sweeping twice a day –farmer experience, not substantiated by field tests), spraying celery with lime (apparently very effective in Indonesia), pruning the lower portion of the tomato canopy, treating the crop with plant extracts, left-overs removal, crop rotation and using netting as barriers. However, these methods need to be evaluated and confirmed.

(FAO – Workshop on leafminers, 1999; Murphy & LaSalle, 1999).



Points to remember about leafminers:

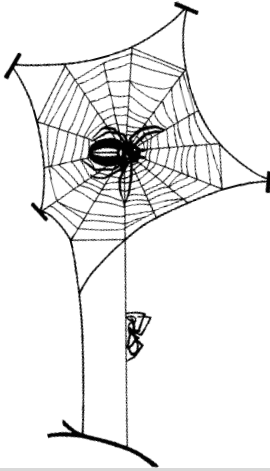
1. Leafminers are an increasingly serious problem in many vegetables.
2. Chemical pesticides usually are not effective against leafminers.
3. Leafminers have many indigenous natural enemies. However, these may not always be effective enough to reduce leafminer populations.
4. Natural enemies are killed by pesticides.
5. Introduction of parasitoids may be considered.

Related exercises from CABI Bioscience/FAO manual

- 4-E.1. Parasitism of leafminers
- 4-E.2. Mixed cropping of tomato with beans



6 MAJOR NATURAL ENEMIES OF TOMATO INSECT PESTS



SUMMARY

Predators, parasitoids and pathogens are the main groups of natural enemies that can control large numbers of tomato 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 hover flies. 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 lady beetles 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. Most parasitoids of tomato insect pests occur naturally. 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 releases and can give very good control. For example HaNPV is very effective in control of tomato fruitworm *Heliothis armigera*. NPV and some fungal pathogens can be produced at farm level, after basic farmer training. However, some quality control is recommended. Nematodes such as *Steinernema* sp. are also increasingly available for insect control.

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 prey 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 mantids.

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 tomato plants. 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 tomato pest insect control are described.

6.1.1 Lady Beetles - *Coccinellidae*

Also called ladybugs, ladybird beetles or coccinellid beetles. There are many different species of lady beetles. However, not all lady beetles are predators. Some, like *Epilachna* sp., are herbivores, particularly on solanaceous crops. Check feeding habits in insect zoo studies (section 4.4)!

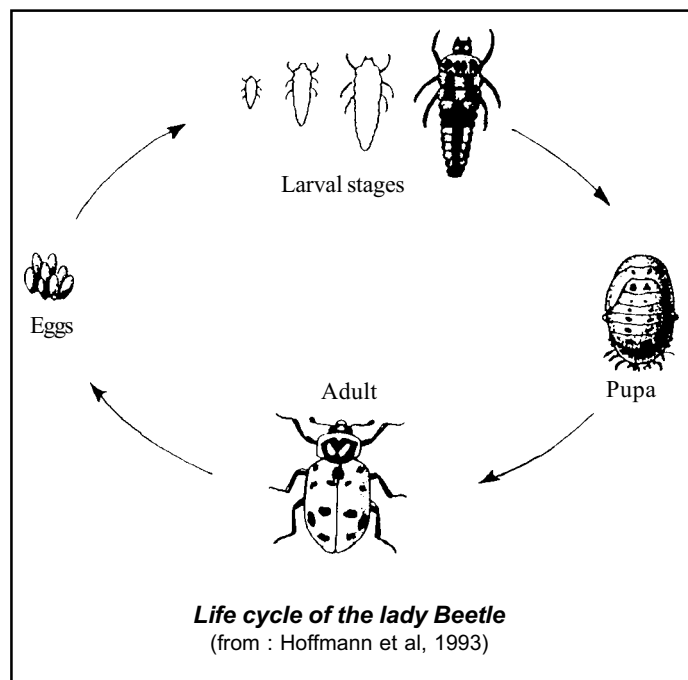
Primary prey: aphids, mites, whiteflies, small insects, insect eggs.

Predatory stages: both adults and larvae.

Description and life cycle

Adult lady beetles 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 lady beetles have a different color or different markings. Both larvae and adults of lady beetles are predators: they eat aphids, small caterpillars, mites and insect eggs. Many lady beetles 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. Lady beetles 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.

Female adults lay 200 to more than 1000 eggs in a few months time. 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

Lady beetles 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. Lady beetles are thought to be less effective when pest densities are low. There may also be some crop damage before lady beetles have an impact on an aphid population.

Because of their ability to survive on other prey or on pollen when there are not so many aphids, lady beetles are very valuable.

In Thailand, at Biocontrol Centers of Dept. of Agricultural Extension, ladybeetles are reared and available to farmers for field releases.

Conservation

Like many other natural enemies, lady beetles are easily killed by broad-spectrum insecticides. Avoid the use of these pesticides as much as possible!

Lady beetles 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*

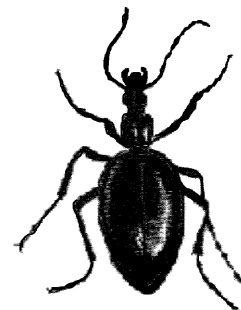
Primary prey: soil-dwelling beetles and fly eggs, larvae, pupae, other insect eggs, small larvae and soft-bodied insects, some caterpillars.

Predatory stages: both adults and larvae are predators.

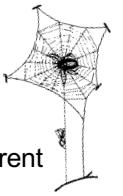
Description and life cycle

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.

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.



Ground Beetle



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

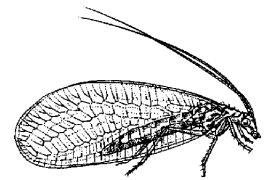
Ground beetles are easily killed by (broad-spectrum) insecticides. Avoid using these pesticides when possible.

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.



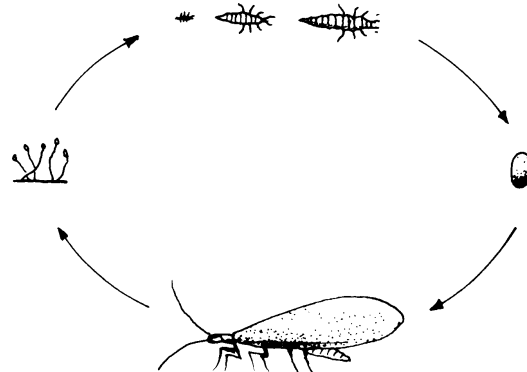
There are several species of green lacewings (*Chrysopa* and *Chrysoperla* sp.). The common green lacewing, *Chrysopa carnea*, is native to much of North America, several countries in Europe and India. *Apertochrysa* sp. was also found in India (Tamil Nadu). Another green species is *Chrysopa rufilabris*, 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.

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



Life cycle of the common green lacewing, *Chrysopa carnea*

(from : Hoffmann et al, 1993; www12)



Major Natural Enemies of Tomato Insect Pests

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.

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*). In all cases, 3rd-instar larvae consumed the major portion of the total number consumed (60-80%) (Balasubramani et al, 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 Biocontrol Centers of Dept. of Agricultural Extension, 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. www17)



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.

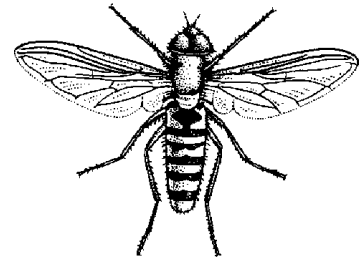
The green lacewing appears to have some natural tolerance to several chemical insecticides although there may be considerable variation. Populations tolerant of pyrethroids, organophosphates, and carbaryl have been selected in the laboratory. Still, when lacewings (and other natural enemies) occur in the field, it is advisable to avoid using pesticides.

6.1.4 Hover flies - *Syrphidae*

Hover flies are also called syrphid flies or flower flies.

Primary prey: aphids, small caterpillars, sometimes thrips, possibly jassid nymphs.

Predatory stages: only larvae of hover flies are predators.

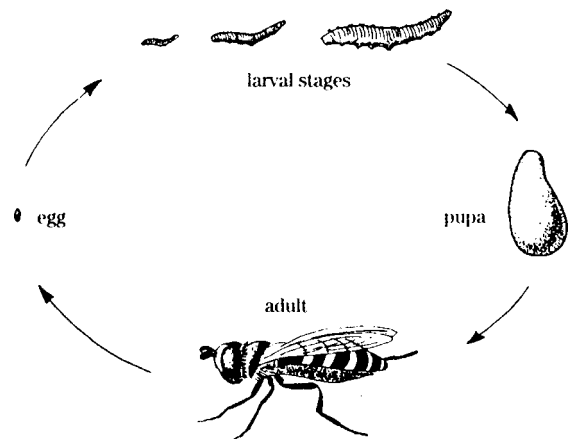


Description and life cycle

Adults of the hover fly eat pollen and nectar from flowers. Only the larvae are effective aphid predators. The adult hover flies 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 hover flies. 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!

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.

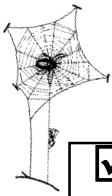


Life cycle of a typical hover fly
(from : Hoffmann et al, 1993)

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 hover fly 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, hover flies are easily killed by broad-spectrum insecticides. Avoid use of these pesticides when possible.

Adult hover flies 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 NE's.

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.

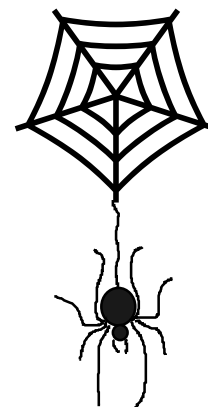
Predatory stages: nymphs and adults

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 adults of 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.

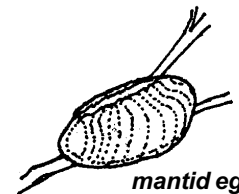


adult praying mantid

Description and life cycle

Both adult and nymphs have large front legs which they held in a “praying” position. The nymphs look like small adults.

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.



mantid egg mass

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.

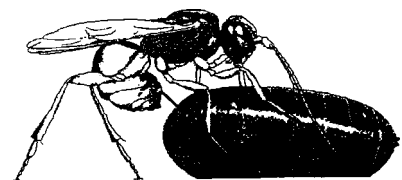
Conservation

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 tomato field. The young nymphs may start feeding on pest insects of tomato.

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



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A parasite also lives in or on another organisms (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: also 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. Parasitoids are usually grouped into several broad categories based on their development patterns. Egg parasitoids attack the egg stage of their host, larval parasitoids attack the larvae etc.



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 box below).

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.

Rearing Parasitoids: A Study Example

A method to rear parasitoids of leafminer (*Liriomyza* sp.) is the following:

- Select a number of plants in field with heavy leafminer infestation.
- Cover the soil below plants with a broad layer of black plastic.
- Check daily and continue collecting larvae/pupa for at least 2 weeks! Fully grown leafminer larvae drop to the soil to pupate and can easily be collected from the black plastic.
- Leaves are carefully checked for pupa attached to the leaves. These are also collected.
- All pupa are placed in marked jars and left until emergence.
- Identify adults emerging from pupae.

In general, larvae of *Liriomyza* are first to emerge from the leaves. Parasitized larvae (by *Hemiptarsenus*) pupate in leaf gallery made by the *Liriomyza* and the adult emerges by piercing the epidermis (top layer) of the leaf. Braconid larvae (other natural enemies) crawl out of the leaf, drop to the ground (on the plastic) and pupate on the soil surface. See also section 5.5.

Related exercises from CABI Bioscience/FAO manual

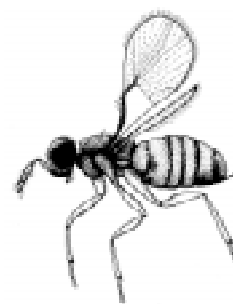
1.6 Show effects of beneficials incl. natural enemies

6.2.1 *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. For tomato the most important species is *Trichogramma chilonis*: parasitoid of borer insects such as tomato fruitworm (*Heliothis armigera*), corn borer (*Ostrinia nubilalis*) and eggplant fruit and shoot borer (*Leucinodes orbonalis*).

Several species have been mass-reared for use in biological control programs. In some countries, *Trichogramma* wasps are commercially available. 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).



Trichogramma



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 may 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.

When field releases are properly timed *Trichogramma* can greatly reduce *Heliothis armigera* in tomato (FAO – Dalat report (V. Justo), 1998).

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 search 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.

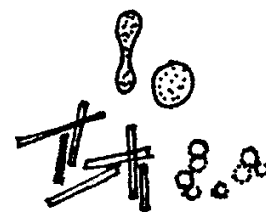
Regular field monitoring is essential for the success of *Trichogramma*.

Conservation

When *Trichogramma* is active (and especially when it is released into the field) and/or 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. See section 6.3.3 below.

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 tomato 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, including diamondback moth
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. 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 can be applied using conventional spray equipment. Good spray coverage is essential because the bacteria must be eaten by the insect to be effective.

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

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. 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 a 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.

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.


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).

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.

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)

Conservation

Bt formulations are applied like an insecticide. The 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

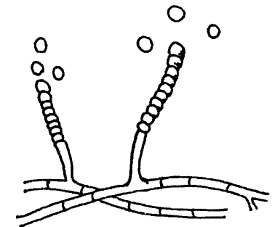
Farmers in Dalat were very excited about this scoring system because it provided a better opportunity to study how Bt works. They observed that just counting dead caterpillars in Bt studies is not enough and may even lead to a false conclusion.

(Ooi, 1999)



6.3.2 Fungi

There are fungus 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 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 fungus species that infect and reduce fungi that cause plant diseases. These are called *antagonists*. An examples of an effective antagonist is *Trichoderma* (*Gliocladium*). This section describes insect-pathogenic fungi only. Antagonists are described in section 7.10.

There are several fungus 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 focussed 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.



Major Natural Enemies of Tomato Insect Pests

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 lady beetles 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: is being tested as natural enemy 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 www25 and www29 (chapter 12, 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.



It is not important to know all the Latin 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 spread by wind, rain or contact with other insects, the spores can spread the infection.

Infected insects stop feeding and become lethargic. They may rapidly die, 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 ❶ or secondary ❷ ???

When you leave a plate of food with for example some chicken meat in your kitchen and leave it 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) but it 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 “trashmen 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 can 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!



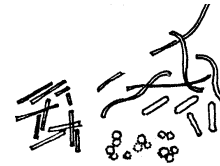
Conservation

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

Baculoviruses 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 Baculoviruses, important for insect pest control:



- Nuclear polyhedrosis virus (NPV) has been successfully controlling 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*).

Baculoviruses are composed primarily of double-stranded DNA. This is genetic material needed for virus establishment and reproduction. Because this genetic material is easily destroyed by exposure to sunlight or by conditions in the host's gut, infective baculovirus particles (virions) are protected by protein coats called "polyhedra" in NPVs, and "granules" in GVs. The protective coating allows the virus to exist in the open air, outside the host's body. It can only multiply inside a host.

The majority of baculoviruses used as biological control agents are in the genus NPV .

There are different strains (or "varieties") of NPV and they are commonly present at low levels in many insect populations. Virus strains are usually specified with a letter-combination. For example:

SeNPV	NPV for control of armyworm <i>Spodoptera exigua</i>
SINPV	NPV for control of armyworm <i>Spodoptera litura</i>
HaNPV	NPV for control of tomato fruitworm <i>Heliothis armigera</i>



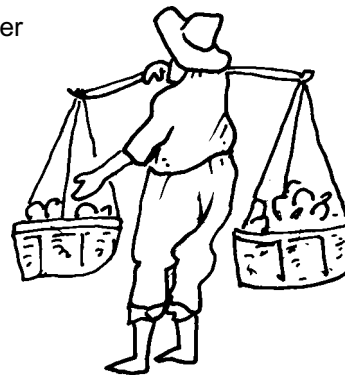
caterpillar wilt

Control of *Spodoptera exigua* by SeNPV: a success story from Indonesia.

Spodoptera exigua is the major constraint to shallot production in several areas in Indonesia. Experiments were carried out under the Clemson Palawija IPM project with the Institut Pertanian Bogor in order to assess the SeNPV's potential at different *S. exigua* population levels, as compared to insecticides. Treatments included: SeNPV, SeNPV + hand picking larvae, hand picking larvae (no SeNPV) and control. Those involving insecticides included: Insecticide treatment, insecticides + hand picking, hand picking alone, and control.

SeNPV and SeNPV along with hand picking larvae provided the best control of *S. exigua*. Yields in the untreated control plots were nearly zero. Plots with hand picking alone significantly improved yields but highest yields were obtained when SeNPV was carried out with hand picking.

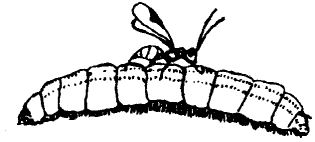
Since this IPM project began, the use of SeNPV has been incorporated into the biocontrol program in West Sumatra. It is estimated that over 10,000 farmers are currently using SeNPV for *Spodoptera exigua* control in shallots. Many farmers are producing NPV on-farm. Farmers are involved in the production, multiplication, and distribution of biopesticides (NPV as well as other biocontrol products) and training in their use. The production and use of the virus has become an essential part of TOT and FFS training with idea of helping to stabilize the shallot ecosystem and let other natural enemies colonize the crop. Farmer training is the key to the long term stability of the program (Shepard, 2000).





Mode of action and symptoms

Insect viruses must be eaten by an insect to cause infection. They may also be spread from insect to insect during mating or egg laying. In some cases, for example while searching for suitable hosts for egg laying, beneficial insects such as parasitoids may physically spread a virus through the pest population. An example is the parasitoid *Cotesia* sp. that can spread granulosis virus in *Pieris rapae* (ref. www18).



Cotesia

Viruses enter an insect's body through the gut. They replicate in many tissues inside the insect and interfere with the feeding, egg laying and movements of the insect.

Different viruses cause different symptoms. NPV-infected larvae may initially turn white and speckled or very dark. Some may climb to the top of the plant, stop feeding, become limb and hang from the upper leaves or stems ("caterpillar wilt" or "tree top disease").

Insects infected with a granulosis virus (GV) may turn milky white and stop feeding. In both cases, the body contents of the dead larvae are liquid and the skin of the insect breaks easily to release the infectious virus parts. Death from a virus infection occurs within 3 to 8 days.

Effectiveness

A virus infection, either naturally occurring or applied, can seriously reduce a pest population, especially when the pest population is high. Infected insects fall apart on foliage, releasing more virus. This additional infective material can infect more insects. Transmission of the virus through the population may take days or weeks but, if conditions are suitable, the entire population may eventually collapse. See also box above.



Insect viruses are not harmful for humans, animals, predators and adult parasitoids. Larval parasitoids that are still developing inside an insect are affected when the host insect dies due to viral infection.

Advantages and disadvantages of NPV are given in the table below (6.3.3)

Table 6.3.3 Advantages and disadvantages of NPV

<u>NPV - Advantages</u>	<u>NPV - Disadvantages</u>
Host specific	Host specific
Easily produced (if live hosts are available)	Slow acting
Symptoms easily recognized in the field	Breaks down by sunlight (becomes inactive)
Safe	Large sized larvae not affected
May recycle in the field (e.g. spread through populations in the field)	Requires living host to produce
Easy to apply and evaluate	Needs proper storing (cool and dark)

(modified from FAO Dalat report (Carner&Shepard), 1998)

Conservation and production

For viruses that occur naturally, conservation is not an issue because the circumstances in which the viruses occur can usually not be influenced very much. Naturally occurring viruses, as well as virus cultures from laboratories or commercial sources, can be multiplied on-farm. Both in Vietnam and Indonesia NPV is locally reproduced by IPM farmers with mixed results. Quality control issues remain an important aspect of on-farm reproduction of NPV. See box below.



Virus products are prepared based on two sources: infected larvae from the field and infected larvae in the “laboratory”. With larvae infected in the laboratory, observations should be taken daily. Three to four days after the symptoms of disease have appeared and larvae begin to die, remove all the dead larvae and transfer them into a dark (non-transparent) glass container with a lid/cover. Do not use dead larvae not caused by NPV. Let it putrefy for 2 – 3 days. Then macerate in mortar. Filter solution through cloth to remove hard parts. Add 1 liter drinking water (not tap water!) to 250 – 300 large-sized, filtered larvae.

After filtering, store products in colored bottles or dark cans, and place them in a dark, cool place (refrigerator if available).

Storing NPV

A study on storing methods for NPV was done by the National Institute of Plant Protection (NIPP) in Vietnam. They compared NPV and NPV plus 50% glycerin, stored both in the laboratory and in the refrigerator. After certain periods of storing, the effect of NPV was assessed against 4th stage larvae of *Spodoptera litura*. NIPP found that the NPV stored in the refrigerator (both with and without glycerin) gave over 81% control after 36 months of storing. Non-refrigerated NPV, with glycerin resulted in 58% control; without glycerin only 37% after 36 months.

It seems that when storing NPV in the refrigerator is not possible, adding glycerin may help to keep the viability. However, newly produced NPV is the most effective. (Viet, 1998).

NPV Quality matters

When producing NPV on-farm, a number of quality issues should be taken into consideration. See box below.

NPV production on-farm: some quality matters

It was noted that when NPV was multiplied on-farm the virulence of the NPV solution could vary from one season to the next. In fact, an NPV highly effective in controlling e.g. *Spodoptera* sp. in one season could give low control in the next season, when diseased caterpillars were used to make a new NPV solution. A number of issues may contribute to this:

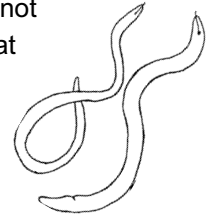
- When wild insects (from the field) are used to prepare NPV solutions (see production schedule above), it can be difficult to distinguish larvae of susceptible and non-susceptible species. For example, In India and Thailand, larvae of *H. armigera*, *Spodoptera exigua* and *Spodoptera litura* can occur together and at the third instar, when inoculation is most effective, they are difficult for untrained observers to distinguish. Mixing different insect species reduces the viability of any one NPV strain.
- Wild larvae can themselves be carrying pathogens that may enter the production system and compete with the NPV. For example, microsporidia and *Bacillus* sp. can be difficult to distinguish from NPV unless staff are well trained. Co-infection with other pathogens may reduce the “yield” of NPV.
- When fresh leaves are used to feed the larvae, these leaves may also be contaminated with unwanted entomopathogens. These pathogens can reduce NPV production.
- When healthy larvae are inoculated, it is important to infect insects at the right stage. Optimizing the age/weight at infection is crucial to maximizing productivity in individual insects. Also, last instar caterpillars are usually unaffected by NPV.

Strict quality control procedures are not only essential for product consistency, but also for safety. Where quality control is inadequate, microbial contamination of the final product is inevitable. In most of these cases this will merely lead to a loss of efficacy due to dilution of the active ingredient by competing micro-organisms. However, it is possible that potential human pathogens may also contaminate these production systems. Quantification of the degree of contamination and identification of these contaminants is important in determining the likely risk to human health. Many low technology production systems (such as many on-farm NPV production areas) in use around the world have minimal or no quality control procedures. This is an unsatisfactory situation and can damage the reputation of microbial control in addition to posing a serious health risk to those who produce or come into contact with the product (Jenkins & Grzywacz, 1999).



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 many of these species is not well 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.

The main species of beneficial nematodes include:

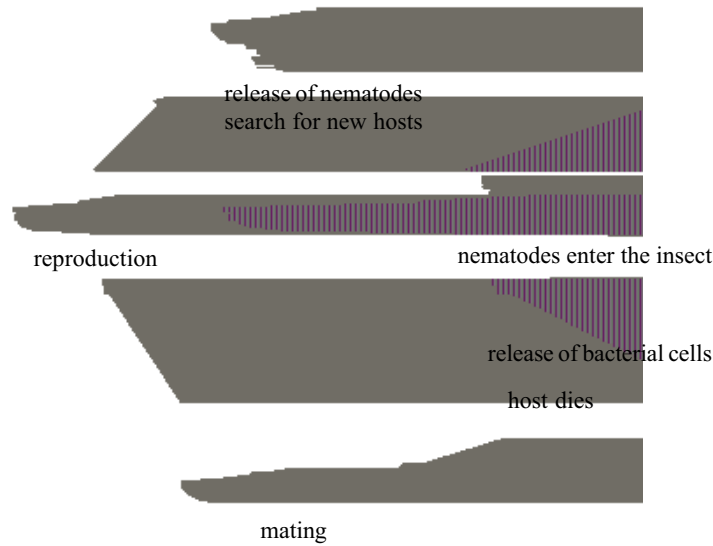
- *Steinernema* species (previously called *Neoaplectana*): There are several species of this nematode and all of them have a very broad host range. Different *Steinernema* species carry different strains of a bacteria. Two important members of *Steinernema* are (D'Amico, www14):
 1. *Steinernema riobravis* - 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.

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.

Steinernema carpocapsae is recommended by the Dept. of Agr. Extension of Thailand against webworm *Hellula undalis* and fleabeetle *Phyllotreta* sp. (larvae live in the soil). 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 bacteria 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 an available opening in the skin of the insect, 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.



(modified from Hoffmann et al, 1993)

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.

Effectiveness

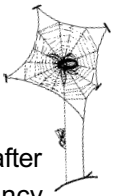
Insect-attacking nematodes are best suited for use against pest insects that spend some or most of their life cycle in the soil or in moist, protected places (like inside shoots and fruits). However, nematodes are often not effective against insects feeding on open foliage because they quickly lose effectiveness in dry conditions. Nematodes can travel in the soil over considerable distances and actively seek their prey if temperature and humidity are correct.

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 www25 and www29 (chapter 12, Reference list).



nematode movement through soil



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, they 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.

6.4 Other natural enemies

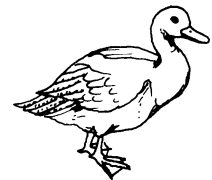
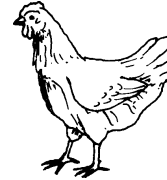
6.4.1 Birds

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.

In several parts of South-East Asia ducks have been effectively used against golden apple snails in rice.

Birds: insect predators



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.

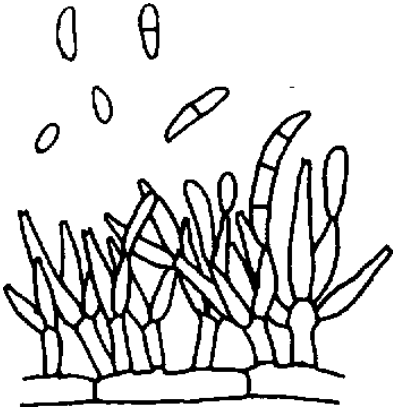


**Natural enemies are very valuable:
they help farmers to control pests!**





7 DISEASE ECOLOGY



SUMMARY

Disease ecology studies pathogens that cause plant diseases in relation to their environment.

Tomato diseases are caused by pathogens such as fungi, bacteria, viruses 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).

A disease is the result of interactions between a pathogen, a host plant and the environment. These interactions are shown in the disease triangle.

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. Disease management is focused on changing or influencing one of these three elements to prevent the disease from attacking the plant. Studying 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 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 tomato 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.

The antagonistic fungi *Trichoderma* sp. have become widely available in many countries in South-East Asia. *Trichoderma* sp. can suppress several soil-borne plant pathogens in vegetables. Other biocontrol agents include a non-pathogenic strain 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

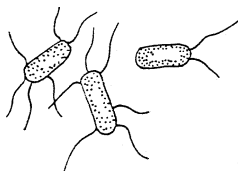
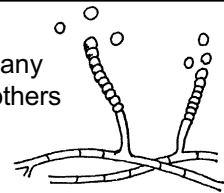
Diseases are an important part of crop protection, but they are usually very difficult to understand in the field. This is partly because the causal organisms are very small and cannot be seen moving around like insects. You can only recognize diseases by their symptoms which vary from dwarfing of the 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”. Well-known examples are the bacterium *Bacillus thuringiensis* (Bt) and 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).

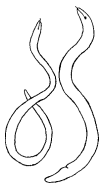
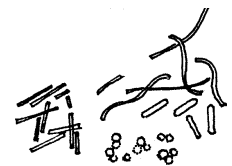
PATHOGENS

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 both 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.



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.



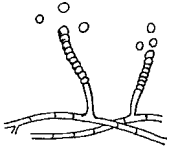
Plant diseases can also be caused by non-living (abiotic) agents. These are called *physiological disorders* rather than diseases. Symptoms of physiological disorders include discoloration of leaves through deficiency or excess of a certain fertilizer, symptoms from sun burn or pesticide burn. It is 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 upperside of leaves). Others live inside the plant and may even use the plant vessels to spread through the plant (for example bacterial wilt in tomato). 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:

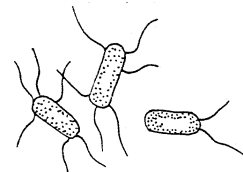


Vegetative reproduction: parts of the fungi, e.g. pieces of mycelium, that can develop further when placed in a suitable environment.

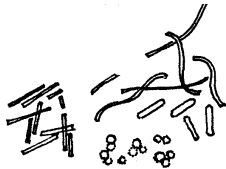
Reproduction by spores: spores are like “seeds” of a fungus: when they land at a suitable place they germinate and the fungus grows from there. Under suitable conditions the fungus may produce spores again. When conditions are not favorable,

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 go 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 worms 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.
- 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. Examples are late blight (*Phytophthora infestans*) and early blight (*Alternaria solani*) of tomato. 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 tomato, 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 man.

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.

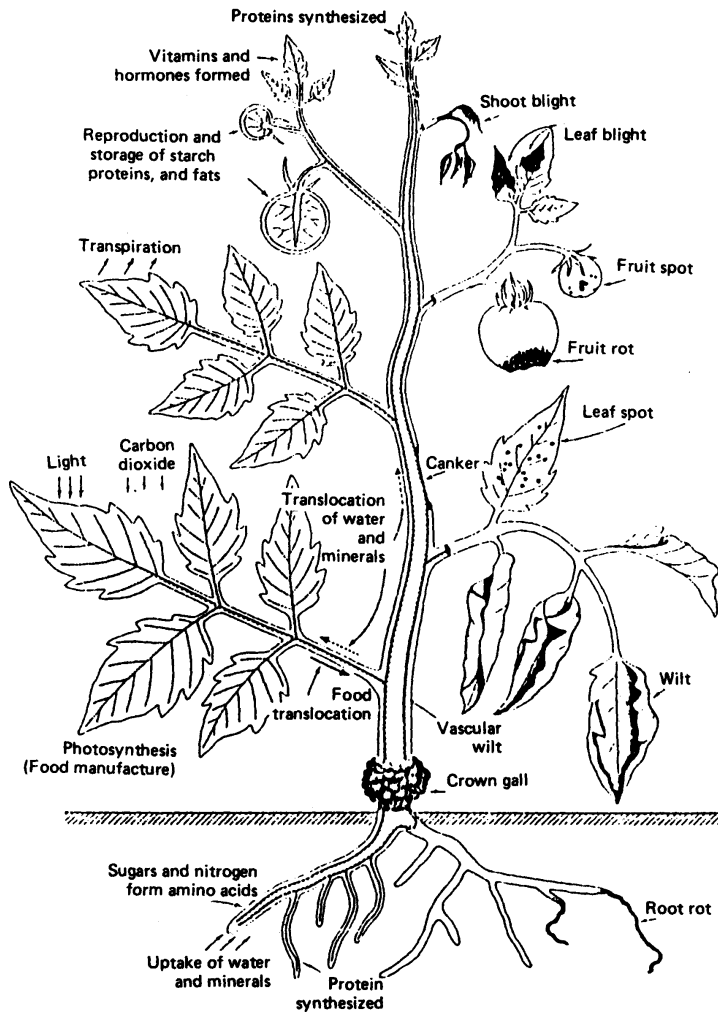
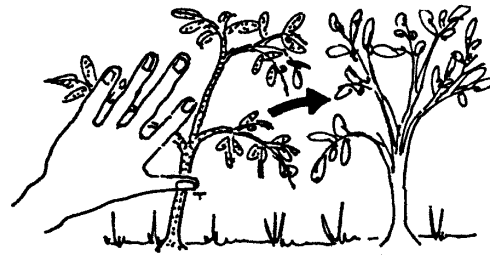
Soil-borne pathogens can be spread by wind, water, vectors or humans and carried with soil particles. An example: *Pythium* sp. causes damping-off disease in seedlings. Dying seedlings contain the spore-carrying structures of the fungus. The spores can drop to the soil (and attack seeds or young seedling 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 whiteflies carrying leaf curl virus) 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 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.



Schematic representation of the basic functions in a plant and of the interference with these functions caused by some common types of plant diseases.
(from AVRDC (Asian Vegetable Research and Development Center), 1990)

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.

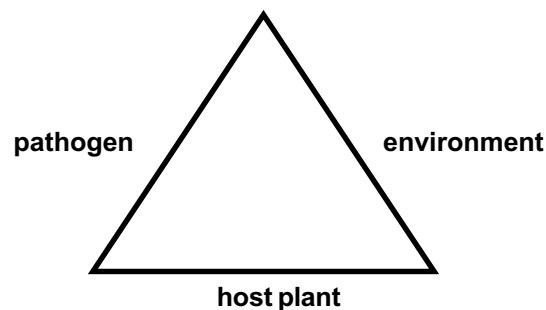
A virus needs a wound to enter, either a mechanical wound or a wound created by an insect. Most nematode species, such as rootknot nematode, can actively penetrate plants.

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 says that a plant will get infected with a disease when:

- the variety of that plant is susceptible to the disease,
- the disease is present and virulent (able to infect the plant),
- 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.

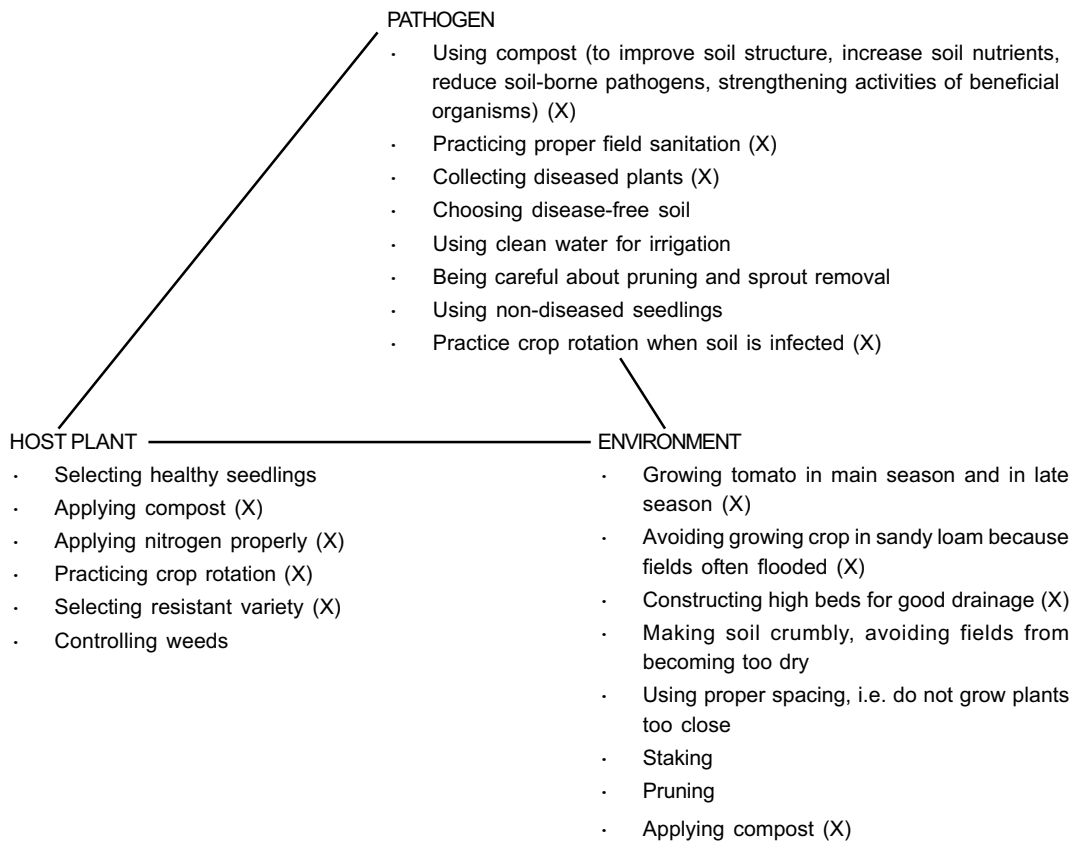
Changing the presence of the pathogen can be: removing leaves with the spores of the disease from the field before planting a new crop so that the disease cannot infect the new plants from the leaves that were left in the field after harvest (sanitation).

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. late 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).

(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 www19).

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 toward evening.

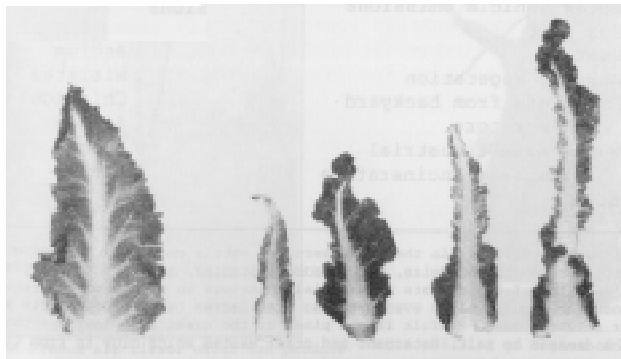
Diseases: look for dead areas on roots, leaves, stems and flowers. Are the plants wilting even though soil moisture is plentiful? Then check the roots for root rot symptoms or root deformations. Are the leaves spotted or yellowed? Are there any signs of bacterial or fungal growth (soft rots, mildew, 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.



Molybdenum deficiency symptoms in cauliflower

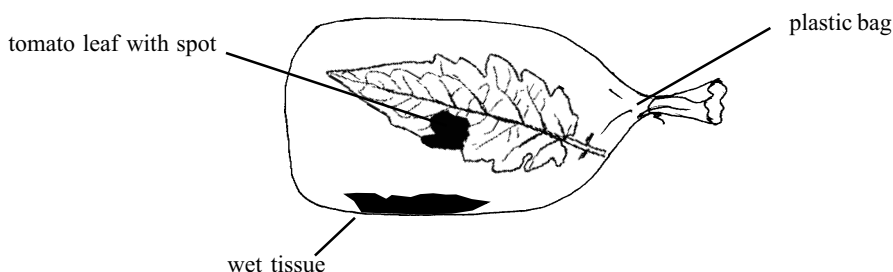
For some illustrations see plate 4

7.7 Studying diseases

When 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 late blight is given below.

Diagnostic method for late blight

If the white fungus growth is not observed, leaves with suspicious spots can be put into a plastic bag containing a moist paper towel (to supply moisture). The plastic bag is inflated with some air and tightened. The bag is held for one day. When the spot is caused by late blight fungus, the underside of the leaf will develop a white downy mold at the margin of the affected area on the lower surface of leaf.



Related exercises from CABI Bioscience/FAO 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 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 different 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 way is to check if there are any resistant crop varieties available (see section 3.2). 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 3.20).

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 7.9 below will summarize some sources and carriers for a number of important tomato diseases.

Table 7.9 A summary of some sources and carriers for important tomato diseases

DISEASE	SOURCE(S) and/or CARRIER(S)						
	contaminated seeds	other infected plants	diseased crop residues	soil	contaminated water	carried by wind	contaminated tools, people, animals, insects
damping-off	-	+	+	+	+	-	+
rootknot nematodes	-	+	+	+	-	-	+
early blight	+	+	+	-	-	+	+
late blight	±	+	+	-	-	+	+
TMV	+	+	+	+	+	-	+
leaf curl	-	±	+	-	-	-	+
bacterial wilt	+	+	+	+	+	-	+
fungal 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 influenced. 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.

- contaminated seeds: sterilize seeds before sowing (section 3.7),
- other infected plants: uprooting diseased plants, pruning infected leaves, increasing plant spacing,
- diseased crop residues: sanitation – removing all left-overs from previous crop from field,
- soil: crop rotation, for small areas, soil sterilization may be an option (section 3.11.1)
- contaminated water: avoid planting down-hill of an infected field,
- carried by wind: cooperation with other farmers for sanitation practices, covering compost piles, windbreaks (though usually of limited value),
- contaminated tools, people, animals, insects: 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 than 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 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.

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, The Biopesticide Manual, 1998)



Antagonists have been applied to the above-ground parts of plants, to the soil (and roots), and to plant 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).

And, 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 South-East 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. In addition, *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 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 et al, 1998).

Related exercises from CABI Bioscience/FAO 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 tomato diseases, especially during prolonged periods of wet weather. They can however, delay infection of diseases such as late blight. 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 will be 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, 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.**

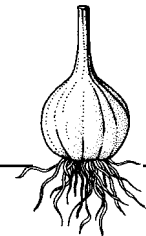
7.11.2 Botanical fungicides

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 3.7.3.), 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.



Milk (not a botanical but of animal origin) can also have a function in preventing fungus and mainly virus diseases in plants. No “official” trial data are available but milk is used a lot in greenhouses in for example Netherlands to dip cutting knives during pruning of tomato. The milk protein inactivates viruses. Effects on fungi are unclear. Milk is expensive for use on larger scale.

7.12 Disease forecasting models

Development of most diseases is dependent on weather conditions. For this reason, researchers have been working on trying to predict if a disease would occur in relation to weather conditions. Other prediction methods would measure the amount of disease “propagules” (such as spores) in the air. Such predictions could then be used to recommend if a fungicide application or other management practices would be necessary. The idea was that forecasting models would improve timing of fungicide applications. This would result in reduced use of fungicides, and therefore less monetary loss for farmers, as compared to the traditional calendar spraying.

Some examples of forecasting models from the USA for tomato are described below:

TOMCAST

In the USA and Canada, a computer model was designed to predict Early Blight, Anthracnose, and *Septoria* Leaf Blight development in tomatoes. The program is TOMCAST, short for TOMato disease foreCASTing, and unfortunately does not predict occurrences of Late Blight, bacterial or viral diseases. It is derived from an earlier model, F.A.S.T (Forecasting *Alternaria Solani* on Tomatoes).

TOMCAST is a weather dependent program. By calculating the number of leaf wet hours (the hours that a leaf stays wet in a 24-hour period) and the temperature, it can be predicted if the conditions are favorable for early blight to infect plants and to spread to other plants. Field data from different locations are used to calculate the spray intervals. When warm, wet conditions exist, fungal development is rapid and the number of fungicide sprays applied over the length of the season may exceed that of a calendar program. Conversely, if cool, dry conditions predominate, expect fewer fungicide treatments to be recommended compared to a calendar program. Farmers are to call to centre closest to their fields to be advised whether to spray or not.

BLITECAST is a Late Blight disease forecasting model similar to TOMCAST, using weather data to generate a daily disease index. If this index for a particular area (the same stations used by TOMCAST) equals or exceeds a set threshold value, a fungicide application is recommended unless a fungicide has been applied in the previous 7 days. Farmers could use BLITECAST in the same way they use TOMCAST, to inform them of periods of high disease pressure.

The blitecast program has also been validated for late blight control on tomato in tropical highlands in Malaysia. However, it did not become operational as it did in the USA.

Numerous examples exist of other forecasting models. In contrast, there are examples of how such models became redundant. This was especially the case for models where farmers had to collect field data from their own fields and enter those either directly in a computer system, or pass on to a central data handling unit which then would come back with the recommendation for the day. In a very short time, farmers did not need the computer model telling them when to spray anymore. Instead, they quickly learned which factors would cause disease problems in their field. They became experts in their own fields!

***Disease forecasting models are predictive models,
but not a substitute for good judgment!***



8 MAJOR DISEASES OF TOMATO



SUMMARY

Tomato can be affected by many pathogens. Major diseases of tomato in Asia are early and late 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 microorganism 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 3.7) 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 3.16).
- Sanitation. Removing diseased plants (or parts) help 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.



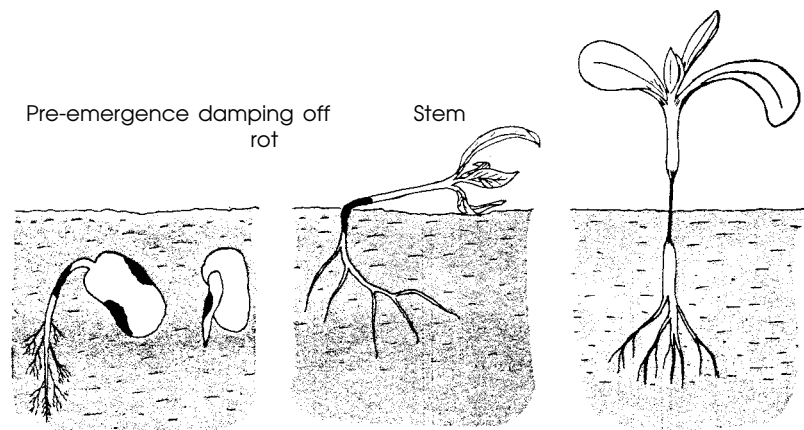
8.1 Root rot and root deformation

8.1.1 Damping-off (*Fusarium*, *Rhizoctonia*, *Pythium* and *Phytophthora* sp.)

See plate 2 Fig. 1 and 2

Causal agent: 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'.



(from Kerruish, 1994)

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.

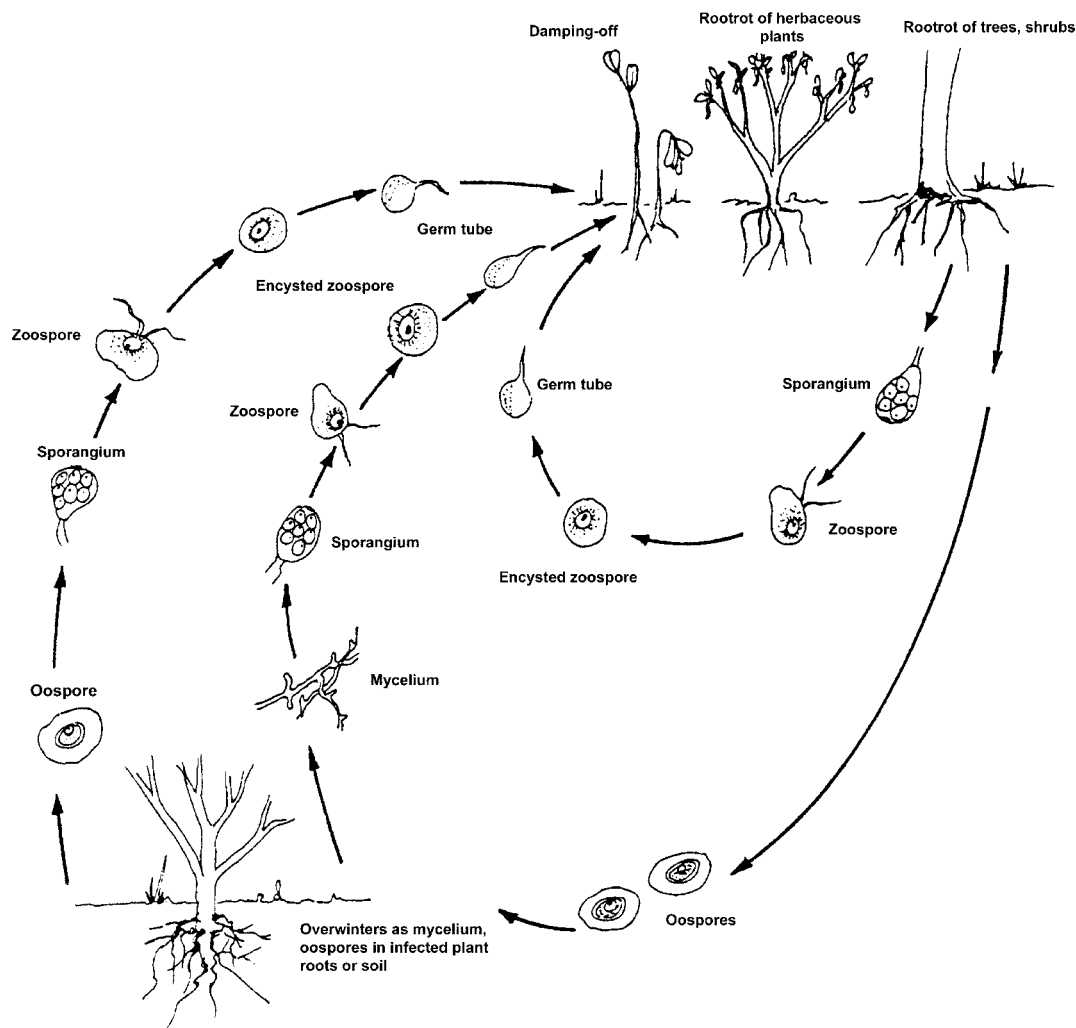
The symptoms of this disease are brown, water-soaked areas around the lesion that shrivel and pinch the seedling off at the base. The dry rot is usually limited to the outer part of the stem and infected plants may fall down or may remain more or less upright. Infected plants remain under-developed and usually die.

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.



Disease cycle *Phytophthora* damping-off and root rot
(from Kerruish et al., 1994)

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.

Natural enemies/antagonists

Many successes have been reported with the use of *Trichoderma* sp. to prevent damping-off. The best effect is obtained when *Trichoderma* is used as a prevention. *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 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 3.9.3.1 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 it 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 outcompetes pathogens and will often prevent disease.
- Crop rotation: If you are raising tomato seedlings every season, use fresh soil that has not been used for tomato or other solanaceous crops for at least 2 years. Plant another crop (not a solanaceous crop) in the 'old' tomato nursery.
- Use vigorous seed or seedlings. Slowly emerging seedlings are the most susceptible.
- Use seed that is coated with a fungicide layer. See section 3.7.
- 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 3.11.1.
- Consider using a layer of sub-soil (taken from a layer of soil below 30 cm) to prepare raised nursery beds. See section 3.11.1.3 for details.
- 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.
- 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 3.9.3.1 on compost.



Once there is an infection in the nursery:

- Unfortunately, the seedlings that are affected by damping-off cannot be saved anymore. 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.
- 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 mainly as a prevention but possibly as a control of damping-off. In Philippines, *T. parceramosum* and *T. pseudokoningii* are being tested. (FAO Dalat report, 1998). The *Trichoderma* is mixed into the soil before transplanting or added to compost before mixing into the soil.
- 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:

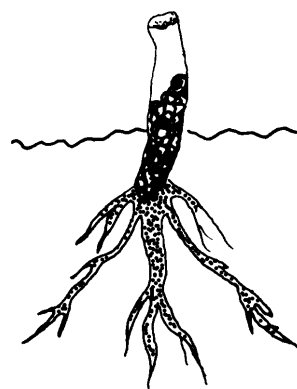
1. Damping-off is a serious nursery problem, caused by several soil-borne pathogens.
2. Damping-off occurs in areas with poor drainage or areas with a previous history of the disease.
3. Crop rotation (including nursery site), proper drainage and sanitation practices (removing crop left-overs) are ways to prevent disease problems.
4. Good control 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 (mainly) and control can be obtained with use of the antagonistic fungi *Trichoderma* sp.

8.1.2 Root rot – *Phytophthora* sp.

Causal agent: fungi – *Phytophthora* sp.

If part or all of the roots are destroyed by a pathogen, the plant is said to have 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 tomato, root rot is caused by the fungi *Phytophthora parasitica* and *Phytophthora capsici* and in eggplant it is caused by *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.

Phytophthora parasitica and *Phytophthora capsici* are related to *Phytophthora infestans*, the fungus that caused late blight in tomato. See section 8.2.2.



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. *Phytophthora parasitica* can also infect tomato fruits, usually those that touch the soil. The first symptom is a grayish green or brown water-soaked spot that usually occurs where the fruit touches the soil. In warm weather half the surface of a fruit may be affected. Dark “buck-eye” bands usually are present within the affected area, that is why this rot is called “Buckeye rot”. Buckeye rot has a smooth surface and lacks a sharply defined margin. This helps distinguish buckeye rot from late blight, characterized by a rough surface and a definite margin (MacNab, 1994).

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 tomato 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, and rotation of the nursery site are ways to prevent disease problems.
4. Good prevention of root rot can be achieved with use of the antagonistic fungi *Trichoderma* sp.



8.1.3 Rootknot nematode - *Meloidogyne* sp.

See plate 2 Fig. 3

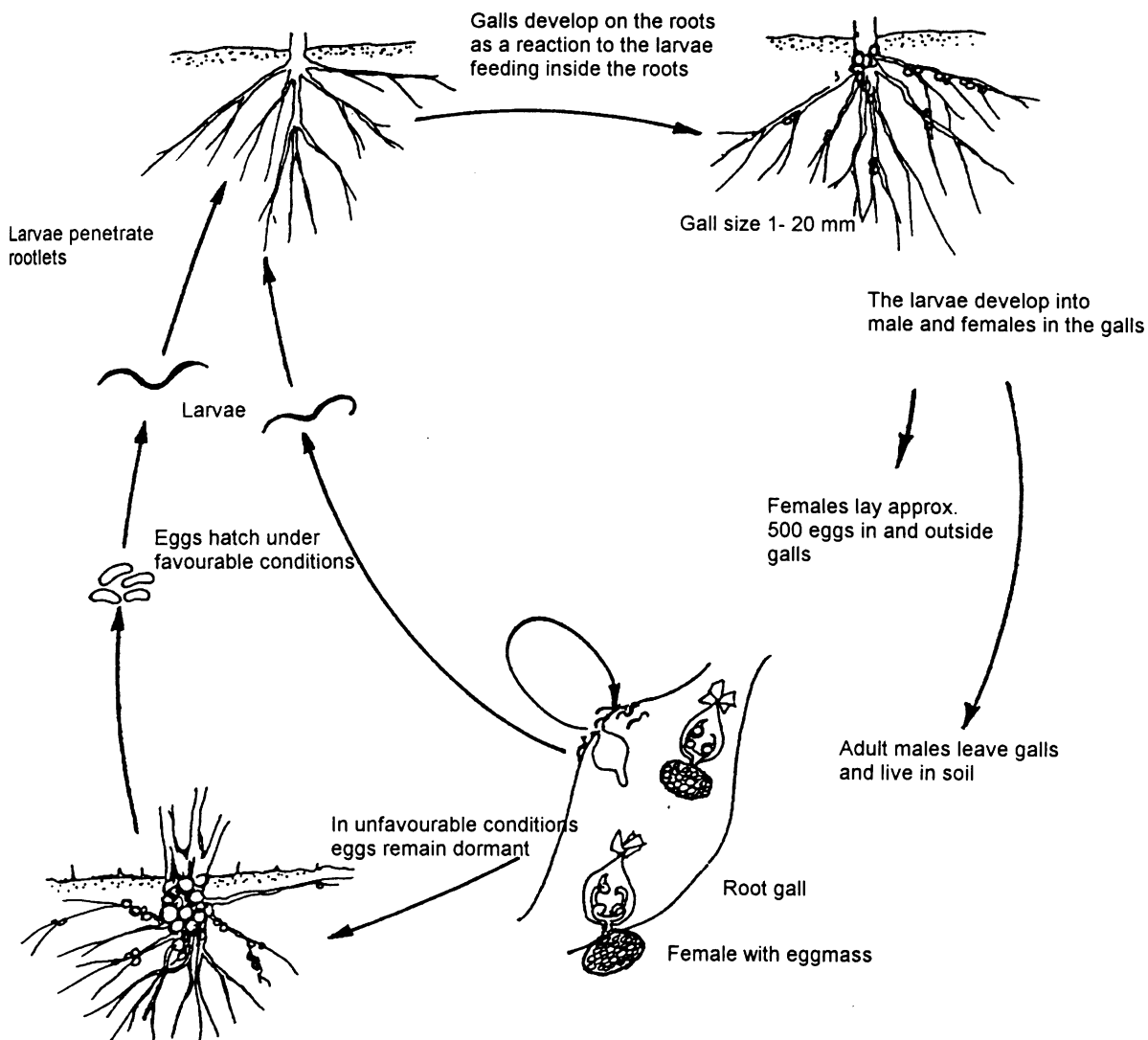
Causal agent: nematode – *Meloidogyne* sp.

Some of the 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

Nematode affected plants 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



Disease cycle *Meloidogyne* rootknot nematode
(from Kerruish et al., 1994)



infection. A large number of (female) nematodes can be present inside a gall. One female can lay up to 600 eggs. The eggmasses (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

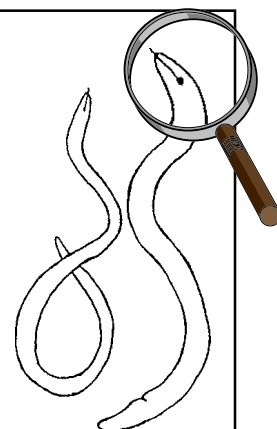
A soil temperature of 26-28°C is highly favorable for the development of this nematode, particularly on light, sandy soils. High temperatures of 40-50°C kill the nematodes. In infested nursery fields, it may be worth trying solarization or other soil sterilization methods mentioned in section 3.11.1.

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. Rootgalls 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.

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.



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.

Management and control practices

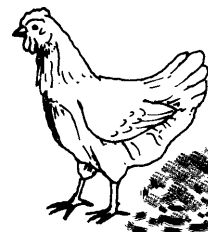
Prevention activities:

- Resistant varieties against root knot nematodes are available. Under high temperatures, there is a chance of the nematodes breaking through this resistance. However, in areas invaded with root knot 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 tomato variety in rotation with onion may help reducing 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 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 neem and marigold are also mentioned as potentially active against rootknot nematodes. It is recommended to study this in a field trial.
- Grafting is sometimes practiced to overcome rootknot and other soil-borne diseases such as bacterial wilt. The tomato variety can be placed on a rootstock of the “wild” eggplant variety *Solanum torvum*, which is resistant against rootknot nematodes and bacterial wilt.

Once there is an infection in the field:

- 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.
- 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 one being the incorporation of fresh organic matter.
3. There are several antagonistic fungi that work against rootknot nematodes. These become increasingly available over the next years.

Related exercises from CABI Bioscience/FAO 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



8.2 Leaf spot, blight, and virus diseases

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 them and the environmental conditions. Blight and leaf spots can be caused by different pathogens such as fungi and bacteria. Leaf spots can also be caused by unfavorable water relationships or temperatures, mineral deficiencies or excesses, insects or pesticides. Viruses can also cause leaf spots, particularly ‘ring spots’. Viruses can also cause “mosaic” discoloration of leaves or curling of leaves.



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 disease and check the key table in chapter 11.

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 Early Blight - *Alternaria solani*

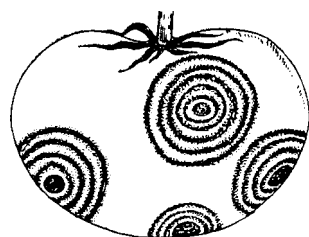
See plate 2 Fig 4 and 5

Causal agent: fungus - *Alternaria solani*

This disease can infect many species of the solanaceous family such as tomato, potato, eggplant, green pepper, and hot pepper.

Signs and symptoms

This disease can be destructive on tomato 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.



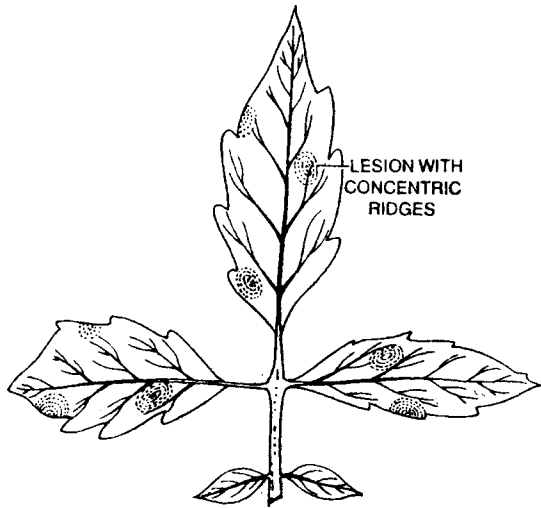
(Pandey, 1997)

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.

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!



Alternaria spores
(from Pandey, 1997)

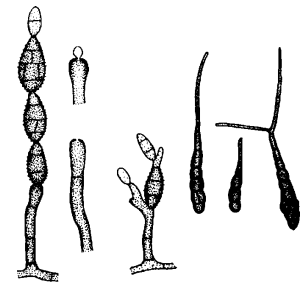
On established plants, dark brown spots with dark concentric rings develop first on oldest leaves. The concentric rings give the spot a target appearance. Leaf spots are characteristic for early blight. The spots are circular and up to about 1,5 cm in diameter. The spots may occur singly or in large 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. Plants which are well fertilized and irrigated are not as susceptible.

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 tomato 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.



Alternaria

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 [www25](#) and [www29](#) (see reference list in chapter 12).

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.

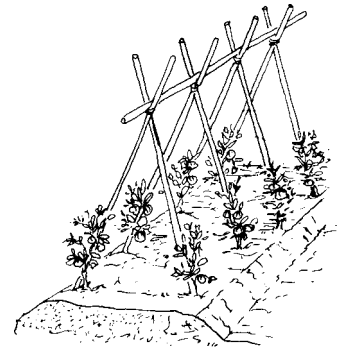
Prevention activities :

- Planting season: In areas with high early blight incidence it may be advisable to plant tomato 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 possibly other diseases) under local conditions. Indeterminate varieties produce foliage all season and are therefore less susceptible than determinates to yield loss related to early blight defoliation (see section 3.1).
- 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 3.11.1) to reduce soil-borne pathogens. Inspect seedlings for any sign of disease and discard and destroy any that are suspected of infection.
- Crop rotation: Tomato should be rotated with plants other than potato, eggplant, 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 tomato 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 tomato field if they will mature



before the tomatoes. 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 tomato in shady areas or areas with little wind as this will increase leaf wetness period.
- Staking or trellising tomatoes facilitates better airflow around plants and improves fungicide coverage, thereby slowing the onset and rate of development of early blight. Where early blight is a problem, increased yields of plants grown on trellises compared to those grown on the ground often compensate for trellising costs..



Once there is an infection in the field:

- 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.



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.



8.2.2 Late blight - *Phytophthora infestans*

See plate 2 and 3 Fig. 6 to 10

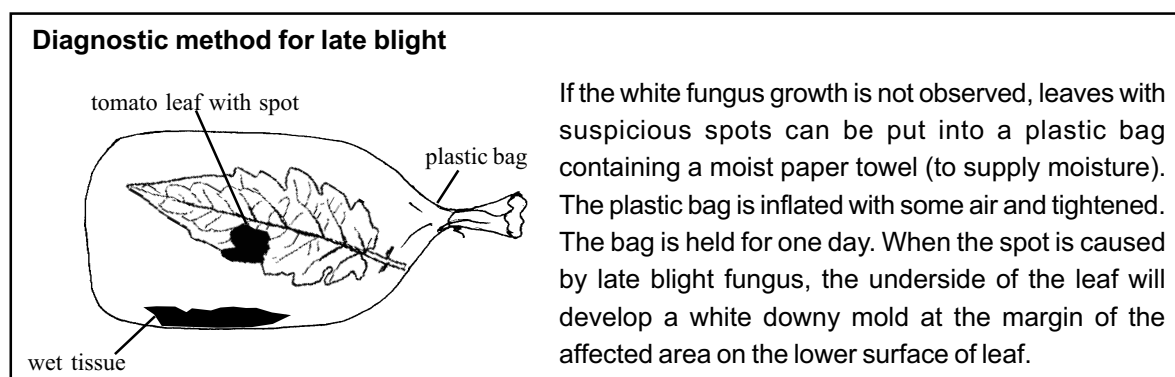
Causal agent: fungus – *Phytophthora infestans*

This is a disease that affects tomatoes, potatoes and eggplant but not pepper. It is one of the most serious tomato diseases of temperate (highland) regions.

Signs and symptoms

Symptoms can appear on leaves, stems and both green and red fruits. On leaves pale green to brown spots, sometime with a purplish color, appear on the upper surface of the leaves. The margin of these leafspots are often pale green or water-soaked. These areas expand rapidly until the entire leaf is killed. During moist conditions, a white downy mold appears at the margin of the affected area on the underside of leaves. When stems are affected, portions of plant beyond the blight spot may dry up. The blight lesions can expand rapidly and result in extensive, sometimes complete defoliation within 2 weeks. In dry weather, affected leaves may appear dry and shriveled.

When leaf infection is severe, fruits can be affected as well. Grayish green water-soaked spots enlarge until the entire fruit is involved. Affected areas become dark brown, firm, wrinkled and have a relative definite margin. The fruit tissue remains firm at first with varying depths of discolored tissue below the skin. In moist weather, a white downy fungus growth may appear on the affected fruit-rot surface. Secondary organisms may invade affected fruits and cause a soft rot.



Source and spread

The fungus may be introduced into tomato fields on transplants or may be wind-borne from diseased potato and tomato fields in nearby fields. Infected potato or tomato plants or transplants are the most important source of infection. The fungus is also able to survive on seeds.

Infected potato tuber may survive in fields or storage, or dumped in piles outdoors. When infected potatoes sprout, the fungus can grow into the sprout and produce spores during favorable environmental conditions. These spores can cause new infections in nearby fields.

Spores can be spread by wind over very large distances: up to many kilometers! Dew and splashing rain may spread spores over shorter distances.



Role of environmental factors

Disease development is promoted by cool wet conditions.

Spore production is favored by temperatures between 18 and 21°C and a humidity near 100%. Moisture is very important: when humidity decreases below 80%, spores die quickly. Infection therefore, only occurs when a layer of water is present on the leaf. The fungus spores penetrate the leaf directly. The fungus grows inside the plant. Symptoms usually appear about 5 days after infection, depending on weather conditions. Soon after symptoms appear, new spores are formed which can cause new infection cycles.

Long, wet periods like the rainy season are prone to heavy late blight infection.

Importance - plant compensation - physiological impact

Late blight is a very serious disease that, especially during favorable weather conditions like the rainy season, can cause a quick loss of complete tomato plants.

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. 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 [www25](#) and [www29](#) (see reference list in chapter 12).

Management & control practices

Prevention activities:

- Some varietal resistance/tolerance against late blight has been reported. However, the resistance may not be complete or may be overcome easily by the fungus. To date, developing late blight-resistant varieties is still a struggle. When varieties with some degree of tolerance are available it would be advisable to set up a trial plot comparing these varieties against the locally used varieties. Check disease incidence, fruit quality and yield.
- Elimination of sources of infection (sanitation) is the most important but also most difficult prevention activity as it should involve many farmers in an area. Spores can spread over long distances with the wind! Sanitation may include destroying potato cull piles, preventing growth of volunteer potatoes (that are left in the field after harvest and sprout as "weeds" in the succeeding crop), removing all tomato plant left-overs from the field and planting tomatoes as far as possible from potatoes or other tomato fields. Do not place infected plant left-overs on the compost pile unless covered with a thick layer of other materials. Spores may still spread from the compost pile when left open on top. Also when removing infected plant parts, make sure to put them in a polythene bag because moving infected material also helps spreading the fungus!

Sanitation alone may have an adverse effect on tomato yield in the end because removing too many leaves may lower plant vigor (Tumwine, 1999). Sanitation is best combined with other management practices.

- Using healthy planting material is another important prevention activity. When transplants have suspected leafspots or brown leaves, destroy them. Otherwise, you may risk introducing the disease into the field!



- Since late blight is common mainly in the rainy season, farmers should be aware that it is better not to grow tomato (or potato) in the middle of the rainy season but to move planting time towards the end of the rainy season (when there is still enough moisture in the ground) or to ensure that the last harvest of tomatoes is done just before the monsoon starts. Early maturing varieties may be an option to achieve this.
- Plants that are properly spaced, staked (when necessary) and pruned are less liable to be severely attacked. Wide spacing and pruned leaves allow wind and sunshine to reach inside the plant canopy which will dry up quickly after rain or (overhead) irrigation.
- 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 tomato in shady areas or areas with little wind as this will increase leaf wetness period. Polythene shelters (big plastic tunnels) also reduce leaf wetness period, and act as barriers for spores, thus reducing or delaying late blight infection. The combination of polythene tunnels and sanitation (removing diseased plant parts outside field) proved effective on tomato late blight in Uganda (Tumwine, 1999).
- Intercrops such as sesame and soybean have the potential to reduce late blight disease on tomatoes, especially when combined with sanitation. Intercrops can act as barriers against dispersing spores of late blight (Tumwine, 1999).

Once there is an infection in the field:

- Fungicide applications have been the most common control practice against late blight. Most fungicides should be applied as preventive sprays, that means before the symptoms of blight appear. There are also fungicides with a curative action, that means they can be applied once the disease is present. Check with providers, for types and characteristics of these pesticides. As late blight is particularly troublesome during the rainy season, fungicides are easily washed off the plants during rainfall (even when using a “sticker” to increase the “stickiness” of the product). So when it rains often, fungicides have to be applied regularly. Most preventive fungicides protect only the leaves they have been sprayed on. That means in time, even when it does not rain, new leaves are formed which are unprotected. These need to be covered regularly.

For example, studies in Uganda showed that the use of the fungicide Dithane-M delayed late blight epidemics for 2 to 4 weeks (Tumwine, 1999).

- As for early blight (*Alternaria solani*), several late blight forecasting systems have been developed in Europe and the USA over the years to help farmers identify when the environmental factors (mainly temperature and humidity) favor disease development and when fungicide sprays should be applied. Many of these forecasting models however, have not taken off in practice as planned. See also section 7.12



Late blight management - some trial suggestions

Determining under which conditions the disease appears and how quickly it can spread under these conditions is the first step to disease management. That means monitoring frequently. As late blight, especially during the rainy season, is known to be a very fast spreading and very destructive disease, monitoring should be done at least 2 times per week. Disease severity can be recorded as number of plants with symptoms, number of leaves per plant with symptoms, or percentage infection per plant.

Given the close relation of late blight occurrence and weather conditions, keeping a daily record of the weather conditions is another very important issue. Temperature should be recorded if possible (one reading at the same time every day could be a start) and especially humidity (daily rainfall (e.g. volume but also hours of rain), cloudiness (sunny, bright sky, or clouded), and wind (no wind - strong wind) are important elements.

Possible "treatments" for late blight management trials may include:

1. Control treatment: no fungicides, just monitoring of disease occurrence in time.
2. Spraying of preventive fungicides at routine basis, for example 2 times per week, no matter what the weather conditions are (may be Farmers' Practice).
3. Spraying of preventive fungicides on the basis of weather conditions: for example when it rains on 3 consecutive days and humidity is high.
4. Spraying a curative fungicides once a certain percentage of blight infection occurs. These percentages could vary: for example when 1% of the leaves show symptoms and 10% of the leaves.
5. Pruning of leaves showing symptoms and destroying these leaves outside the field.



Points to remember about late blight:

1. Late blight is one of the most destructive diseases of tomato.
2. Combining cultural practices with sanitation can effectively reduce and delay late blight infection.
3. Severe infections usually need fungicides in addition to cultural practices to keep infection low. However, the timing and number of fungicides applications can be changed (and possibly reduced) by studying the disease in the field.

8.2.3 Mosaic virus - TMV

See plate 3 Fig. 11 and 12

Causal agent: virus – Tomato Mosaic Virus

This disease is also called Tobacco Mosaic Virus or TMV.

The host plant range of this virus disease is immense: many unrelated plants in many plant families are affected. Host plants include vegetables such as beet, eggplant, pepper, potato, spinach, tomato and turnip, other agricultural crops such as apple, sugarbeet and tobacco and many ornamental crops and weeds.

Many strains of TMV exist: at least five have been reported. All of these strains are the same virus but there are tiny genetic differences. Strains are comparable with different varieties of tomato: all of them are tomatoes but there are differences in appearance, fruit size or time needed to maturity. Different strains of TMV



TMV symptoms on tobacco leaf
(Pandey, 1997)



may cause different symptoms. There are tomato varieties that have resistance against one strain but not against the other.

Signs and symptoms

A wide range of symptoms can occur on susceptible plants. Symptoms can develop on leaves, stems or fruits. Slight differences in symptoms may occur depending on tomato variety, virus strain, plant age at infection and environment.

Symptoms that are most evident are plant stunting, leaf stunting, mottling, deformation and occasionally drying. Leaf symptoms include mottling with raised dark green areas and some distortion on youngest leaves. Mottling is most severe at high temperatures. Leaf symptoms first appear on crown leaves which turn downward, become rough, crinkled and may curl downward at the margins. Young leaves that develop on plants with severe symptoms may show yellow to white areas with small dark green areas.

Fruit symptoms usually are absent. Occasionally fruit mottling, bronzing and internal browning develops.

Virus or herbicide injury !?!

Herbicides like 2,4-D cause severe crop injury in tomato plants. Symptoms are rather similar to those caused by mosaic viruses. Also, some herbicides used in rice for the control of broad-leaved weeds may be harmful to tomato plants when the rice straw containing herbicide residues is used as mulch or in compost.

Symptoms of 2,4-D injury include downward bending of leaves and growing points. New leaves do not expand normally; they are narrow and elongated, twist at the margin and have abnormally pointed tips.

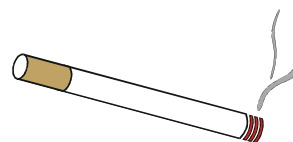
Sources of the herbicide, if not applied to the field directly, may be drift from a neighboring field, or soil, equipment, tools, clothing, etc. contaminated from a previous herbicide use.

However, some farmers in Vietnam use 2,4-D as growth stimulant in tomato. The herbicide is even applied directly on the fruit. Other growth stimulants such as HQ801 and Lendex are used a lot in tomato by Vietnamese farmers. IPM trainers have set up trials with farmers to study the effects of the stimulants or herbicides on crop growth and yield. They compare toxicity to the crop and costs of application. IPM trainers mention that such studies show that there is no need to use such products on tomato (pers. comm. IPM trainers PPD, Hanoi, Vietnam).

Source and spread

Seed and soil-borne left-overs from infected plants are major sources of infection. Seed from infected fruits and plants carry the virus. Virus particles can be present both inside the seed (where it is hardly possible to treat) and on the seed skin. TMV that is present in left-overs in the soil remains infective for about 2 years in dry soil and about 6 months in moist soil. The virus is especially well protected in thick roots from previously infected plants. The virus can persist in dried leaves for over 1 year.

Other virus sources include **infected weeds**, infected plant waste, contaminated clothing or tools and tobacco products used for smoking. The tobacco in cigarettes may contain virus particles that can spread to the crop when cigarette stumps are thrown in the field! **About 80% of cigarettes contain tobacco carrying the virus.**



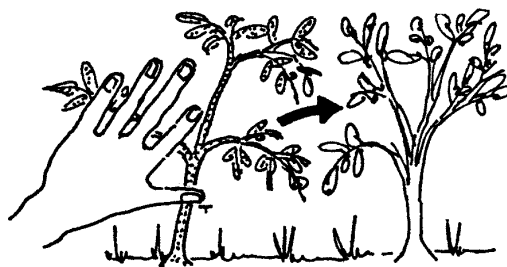


The TMV virus is transmitted easily with **mechanical means**. Merely brushing against a plant is enough to spread the virus! Most transfer probably occurs when young seedlings are transplanted into the field. Workers may carry the virus on their hands and clothing as they work with plants.

Virus spread from soil-borne **residue** to seedlings probably occurs through roots. The time from root infection to symptom appearance on leaves is about 3 - 5 weeks on seedlings and 4 to 13 weeks for plants at the 5 to 7 leaf stage. Upward movement of the virus in a plant is much slower than downward movement. When leaves are infected, the time from infection to symptom development may be as short as one week.

Spread by insects apparently can occur mechanically, for example by feeding grasshoppers but such spread is of minor importance.

Once a few plants are infected in a field, spread to other plants can occur very rapidly. Newly infected plants can be a source of virus for additional spread even before the symptoms appear.



Role of environmental factors

Exact environmental conditions that favor or inhibit TMV are not clear. It seems that different temperature and light conditions may cause different type of symptoms. For example when temperature is high, leaf mottling symptoms may be severe.

Importance - plant compensation - physiological impact

TMV causes reduction in fruit size and fruit number and consequent loss of yield.

Natural enemies/antagonists

In trials, a method to minimize the effect of TMV inoculation in greenhouses has been an early artificial infection of tomato plants with a selected weak strain of TMV that has little effect on plant growth and yield. This method can be successful because infection of a plant by one virus strain, in this case a weak strain, prevented or strongly inhibited infection by another, maybe more virulent, strain.

Management & control practices

Prevention activities:

- Resistance in tomato varieties has been reported, and it is common with hybrid varieties. However, this resistance may not be sufficient to suppress TMV infection because there are many strains of TMV and the variety may not be resistant against all of these strains. Also, it seems that the TMV can overcome the plant resistance fairly quickly.
- The use of clean seed is an obvious, and very important prevention method. Seed should not be used of plants/fruits that are suspected of any disease (including diseases other than TMV). Seed treatment is quite complicated and requires some fairly high-tech equipment as it involves several chemicals and/or a dry-heat treatment for a long period in a special oven (to kill internal seed-borne TMV). Since the level of TMV drops rapidly after the seeds are extracted from the tomato



fruits, a more easy method could be to use only seeds that are 2-years old. However, viability of seed germination percentage decreases in time! Plant susceptibility increases with plant age. Seedlings should therefore be transplanted as early as possible.

- To reduce the importance of soil-borne infective left-overs, a crop rotation schedule of 2 year without susceptible crops is recommended in areas where TMV is a serious problem.
- Proper field sanitation, including the removal of the old tomato roots, is important to reduce the inoculum. Also, removal of waste piles and other crop left-overs piles close to the field can be valuable. Removal of weeds (that may harbor TMV) is another good sanitation practice.
- Ensuring that field workers do not smoke when handling plants, and do not waste cigarette stumps in the field can help avoiding the spread of TMV.
- Personal sanitation: once a person has handled a virus infected plant, he should wash well because his hands and cloths are contaminated with virus particles.

Once there is an infection in the field:

- Uproot and burn virus infected plants. These plants may be a source for further spread of the disease when left in the field. Make sure to wash hands and cloths properly after handling TMV infected plants.
- Milk is known to kill the virus. It does not work as a spray application, but it can be used to disinfect hands and tools when working with plants. In many (European) countries, hands and tools are dipped into a milk solution every time a worker starts handling a new plant (e.g. for pruning or harvesting).
- When TMV is seen in the field, always harvest/manipulate the infected plants last of all plants, then destroy these plants.
- Soil sterilization is not recommended. Most soil sterilization methods are not completely effective against TMV as the virus can be protected in thick pieces of root and stem refuse in the soil. The virus can also be present in deeper layer of the soil, where it is difficult to contact.
- Note: there are no pesticides that prevent or cure virus diseases!



Points to remember about TMV:

- There are at least five different strains of TMV. They can affect many vegetable crops.
- Infected seed and plant left-overs are the major sources of infection. Tobacco (from cigarette stumps left in the field) can be another important source of infection.
- Resistant varieties are available but usually not against all TMV strains. Another important management practice is sanitation: use of clean seed, and removing infected plant material from the field.



8.2.4 Leaf curl disease

See plate 3 Fig. 13

Causal agent: virus - Tomato Yellow Leaf Curl Virus (TYLCV).

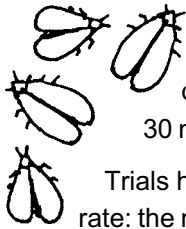
Signs and symptoms

Infected plants may be stunted, with rather erect, rigid leaves. The leaves remain small and leaflets are rather spoon-shaped, rolled or curled. Leaves have a yellow color between the veins. Symptoms appear especially on young leaves on the top of the plant. Plants may be excessively branched.



(Pandey, 1997)

Source and spread



The leaf curl virus is spread by the whitefly (*Bemisia tabaci*). Transmission of this virus goes quick: when the whitefly starts feeding on a tomato plant, the virus is transmitted within 15 to 30 minutes.

Trials have shown that there is a direct relation between the population of whiteflies and infection rate: the more whiteflies there are in the field, the more infection with leaf curl may occur. The virus is not transmitted mechanically.

Much of the initial infection may occur already in the nursery. Plants infected in the nursery become sources of virus which greatly favor disease spread within the crop after transplanting.

Role of environmental factors

Infection follows whitefly population: the larger the whitefly population is, the more problems there are with leaf curl disease. In Vietnam for example, leaf curl is most severe from October to November and March to April, especially when it is warm and sunny with not so much rain.

Importance - plant compensation - physiological impact

The effect on fruit-setting and consequent yield is particularly severe if infection occurs just before and during flowering. Yield losses of over 50% have been reported in certain tomato-growing areas.

Natural enemies/antagonists

Unknown.

Management & control practices

Prevention activities:

- Resistant varieties against leaf curl virus are not available at present.
- Controlling the whitefly is an important prevention measure against leaf curl. See section 5.2 on whitefly prevention and control methods.
- Barrier crops such as pearl millet, sunflower, sesame and sorghum may reduce leaf curl virus infestation in tomato. The barrier crop should be sown around main tomato fields at least two months before transplanting seedling in the fields.
- Proper sanitation practices help reduce the source of virus infection. This includes removal of crop residues and weeds. Leaf curl in tomato also affects weeds such as *Veronica cinneria* and *Cinderella nondifelora*.



Once there is an infection in the field:

- Uproot and burn virus infected plants. These plants may be a source for further spread of the disease when left in the field.
- Note: there are no pesticides that prevent or cure virus diseases !

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 left-overs, 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 left-overs away from the main field for destruction, decomposing or as food for farm animals. When placed on a compost pile, cover the plant material with a layer of soil or straw. Wind-borne diseases such as late blight can still infect the field from a compost pile !



Points to remember about leaf curl disease (TYLCV):

1. Leaf curl disease, caused by a virus, can cause yield reduction when infection occurs just before or during flowering.
2. Leaf curl disease is transmitted by whiteflies.
3. Control of whitefly is an important prevention and control practice (see section 5.2)
4. Removing and destroying all virus-infected plant material (including weeds) helps to reduce the source of virus infection.
5. Pesticides cannot prevent or cure virus diseases!

Related exercises from CABI Bioscience/FAO 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 left-overs 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
- 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 plate 3 Fig. 14 and 15

Causal agent: bacterium – *Ralstonia solanacearum* also called *Pseudomonas solanacearum*.

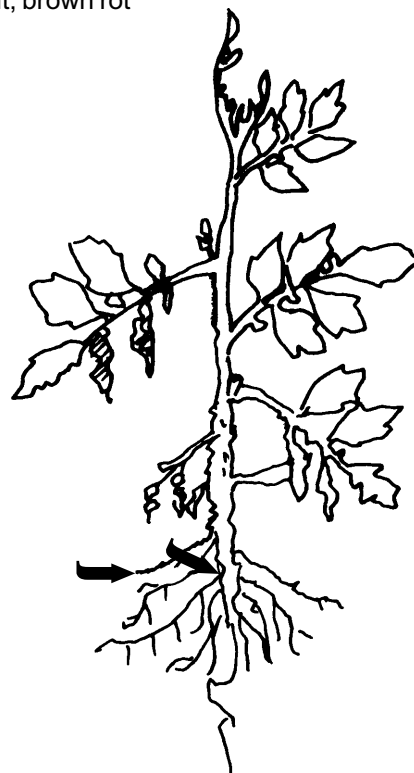
Other names for this bacterial disease are southern bacterial wilt, brown rot and blight.

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.



Bacterial wilt : the arrows show two possible sites for bacteria
(from Blancard, 1992)

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.

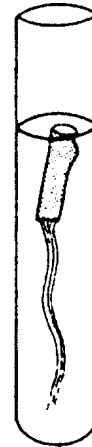
The bacteria enter plants through wounds made by tools, soil insects, broken roots on transplants and through natural openings where secondary roots emerge. Several nematode species that suck on the roots of plants such as the rootknot nematode (see section 8.1.3) can increase the incidence of wilt because 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 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: the 'oozing test'

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.



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 3.9.3.1).
- In USA, a non-pathogenic strain of *Pseudomonas solanacearum* is available as biocontrol agent. (www29)
- Several other antagonistic micro-organisms have been studied against bacterial wilt, such as *Bacillus* spp. (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 or tolerant varieties are available. However, there are different strains of the bacterium so varieties may give differences in actual resistance. 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 3.7.1.
- 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



microorganisms 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, www39).

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 with 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. Another example in the box below. 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 3.11.1.4)

Once there is an infection in the field:

- 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. A six-month rotation schedule was effective in Sri Lanka.

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 the need 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 tomato seedlings on resistant rootstocks (usually wild eggplant varieties, e.g. *Solanum torvum*). This means that initially both the rootstock and the tomato 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.
- 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, use of resistant varieties, 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 tomato plants.
4. Chemical control of bacterial wilt is not effective.
5. Biological control agents such as non-pathogenic *Pseudomonas* sp. may become available in Asia in the future.

8.3.2 *Verticillium* and *Fusarium* wilt

See plate 3 and 4 Fig. 16 and 17

Causal agents: 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. *lycopersici* (tomato), *F. oxysporum* f. sp. *melongenae* (eggplant) 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 tomato 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 fungus 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 as antagonists 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" (editor L.G. Copping, BCPC, 1998) or several internet sites such as [www25](#) and [www29](#) (see reference list, chapter 12).

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. ([www25](#); [www29](#))

Management and control practices

Prevention activities:

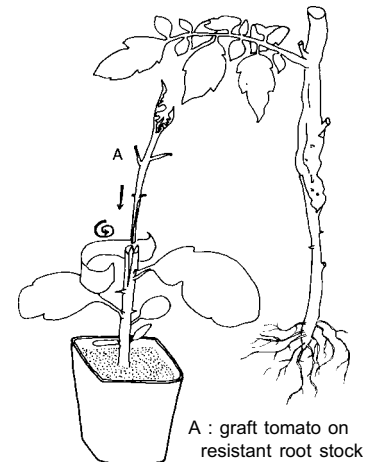
- Using resistant varieties is the best prevention of wilt disease. There are many resistant varieties of tomato available.



- Grafting: where soils are infested with fungal wilt organisms, there is an option to graft tomato 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 (resistant) is not affected by wilt diseases and the seedling will produce normal fruits.
- 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 3.4 and 3.7.
- 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 there is an infection in the field:

- 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 fungus 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.
- A soil pH of about 7 seems to be optimal to suppress this disease. See section 3.8.5. 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!



Grafting
(from Messiaen, C.M., 1992)



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 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.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
- 3-B.15. Grafting to overcome bacterial wilt in tomato or eggplant

8.4 Stem rot

There are several organisms that cause stem rot to tomatoes. 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 11.

8.4.1 Sclerotinia stem rot – *Sclerotinia sclerotiorum*

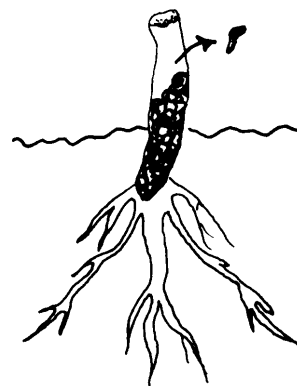
See plate 4 Fig. 18

Causal agent: 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, hard black, irregularly shaped bodies called *sclerotia* form on the surface or in the pith of the stem; they are diagnostic



Black sclerotia present mainly in the pith
(from : Blancard, 1992)



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. Seldom 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*, sold in USA 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 [www25](#) and [www29](#) (see reference list in chapter 12).



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) lower 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 3.11.1.2). 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. Frequent irrigation that keep plants wet for a long time must be avoided.



Points to remember about *Sclerotinia* stem rot:

- *Sclerotinia* stem rot can affect a very wide range of crops. In tomato, it causes stem rot at soil level.
- 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.
- Several biocontrol products such as *Trichoderma* sp. can reduce stem rot. Other biocontrol products may become available in the future.
- Cultural practices, such as sanitation by removing and destroying all infected plant material, and crop rotation, help manage this disease.

8.4.2 Southern stem rot – *Sclerotium rolfsii*

See plate 4 Fig. 19

Causal agent: fungus - *Sclerotium rolfsii*

English 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 form and color of these sclerotia are brown and look like cabbage seeds while the sclerotia produced by the fungus *Sclerotinia sclerotiorum* (see section 8.4.1 above) are numerous large black ‘resting bodies’. 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 deeper depths. 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, ammonium use seems to limit disease development. This may be related to slowed fungal growth, altered host susceptibility, or increased populations of antagonistic soil micro-organisms. 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 under section 7.10.1. Other biocontrol organisms may be effective. See under natural enemies section 8.4.1 above.

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 3.11.1.2) 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 is 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.



Points to remember about *Sclerotium rolfsii*:

- In tomato, *Sclerotium rolfsii* causes stem rot at soil level and rot of roots.
- 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.
- Several biocontrol products such as *Trichoderma* sp. can reduce *Sclerotium rolfsii*. Other biocontrol products may become available in Asia in the future.
- Cultural practices, such as sanitation by removing and destroying all infected plant material, and crop rotation, help prevent this disease.

8.5 Physiological disorders

Physiological disorders or non-parasitic diseases are caused by adverse environmental conditions. Major causes of these disorder include excessively high or low temperatures, soil-moisture disturbances, sun burn, pesticide burn, and deficiency or excess of a fertilizer/nutritional element.

Some common physiological disorders for tomato are listed below.

8.5.1 Blossom-end rot

See plate 4 Fig. 20

Causal factor: Calcium deficiency during fruit formation

Signs and symptoms

Blossom-end rot usually appear on developing green fruits. The earliest symptom is a small brown spot at the blossom end of fruit. This spot gradually expands and becomes a large dry brown to black, and often sunken, leathery area. The affected area shrinks and causes misshapen fruits. Only some fruits on a plant may be affected. Green as well as ripe fruits may be affected.

Causal factors

Blossom-end rot is associated with calcium deficiency during fruit formation. Calcium moves only in water-conducting tissues of the plant. When water movement into the tomato fruit is restricted, a localized calcium deficiency often develops at the blossom end. This area fails to fill out and eventually appears sunken and black. A number of environmental and cultural problems can cause calcium deficiency



which leads to blossom-end rot in tomatoes.

Calcium deficiency usually results from excessive nitrogen fertilization, rapid plant growth and drastic fluctuations in moisture as caused by heavy rainfall, drought and poor pruning during cultivation. Water stress is one of the most important causal factors. It is usually the fruits on the first trusses which are affected.

Management & control practices

Control of the disorder consist of avoiding the conditions which are causing calcium deficiency during fruit formation. This may include the following activities:

- Ensuring regular and even irrigation. The incorporation of organic matter and compost into the soil will help stabilizing soil moisture. Mulching with organic material, which reduces the fluctuations in soil moisture and temperature, will help preventing blossom end rot. Do not plant tomatoes where drainage is poor, surface water accumulates, or soil is droughty.
- Using only moderate amounts of additional fertilizers to keep plants normally green and vigorous but not luxuriant.
- Liming to adjust the soil pH to an optimum range between 6.8 to 7.2. This practice is reported to reduce blossom end rot incidence. The lime should be mixed thoroughly in the top layer (up to about 30 cm) of the soil. Soil liming should normally be done at least a month before transplanting tomato seedlings. See also section 3.8.6.
- When symptoms of blossom end rot are detected, some countries recommend spraying the leaves and fruit with a calcium chloride solution. Apply two or more sprays at 1-week intervals. This may prevent more fruits being affected with the symptoms but will not cure the fruits already affected. The spray may cause some injury to the margins of the leaves.
- If serious problems with blossom-end rot occur, try growing another variety that may be less susceptible.

Table 8.5.1 Blossom end rot: some common problems and prevention

Problem	Prevention
During the first 14 days after fruit set, <u>water uptake is restricted</u>	<u>Regular watering, good drainage</u> and mulch are good preventative measures.
Rapid evaporation. This can happen rain, humid weather follows a dry, hot period.	Adequate irrigation should help.
High soluble salts and high cation (potassium, magnesium or ammonium) levels in the soil out-compete <u>calcium</u> on soil exchange sites, making it <u>unavailable to the plant</u> .	Monitoring soil soluble salts and cation ratios, and maintaining adequate Ca in the soil should help. Avoiding ammonium-forms of nitrogen fertilizers can also help.
Soil pH is below 5.5 or there is inadequate calcium in the soil.	Regular soil testing should reveal potential problems.
Fruit growth is so rapid that calcium import cannot keep up.	Maintain uniform growth.

(from: Peet, www42)



8.5.2 Sunscald

See plate 4 Fig. 21

Causal factor: sudden exposure of fruit to direct sunlight (scorching)

This is a common disorder particularly during hot and dry weather.

Signs and symptoms

Sunscald is most prevalent on green fruits. It appears as a whitish or yellowish area on the side of the fruit towards the sun. When sunscald is severe, the affected area becomes dry and papery. Eventually, secondary infection may occur with pathogens causing soft-rot.

Causal factors

The damage is caused by an excessive exposure to bright sunlight. This might follow defoliation by insects or by diseases. Movement of foliage during picking may also provide conditions favorable for sunscald.

Management & control practices

In very sunny climates/seasons, tomato plants should have leaves to protect the fruits from sunburn. The best prevention is to protect against defoliating diseases and leaf-eating pests, but less severe pruning and closer spacing will also increase foliage cover.

8.5.3 Cracking of fruits

Causal factor: fluctuation of moisture and temperature

Signs and symptoms

Cracking of the surface of the fruit at the stem end is a common occurrence and can result in serious quality loss of the fruits. There are three types of growth cracks. With all three types, there is considerable variation between cultivars in susceptibility.

1. Concentric cracking: Rings of brown scar tissue encircle the stem end of the fruit. When water droplets on the shoulder of the fruit are exposed to bright sunlight (burning effect).
2. Radial cracking: Susceptibility to this type of cracking increases with ripening. Deep v-shaped openings start at the stem end and sometimes extend almost to the tip. Typically this disorder appears after rain when plants grown in dry soil suddenly experience high moisture levels. Radial cracking can also result from overwatering.
3. Russetting: Brownish scar tissue (callus) develops over microscopic tears in the tomato skin, giving the fruit a rough, clouded appearance. Russetting most often develops in very humid conditions.

Radial cracking is more common and causes greater loss than concentric cracking.

Causal factors

Several environmental factors seem to be involved in the cracking. Fruit cracking is promoted by fluctuations in moisture and temperature. This is often seen when varieties developed for hot, arid climates are exposed to or grown in humid, wet conditions.



Fruit cracking is common during rainy season when temperature is high, especially when rain follows long dry spell. Radial cracking is more likely to develop in fully ripe fruit than in mature green fruits. Fruits exposed to sun develop more concentric cracking than those which are covered with leaves.

Management & control practices

There are differences in susceptibility between tomato varieties. Main prevention activities of fruit cracking include ensuring uniform moisture levels in the soil and not pruning too many leaves at one time. However, especially during the rainy season, and when rains follow a longer dry period, fruit cracking cannot always be avoided.

8.5.4 Healthy plants but no flowers

Causal factor: too much water and nitrogen at the early growth stages

If the tomato plant is very healthy, has many leaves but it does not produce any flowers, the problem is too much water and nitrogen at the early growth stages. Too much nitrogen and too much water stimulates vigorous leaf growth but delays the reproductive growth stage. Avoid use of excessive nitrogen fertilizer and water to induce flowering.

8.5.5 Blossom drop

Causal factor: poor pollination due to extreme temperatures

Flowers that have not been pollinated, drop off naturally. No fruits can form if no pollination has occurred. Temperature is an important factor in pollination. At night-time temperatures below 12°C germination and tube growth of the pollen are so slow that blossoms can drop off before they can be fertilized. As a rule, most early maturing varieties set fruit at lower temperatures than the main-season varieties. Fruit set can also be hampered by rain and prolonged humid conditions or by very dry periods, and very high temperatures.

8.5.6 Poor fruit color

See plate 4 Fig. 22

Causal factor: high temperatures

In hot-summer areas, high temperatures can prevent the normal development of fruit coloring. The plant's red pigment does not form when the temperature is above 30°C. Uneven coloring is common if fruits mature in high temperatures. Both high temperature and high light intensities will stop the color from forming in fruit exposed to the direct sun, and fruits may develop sunscald.

Where high temperatures are the rule, choose varieties with a dense foliage cover and do not intensively prune the plants.

8.5.7 Nitrogen (N) deficiency

Nitrogen deficient plants grow slowly. Leaves are small and light green, yellowish green or pale yellow. Leaves near the top will be yellow-green with purple veins. Stems are thick and hard. Flower buds turn yellow and drop off. Fruits may be small and pale green before ripening. Yields are reduced.



8.5.8 Phosphorous (P) deficiency

Plants deficient in phosphorous grow slowly and maturity is delayed. Seedling growth is stunted, especially during cool weather. Leaves become dark green with purple tissue between the veins on the underside of the leaf. Stems become slender, fibrous and hard.

Seedlings require a high concentration of P for normal growth.

At air temperatures below 15°C, growth is slowed. The underside of leaves can turn purple, resembling P deficiency but this is caused by the low temperature, not by P deficiency.

8.5.9 Potassium (K) deficiency

See plate 4 Fig. 23

Potassium deficiency causes a bluish green color of the leaves. Young plants have dark green leaves with small, short stems. The young leaves become crinkled and curled. In a field of potassium-deficient plants, the plant tips have a spiky appearance.

Older leaves are yellowish and bronzed; leaf margins become brown and tissues break down between the veins. Fruits of deficient plants drop off soon after ripening. Fruits of deficient plants ripen unevenly, giving a blotchy appearance. The flavor is acid.

8.5.10 Magnesium (Mg) deficiency

Lower and older leaves are first affected by Mg deficiency. Leaf veins remain dark green and areas between the veins become bright yellow. This coloration progresses rapidly to the younger leaves. In severe cases, the fruits show pronounced "green back" with a hard yellow or orange area at the stalk end of the mature fruit.

Nitrogen deficiency intensifies the development of Mg deficiency. Mg deficiency is also liable to appear where the potassium content of the soil is high. In such cases, potassium applications should be temporarily reduced.

In severe Mg deficiency cases, application of magnesium sulfate at the rate of about 1 kg/m² could give sufficient control. Check with local providers for the appropriate dose and application method.



9 WEED MANAGEMENT



SUMMARY

A good weed IPM program is one that will *manage* existing weeds economically and *prevent* a buildup of weed seed or tubers, rhizomes, etc. in the soil.


The most important time to keep the field free of weeds for tomato production is generally in the first 4 to 5 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. Weed prevention practices are listed in section 9.4. Use of herbicides alone is usually not the most economical weed control. Good cultural and crop management practices, are the backbone of any weed management program. 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 a tomato field are usually unwanted because they compete with tomato plants 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 3.9.3.2).

There are also weeds that have a medicinal use. Under certain circumstances, weeds may have a beneficial effect in preventing soil erosion. And, very important, some flowering weeds can be food sources for adult parasitoid wasps that feed on the nectar inside the flowers, and provide shelter places for predators and other beneficial insects.

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

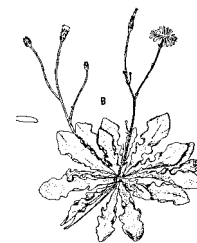
1. *Annual weeds*: these are the most common weeds that germinate, flower, produce seed and die within one year. In some cases annual weeds have several generations per year. Most are producing a lot of seed. The seed can remain viable for many years in the cool depths of the soil, ready to germinate 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.



broadleaf weed

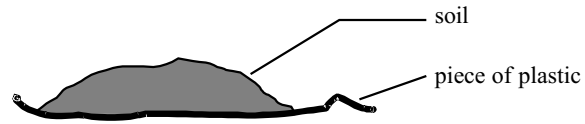


2. Grasses: seedlings have only one leaf. Next to grasses, other common weeds in this group are sedges and bamboo.



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 is a 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 pest management of weeds, 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 below.

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.

The critical weed-free period concept, does not mean that weeds can be ignored except during 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 tomato. (Peet, www6).

9.4 Prevention of weed problems: some tactics

"The best control is prevention" is also valid for weed management.

Some tactics for weed prevention:

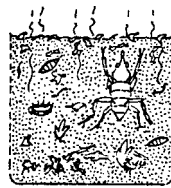
- Crop rotation is an effective practices for long-term weed control. Crop rotation alone is usually not sufficient to control weeds, but it does introduce conditions and practices that are not favorable for a specific weed species, reducing growth and reproduction of that species. Crop rotation provides 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. A 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 weed 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 3.9.3.4.
- 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 contains weed seed.

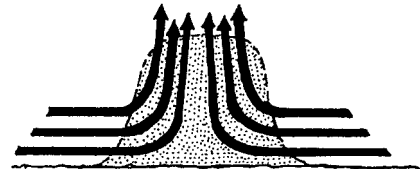




- Using cover crops to smother weeds is another widely used cultural practice. Cover crops can either be planted ahead of the vegetable crop, or they can be seeded at the same time the crop is planted to form a living mulch under the crop as it develops. Grasses, or legumes such as soybeans grown in narrow rows quickly form a complete cover, outcompeting weeds. See section 3.9.3.2 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 3.9.3.1 on compost.



*Temperatures of 45-65° C
kill most pest organisms*



*Temperature rising in a free
standing compost heap*

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. 😊

Some vegetables may also be sensitive to these residues. ☹️

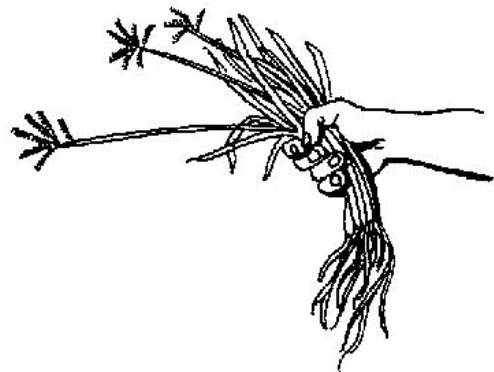
(Peet, www8).

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, www6; www8; www7; www9 and www20).

9.5.1 Physical control

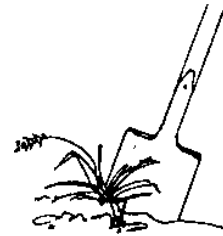
- Handweeding is the oldest, simplest and most direct way of controlling weeds. Weeding can be done by hand or with some kind of hoe or other tool which will cut off or uproot the weeds. Hoeing is useful where there is a large area to clear of annuals or when weeding is done around very small plants. 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 3.9.3.4 and 3.12.4.
- 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.

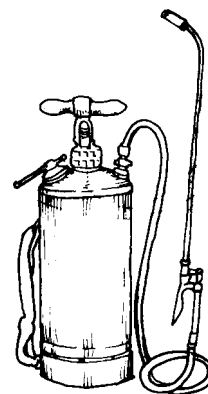


9.5.2 Chemical control

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 uptaken by the 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 tomato plants.

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 selective? 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! In some cases insect populations increase, and in other cases they decrease or



are not affected. The effects can be directly toxic, with herbicides applied during oviposition or early larval development. They can also be indirect as with populations of the egg parasitoid *Trichogramma* which were reduced after feeding on insects which had ingested the herbicide alachlor. In other experiments, aphid and thrips populations increased after herbicide use. Green peach aphids preferentially invade weed-free collard patches, probably because there were fewer predators than in more weedy areas.

(Peet, www6).

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 lady beetles 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.

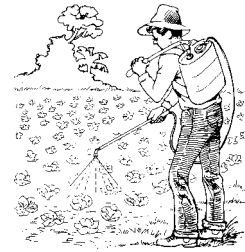
- Some herbicides are known to kill or severely limit the germination and growth of beneficial fungi in the soil, for example *Beauveria bassiana*, a fungus that can kill pest insects.
- Some herbicides are very persistent in the soil: they can stay in the soil for a long time. They may even stay active in the soil until after harvest and may cause damage to the next crop.
- Some herbicides can damage the crop, causing “burning” of leaves, when 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 on amount of pesticide and may save part of the beneficial population.

Dependence upon herbicides alone seldom provides the most economical 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.

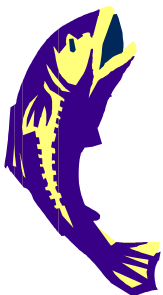
9.5.3 Biological control

Weeds, just like insects and pathogens, have natural enemies! These include insects, fungi and nematodes. Just like a tomato plant 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.

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. (www18).

Related exercises from CABI Bioscience/FAO manual:

2-C.7. Mulching of plant beds: organic and inorganic mulches



10 RODENT MANAGEMENT



SUMMARY

- Rats can be an important pest of vegetables in areas where vegetables are grown in rotation with rice, or in fields close to rice areas.
- Community involvement is essential for rat control.
- Rat control should be implemented continuously throughout the vegetable/ rice season.
- Rat management includes prevention methods (reducing habitat and cover), mechanical methods (direct killing in rat drives or traps), biological control (enhancing predators, possibly application of pathogens), and chemical baiting methods. All these methods should be used together. However, limit/restrict the use of chemicals because of possible side-effects to other animals and humans.



Rats are a common problem in agriculture, especially in rice. In areas where vegetable are grown in rotation with rice, or close to rice areas, rats can also migrate to vegetable plots and cause damage.

In recent years, rats have been an increasing problem for vegetable farmers, for example in Vietnam.

Several research institutes have been working on rat management more intensively in the last few years. The reasons they give for an increase of rat populations is the intensification of agriculture (more crops per year) combined with destruction of natural habitats for rats.

Many rat management programmes have been used to attempt to control rats such as rat drives, rat trapping, rat tail campaigns and burrow destruction. However, long-term rat control requires sustained interests and an understanding of the ways rats live. The focus of rat control must be on reducing yield losses. Several control methods should be used together for effective rat control.

Community involvement is very important for control of rats. Proper motivation and information should be supplied through various types of participation activities and media.



Community action is the key to rat management.

There are several species of rat. A very common species is the big field rat (*Rattus argentiventer*), and the focus of this chapter is on this rat.

10.1 Ecology of the field rat

Almost everyone knows what a rat looks like, but it is the behavior of the rat which is important to know. Rats are active mostly at night. The vision of a rat is not very good, and rats may not even be able to distinguish colors. But the senses of hearing, touch, smell and taste are very good. Rats need food and shelter to survive and reproduce. Understanding how they behave to find food and shelter helps in controlling rats.

Food

Food is one factor which determines rat reproduction. Field rats can reproduce when they have enough food from the different food groups: proteins, carbohydrates, minerals and vitamins. Reproduction is reduced substantially if there is a lack of one of these food groups in the diet of the rats. Because rats are eating food throughout the vegetable/rice season, the longer the crop season, the more rat litters are produced. Rats often travel 200-800 m to find food.

Habitat

Rats usually live in burrows in the ground, especially in rice bunds. But as the rice matures most rats live and move mostly in the open (rice) fields, often making nests right in the rice plants. You can find nests of field rats in the following places:

- Straw piles, weedy bunds or the center of the fields (if fields are dry)
- Burrows: Most female rats dig burrows to live when they are pregnant. Male rats rarely live in burrows. Some burrows are very simple like underground trenches with one entrance. Some burrows are relatively complicated with many entrances and exits. Exits are covered with a thin soil layer.



Water

Water is a limiting factor for rat development. Rats reproduce much more in dry fields than in fields with water. They do not reproduce when (rice) fields are flooded. During drought, there is a higher probability of rat outbreaks than in years when there is much rain.

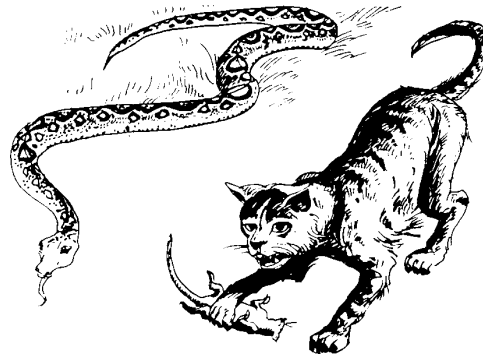
Rat movements

Rats will often travel the same route to the same feeding place each night. In some areas it is possible to distinguish rat trails where the rats pass very often.

It is necessary to study rat movements for decision making on suitable rat management methods. For example, in some areas with high rat populations farmers have experienced that rats are not attracted by the trap crop, i.e., that the number of rats trapped is low. In this case, it would be helpful for farmers to know that rats may travel to other places where there is more suitable food for their stage of development.

10.2 Natural enemies of rats

There are many animals that are natural enemies of rats. These include owls, cats, dogs, and many kinds of snakes (e.g. pythons). It is important to limit pesticide use which harm these natural enemies. For example, the use of rodenticides which rats may eat can consequently kill dogs that eat poisoned rats.

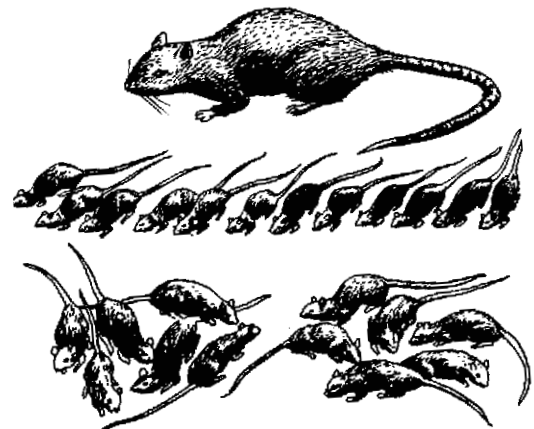


10.3 Rat damage and rat population dynamics

Rat development depends on many factors like food, habitat, water, and natural enemies. Among these factors, food is most important in determining rat population dynamics.

It is important to observe fields regularly for rat damage, and use the observations in decision making on what to do about rats. Rat populations can increase very rapidly. Besides the damage in the field, regular observations can be done by farmer groups on the development of rat populations. When observations are done on a regular base, they give farmer groups information on the changes in the rat populations, even if damage in the field is low. This can allow for timely action against rats, before populations get so high that damage in the field is occurring.

Rats reduce yields of plants by direct feeding on plant parts. Methods to evaluate damage in rice fields have been developed, for example by IRRI (International Rice Research Institute, the Philippines). This is not standardized for vegetable because of the large variety in vegetable crop, and the fact that rats usually are not a major pest in vegetables.



rat population growth in one year
(from Philippine Research Institute, 1993)



10.4 Rat management methods

Prevention activities

The best protection of the crop for rat damage is through early season control of rats. If rat damage was heavy in the previous season, rat control must begin at the beginning of the season and continue until crop maturity. Individual protection of fields by using a combination of plastic fences, habitat management, and baiting is possible, even if not all farmers in the area are cooperating in the rat control.

Before transplanting: Cut weeds along bunds and irrigation canals, looking for rat burrows which should be destroyed. Fumigation guns which use burning straw and sulfur are available in some areas for killing rats in their holes. If rat damage was very severe in the previous season, using an acute poison under the advice of a technician in the field and village areas, or rat drives to kill rats directly during the seedbed period will reduce populations significantly. However, initial investments must be followed by a sustained programme.

After transplanting: A sustained baiting programme is the best way for farmer groups to control rats. For sustained baiting, poisons which kill after several feedings are used. The rats must eat the poisoned bait for rats to die. Unlike other methods, many dead rats will not be accumulated in a short time because many rats will die inside the burrows. This may be a problem for some farmers who usually like to see the results of the baiting quickly. It is possible to demonstrate the effects of these poisons on captured rats and this may be necessary to convince farmers that these poisons are useful.

Community action: Group activities which emphasize participation and co-operation can be used to begin a programme of working together to control rats. Individuals cannot control rats alone on areas smaller than several hectares. Poster making by members of farmer groups are good activities to alert other farmers to proper sustained baiting programmes and other methods to prevent the build-up of rat populations.

It is always better for groups to participate in rat control programmes.

In some areas, planting at the same time may be possible. Areas which are planted and harvested together seem to have less rat damage than areas where rice (mainly rice because rats are usually connected to rice areas) is always available. This is because rats can migrate from field to field in areas with continuous planting and always find a good meal. In areas with simultaneous planting, the best meals are available a short period during the year. In population growth terms, more food - more rats, more continuous food - more continuous rats.

A number of other rat management methods are listed below.

10.4.1 Cultivation methods

- Cropping pattern : Use of cropping pattern which limits food supply and habitat for rats. For example, do not grow dry crops continuously. Do rotation cropping with rice.
- Timing of the season: Synchronize planting. Seeds should be sown at the same time and harvested at approximately the same time to limit continuous food supply and habitat of rats.
- Field sanitation: Cut weeds on bunds regularly, clean out bushes, level off hillocks and remove and destroy crop residues before the season and after harvest, to limit rat habitat.
- Cultivation technique: Limit high and large bunds. Irrigating fields limits and narrows down rat habitat which facilitates rat management.



10.4.2 Mechanical methods

- **Traps:** Make use of all kinds of existing traps, simple to complicated ones, cheap, easy to find, effective in catching rats (live traps, snap traps, etc.). Experience sharing and training should be conducted on how to make traps, set up traps, prepare baits to increase effectivity of traps as a management method.
- **Rat drives:** Use dogs to hunt rats. Combine with burrow digging, fogging and driving to catch rats. In Vietnam, for example, farmers make plastic fences around fields, put the traps at the end, and make noise so the frightened rats run into the traps.
- **Burrow digging, fogging and flooding:** Mobilize many people as in a campaign. Conduct burrow digging, fogging and flooding regularly combined with other methods to achieve more effect. It is necessary to train and guide people in using these methods to protect the irrigation system.
- **Plastic fences:** Put plastic fences around the field bunds (about 50 - 100 cm high) to prevent rat damage. It is very easy to do but it requires much investment for materials.
- **Trap crop:** Combine plastic fences and traps with early crop to catch rats. This method is effective but costly and should have the participation of the community.
- **Torches and scoop nets:** In general, rats have poor eyesight. At night, blinded by light from the torch, they move badly. You can hit them to kill or use scoop nets to catch. This method is not popular and can only be used by people with the necessary equipment and experience.
- **Sticky glue:** Put the sticky glue along routes where rats often cross/pass. In the middle of the trap put baits to attract rats. This method is effective when used in houses or in store houses.



rat trap

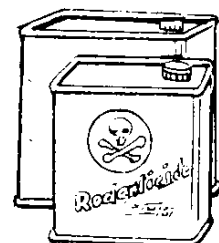


baiting

10.4.3 Chemical method

Rats can taste food without putting the food in their mouth because their teeth stick out so far. Rats are very suspicious of new places and foods. When using poisons which kill after one feeding (acute), it is important to remember that rats will taste the food before regularly feeding. This is why acute poisoning methods recommend putting out unpoisoned bait for 5 days before putting out poisoned baits. The rats 'learn' that good food is readily available at a particular place, and will visit for several days eating the bait. By the time poisoned bait is placed, the rats already are happy to eat a lot. If poisoned bait is placed directly in the bait holder, the rats will try a little bit of the food, get a sick stomach, recover, and never go back to the bait again. It is the same as trying a new restaurant. If the food is good we visit again. If we get sick from the food, we never go back..

- **Acute poisons:** Zinc Phosphide (20%) can be used to kill rats. This method can kill rats fast and is highly effective at first use. But it is **very poisonous for people** and warm-blooded animals. Baits mixed with poisons should be changed regularly to increase effectivity.
- **Chronic poison** (slow action): This poison often uses anti-coagulants such as Klerat. Rats die slowly and they are less fed up with baits. It is less poisonous for people and warm-blooded animals compared to acute poisons.
- **Chemicals for fogging rat burrows/nests:** Use sulfur (SO_2) and calcium carbide to fog the rat burrows/nests. Put sulfur or a piece of calcium carbide about 100 - 200 grams. Pour water and close the burrow by soil or clay. Calcium carbide or sulfur gas will kill rats. This method can be applied only to loamy soil with few cracks or in sandy soil. In the dry season it is less effective.





Chemical methods are often used especially in rat campaigns or when rat populations are high because at that time we should reduce rat populations in a short time. However, limit use of chemicals, especially acute poisons, because they are harmful to people and animals!

10.4.4 Biological and botanical methods

Natural enemies of rats:

- Encourage and help farmers raise cats. Limit use of rodenticides which causes death of natural enemies like cats when they eat poisoned rats.
- Disseminate information on problems brought about by hunting, killing and eating natural enemies of rats such as cats, snakes, and owls.
- Advocate for laws and decrees which favor the restoration and protection of natural enemies of rats. For example against their selling and exportation.
- Advocate for laws and decrees which support the implementation of management methods for rats.

Micro-organisms:

Some micro-organisms can cause infectious disease that kill rats. Advantages and disadvantages are summarized in the following list.

Advantages	Disadvantages
<ul style="list-style-type: none">• Kills rats on a large scale at the same time.• Mostly safe for humans, other animals and the environment.• Considerably reduces rat populations and its damage over long periods of time	<ul style="list-style-type: none">• Expensive.• Short shelf life/storage period (the time it keeps its potency).• Does not cause immediate death (rats die from 4 - 14 days after eating) so farmers do not like to use.• Use in the field is very much affected by weather conditions

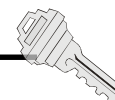
Use of preparations with micro-organisms will be more successful if the following are considered:

- Avoid using in weather conditions such as scorching sun or heavy rains.
- Use at the same time on a large area.
- Use recommended dosage of 3 - 5 kg/ha or higher, depending on rat density. Concentrate on edges of large fields, hillocks/earth mounds, bushes, cemeteries, etc., where rats usually dig burrows. If an under dose is used, the effectivity cannot be guaranteed.
- Should not be used more than twice a year in one place.
- Apply when food is not available in the field. Rats will eat more baits.

Botanicals

Following traditional experience, use seeds of *pachyrrhizus*, *nux vomica* for poisons. Care must be taken when these are used because they are **very poisonous for humans** and animals.

(modified from: FAO - Vietnam National IPM Programme, Hanoi. Integrated Rat Management, 1998; and FAO - Vietnam National IPM Programme, Hanoi. Integrated Rat Management, Ecological Guide, 1998).



11 KEY TO SOME COMMON TOMATO PROBLEMS

Affected plant part	Symptoms/findings	Possible cause(s)	See section
Fruit	Holes in fruit	Tomato fruitworm (<i>Heliothis armigera</i>)	5.1
Fruit	Fruit spots develop into brown to black leathery sunken areas, often with dark concentric rings.	Root rot (<i>Phytophthora</i> sp.) Early blight (<i>Alternaria solani</i>)	8.1.2 8.2.1
Fruit	Fruits have green or brown water-soaked spots	Root rot (<i>Phytophthora</i> sp.) Late blight (<i>Phytophthora infestans</i>) Blossom-end rot	8.1.2 8.2.2 8.5.1
Fruit	Fruits have dry, papery spots	Sunscald	8.5.2
Leaf	Holes in leaves	Tomato fruitworm (<i>Heliothis armigera</i>)	5.1
Leaf	Leaves turn yellow	Whitefly (<i>Bemisia tabaci</i>)	5.2
Leaf	White spots on and/or mines in leaves	Leafminer (<i>Liriomyza</i> sp.)	5.5
Leaf	Leaves have black or brown, irregular shaped, spots or dead areas	Pesticide burn Sunburn Root rot (<i>Phytophthora</i> sp.) Late blight (<i>Phytophthora infestans</i>) Early blight (<i>Alternaria solani</i>) <i>Verticillium/Fusarium</i> wilt	- 8.5.2 8.1.2 8.2.2 8.2.1 8.3.2
Leaf	Leaves are mottled with raised dark green areas	Tomato Mosaic Virus (TMV)	8.2.3
Leaf	Crown leaves turn downward, become rough, crinkled	Tomato Mosaic Virus (TMV) Leaf curl virus (TYLCV) Potassium deficiency Herbicide injury (2,4-D)	8.2.3 8.2.4 8.5.9 8.2.3
Leaf	Yellowing of leaves	<i>Verticillium/Fusarium</i> wilt Southern stem rot (<i>Sclerotium rolfsii</i>) Nitrogen deficiency Magnesium deficiency	8.3.2 8.4.2 8.5.7 8.5.10
Leaf	Leaves have a purplish color	Phosphorous deficiency	8.5.8
Roots	Enlargements (galls) on roots	Rootknot nematodes (<i>Meloidogyne</i> sp.)	8.1.3
Roots	Roots are softened, rotting	Southern stem rot (<i>Sclerotium rolfsii</i>) Root rot (<i>Phytophthora</i> sp.)	8.4.2 8.1.2
Seedling	Stems of seedlings in nursery or young plants in the field are cut through at soil level	Cutworms (<i>Agrotis</i> sp.) Mole cricket	5.3 -
Seedling	Seedlings in nursery wilt and fall over from one day to the other	Damping-off (<i>Pythium</i> sp.)	8.1.1
Seedling	Dark spots develop on the cotyledons (seed leaves), stem and true leaves	Early blight (<i>Alternaria solani</i>)	8.2.1
Stem	Stems are hollow at soil level or just below soil level	Cutworms (<i>Agrotis</i> sp.)	5.3
Stem	At soil level, soft, water-soaked spots occur, causing the plants to wilt and die	Root rot (<i>Phytophthora</i> sp.) Sclerotinia stem rot (<i>Sclerotinia sclerotiorum</i>)	8.1.2 8.4.1
Whole plant	Plants are defoliated	Armyworm (<i>Spodoptera</i> sp.)	5.4
Whole plant	Plants are excessively branched	Varietal characteristic Leaf curl virus (TYLCV)	- 8.2.4
Whole plant	Plant wilts	Water shortage Whitefly (<i>Bemisia tabaci</i>) Root rot (<i>Phytophthora</i> sp.) Rootknot nematodes (<i>Meloidogyne</i> sp.) Bacterial wilt (<i>Ralstonia solanacearum</i>) <i>Verticillium/Fusarium</i> wilt Sclerotinia stem rot (<i>Sclerotinia sclerotiorum</i>) Southern stem rot (<i>Sclerotium rolfsii</i>)	- 5.2 8.1.2 8.1.3 8.3.1 8.3.2 8.4.1 8.4.2
Whole plant	Starting with older branches, the whole plant wilts. Root development on the main stem, hollow stems, oozing, rotting and dark coloured patches on stems.	Bacterial wilt (<i>Ralstonia solanacearum</i>)	8.3.1



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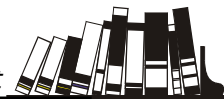
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