Cabbage
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 CABBAGE

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 Cabbage IPM Ecological Guide dated June 1996.

The objective of this ecological guide is to provide general technical background information on cabbage 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.
1.1 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 150 FFSs in the period winter 1996 to summer 1999, was only 40% of that of untrained farmers. Yields of cabbage in the same period were slightly higher (about 6%) in the IPM field 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 IPM in Vegetables in South and Southeast Asia has branched off from the Inter-Country Programme for IPM in rice in South and Southeast Asia. This programme, on rice IPM, has been running for many years and has trained thousands of trainers and nearly one million rice farmers in Asia.

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 Cabbage: a bit of history

The Latin name for cabbage is *Brassica oleracea* var. *capitata*, member of the family Crucifers.

Similar to many other vegetables, cabbage is not indigenous to Asia. It originates in Western Europe, with temperate climates. A kale-like ancestor was grown in gardens as far back as the time of the Roman Empire. In Europe, cabbage gardens were very important food sources during the Middle Ages.

It is not exactly known how cabbage and other vegetables came to Asia. However, some literature references mention European vegetables in Asia. For example, Sir William Baker, Governor of Ceylon for 7 years in the middle of the last century, mentioned that potatoes and other European vegetables were already cultivated around the Hill Station Nuwara Eliya specializing in the cultivation of European vegetables. These included potatoes, cabbage and leeks. Until the end of World War II European vegetables were mainly grown to supply the European communities and for ships stopping in the harbour of Colombo and Trincomalee.

A similar development could be seen in the Nilgiri Hills in India and the Cameron Highlands in Malaysia. (Baker, 1966; Senewiratne and Appadurai, 1966; Macmillan, 1936)

Most cole crops are in the species *Brassica oleracea*. Differences in morphology between cole crops are undoubtedly the result of early selection by farmers for various edible parts. This selection is easy because all cole crops can be crossed and many are self-incompatible (i.e., flowers cannot be fertilized by pollen from the same plant). These characteristics have made it easy to select for new types of cole crops. Self-incompatibility also makes hybrid seed production economical.
SUMMARY
This chapter describes general growth stages for cabbage. 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 cabbage 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 cabbage growth stages like there is for rice. Although terms such as “head formation” and “cupping” do exist, it can be confusing because this terminology is often regional and can vary among farmers and others involved in agriculture. Accurate cabbage growth stage descriptions are particularly useful in pest management since plant susceptibility to cabbage pests varies with the growth stage.

As an example, this chapter describes cabbage growth stages as they are used in the U.S.A. It also lists the susceptibility of these growth stages to injury from various insect pests and diseases. The growth stages below can used to develop, with farmers, a more appropriate growth stage description or cropping calendar for a specific area, based on locally used classification.

(modified from Andaloro, J.T. et al, 1983)

2.1 Cabbage growth stages

**Stage 1**: Cotyledons (seed leaves).
No true leaves present.

**Stage 2**: Seedling
Up to 5 true leaves.

**Stage 3**: 6 to 8 true leaves
ready for transplanting

**Stage 4**: 9 to 12 true leaves.
Base of stem still visible from above.

Stage 5: **Precupping**. Approximately 13 to 19 leaves. By the end of this stage, the base of the stem and the bases of all leaves are concealed when the plant is viewed from above. The innermost heart leaves are growing in an upright fashion and are visible without moving any of the surrounding leaves.
Stage 6: **Cupping.** Approximately 20 to 26 leaves. The innermost heart leaves, which are still growing in an upright fashion, are concealed by the larger, older leaves surrounding them. All visible leaves will later become the frame leaves (leaves not touching the mature head) of the mature plant.

Stage 7: **Early head formation.** Head diameter will be approximately 10 cm. The inner heart leaves, now quickly developing as a ball-like structure of overlapping leaves, are concealed by the surrounding larger leaves. These leaves do not press tightly against the developing head and will later unfold to become frame leaves.

Stage 8: **Head fill.** Head diameter will be approximately 10 - 20 cm. A firm round head is visible within the wrapper leaves (the 4 outer loose leaves that touch the mature head). The head has not yet fully developed and thus, is not of harvestable size.

Stage 9: **Mature.** Head diameter will be approximately 15 - 30 cm. No new visible leaf production will occur after the head has attained maximum hardness and size. The head is ready for harvest and may split if not harvested in time.
2.2 Susceptibility of growth stages to cabbage pests

Whether various pest and disease species that attack cabbage plants will cause yield loss depends partly 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. Spraying a fungicide to control a slight *Alternaria* leafspot infection occurring at the older leaves, is simply a waste of money.

For fresh market cabbages for example, the quality could be reduced if even slight injury occurs on the wrapper leaves or the head. In earlier stages, stages 1 to 6 however, the wrapper leaves are not yet present and injury need only be prevented if a loss in head weight (yield) is expected. The cabbage plant can compensate for a lot of injury by producing more leaves.

In the TOT and FFS, studies on defoliation and removal of the growing point can be conducted to obtain information about compensation ability of the cabbage plant. An example is given in the box below.

**Compensation study result from Ban Nongkeo, Vientiane, Lao PDR**

During a field study by farmers of the village of Ban Nongkeo, farmers defoliated cabbage plants for 25% and 50% at both 14 and 28 days after transplanting (DAT) and looked at resulting yields compared to an undefoliated control. Defoliation simulates the effect of leaf damage due to leaf-eating insects like diamondback moth.

Farmers found that all 4 defoliation treatments had no effect on yield compared to the control, in fact, yields were the same or slightly higher in the treatments. Farmers concluded that limited defoliation in the first month after transplanting did not affect yield.

(from: FFS on IPM in tomato and cabbage, Lao PDR, Nov 98 – Mar99).

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

**Always analyse all components of the agro-ecosystem and their interactions when making crop management decisions!**

The following table (2.2) shows when potential injury from common cabbage pests and diseases may occur at specific growth stages. Please note that these are general values. There may be considerable difference in each region!
### Table 2.2: Susceptibility of growth stages to cabbage pests

<table>
<thead>
<tr>
<th>growth stage</th>
<th>pest/disease</th>
<th>cotyledon</th>
<th>seedling</th>
<th>6-8 true leaves</th>
<th>9-12 true leaves</th>
<th>precupping</th>
<th>cupping</th>
<th>early head formation</th>
<th>head fill</th>
<th>mature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Damping-off</td>
<td>(Pythium sp.)</td>
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<tr>
<td>Flea beetles</td>
<td>(Phyllotreta sp.)</td>
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<tr>
<td>Cutworm</td>
<td>(Agrotis sp.)</td>
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<td>Black leg</td>
<td>(Phoma lingam)</td>
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<tr>
<td>Black rot</td>
<td>(Xanthomonas sp.)</td>
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<tr>
<td>Diamondback moth</td>
<td>(Plutella xylostella)</td>
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<tr>
<td>Webworm</td>
<td>(Hellula sp.)</td>
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<tr>
<td>Cabbage worm</td>
<td>(Pieris sp.)</td>
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<td>Stemborer</td>
<td>(Melanagromyza sp.)</td>
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<tr>
<td>Downy mildew</td>
<td>(Peronospora sp.)</td>
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<tr>
<td>Clubroot</td>
<td>(Plasmodiophora sp.)</td>
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<tr>
<td>Aphids</td>
<td>(Brevicoryne sp.)</td>
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<tr>
<td>Cabbage looper</td>
<td>(Trichoplusia ni)</td>
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<td>Armyworm</td>
<td>(Spodoptera sp.)</td>
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<tr>
<td>Heart caterpillar</td>
<td>(Crocidolomia sp.)</td>
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<td>leaf spot</td>
<td>(Alternaria sp.)</td>
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<tr>
<td>Soft rot</td>
<td>(Erwinia carotovora)</td>
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<tr>
<td>Whitefly</td>
<td>(Bemisia sp.)</td>
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<tr>
<td>Bottom rot</td>
<td>(Rhizoctonia sp.)</td>
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</table>

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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 studies
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 and destroying all crop left-overs at the end of the season.
In this chapter, the major agronomic practices for growing cabbage are described. Agronomic practices differ in every country, region, and province, even within one village. This chapter gives general guidelines for growing cabbage based on the crop ecosystem. Examples of agronomic practices from several locations are given.

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

3.1 Climate

Cabbage can be grown both in temperate and in (sub)tropical climates. The best cabbage quality is usually obtained with cool daytime temperatures of 15 - 25°C, such as in tropical highlands. This is because cabbage originally comes from Europe, which has a temperate climate. See section 1.4. Nowadays, tropical lowland varieties are available that tolerate higher temperature values.

In the temperate zones, the cabbages are biennial. That means that after sowing, the plants first develop vegetative and after exposure to low temperatures, they pass into a generative phase in the second year during which they produce flowers and seed.

3.2 Selecting a variety

Variety selection is an important decision for profitable production. A large number of cabbage 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).

3.2.1 Hybrids and OPs

Many cabbage 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, with 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.

3.2.2 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.

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 cabbages 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 suitability to a specific climate/season, resistance/tolerance to insect pests and diseases, yield or other factors. Make sure to include the locally used varieties for comparison.
### 3.2.3 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 important because hybrid seed is often the most expensive input of cabbage production! Good quality seed will also be disease-free.

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 cabbage 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.

**Related exercises from CABI Bioscience/FAO manual:**

2-C.4  Testing of cultivars  
2-A.10 Test for seed germination

### 3.3 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 in cabbage are black rot (bacterium *Xanthomonas campestris*), Alternaria leafspot (fungus *Alternaria brassicae*) and black leg (fungus *Phoma lingam*).

Most seed companies do not normally treat cabbage seed. Only when a seed-borne infection such as black rot is suspected, seed lots may be treated (usually hot water treatment, sometimes by treating seed 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.

#### 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 3.7.1. and 3.12) to coat seed before sowing.
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 cabbage or other cruciferous crops for at least 2 years) and the use of resistant or tolerant cabbage varieties. See also sections 3.2 on variety selection, 3.4 on soil, 3.7 on nursery management, 3.12 on crop rotation, and box in section 3.4.3.

3.3.1 Hot water seed treatment

To kill most spores or bacteria attached to or within the seed, seed should be soaked in hot water at $50^\circ C$ 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 $50^\circ C$ on a small fire or burner. Carefully check the water temperature with a thermometer. Poor the $50^\circ C$ 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 3.3.2 below.

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

3.3.2 Chemical seed treatment

Many seed companies use chemical treatments, such as sodium hypochlorite, 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.
Unfortunately, chemical seed sterilization cannot guarantee that the seed are completely disease free. This is because some pathogens are present within the seed. An example is the bacterium black rot in cabbage. Chemicals only sterilize the surface of the seed and do not reach infections inside the seed. Research has shown that hot-water treatment can penetrate the seed sufficiently to eradicate bacterial infections inside the seed (Boucher, www24).

3.3.3 Botanical seed treatment

Seed can be protected from some soil-borne fungi and from cutworms by a coating with 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).

3.3.4 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.)” for details.

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, G.F. et al, 1998; USDA, www25).

Related exercises from CABI Bioscience/FAO manual:
2-A.10. Test for seed germination
2-A.11. Preparing seed for sowing
### 3.4 Soil

#### 3.4.1 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 3.5.3 on role of microorganisms.

**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 microorganisms),
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!
3.4.2 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).

Cruciferous crops grow well in any soil that is well-drained and moisture retentive. On heavy soils, plants grow slower but the keeping quality (shelf-life) of the cabbages is usually better.

A soil pH of 6 to 6.5 is optimal, although cabbage is sometimes grown at higher pH (pH >7.2) for clubroot control. Lower pH values reduce growth. See section 3.4.5 on soil pH.

A good site has not grown any cruciferous crops for at least two years. This reduces the chance of (soil-borne) diseases. See section 3.12 on crop rotation.

Related exercises from CABI Bioscience/FAO manual:
2-A.3. Soil structure and effects on root growth
2-A.8. Soil test kits

3.4.3 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 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 tools used in several fields, or with bits of soil on your slippers or shoes! They may also be spread with the ground water.
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 3.12).
2. Use of clean seed (see section 3.3).
3. Use of disease-free planting material.
4. Sanitation practices such as:
   - removal and destruction of left-over plant material 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 3.5.3).
6. Proper water management: mainly providing drainage to keep soil around roots from becoming waterlogged (see section 3.9).
7. Application of antagonistic fungi such as Trichoderma sp. into the soil. See section 7.10.

Pathogens are so small that they cannot be seen with the naked eyes. 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. See box above.

3.4.4 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 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 3.7 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 be protected inside plant waste, 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 3.7.1.4 and 3.7.1.5 for details on biofumigation and other options for biological soil sterilization.

3.4.5 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.

Next to this, the pH is important for growth of soil pathogens. Clubroot for example (see section 8.6) is most harmful in acid soils.

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, cabbage is sensitive to acid soils and will perform best in soil with a pH range of about 6.0 to 7.0. Cabbage is sometimes grown at higher pH (pH > 7.2) for clubroot control. Lower pH values will reduce growth.

### 3.4.6 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 with the provider how quick it acts and how it should be applied.
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 3.4.6

<table>
<thead>
<tr>
<th>Soil pH</th>
<th>Lime required (kg/m²) to raise to pH 6.5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Soil type: Sand</td>
</tr>
<tr>
<td>6.0</td>
<td>0.10</td>
</tr>
<tr>
<td>5.5</td>
<td>0.22</td>
</tr>
<tr>
<td>5.0</td>
<td>0.32</td>
</tr>
<tr>
<td>4.5</td>
<td>0.39</td>
</tr>
<tr>
<td>4.0</td>
<td>0.49</td>
</tr>
</tbody>
</table>

**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).
3.4.7 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 3.5.3.2.

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 3.5.3 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.

   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?

### 3.5 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. The importance of using organic fertilizer is strongly emphasized in this guide.

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 organic fertilizers such as compost or green manure, 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 (ref. www2).

#### 3.5.1 Macro and micronutrients

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

Secondary nutrients (calcium, sulfur, and magnesium) and micronutrients (boron, copper, iron, manganese, molybdenum and zinc and chlorine) are essential for growth, but required in smaller quantities than N, P, and K. Usually, secondary and micronutrients are lumped together under *micronutrients*, also called *trace elements*. Addition of micronutrients should be made only when a clear deficiency is indicated, preferably by a soil test analysis. See section 3.5.7 for fertilization needs of cabbage.
Some of the micronutrients are found in the mineral particles of the soil but most come from *humus*. Humus comes from the breakdown of organic matter. The micronutrients exist in very complex forms and have to be broken down into simpler forms which the plant roots can absorb. This process is comparable with the breakdown of leaves in the soil: slowly they will become soft, fall apart into very small pieces and eventually disappear. This breakdown process is done by micro-organisms, mainly bacteria that live in the soil. That is why it is important to stimulate the biological activity in the soil: it results in better soil fertility! To function effectively, the micro-organisms need air, water, neutral soil (pH 6 to 7.5) and lots of organic matter.

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

### 3.5.2 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 need 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.

### 3.5.3 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, and this affects the availability of nutrients in the soil. Soil that 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 of time, as the nutrients from the organic material will be released gradually.

**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 3.4.5 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* 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.

### 3.5.3.1 Compost

Composting is the most popular practice for improving soil fertility. Composting involves mixing various organic materials such as crop waste 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 macro elements N, P, K and many micronutrients. 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. It is therefore **cheap** to produce. Compost allows the use of materials such as domestic wastes and sawdust that otherwise tie up soil nitrogen.
Major Agronomic Practices

- **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. It is food for micro-organisms that make nutrients available by producing humus and by releasing nutrients from organic matter. See also section 3.5.3 above 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.

- **Nitrogen regulator**: compared to use of manure, compost prevents the loss of N through ammonia gas ($\text{NH}_3$) by fixing N into organic forms. However, some N is lost through $\text{NH}_3$ 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 ($\text{NH}_3$) 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 www1)

**How to prepare compost**

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

The simplest method for composting is to pile up organic domestic and field waste material, finally covering the pile with a layer of soil and possibly straw for insulation. Although many publications advise layering of materials, the best way is to thoroughly mix plant materials throughout the pile. Use equal proportions of dry and wet material. Dry material such as straw, sawdust, and corn stalks contain little water and decompose slowly but they provide air to the pile. Make sure that woody material is chopped into smaller pieces for quicker decomposition. Wet material such as fresh weeds, crop residue and fresh manure contain more water and decompose quicker than dry materials. Wet material contains 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
Major Agronomic Practices

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. 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 such as clubroot (Plasmodiophora brassicae) and bottom rot (Rhizoctonia solani). Temperatures around 80°C are needed to kill most weed seed.

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 moister than on flat soil.

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

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

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

Disease control with compost

An additional benefit of using compost is that it can reduce disease problems for plants. This is being studied for several years now because it offers an opportunity to further reduce fungicide use.

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

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

This type of suppression is effective on those pathogens that have small propagule (e.g. spores) size. Small spores do not contain many nutrients so for germination they need an external energy (carbon) source. Examples of this mechanism are suppression of damping-off and root rot diseases caused by Pythium species and Phytophthora species.
2) **Specific suppression**, on the other hand, is usually explained by one or a few organisms. They exert hyperparasitism on the pathogen or induce systemic resistance in the plant to specific pathogens, much like a vaccination. With specific suppression, the causal agent can be clearly transferred from one soil to another. Pathogens such as *Rhizoctonia solani* and *Sclerotium rolfsii* are examples where specific suppression may work but general suppression does not work. This is because these organisms have large propagules (e.g. spores) that are less reliant on external energy and nutrients and thus less susceptible to microbial competition. Specific hyperparasites such as the fungi *Trichoderma* and *Gliocladium* species will colonize the propagules and reduce disease potential (ref. www33).

Other biocontrol agents (or antagonists: for more information see section 7.10) that colonize composts include bacteria like *Bacillus*, *Enterobacter*, *Flavobacterium balusstinum*, and *Pseudomonas*; actinomycetes like *Streptomyces*.

These antagonists may appear naturally in compost. In some cases, antagonistic fungi or bacteria are added to the compost just after the hot phase, when the compost is cooling down. There are not many micro-organisms present inside the compost at that moment. When antagonists are added at that time, they can quickly build up their populations and this will result in compost with good disease suppressing quality. See box below.

**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-organism, 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.

**3.5.3.2 Cover crops / Green manure / Living mulch**

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

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

For a cover crop to be an effective fertilizer, it must also accumulate nutrients that would not otherwise be available to the following crop. Legume cover crops supply some or most of the following crop's nitrogen needs, but some other cover crops also increase plant nutrient availability. For example, buckwheat and sweet clover are able to accumulate phosphorus even in soils with low available phosphorus. Others may have root systems that go deeply into the soil. The decaying year after year of these deep roots leaves stores of organic matter into the soil. This type of deep fertilization cannot be duplicated in any other form so cheaply and easily! In general, cover crops need to be incorporated to speed up nutrient availability to the following crop (Peet, 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. cabbage, 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
- cowpea, grass pea, sweet pea
- clovers
- 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 3.7.1.4 and 3.7.1.4.

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 3.5.3.3 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 cabbage diseases, particularly weeds that belong to the family of Cruciferae.

Related exercises from CABI Bioscience/FAO manual:

2-A.5. Use of green manure

3.5.3.3 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 \( \text{NH}_3 \)) 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 and www1). Average nutrients available in manure from different sources, and from ashes are listed below.

### Table 3.5.3.3 : Average nutrients available in manure

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

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

- **Fresh manure may contain diseases** that tolerate the digestive passage (such as spores of clubroot in cabbage) and may contain insect larvae such as maggots which can destroy roots of cabbage plants. In fact, decaying manure attracts insects such as cabbage 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 cabbage may result in long, stretched plants which fall over easily.
- 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 3.7.1 on soil sterilization of nurseries.
- Decomposition process produces methane, a gas harmful to plant roots. Also see section 3.7.1 on soil sterilization of nurseries.
- Regular supply of fresh manure leads to lower soil pH.

### 3.5.3.4 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 Carbo/Nitrogen (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 3.5.3 above and box below.
### Effects of undersowing with clover on pest insect occurrence

Various studies report that when cabbage is intercropped with clover, fewer pest insects are found on cabbage plants in clover than on those in bare soil. The insect species reduced vary in every publication but in several studies, fewer flea beetles (*Phyllotreta* sp.), *Pieris* sp. and cabbage aphids (*Brevicoryne brassicae*) are mentioned. Some studies report reduction of diamondback moth (*Plutella xylostella*) but this is not consistent.

The number of natural enemies is usually higher in the undersown plots; especially syrphid flies and caterpillar parasitoids are found. 😊

A reduction in the weight of the cabbage heads is also regularly mentioned in the studies. 😊 (Wiech, 1993; Wiech, 1996)

However, a study from the Netherlands reported that although no pesticides were used and competition reduced cabbage head weight, the better quality of the intercropped cabbages (due to less pest injury) lead to a better financial result compared with the monocropped cabbage. (Theunissen, J. et al, 1995)

### 3.5.4 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), phosphorus (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.

### 3.5.5 Comparing organic and chemical fertilizers

When comparing organic and chemical fertilizers on the amount of nutrients they contain, the following points must be kept 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 the table below a list of the advantages and disadvantages of both fertilizers is given:

Table 3.5.5 : Comparing organic and chemical fertilizers

<table>
<thead>
<tr>
<th>Advantage</th>
<th>Organic fertilizer</th>
<th>Chemical fertilizer</th>
</tr>
</thead>
<tbody>
<tr>
<td>• rich in nutrients</td>
<td>• usually provide (part of) the micronutrients N, P &amp; K, and wide range of micronutrients</td>
<td>• high content of a few nutrients per volume unit (kg)</td>
</tr>
<tr>
<td>• usually provide (part of) the micronutrients N, P &amp; K, and wide range of micronutrients</td>
<td>• improves soil structure</td>
<td>• fast release of nutrients</td>
</tr>
<tr>
<td>• improves soil structure</td>
<td>• increases water holding capacity soil</td>
<td>• easy to determine dosage</td>
</tr>
<tr>
<td>• improves nutrient exchange system</td>
<td>• gradual release of nutrients</td>
<td>• easy to apply, not labour intensive</td>
</tr>
<tr>
<td>• stimulates activity of micro-organisms that make nutrients from the soil available to plants</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Disadvantage                                  | • organic fertilizers such as compost very widely in composition depending on the raw material used in their preparation | • usually very water soluble, may be washed away/drained off quickly during wet season |
| |                                                                                                                       | • expensive                                                                        |

3.5.6 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.

Field studies with foliar fertilizers in Dalat and Hanoi (Vietnam) showed a slight increase in yield but the economic efficiency was not clear (FAO- Updates on Vietnam national IPM programme in vegetables, 1999).

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.

3.5.7 Fertilization needs of cabbage

An indication for the amount of organic and inorganic fertilizers for cabbage are given in the table below. These guidelines are very general and the range in doses for the fertilizers is broad. The exact dosage to be applied depend on the nutrients already available in the soil (soil test service, see 3.5.2), soil type and structure, environment, etc. It is recommended to prefer organic above inorganic (chemical) fertilizers! When lots of organic matter is used regularly, the doses of chemical fertilizers can usually be (very) low, a lot lower than indicated in the table!

It is recommended to set up a field study to test different types and doses of fertilizers to check the best combination for your crop and field situation. In Dalat and Hanoi, Vietnam, for example, cabbage field studies showed that chemical fertilizers alone were not sufficient for good plant development. 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).
An example of a recommendation for total application of fertilizers for cabbage is:

Table 3.5.7 : An example of a fertilizer recommendation for cabbage

<table>
<thead>
<tr>
<th>Fertilizer</th>
<th>Total dose</th>
<th>Split applications</th>
<th>Method</th>
<th>Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compost</td>
<td>15 – 20 tons/ha</td>
<td>no</td>
<td>Mixed into planting holes</td>
<td>• Before/at transplanting</td>
</tr>
<tr>
<td>Nitrogen (N)</td>
<td>100 – 170 kg/ha</td>
<td>60 – 85 kg/ha</td>
<td>Broadcasted</td>
<td>• Before transplanting At 14 to 21 DAT</td>
</tr>
<tr>
<td>Phosphorous (P$_2$O$_5$)</td>
<td>60 – 150 kg/ha</td>
<td>30 – 80 kg/ha</td>
<td>Broadcasted</td>
<td>• Before transplanting At 14 to 21 DAT</td>
</tr>
<tr>
<td>Potassium (K$_2$O)</td>
<td>60 – 225 kg/ha</td>
<td>35 – 170 kg/ha</td>
<td>Broadcasted</td>
<td>• Before transplanting At 14 to 21 DAT</td>
</tr>
<tr>
<td>Boron</td>
<td>2 – 3 kg/ha</td>
<td>no</td>
<td>Broadcasted</td>
<td>• At transplanting</td>
</tr>
</tbody>
</table>

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

Part of the recommended nutrients can have organic sources, such as compost or green manure. See section 3.5.3.

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

The effects of N, P, K and boron in cabbage

Nitrogen (N) promotes vegetative growth. Like most leafy vegetables, cabbage needs a lot of nitrogen. Too little nitrogen reduces yields, delays maturity, and shortens storage life. Too rapid growth at high nitrogen, however, can lead to coarse, loose heads, cracking, tipburn, and poor processing and storage quality.

The application of too much nitrogen (urea) however, may result in a high percentage of nitrate in the leaves of the cabbages which is detrimental to the human health.

An excess of potassium (K) can cause the heads to burst and a deficiency of potash can result in necrosis at the margins of the leaves and a reduction in the keeping quality of the heads.

High level of phosphorus (P) throughout the root zone is essential for rapid root development and for good utilization of water and other nutrients by the plants.

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.

Cabbage has a high boron requirement. Symptoms of boron deficiency vary with the cole crop attacked. Cabbage heads may be small and yellow. Most cole crops develop cracked and corky stems, petioles and midribs. The stems of broccoli, cabbage and cauliflower can be hollow and are sometimes discolored. Cauliflower curds become brown and leaves may roll and curl. If boron is added, and beans or other boron sensitive crops follow cabbage in a rotation, a soil test is advisable before planting to ensure that boron levels are not too high.

(Peet, www3)
3.6 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, there will usually be less problems with diseases. 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 and insects, an example from Lao PDR:

During the cool season in Lao PDR, October to January, there are no major problems with pests or diseases of cabbage. From February onwards, the temperature rises and pests such as diamondback moth (Plutella xylostella) and webworm (Hellula undalis) become a problem.

3.7 Nursery management

3.7.1 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 is shortly 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!

3.7.1.1 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, Nepal 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
Major Agronomic Practices

seed beds, root-knot nematode galls on the following crop of eggplant were reduced to 23 and 37%, respectively, of the number of galls on roots 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)

### 3.7.1.2 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 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 wet 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.

It should be noted that polythene sheets may be expensive, and when no longer usable, they may create environmental pollution.

Solarization can be combined with another soil sterilization method described in section 3.7.1.5. 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 3.7.1.5 for details.
3.7.1.3 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.

![Diagram of top soil removed and sub soil used](image)

3.7.1.4 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).

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.

3.7.1.5 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 naturally present organisms in the soil. It requires air-tight plastic sheets. Fresh plant material (from previous crop or a green manure crop) is worked into the soil deep and homogeneously. The field is watered and covered with an air-tight plastic sheet (0.12-0.15 mm thick), properly fixed at all sides. The sheet is left on the field for 6 – 8 weeks (Note: study 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 pathogen 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 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 3.7.1.2). 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 microorganisms 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.


3.7.1.6 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 poured 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. Chittagong farmer Bangladesh).

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 study to compare the method against the common practice!”

3.7.2 Sowing

Cabbage can be sown directly in the field or sown in a nursery and transplanted later. Usually, cabbage is sown in a nursery. This nursery should ideally be located at a sunny place where the soil is not too wet. High humidity may provoke diseases like damping-off which can destroy seedlings in a very short time. If possible, the nursery should be sited on land which has not grown cruciferous crops like cabbage, cauliflower, or broccoli for 3 years or more. This is a prevention for the occurrence of (soil-borne) diseases.

3.7.2.1 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 more quickly than flat-field plantings.

Compost can be mixed in the seedbeds to get a fine soil structure with sufficient nutrients. Compost may also help prevent damping-off. See section 3.5.3.1. Make sure the seedbeds are properly leveled. Dig trenches between the seedbeds to facilitate drainage of the nursery.
Seed is sown about 1.5 - 2 cm deep in rows at a spacing of about 2.5 cm between the plants and 30 cm between the rows. Seed is either broadcast in rows and thinned out later or placed individually every 2.5 cm. If the seed is placed deeper, it will take more time to germinate, so it takes longer before seedlings are ready for 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 and results in irregular patches of seedlings which need to be thinned out to obtain strong seedlings.

**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 weeds from germinating. 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.

### 3.7.2.2 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 pots are usually removed at transplanting. 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 3.7.1.3).

One or two seeds are sown in each pot. The pots are watered regularly and protected from full sun or rain if necessary.
Potting seedlings versus flatfield beds, experiences from Asia:

In a tomato study in Hai Phong Province, Vietnam, seedlings for the IPM treatments were raised in banana leaf pots filled with clean soil and compost, whereas farmers traditionally raise them in flat field seed beds. Farmers found that there was less damping-off in seedlings, and less seed was needed, when plants were raised in clean conditions in pots rather than in traditional seedbeds. 🤗 (pers. comm. Dr. J. Vos, 2000)

Similar experiences are reported from Lao PDR, where cabbage seedlings raised in polybags are found to recover quicker after transplanting and are ready for harvest about 7 to 10 days earlier, compared to traditionally raised seedlings (pers. comm. A. Westendorp, 2000).

Cabbage transplants are usually about 4 - 6 weeks old and have 4 or 5 true leaves when set into the field. Transplants usually have crooked stems; these should be planted up to the first leaves to ensure a sturdy plant that will not fall over when full sized.

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

3.8 Field preparation

3.8.1 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 debris in the soil.

Ploughing however, also disturbs the micro-organisms in the soil and this may reduce soil fertility. To maintain and improve soil fertility, it is important to apply organic materials such as compost every year.

Sustainable soil practices are 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 3.5.3.4 and 3.8.4, and box below on conservation tillage.
Left-overs from a previous crop should be carefully removed and destroyed as it may still contain diseases and pests which can spread into the new crop. These left-overs can be used for composting which, if properly done, will kill pathogens.

When drainage of the field is problematic, or when crops are grown during the rainy season, it is recommended 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)

### 3.8.2 Transplanting

Cabbage transplants are usually about 4 - 6 weeks old and have 4 to 6 true leaves when set into the field. Thoroughly water plants 12 to 14 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 withholding 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. Transplants usually have crooked stems; these should be planted up to the first leaves to ensure a sturdy plant that will not fall over when full sized. Irrigate frequently after transplanting during dry periods. Transplants are very sensitive to water stress.

**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. The 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.


### 3.8.3 Planting density

Planting density has an effect on crop production and susceptibility to diseases. The wider the density, the more area one plant has to grow and the more nutrients are available to the plant. More space and nutrients usually result in larger plants with bigger heads. This can be both an advantage and a disadvantage, depending on market requirements. Despite the larger head size, the overall production of an area with a low planting density may still be low because there are less plants.

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 leaf spot, 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.

**Adjusted spacing to meet market requirements: a Philippine experience**

In some areas in the Philippines, farmers plant their cabbages closer than the “official” 45 x 45 cm. This results in a smaller head size which is in demand in market and sells at higher prices than large heads.

<table>
<thead>
<tr>
<th>Close planting small heads</th>
<th>Wider spacing larger heads</th>
</tr>
</thead>
</table>

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

**Table 3.8.3: Some factors related to plant spacing**

<table>
<thead>
<tr>
<th>Narrow spacing</th>
<th>Wide spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>more plants per area = higher initial costs</td>
<td>fewer plants per area = lower initial costs</td>
</tr>
<tr>
<td>small plants</td>
<td>larger plants</td>
</tr>
<tr>
<td>more, but smaller size, heads</td>
<td>fewer, but larger size heads</td>
</tr>
<tr>
<td>might increase disease incidence</td>
<td>might reduce disease incidence</td>
</tr>
</tbody>
</table>
### 3.8.4 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 extend. This is particularly useful where aphids transmit virus diseases, such as in tomato, or chili. It is probably not economical for use in cabbage.

Diseases that spread with soil particles with splashing water from rain, such as black rot (\textit{Xanthomonas campestris}), and leaf spot (\textit{Alternaria brassicae}) cannot spread so easily when the soil surface is covered with a mulch.

See also section 3.5.3.4 on organic mulch.

**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
3.9 Water management

3.9.1 Drainage

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

3.9.2 Irrigation

Proper irrigation can be critical for maintaining high yields and quality. Soils with adequate organic matter usually have a large water absorption capacity and do not need frequent irrigation. Soil type does not affect the total amount of water needed, but it 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!

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. See section 3.12 on crop rotation (Vos, 1994).

The irrigation method may also have consequences for the insect and disease populations. There are examples of effective diamondback moth reduction by using overhead sprinkler irrigation during dusk. The irrigation disrupted the mating and oviposition of the adults.

However, overhead irrigation can increase diseases. The spores of leafspot in cabbage for example, can easily germinate when the leaves are wet.
The use of ditch and furrow irrigation is usually preferred to overhead irrigation. Ditches also ensure rapid drainage of excess soil moisture during the rainy season.

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

- planting in wide rows 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 during the day.
- working with plants only when leaves are dry.

Related exercises from CABI Bioscience/FAO manual:

2-C.8. Flooding and overhead irrigation

3.10 Intercropping and trap crops

3.10.1 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 cabbage 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 cabbage with tomatoes is reported to reduce diamondback moth (*Plutella xylostella*) infestation. See box below.

Intercropping for diamondback moth control?

In both Indonesia and Malaysia, it was found that the population of diamondback moth (DBM) on cabbage was less in cabbage-tomato intercropped plantings than in fields with cabbage alone. Also, parasitism rates of DBM larvae were higher in the intercropped field. 😊

Similar results were found in Sri Lanka but in Singapore it didn’t work so well. (In: Sivanaser, 1991). Because the results vary from location to location it might be worth trying if this cropping system would be practically useful in your area. See box below.

Other plants may have nematicidal activity, killing nematodes in the soil. An example is sesame: root extracts caused mortality of nematodes in laboratory tests. Another “famous” nematode-killer is the flower *Tagetes* sp. which can be effectively controlling nematodes on tomato (Tumwine, 1999).

Intercrops could also reduce the risk of crop failure by providing an alternative crop and additional income to a farmer.
However, when the intercrop is taller than cabbage, or grown very close to the cabbage plants, it may cause yield reduction due to competition for light, space and nutrients. 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.

### How to try intercropping in your field:

Take a small portion of your field, for example a few square meters and plant both cabbage and tomato, a few rows of each. The remaining part of the field is planted with cabbage. Monitor a few plants weekly for the numbers of pest insects and the incidence of diseases. Check if there is less infestation of diamondback moth (*Plutella xylostella*) and other insect pests or diseases in the intercropped area as compared to the portion of the field in which only cabbage is grown. Try different crops for intercropping, for example cabbage-onion, tomato-onion.

### 3.10.2 Trap crops

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

The trap crop should be sown thickly all around the area where crucifers will be grown, at least 10 days before the cabbage is transplanted. The idea is that the trap crop is established in the field earlier than the cabbage so that pests will attack the trap crop first. Then the infested trap crop can be destroyed but it can also be treated with pesticides, or left in the field. The advantage of leaving the trap crop may be that the infested trap crop attracts natural enemies that will be present when the cabbage plants will be attacked by pests. When pesticides are used on the trap crop, there is a risk that (especially) diamondback moth builds up resistance against pesticides faster than without treatment.

Several studies report that (Indian) mustard is an effective trap crop because it reduces numbers of pest insects, and in some cases, improves yield of the main crop.

For example, field studies in India showed that diamondback moth (*Plutella xylostella*), cabbage heart caterpillar (*Crocidolomia binotalis*), and aphids (*Brevicoryne brassicae*) preferred mustard to cabbage when the choice was available. The ideal crop combination in this study was 9 rows of cabbage followed by 1 paired row of mustard. In one of these rows mustard should be sown 15 days before cabbage, and in the other row, mustard should be sown 25 days after cabbage (Srinivasan, 1991).
3.11 Harvest and post-harvest

Heads should be firm-to-hard at harvest, but delaying harvest may increase the risk of splitting mature heads if soil moisture increases suddenly. Heads are cut at the base and the outer leaves are trimmed off. For the fresh market, fields may be cut 3 to 5 times. When hybrid varieties are used, a higher percentage of the plants can be harvested at one time.

Heads must be cooled immediately after harvest. Cabbage can be stored at 0 - 2°C and 95% relative humidity for 3 to 6 weeks (early crop) or 5 to 6 months (late crop). Storage life can be prolonged even further at low O\textsubscript{2} (2%) and high CO\textsubscript{2} (5%) and with controlled atmosphere storage systems, where available.

Bacterial soft rot is the main problem in storage.

3.12 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 of. 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 3.5.3.2) 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:

<table>
<thead>
<tr>
<th>Crop Family</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crucifers</td>
<td>cabbage, Chinese cabbage, radish, cauliflower, pak choi, broccoli, turnip, mustard, rape</td>
</tr>
<tr>
<td>Solanaceous</td>
<td>tomato, potato, pepper, chili, eggplant</td>
</tr>
<tr>
<td>Legumes</td>
<td>all types of beans, all types of pea, groundnut, alfalfa, clovers</td>
</tr>
<tr>
<td>Onions</td>
<td>onion, garlic, shallot, leek</td>
</tr>
<tr>
<td>Cucurbits</td>
<td>cucumber, gourds, luffa, melon, pumpkins, courgette</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>Disease</th>
<th>Can stay alive in soil without cabbage plant for ..</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black rot</td>
<td>1-2 years</td>
</tr>
<tr>
<td>Black leg</td>
<td>2-3 years</td>
</tr>
<tr>
<td>Clubroot</td>
<td>7-20 years</td>
</tr>
</tbody>
</table>

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

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

Plant a non-cruciferous crop in your field but leave about 2 or 3 small areas within the field which you plant with cabbages. 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 cabbages or another cruciferous crop again. Check if there still are old cabbage 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 cabbages 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
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! Cabbage plants can compensate for feeding injury because more leaves and roots are produced than actually needed for head formation. So, not all "pests" are "pests"!

Actually, some insects are needed to keep the natural enemy population alive. By setting up insect zoos, the functions and life cycles of insects and natural enemies can be studied.

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

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

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, insects are considered as populations rather than individuals. One single insect that eats a cabbage 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 the legs (three pairs) and, if present, for one or two pairs of wings. The legs may be adapted for running, grasping, digging, or swimming. The abdomen functions in digestion and reproduction.

**Insects have**

- **Three body regions**
- **Six legs**
- **One or two pair of wings**
- **One pair of antennae**
- **Chewing insects**
- **Piercing and sucking**

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.
### 4.3 Insect Life Cycles

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

Complete life cycles can be found with moths, butterflies, beetles, flies and wasps.

In incomplete life cycles, or better: life cycles with an incomplete metamorphosis, insects go through egg, nymph and adult stage. There are generally several 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 dependents 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 additions, 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. 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.
There are some virus diseases known in cruciferous crops, however, in most areas in South East Asia, they are considered to be of minor importance and will therefore not be discussed in this guide.

4.5 Plant compensation

Not all insect feeding reduces yield. The cabbage plant is able to compensate for feeding because more leaves and roots are produced than actually needed for head formation. Some studies even show that young cabbage plants that loose the main bud (growing point) compensate for that loss by producing other shoots and when all shoots are removed but one, a normal head can develop! Studies in Vietnam for example, showed that when the growing point of cabbage plants were removed up to 14 days after transplanting, the cabbage yield was still 75% of the plants were the growing point was not removed. When the growing point was removed later, up to 35 days after transplanting, the cabbage yield dropped to 55% (FAO - TOT report Vietnam, 1995).

☑ Plants beyond the four to five true leaf stage can tolerate up to fifty percent defoliation until the prehead stage without yield loss.

For example, studies done in Vietnam showed that cabbage plants that were defoliated up to 50% at 7, 14, 21 and 28 days after transplanting, still gave more than 90% yield compared to the undefoliated plants (FAO - TOT report Vietnam, 1995).

Low levels of insect feeding and minor disease infections do not significantly reduce yields. 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.2. Diamondback moth injury symptoms on cabbage
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 cabbage field. Not all of them can be called “pests”, in fact, very few insects have the potential to cause yield loss to cabbage. 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 chew a few leaves here and there but this does not affect the yield or quality of the cabbage. 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 cabbage 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.

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.

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.

**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 or 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. (don’t 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 (aphids or small diamond-back moth 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.

When you find that an insect is eating the cabbage 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, most caterpillars can severely damage cabbage plants when they feed on young seedlings. When they destroy the growing points, this may result in multiple heading (check section 4.5 on plant compensation!). Also caterpillar feeding during the heading stage is unfavorable as it may result in damaged heads which fetch a lower price in the market. But similarly, when flea beetles eat holes in the leaves when the plants are already quite large, it does not influence the yield or quality of the cabbages.

**Related exercises from CABI Bioscience/FAO manual:**

1. Show effects of beneficials incl. natural enemies
4. 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 cabbage 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 below. The major natural enemies of cabbage 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-A.6. Parasitisation on diamondback moth of cabbage
4-A.7. Effect of parasitisation on feeding behavior of diamondback moth
4-A.17. Life cycle and biology of the parasite *Diadegma semiclausum*
4-A.18. Life cycle and biology of the parasite *Cotesia plutellae*
4-A.19. Life cycle and biology of the parasite *Diadromus collaris*
4-A.20. Life cycle and biology of the parasite *Cotesia glomerata*
4-A.21. Preference of host stages by *Diadegma semiclausum* (or *Cotesia plutellae*)
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 tactics 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. Cabbage 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.

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, *Diadegma* sp.) 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. Some
of those include the release and establishment of the parasitoid *Diadegma semiclausum* for control of
diamondback moth in highland cabbage in various Asian countries. Other examples are the introduction
of the parasitoid wasp *Diadromus* for diamondback moth control in Vietnam. 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 cabbage pest insect 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 cabbage 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 flea beetles. 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!

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 diamondback moth and 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.

**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. In China for example, light traps are used for trapping and monitoring the populations of the cabbage moth, aphids and whitefly in both greenhouses and fields. 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.

**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.

**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:

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

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 (AESA) are not considered in ETL values.
The next table gives examples of a number of factors involved in decision making for ETL and for AESA.

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<td>● cost of control</td>
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<td>● harvest value of crop (estimation)</td>
<td>● weather conditions</td>
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<td>● loss of income due to pests (estimation)</td>
<td>● crop development factors (incl. compensation ability)</td>
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<td>● fertilizer applications</td>
</tr>
<tr>
<td></td>
<td>● activities in the field since last week</td>
</tr>
<tr>
<td></td>
<td>● other observations</td>
</tr>
</tbody>
</table>

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 such as *Cotesia* sp. can be negatively affected by neem applications (Loke et al, 1992).

**Neem seed kernel extract: the recipe**

In Ghana, Africa, neem seed kernel extract is used against insect pests on various vegetable crops. It has been tried on cabbage in a TOTs and FFSs and had a very good effect on diamondback moth (*Plutella xylostella*), probably due to the repelling action of neem.

Here is their recipe:

Pound or grind 30 g neem kernels (that is the seed of which the seed coat has been removed) and mix it in one liter of water. Leave that overnight. Next morning, strain or sieve it and use it immediately for spraying. It should not be further diluted. Of course any neem preparation and spray application should only be done after a previous AESA has shown the need for a neem application (pers. comm. Dr. J.Vos, 2000).

**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 repellant 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 DBM larvae, 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.

In experiments in Kenya on botanical concoctions for aphid and diamondback moth (DBM) control in kale, highly concentrated chili
solution treatments produced the same number of marketable leaves as the pesticide Karate (lambda-cyhalothrin).

Other studies from Kenya showed that chili sprays reduced pest numbers by 50% in the first week after application but these built 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 allicin, 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 3.3.3. 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 3.10.

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 cabbage 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 other 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.

Non-systemic

systemic

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.

<table>
<thead>
<tr>
<th>Class Ia Extremely hazardous</th>
<th>Class Ib Highly hazardous</th>
<th>Class II Moderately hazardous</th>
<th>Class III Slightly hazardous</th>
<th>Class IV* unlikely to present acute hazard in normal use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methylparathion (Folidol)</td>
<td>Methamidophos (Monitor, Tamaron)</td>
<td>Fenitrothion (Ofatox)</td>
<td>Trichlorfon (Dipterex)</td>
<td>Kasugamycin (Kasai)</td>
</tr>
<tr>
<td>Mevinphos (Mevinphose)</td>
<td>Edifenphos (Hinosan)</td>
<td>Dimethoate (Bi58)</td>
<td>Dicofol (Kelthane)</td>
<td>Zineb</td>
</tr>
<tr>
<td>Alachlor (Lasso)</td>
<td>Dichlorvos (DDVP)</td>
<td>Cypermethrin (Sherpa, Vifenva, Cyrin)</td>
<td></td>
<td>Validamycin A (Validacin)</td>
</tr>
<tr>
<td>Monocrotophos (Azodrim)</td>
<td>Fenvlarate (Sumicidin)</td>
<td>Deltamethrin (558)</td>
<td>Atrazin (Gesaprim, others)</td>
<td></td>
</tr>
<tr>
<td>Metomil (Lannate)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fenobucarb (Bassa)</td>
<td></td>
<td></td>
<td>Benomyl (Benlate)</td>
<td></td>
</tr>
<tr>
<td>Cartap (Padan)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fipronil (Regent)</td>
<td></td>
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<td></td>
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<tr>
<td>2,4-D</td>
<td></td>
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<tr>
<td>Endosulfan (Thiodan, a.o.)</td>
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<tr>
<td>Fluvinate (Maverik)</td>
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<tr>
<td>Paraquat (Gramoxone)</td>
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</tbody>
</table>

(Murphy H., 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 programme. Previously, health studies were aimed to change national pesticide policies. While some of the more hazardous pesticides were banned or restricted, frequently these were not enforced. Therefore in the IPM tradition, 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.

Pesticides and health: some unhealthy figures…..

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.
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*. One case of diamondback moth resistance against pesticides is described in the box below. 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.
The case of DBM resistance in Cordillera Region, Philippines.

Over the years, diamondback moth (DBM) had become resistant to most available pesticides in the Cordillera region in the Philippines. Human poisoning incidents due to spraying of cyanide on cabbage in farmers’ desperate attempt to control DBM, were a major reason to start a project. Collaborators of this project were ADB (donor), the International Institute of Biological Control (now integrated in CABI Bioscience), Philippines Dept. of Agriculture (Cordillera Region), Benguet State University, and Local Government Units in Benguet and Mountain Provinces. The project aimed to transfer proven IPM practices to vegetable farmers in the Cordillera region, to reduce agrochemical input use, particularly of toxic insecticides, and to promote IPM as the standard approach to pest and crop management in cabbage and potato.

The project reached 1719 farmers in 65 FFS groups (average farm size 1ha).

Impacts of the project (1994 – 1996) included:

- Cabbage yield increased by 4.8t/ha (21% increase) in dry season cabbage
- Potato yield increased by 3t/ha.
- Decreased production costs/ha of cabbage (11%) and potato (2%)
- Before training, 100% farmers used insecticides, after FFS only 25% using insecticides and not for DBM.
- Before FFS , 80% farmers preferred Category I and II highly toxic products. After FFS, 90% farmer shifted to Category IV products with lower mammalian toxicity and biopesticides
- Due to successful biological control of key pest DBM (through parasitoid Diadegma sp.), many farmers now produce insecticide-free cabbage and consumers no longer worry about residues.
- Conservation of native natural enemies encouraged. More species diversity in IPM fields than regularly sprayed fields (159 vs.125) and lower proportion of pests
- Net income of FFS farmers increased by 17%
- 80% average decrease in insecticide use (13.8 to 2.9l cabbage crop) in dry season and 55% in wet season.
- Farmers rely less on agrochemical salesmen and more on own knowledge and other farmers for pest management information.
- Synthetic fertilizer rate halved without negative effect on yield while organic fertilizer rate maintained.

(CABI Bioscience. TSG IPM Analyses No. 6: Impact of Farmer Field School training on natural, human and social capital: case studies from the Philippines and Kenya)

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
Major Cabbage Insect Pests

5 MAJOR CABBAGE INSECT PESTS

SUMMARY
The diamondback moth (Plutella xylostella) is the major pest insect of cabbage, in both temperate and tropical areas in Asia. Other pests such as webworm (Hellula undalis), heart caterpillar (Crocidolomia binotalis), and white butterflies (Pieris sp.) can locally be severe. Flea beetles (Phyllotreta sp.), aphids (Brevicoryne brassicae), and cutworms (Agrotis sp.) can be a problem in nurseries. Stemborer (Melanagromyza cleomae) is a relatively "new" pest but appears to occur on a wider scale in Asia than so far reported in literature.

Biocontrol options exist for many insect pests of cabbage, such as Diadegma parasitoids for diamondback moth control, NPV virus for armyworm (Spodoptera sp.) control, and Bt (Bacillus thuringiensis) applications against various caterpillars. Other naturally occurring biocontrol agents, such as predators (ladybeetles, spiders), parasitoids and pathogens (e.g. fungi killing aphids or webworm) can locally, and in some seasons, give additional control.

Most biocontrol options should be part of an IPM programme that includes farmer training.

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 several cabbage insect pests, insecticide use is not effective nor economical and may in some cases (e.g. whitefly) even aggravate pest problems. Most insect management options focus on prevention of high populations, and biocontrol, either by conserving and augmenting naturally occurring natural enemies, or by releasing/applying biocontrol agents.
In the following sections an indication of the duration of parts of the insect’s life cycle is given. It is emphasized that these figures are indications only as they depend on local climate and season. 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 Diamondback moth - *Plutella xylostella*

The diamondback moth is a major pest of cruciferous vegetable crops in both temperate and tropical areas. It attacks a wide range of wild and cultivated cruciferous crops.

**Description**

Adult moths are about 6 –10 mm long. They are grayish-brown in color and have three light brown to white, triangular marks on the edge of each forewing. When the moth has settled at rest, marks join together to form three diamond shapes along the middle of the back. This is why the moth is called *diamondback* moth. Usually, the females are lighter colored than the males. The moths are poor flyers but they are often transported long distances on the wind. Moths are more active and visible at dusk. They fly around plants searching for a mate or a place to deposit eggs.

Eggs are very small, less than 1mm and yellow in color. They are laid either individually or in small groups under the leaves near the center line of the leaf, or close to the leaf veins.

The caterpillars can be up to 13 mm long. DBM caterpillars vary in coloration from a light brown at hatching to dark green when fully grown. The body can have white patches and black spots. Caterpillars usually feed on the underside of leaves.

First instar caterpillars feed as leafminers inside the plant tissue. The three later instars feed on the underside of leaves. They do not eat the veins and often leave the upper skin of the leaf intact, which leaves a window-like appearance. If disturbed, they wriggle away quickly and drop from the leaf on a silk thread. They climb back on the leaf on this thread once the danger has passed.

Fully-grown caterpillars spin a greenish cottony cocoon of about 10 mm long on the underside of the leaves or in litter under the plant. The silk mesh is added to the surface of the leaf making its removal difficult.

**Life cycle**

The life cycle can be completed in one to two weeks, depending on the temperature. Generally, the higher the temperature, the quicker the life cycle and the more generations of DBM are formed. In the tropics, the life cycle is shorter in the lowlands than in the mountains.
On cabbages, eggs are usually laid on the upper leaf surface. Each female lays between 50 and 400 eggs. The eggs hatch in about 2 - 7 days and the small caterpillars crawl to the lower leaf surfaces and feed as leaf miners inside the leaves for a few days. After the first moult the caterpillars emerge from the leaves and feed on the lower surfaces. The total larval period varies from 14 - 28 days. The pupal stage lasts for about 5 - 10 days.

**Plant damage and plant compensation**

Diamondback moths caterpillars destroy the foliage of most cruciferous crops. Severe infestations of DBM are particularly destructive when the caterpillars attack plants at the seedling or newly transplanted stage.

Initial damage results in small incomplete holes caused by young larvae and larger complete holes caused by mature larvae. The entire plant may become riddled with holes under moderate to heavy populations. In a heavy attack, the caterpillars skeletonize the leaves and only the midribs and veins of leaves remain. Larvae also feed in the developing heads of cabbage, causing deformed heads and encouraging soft rots. Destruction of the main buds of seedlings by feeding larvae may result in headless plants or plants with multiple undersized heads. However, removing all new shoots but one to form a new head (compensation) may still be feasible (see section 4.5 on plant compensation). Early crop damage reduces the leaf area that produces sugars (photosynthesis) and this may lower yield. Although late damage may have little effect on yield, the quality and thus the value of the crop may be lowered due to damaged wrapper leaves. Severe damage may occur especially during hot, dry weather.

**Natural enemies**

Many parasitoids of DBM have been recorded but only a few are effective in the field. These are parasitoids belonging to *Diadegma* sp., *Cotesia* sp. and *Diadromus* sp. The effectiveness of these parasitoids depends on climate. Usually, parasitoids are introduced and released in the field for effective DBN control. This is necessary because cabbage (and other Brassica crops) originate from Europe and there are no effective indigenous natural enemies for DBM in Asia.

- *Diadegma semiclausum*

*Diadegma semiclausum* has been successfully introduced in highland areas in Philippines and in Vietnam. In the highlands of Cordillera, Philippines, introduction and release of *Diadegma semiclausum* has reduced the use of chemical insecticide sprays by up to 80% in the dry season and 55% in the wet season. Many more benefits for farmers from the Cordillera project are listed in box at the end of section 4.11.11.

Similar examples from other countries, e.g. Indonesia, Malaysia and Taiwan, have shown that DBM can be effectively controlled by *D. semiclausum*, as long as there is restricted use of insecticides (Ooi, 1992). Success in such IPM programmes is limited only to the cooler highland areas. *D. semiclausum* is very efficient in keeping DBM populations low at temperate conditions. However, it does not perform well at temperatures above 25°C. As a result, DBM is still a problem in tropical lowland areas.
**Diadegma semiclausum** is mass-produced in rearing facilities in the highland areas of many countries in Southeast Asia. See box below for an example.

### Diadegma semiclausum in the Philippines

Farmers in the mountain province Cordilleras applied insecticides for DBM control 24 to 32 times during the dry season and 18 times during the wet season. DBM had become resistant to many pesticides and farmers were resorting to highly toxic compounds. When the National IPM Program was implemented and the parasitoid *Diadegma semiclausum* was introduced, many of the farmers reduced their pesticide application to only 2 times, for control of other pests. *Diadegma* is being released into cabbage fields at regular intervals. It can survive by transferring to neighboring fields as long as farmers do not spray chemical insecticides.

It should be noted that **farmer training** is an essential element in the success of *Diadegma*. (FAO-ICP Progress report ‘96 – ’99)

- **Diadegma insulare**

  The parasitoid *Diadegma insulare* is better adapted to warmer conditions and may play a major role in controlling DBM in areas that are too warm for *D. semiclausum*. *Diadegma insulare* from Florida (USA) was recently introduced in the Philippines for DBM control under lowland conditions. Currently, parasitoid rearing methods are being studied and small scale experiments under nethouse conditions are being done.

- **Cotesia plutellae**

  The parasitoid *Cotesia plutellae* is also better adapted to warmer climates than *Diadegma semiclausum*. *Cotesia plutellae* is mass-produced in countries like the Philippines for field releases and demonstrations in farmers' fields. Cocoons are used for field release (FAO-ICP Progress report '96 – '99).

  However, *Cotesia plutellae* is found a less effective parasitoid than *Diadegma semiclausum* because it performs well at high DBM densities, but not so well when DBM populations are low. Therefore, introduction of *Diadegma insulare* for the lowlands is being considered by Vietnam and Philippines (pers.comm. Mr.J.W.Ketelaar, Vietnam, 2000).

- **Diadromus collaris**

  A parasitoid that was introduced into Vietnam is *Diadromus collaris*, This little wasp parasitizes the pupae of DBM. *Diadromus* was released in cabbage fields in highland areas of Dalat, Vietnam in 1998. Monitoring and ecological studies were conducted by Farmer Field Schools and farmer study groups (FAO-ICP Progress report '96 – '99). However, *Diadromus collaris* has not established yet (Ooi, 1999). *Diadromus collaris* is established in highland areas in Malaysia (Cameron Highlands).
Other parasitoids

Several other species of parasitoids have been recorded on DBM. These include the larval parasitoid *Microplites plutellae*, which is common in North America, and *Apanteles ippeus*, which is widely distributed in eastern Australia (*CABI Dossier Diadegma insulare*).

Other parasitoids can occur naturally in certain areas and may play a role in reducing damage from DBM infestation when (broad-spectrum) insecticides are not intensively used. In general, their levels of parasitism are relatively low.

Pathogens

A number of pathogens are known to kill DBM. The most common ones are the fungi *Entomophthora blunckii* and *Entomophthora radicans*. Other DBM-pathogens are *Paecilomyces fumosoroseus*, and *Zoophthora radicans*. DBM caterpillars can also be killed by a granulosis virus, and a nuclear polyhedrosis virus (NPV). Except for Bt, there are restrictions on the effectiveness of these pathogens since they need specific conditions (temperature, humidity) to be active (Ref. www12).

Commercial preparations of *Bacillus thuringiensis* (Bt) can effectively control DBM caterpillars as well as some other caterpillars. It should be noted here that in some areas resistance to Bt has been found. Use Bt only on the basis of careful field observations. Care should be taken that Bt is not used very frequently, and that different brands are rotated. Bt kills DBM larvae slow: only after about 3 days. However, affected larvae stop feeding on the crop after a while. Thus, although alive, they do not damage the crop anymore. See also section 6.3.1 on Bt.

Predators

Predators may also play a role in the control of DBM. For example, spiders, lady beetles, lacewings (*Chrysopa* sp.) and some beetles are reported to attack DBM. These predators tend to build up only in the later part of the cropping season. Efficiency of predators varies greatly between sites.

Management and control practices

Prevention activities:

- Although there seem to be differences in susceptibility to DBM attacks in different varieties of cabbage, no resistant variety is known to date. Due to the many generations that DBM can produce in a season, resistance may be broken down very quickly.
- The adults can be monitored with pheromone traps. Pheromone-impregnated strips are also being tested that disrupt diamondback mating.
- It is preferable to plant cabbage in the rainy season when the population of DBM is deterred by the rain.
- Intercropping with tomato (or other crops not susceptible to DBM) may help reducing populations of DBM. The idea of intercropping is that DBM adults will have more difficulty in finding cabbage plants when these are camouflaged between other crops. See section 3.10.1.
Trap cropping for DBM control in India

In India trap crops are being used in IPM Farmer Field Schools. The trap crop used was mustard. The recommendation of the Indian FFS is to sow two rows of mustard after every 9 rows of cabbage. The first row of mustard should be sown 15 days before the cabbage is transplanted and the second row of mustard about 15-25 days after transplanting the cabbage. Diamondback moth prefers mustard to cabbage. The trap crop was also an effective trap for other caterpillars and aphids (Srinivasan, 1991). Whether or not the mustard needs to sprayed or destroyed to remove the pest insects, is disputable. This can be tested in a study.

- Sometimes, planting a trap crop around the field helps to control DBM. The trap crop, which should be established before the cabbages are transplanted, will attract pest insects. These pest insects in addition, will attract natural enemies. The trap crop is either destroyed together with the DBM larvae or left in the field as a “natural enemy reservoir”. See box above and section 3.10.2. These trap crop plants should be monitored with more frequency than the main crop and require control of the DBM before it can be passed to the main crop. Unattended trap crops can generate large populations of DBM! Special care is needed to manage these crops to use them as part of a control practice.

In fact, several researchers report that combining trap crops with release of parasitoids is a very good DBM management practice. See example in box below.

Combining trap crops with release of parasitoids

For highland areas the Indian Institute of Horticultural Research (IIHR) advises to grow the bold-seeded Indian mustard as a trap crop. This attracts up to 80% of DBM, and should be sown thickly all around the area where crucifers are to be grown, at least 10 days before the cruciferous crops themselves. Releasing the parasitoid Diadegma semiclausum on the 16th and 21st days after planting. The recommended number of parasitoids to release is 3,000 pupae per hectare per release date in a crop cycle of 70 - 80 days. Spraying with 4% neem seed kernel extract (NSKE) once every three weeks, if necessary, to help control aphids. NSKE can be sprayed onto the mustard to control DBM and aphids. Not more than 3 NSKE sprays are required (ref. www22).

For lowland areas, the following research results were good:

Plants collards as a trap crop in and around cabbage fields lured a significant number of DBM adults away from the cabbage. Supplemental releases of Cotesia plutellae in the collard plantings would allow this parasite to build its numbers along with Diadegma insulare, and both species could spread into the cabbage to attack DBM larvae. This approach could greatly reduce grower costs as fewer C. plutellae parasites would need to be released, and the number and frequency of pesticide applications also would be reduced. This strategy also would provide less opportunity for DBM to develop resistance to pesticides (ref. www23).
Once DBM is present in the field:

- **Where effective natural enemies are present**, a few DBM larvae are necessary to maintain the population of natural enemies. Trying to eradicate all DBM larvae may actually reduce the natural enemy population.

- **Parasitoids released in cabbage fields** have proven to be able to effectively control DBM as long as no pesticides are used. Release should be part of a larger DBM management programme that includes farmer training.

- Where irrigation facilities exist, water sprays may be used to control DBM. Overhead irrigation, especially when applied during dusk, interferes with mating and oviposition of DBM. In addition, young larvae may be washed off the leaves and drown. Overhead irrigation may have a negative impact on disease that can generally spread more easily with splashing water from irrigation.

- When after careful monitoring the field, and comparing numbers of natural enemies and pest insects, it is found that natural enemies in the field are not controlling DBM sufficiently, applying *Bacillus thuringiensis* (Bt) may be considered. Bt is safe for most natural enemies and, if applied correctly, will provide effective control of DBM (Note: in some areas DBM has developed resistance against Bt!). It should be noted that DBM larvae that are parasitized by parasitoids like *Diadegma*, will also be killed by Bt sprays! In addition, Bt should be rotated to decrease the chance that DBM develops resistance to Bt.

- In some countries, certain botanical insecticides like the extracts of the neem tree, have been found effective against DBM on cabbage. It is recommended to test these botanicals in small trial areas first before applying them full scale. There may be negative side-effects on natural enemy populations. See section 4.11.4. and box in section 4.9.

- **Removing all crop debris** after harvest helps to reduce populations. The cabbage leaves can be used to feed farm animals, or put on a compost pile. DBM can survive in plant residues and migrate to the next plot.

- **Pesticide use for DBM control is not recommended.** See box below.

- A new method of insect control now in the experimental stage is to attract adults to a trap where they are infected with a pathogen before exiting. Researchers in England have developed special traps that allow diamondback moths to enter the trap, pick up the fungal pathogen *Zoophthora radicans* and then exit the trap. The moth then carries the pathogen to the crop where it can infect both moth larvae and other adults (Peet, www10).
The sad story of chemical control of DBM

Chemical control has been the major control tactic used in the past. Due to the many generations that DBM can produce in a season, it can also develop resistance to insecticides very quickly. More and more, insecticides became ineffective in controlling DBM. Some insecticides to which DBM has developed resistance include cypermethrin, deltamethrin, fenvalerate, diazinon, permethrin and phenthoate. For example, in Taiwan, DBM has developed resistance against 33 out of the 34 available insecticides! It seems like the insect could develop pesticide resistance more quickly than the chemical industry could develop new pesticides!

Due to the ineffectiveness of insecticides, farmers began to spray more often, at higher doses, with different chemicals and with mixtures and cocktails of pesticides. The result? Higher costs for farmers to buy the pesticides, more health risks from applying sometimes very dangerous chemicals, more environmental pollution and eventually more resistance of DBM against these pesticides. The big winner of the game? DBM! Still a major pest in many regions. The other winners of the game? Other insects such as armyworms and the cabbage webworm, once minor pests of cabbage, could become major problems because all natural enemies were destroyed.

Points to remember about diamondback moth:

1. Diamondback moth (DBM) is the most serious pest of tropical cabbage areas.
2. Very effective biological control of DBM is possible through parasitoids.
3. Parasitoid release should be part of a larger IPM programme, that includes farmer training.
4. Pesticides are not effective for DBM control.
5. Natural enemies are killed by pesticides.
6. Bt is usually very effective for DBM control, but brands should be rotated (resistance!).

Related exercises from CABI Bioscience/FAO manual:

4-A.1 Life cycle of caterpillar pests
4-A.2 Diamondback moth injury symptoms on cabbage
4-A.3 Plant compensation study
4-A.4 Assessment of impact of ground-dwelling predators
4-A.5 Measuring the parasitism level of caterpillars
4-A.6 Parasitisation on diamondback moth of cabbage
4-A.7 Effect of parasitisation on feeding behavior of diamondback moth
4-A.8 Rainfall as mortality factor
4-A.12 Mixed cropping examples: tomato/beans and cabbage/mustard
4-A.13 Comparison of biological and chemical pesticides used in caterpillar control.
5.2 Aphids - *Brevicoryne brassicae*

**Description**

Cabbage aphids are a serious pest on most cruciferous crops including a wide range of cruciferous weeds.

The wingless aphids are up to about 2.5 mm long, grayish-green in color, with a dark head and black stripes on the body. The aphid is covered with a grayish-white colored waxy powder, which is also secreted onto the surface of host plants.

The winged aphids are slightly longer than the wingless ones and have a dark-colored head and body. The veins on the wings appear brown in color. The aphids have small syphons (looking like small antennae) at the back of their body. Syphons are a good way to recognize aphids.

Colonies of these aphids are usually found on the undersides of cabbage leaves.

Unlike other aphid pests of vegetables, the cabbage aphid is a one-host aphid: it remains on cruciferous crops throughout its life.

The aphids can reproduce asexually: that means that males and females do not have to mate in order to produce young. One female gives birth directly to small nymphs. That means large numbers of aphids can be produced in a very short time! Only in cool areas, eggs are produced after mating. The eggs overwinter and young nymphs emerge when the temperature rises. All winged aphids are females. In the tropics, most unwinged aphids are probably also females. Most reproduction in the tropics will be asexual so males are not needed.

**Life cycle**

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

Warm, dry weather favors a rapid build-up of aphid colonies.
Plant damage and plant compensation

The first signs of attack are small bleached areas on the leaves of infested plants. The leaves then turn yellow and become crumpled. The aphid colonies are protected inside the crumpled leaves. The effects of infestation are worst on seedlings and young plants. They can be stunted and may die in unfavorable weather. Early damage to the growing point of a cabbage plant distorts the head. Even when young plants are infested only lightly, the leaves of the plants when they are mature continue to show signs of the original attack. Infestations on larger plants may reduce yield and also spoil the plants by contaminating them with wax, cast skins and honeydew. Honeydew is the excretion of aphids. It is slightly sweet and is excreted from the syphons. Honeydew can make the leaves sticky and several fungi species grow on the honeydew producing black marks on the surface of the cabbage. This lowers the quality. When infestation is large, the aphids sometimes penetrate the heart of the cabbage.

Aphids tend to be very localized: they usually colonize just a few plants but can be very abundant on each plant.

In addition to the direct crop damage, cabbage aphids also transmit the cauliflower mosaic virus and the turnip mosaic virus to cruciferous crops. Good crop hygiene (uprooting and destroying the virus infected plants), rather than trying to kill the aphids, is the only way of reducing the impact of these viruses as the time taken by virus-carrying aphids to infect new crops is often less than one minute. This is too short to kill the aphids by any control practices.

Aphids as milk cows for ants...?!

Ants are attracted to aphid colonies because the aphids produce honeydew when they are disturbed. Ants like to eat the sweet honeydew. The ants keep and sometimes even protect the aphid colonies. They “milk” the aphids to get the honeydew.

Although ants can be natural enemies of some pest insects, in this case, ants cannot be considered as natural enemies of aphids because they do not kill aphids but may in fact protect them.

Natural enemies

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

Predators such as lady beetles and hover flies (Syrphids) and parasitoids like the wasp Diaeretiella rapae are important natural enemies of the cabbage aphid.

In wet seasons, outbreaks of fungi that kill aphids may occur. This often coincides with period of high humidity and rain. Dead aphids may be seen covered with white colored fungus growth on the body. These fungi can spread quickly to reduce aphid populations. See chapter 6 for details on these natural enemies.
Management and control practices

Prevention activities:

- Healthy, quickly growing plants are the best way of preventing many pests and diseases. Aphid infestation often occurs when plant condition is slightly poor, for example just after transplanting, or when too much or too little fertilization is added or when the soil structure is poor.

- Host plant resistance: There is little chance of producing a cabbage variety with a durable resistance to cabbage aphids. This is because there are many biotypes (individuals with slightly different characteristics) of aphids present in the field and new biotypes can form regularly. It is very difficult to produce a variety that has a resistance against all these biotypes.

- Cultural control: Cruciferous plants that remain in the field after harvest are largely responsible for large numbers of eggs and/or adults staying over. Therefore, the most effective prevention and control measure is to eliminate as many of these sources of infestation as possible to prevent the aphids from spreading to the new crop. The crop left-overs can be buried into the soil, fed to farm animals, added to a compost pile or collected, slightly dried and burnt. Removing crop left-overs is also very valuable for disease prevention.

- Undersowing with clover may help to reduce aphid infestation. In a study where cabbage was undersown with white clover, cabbage aphid population was reduced with 90%! (Finch, 1996). See section 3.5.3.4 on organic mulch.

Once aphids are present in the field:

- Monitor the field regularly to check population growth. Cabbage aphid population build up rapidly but locally. It is important to examine plants regularly, both in seedbeds and in the field. When aphids are found but the number of infested plants is low and at the same time there are natural enemies like lady beetles present, no additional control measures are necessary.

- On a small scale, aphids can be washed off the plants with water or rubbed by hand.

- Small populations can also be removed by removing the infested leaves by hand and destroying these.

- When large populations of aphids are present in the field at an early stage (newly transplanted or young plants) and the weather is warm and dry, chances are that the aphid population will expand very quickly and causes damage to the growing points of the plants. Monitor the field carefully for presence of natural enemies (particularly note lady beetles and aphid “mummies” (see sections 6.1.1 and 6.2.1)). When there are large numbers of natural enemies, do not apply insecticides but continue monitoring. When natural enemy populations are low compared to the aphid population, consider localized sprays. See next paragraph. Also see section 4.8 on natural enemy efficiency.

- Soap solutions (concentration of 0.5 % (5 g per liter)) kills aphids instantly. See section 4.11.6.

- Botanicals such as neem solutions may control aphids. Good results are obtained from various locations. See section 4.11.4.

- Biopesticides: see box below for an example from Bangladesh.
Free biopesticides for aphid control

During a TOT in Mymensingh, Bangladesh, the newly transplanted eggplant field suffered from aphid infestation. Participants from the TOT discovered aphids covered with fungus on various locations around their eggplant field. They collected as much diseased aphids as they could get, mixed them in water, and stirred firmly. This will release spores from the fungus into the water and this water becomes infectious for aphids. Then the solution was slightly filtered through a cloth (to remove large parts) and sprayed on the eggplants using normal backpack sprayers (pers. comm. Prabhat Kumar, 1999).

- **Localized sprays.** There are insecticides that control aphids. However, spray applications of insecticides can kill lady beetles and many other natural enemies of the cabbage aphid and other pest insects! Balance the benefits of spraying against the harm done to the beneficials! When applying insecticides is considered necessary, apply only on those plants that have aphid colonies, not on all plants. This reduces the amount of pesticides needed and, may save at least part of the beneficials present in the field.

**Points to remember about aphids:**

1. Aphids have many natural enemies.
2. On small scale, aphids can be removed by hand rubbing, washed off with water spray, or destroyed by removing and destroying infested leaves.
3. Localized (infested plants only) spray with soap solution (0.5%) controls aphids.
4. Biopesticides, where available, may offer good control.
5. Insecticides are usually not necessary for aphid control.

**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

**5.3 Flea beetle - *Phyllotreta sp.***

The main host plants for flea beetles are cruciferous crops but they can also live on cotton and cereals.

**Description**

There are many species of flea beetles that damage cruciferous crops, most of them belong to the genus *Phyllotreta*. The adult beetles can be separated by color into two major groups: one in which the back is black with two longitudinal yellow bands (the **striped flea beetle**) and the other group in which the back is of one color, usually black. All adults have backs with a metallic appearance and are about 1.5 - 3.0 mm long.

Flea beetles are characterized by their enlarged hind legs with which they make long flea-like leaps. As their name implies, flea beetles have the habit of jumping when disturbed.

**Life cycle**
The adults can overwinter in sheltered sites where leaf litter and plant debris is present. They become active with temperatures rising above 20°C. When the temperature is always high, like in tropical lowlands, the flea beetles will not have a resting phase but just continue reproducing.

Adults disperse, frequently in large numbers, on prevailing winds. They can travel long distances. When they locate a suitable host crop, they settle and start to feed, often on seedling tissues below ground.

After mating, the beetles lay their eggs in the soil near host plants. The eggs are pale-yellow in color, about 0.3 mm long and 0.15 mm wide. The larvae of all species are generally white or pale-yellow in color and have very short legs. The larval head is dark in color. The larvae of most species feed on the plant roots. After living in the soil for about 4-5 weeks, the fully grown larvae are about 5-6 mm long. They pupate in the soil. The pupa is about 2.5 mm long, white to yellow in color at first but later turns darker. The duration of the pupal stage depends on climatic factors like the temperature, it may take up to 4 weeks.

**Plant damage and plant compensation**

Damage by flea beetles is most evident on seedlings. Severe damage can be caused by beetles feeding on the seedlings below soil surface, before the seedlings emerge above the soil. With emerging seedlings, the beetles chew holes, particularly in the cotyledons (seed leaves), giving them a characteristic shot-hole appearance. Occasionally, seedlings may be completely destroyed. Loss can be greatest in a dry period when the seedlings grow very slowly after germination.

Flea beetles are especially damaging to Chinese cabbage, which is sometimes used as a trap crop to keep flea beetles off other crucifers.

Apart from the direct damage they cause, flea beetles can also transmit turnip yellow and turnip mosaic virus. Crops are at risk mainly when the new generations of flea beetle emerge. Although the plants are by then large, damage may be severe if large numbers of beetles enter the crop.

**Plant compensation study example for flea beetle damage**

How much leaf damage can cabbage seedlings sustain? When does crop injury result in yield or quality loss? How much damage can be tolerated before something has to be done to control flea beetles? Find out in a compensation study!

Select a number of seedlings (e.g. 100) in a separate area of the nursery. Cut different percentages of the seedleaves (cotyledons) and different percentages of the first true leaves at different times. For example: cut 10, 25, 50 and 75% of the cotyledons one week after emerging, another 10, 25, 50 and 75% of all leaves per plant at 2 weeks after emerging, etc. Cutting the leaves will simulate the damage done by flea beetle (and some other leaf-eating insects). Label the different “treatments” carefully to avoid mixing up. Transplant the seedlings in a separate area of the field and include plants that have not been cut as the control. Compare plant vigor, yield and quality during growing and at harvest time.

**Natural enemies**

The rainy season is not favorable for flea beetles. When the soil is more or less permanently moist, seedlings establish quick and are soon large enough to tolerate most flea beetle infestations. The sensitive growth stage is shortened and damage is reduced. Rain can also have a direct impact on flea beetles, washing them off the leaves, disturbing emergence from eggs in the soil, or destroying the larvae in the soil by washing them away.

Except for general predators like spiders, there are no specific predators or parasites that control flea
beetles. Some research was done with the application of a water solution containing the nematode *Neoaplectana feltiae* but no satisfactory control of the flea beetle was obtained.

In Thailand, the nematode *Steinernema carpopcapsae* is recommended by the Department of Agriculture Extension at concentration of 2000/cc. to control nymphts of flea beetle (FAO Dalat report, 1998).

**Management and control practices**

**Prevention activities:**

- **Solarization** of the nursery soil may help to reduce the number of larvae and pupae in the soil.
- **Healthy plants** grow quickly through the susceptible seedling stage. Proper seedbed preparation, or growing seedlings in pots (see section 3.7.1) and proper fertilization (e.g. compost) will help to get healthy plants. See chapter 3 on agronomic practices.
- **Weed control** is another good prevention activity as flea beetles are often associated with weedy areas.
- **Intercropping with white clover** may help reducing numbers of flea beetles. Several studies show this link. See section 3.5.3.4 on organic mulch.
- **Seed treatment with insecticides** is becoming a common practice in many countries. Seed is (sometimes already by the seed company) covered with a thin layer of both a fungicide and an insecticide, so that the crop is protected from seedling diseases as well as insect damage from flea beetles. The insecticide protects the crop from moderate attacks between germination of the seeds and the first true leaf stage. If the seeds are not treated with an insecticide by the seed company, farmers can do this themselves. The advantage of seed treatment is that a relatively small quantity of insecticide is needed to obtain good protection.

**Seed treatment with an insecticide**

Take a recommended insecticide powder that is effective against flea beetle. To increase the adhesiveness of the powder, 15 ml of paraffin or vaporizing oil can be mixed with each 2 kg of seed before mixing the powder. Seed treated with the paraffin or oil has to be sown within a week of treatment.

Use protective gloves while handling treated seeds!

Set up a field study to compare treated and untreated seed and compare the damage that may occur.

**Once flea beetles** are present in the nursery/field:

- Part of the adults can be trapped using **sticky traps**. See box below. In some areas, sticky boards are even swept over the crop to catch adults. Some control may be achieved by sticky traps, however, large populations will not be effectively controlled.
- **Treating just the outside rows** of a field is effective, since flea beetles migrate in from weedy areas.
If attacks in the nursery are very heavy, additional application of insecticides can be made when the seedlings have emerged from the soil.

Crop compensation: From the transplantable stage of the seedlings (at about 5 true leaves), cabbage plants are able to compensate for most of the damage from flea beetles. Compensation capacity of cabbage plants can be studied in trials (see also box above).

No control measures are necessary when the cabbage plants have at least 9 true leaves. Damage from flea beetles is usually not harmful to the plants at this stage and later.

Flea beetle traps
Flea beetles can be trapped by a piece of wood coated with heavy grease. If put in the soil a few centimeters above infected plants at regular intervals, the flea beetles will jump onto the wood and stick to the grease. Some farmers even used small sticky plates to sweep over the crop in order to catch adults.

Points to remember about flea beetles:
1. Flea beetles can be a problem in nurseries and transplants, but seldom in larger plants.
2. Preventive activities include solarization of the nursery soil, weed control, and seed treatment.

5.4 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.

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 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 debris 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 *Hexamermis arvalis* and a granulosis virus. The entomopathogenic nematode *Steinernema bibionis* is being used on a commercial scale in Western countries such as the Netherlands for 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 cabbage 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 moisture in the soil 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 cabbage leaves mixed with an insecticide can be spread between the cabbage 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.

- 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.
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.

5.5 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.

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 cabbage plants. This is usually a problem from seedling until cupping stage. When the cabbage head is formed, usually not much damage is done.

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. Some countries are already using it on large scale.
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 Helicoverpa 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).

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.

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).

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 stubble 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 cabbage. It might be worth trying a few crops to see if the armyworm population is larger on the trap crop than on the cabbages. A potential trap crop may be sunflower. These were promising when used as trap crop for groundnut.

Once armyworms are present in the field:

- **Hand collection** of larvae and egg masses may be possible for small plots. It is not practical for cabbage 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 a pesticide application is considered, balance benefits from pesticide application against harm done to natural enemy population. Spraying for armyworm may result in more trouble with e.g. DBM because their natural enemies are killed!

Points to remember about armyworm:

1. Yield loss from armyworm damage in cabbage 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

5.6 Cabbage heart caterpillar - *Crocidolomia binotalis*

See illustration Plate 1 Fig. 1

This insect has become an important secondary pest in some areas, for example in Indonesia.

Another name used for this insect is the webworm, cabbage head caterpillar or cabbage leaf-webber. There seems to be some confusion with the name “webworm” being either *Crocidolomia binotalis* or *Hellula undalis*. See section 5.7 below.

**Description and life cycle**

These slightly hairy, small (15 - 25 mm) caterpillars have orange heads, a creamy-yellow underside and a light green back with fine, longitudinal white lines. They are easily recognized by their distinctive yellowish white stripes: three dorsal and two lateral. These stripes disappear only when larvae are close to pupation. The sides of the body are brownish with black spots. Up to 50 caterpillars may be found grouped together in a network of threads on a single cabbage.
Adults are active at dawn and at night. Adult females can live as long as 30 days and lay as many as 10 or more egg clusters for an average total of 350 eggs. Eggs are laid in batches of up to one hundred. These are flattened and are packed neatly like roof tiles on young cabbage leaves. Egg masses are light green in color and are usually laid on the underside near the base of leaves.

The caterpillars hatch in about 4 days. The caterpillar stage may take about 12 days with a total of five molts. Larvae burrow into the soil near the base of the host plant to pupate. They weave a loose cocoon which they cover with bits of available substrate, usually soil. This makes the pupa difficult to find. The *Crocidolomia* life cycle is completed in approximately 28 days, depending on temperature and humidity. They are almost exclusively found in hot humid highland tropics. They are a more serious pest problem during the dry season since heavy rains can drown small larvae.

**Plant damage and plant compensation**

Large numbers of caterpillars are feeding together on a single plant. For the first 4 or 5 days from hatching, the small larvae feed on the underside of the leaf without eating through the upper leaf layer, creating window-like damage in the leaves. After this they move to the growing point of the plant center or bore to the center of the head. In the open center, groups of caterpillars will conceal themselves beneath silk webbing and frass. *Crocidolomia* damage results in a completely destroyed plant or false cabbage head with no real head or several small heads.

Larvae are very mobile and can easily travel 2 or more meters to reach a preferred host plant. Also, as soon as larvae have begun boring into a cabbage head they are protected from contact with insecticides or biocontrol agents.

**Natural enemies**

*Bacillus thuringiensis* (Bt) works for *Crocidolomia* caterpillar control.

Two fungi, *Nomuraea rileyi*, and *Erynia* sp. have been found killing webworm larvae in Indonesia (FAO-ICP Progress report ‘96 – ‘99; Shepard et al, 1999). Methods for production and distribution are being investigated. See section 6.3.2 on fungi as natural enemies.

Several Hymenopteran larval parasitoids have been identified for *Crocidolomia*. In the Philippines, the larval/pupal parasitoid *Aulacocentrum philippinum* (*Braconidae, Hymenoptera*) is being studied for control of *Crocidolomia binotalis*. A field study by the Department of Entomology/UPLB in Quezon Province in 1996 showed 59% parasitism (pers. Comm. Dr. Belen Rejesus, July 2000).

There may be potential for entomopathogenic nematodes as biocontrol agents. Further studies are needed.

**Management and control practices**

**Prevention activities:**

- It is preferable to plant cabbage during the rainy season when populations are reduced. However, cabbage crops in the rainy season may have more disease problems.

- **Trap cropping:** *Crocidolomia* caterpillars prefer mustard plants to cabbages. That means there is a potential for planting mustard as a trap crop. In India for example, 15 rows of cabbage were successfully intercropped with Indian Mustard (planted 12 days prior and 25 days post cabbage transplant). See also section 3.10.
Major Cabbage Insect Pests

- **Ploughing field** to will expose pupae to drying sun and birds.
- **Removing plant debris** after harvest and before transplanting to reduce populations.

Once the *Crocidolomia* caterpillar is present in the field:

- **Hand removal of egg masses and early instars**: trials done reflect that handpicking of caterpillars is a good way of control. During the first 40 days after cabbage transplant, while leaves are still open and relatively few, caterpillars are easy to spot in the field. The first symptoms are “windows” in the leaf. Handpicking was easier and quicker than spraying individual plants with an insecticides because for good chemical control, the whole plant needs to be sprayed very thoroughly. At a later cropping stage, removing infested plants and destroying them is an effective control measure. Regular handpicking of egg masses in combination with Bt applications has also been found effective in reducing damage (Shepard et al, 1999)

- **Preparations of Bacillus thuringiensis** (Bt) can be effective against this caterpillar. Spot spraying only those cabbage plants with visible *Crocidolomia* caterpillars is an effective means of control. When cabbage plants enter cupping stage, *Crocidolomia* caterpillars become more difficult to detect. In areas with high populations, it may be an option to spray Bt regularly when damage is seen. However, once larvae are inside cabbage heads, Bt are no longer effective.

- **Spraying chemical pesticides is not recommended.** Most pesticides are no longer effective when larvae begin boring into the cabbage heads where they are inaccessible. Pesticide application cannot be considered in isolation from other pests such as diamondback moth. Spraying against *Crocidolomia* decimates the natural enemy population that may control DBM (e.g. *D. semiclausum*).

### Points to remember about cabbage heart caterpillar:

1. *Crocidolomia* caterpillars can locally be a serious pest.
2. Handpicking egg masses and early instars during early growth stages is a good way of control.
3. Destroying infested plants is valuable after cupping stage to prevent further damage.
4. Spot applications of Bt can work against caterpillars but only before the cupping stage.
5. When caterpillars have bored inside cabbage heads, Bt and chemical pesticides are usually not effective.

### 5.7 Cabbage webworm - *Hellula undalis*

See illustration plate 1 Fig. 2

This insect is also called *cabbage borer* and *oriental cabbage webworm*.

There seems to be some confusion with the name “webworm” being either *Crocidolomia binotalis* or *Hellula undalis*. See section 5.6 above.

**Description and life cycle**

Eggs are laid singly or in a row on cabbage plants.

The larvae of this insect have a length of about 15 mm and they are pale cream to green or gray in color. The head is dark brown to black. The body has several narrow dark stripes along the back and sides of the body. The larvae mine the leaf midribs or feed inside the cabbage heart under protective silken webs. Pupation occurs inside a cocoon made of soil just below the soil surface.
The adult moth is small (up to 9 mm) with light brown wings.
The life cycle extends to about 4 weeks, depending on the temperature.

**Plant damage and plant compensation**
The main damage is caused to young seedlings and to young cabbage transplants, unlike *Crocidolomia* caterpillars which can affect cabbage plants at any stage. On hatching from the egg, the young *Hellula* larvae bore into the base of the leaf-midribs, and also into the stem, sometimes going down as far as the roots before emerging for pupation. Seedlings may be attacked by several larvae at the same time, and either die or develop into poor feeble plants. Cabbages often develop small, multiple distorted heads of no commercial value. Nurseries can be totally destroyed in a few days.

Webworm attack can be particularly high during and immediately after the wet season. High temperatures and high humidity, such as would occur during and just after the rainy season, favor the development of this insect. The critical period begins when the first true leaves are forming.

This insect is often considered a serious pest in lowland crucifers, but is less serious in highland areas.

**Natural enemies**
Preparations of *Bacillus thuringiensis* (Bt) may be effective but only before larvae have bored into stems or cabbage heads, and before they are protected by silken webs.

**Management and control practices**

*Prevention activities:*
- Burning of crop stubble and removal of weeds help to lower the pest population. Some webworms may survive on crop stubble and weeds after harvest and infest a newly transplanted crop, causing serious crop injury.
- The critical period for webworm attack begins when the first true leaves are forming. It is important to inspect the nursery every few days for presence of these caterpillars, especially during or shortly after the rainy season.

*Once the webworm* is present in the field:
- Low populations in the nursery may still be controlled by handpicking the caterpillars or eggs.
- Removal of infested leaves or even the growing point may be considered. The cabbage plant will compensate for the loss of leaves and even the loss of the main shoot by producing new leaves and shoots. All but one shoot will have to be removed. See section 4.5 on plant compensation.
- Larger populations in the nursery or in the field may be controlled by a spot application of Bt or a (systemic) insecticide. Spot applications minimize the use of biological or chemical insecticides and may save at least part of the beneficial insect species. Bt applications can work against webworm but need to be applied before caterpillars are protected inside the leaf or under webbing.
Points to remember about webworm:

1. Webworm caterpillars can locally be a serious pest, especially of nurseries and young transplants.
2. Handpicking of caterpillars helps to prevent population build-up.
3. Removing infested leaves or the main bud may be considered. The cabbage plant will compensate by producing more leaves and shoots.
4. Bt applications can work against caterpillars but need to be applied before caterpillars are protected inside the leaf or under webbing.

Related exercises from CABI Bioscience/FAO manual:

4-A.9 Handpicking of eggs and caterpillars
4-A.10 Integrated management of webworm on cabbage
4-A.13 Comparison of biological and chemical pesticides used in caterpillar control

5.8 Cabbage looper - *Trichoplusia ni*

There are several English names for this insect: cabbage looper, cabbage semilooper, ni moth or the false cabbage looper.

Description

The adult looper is a dark brownish moth with two small white markings on the forewings, sometimes resembling the figure “8”. Wingspan is about 35 mm. Adults live for about 3 weeks.

The moths are night fliers, but can be seen during the day resting on the underside of cabbage leaves.

The cabbage looper is a smooth yellow-green caterpillar with a whitish line down each side, and the forepart of the body slightly narrower than the rest. It can have two white lines along the middle of the back. Fully grown caterpillars measure 30 - 35 mm. There are two pairs of prolegs so a caterpillar walks by arching its body as a “looping” action which is characteristic for this insect. The caterpillars first eat on the leaf borders but as they mature, they move deeper into the cabbage heads.

The main host plant for the semi-looper are cruciferous crops but it can also feed on cotton, legumes, solanaceous crops like potato and tomato, sweet potato, some cucurbits and many other vegetables.

Life cycle

Eggs are laid singly on the underside of the lowest leaves, and hatch in about 2 - 3 days. Each female can lay up to 200 eggs. The eggs are white to yellow in color, round, about 0.5 mm in diameter and hatch in 2 to 3 days. The eggs are not securely glued to the leaf and can be brushed off easily.
Larval development takes some 30 to 35 days. There usually are five instars.

Pupation takes place in a silken cocoon, usually in the leaf litter or crop debris. In cabbages, the cocoon may also be in the heart of the plant between leaves. The pupa is brown and about 20 mm long. Under optimum conditions, development of the adult inside the cocoon takes about 15 days.

In (sub)tropical areas there may be 5 generations per year or more as a result of continuous breeding. Even in temperate areas, the caterpillars continue to be active at low temperatures.

**Plant damage**

The caterpillars of the semilooper eat large, irregular holes in the leaves. Young larvae skeletonize leaves, the older larvae eat the entire leaves, sometimes causing plant defoliation. As loopers mature, they move deeper into the cabbage heads. They can consume large parts of the hearts of cabbages, and contaminating it with frass. Plant development may be retarded and the quality of cabbages will go down.

Compared to other caterpillars, cabbage loopers are not very destructive. Although one looper larvae does approximately three times the damage of one *Pieris rapae* larva and can consume almost 20 times as much foliage as a diamondback moth larvae, their numbers are less and they do not eat deep in the heart of the cabbage.

There are *pheromones* available for looper monitoring.

**Natural enemies**

Many natural enemies are recorded for this species and natural field mortality may sometimes be high. Nuclear Polyhedrosis Virus (NPV) and *Bacillus thuringiensis* (Bt) are effective against this pest. However, some trials report that Bt is less effective against the cabbage looper.

During the wet season, some fungus species may attack and kill the cabbage looper.

**Management and control practices**

**Prevention activities:**

- Removing or burning of crop residues and removal of weeds help to lower the pest population. Cabbage loopers may survive on crop stubble and weeds after harvest and infest a newly transplanted crop, causing new crop injury.
- **Ploughing the field** may bury crop residues containing looper pupae in the soil where they die.

**Once cabbage loopers** are present in the field:

- **Hand collection of larvae** may be possible for small plots. It may not be practical for cabbage production on larger scale.
- **Biological control with preparations of *Bacillus thuringiensis*** (Bt) may be effective. Bt is most likely to be effective on young, active looper larvae exposed during time of application.
- Chemical control has been difficult to achieve as the **cabbage looper has developed resistance to many insecticides** including carbaryl, parathion, methomyl and others.
5.9 Cabbage white butterfly - *Pieris rapae* and *Pieris brassicae*

Both *Pieris rapae* and *Pieris brassicae* are widespread pest insects of crucifer crops in Asia, mostly in the cooler region or highlands. *Pieris rapae* seems to be more important than *Pieris brassicae* in Asia.

**Description**

The adults of *Pieris rapae* have white wings and the forewings have black tips. Females have two black spots in the middle of each forewing. These spots may also appear grayish in color. The male has one black spot in the middle of each forewing, although occasionally the wings may be pure white without dark spots on the tips. The hindwings are all white on the surface except for a black spot on the outer front margin.

Adults of *Pieris brassicae* look much like *Pieris rapae* but they are slightly larger with a wingspan of 50 - 70 mm. The wings are white in color with black tips on the forewings. In addition to these black tips, the female has two large black spots on the upper surface of each forewing.

Caterpillars of *Pieris rapae* have a green velvet appearance, with faint yellow lines down the back and yellow patches along their sides. When fully grown, they are about 25 - 30 mm long.

*Pieris rapae* usually pupates on the plants although pupae can be found on sheds and walls. They rest vertically on a pad of silk to which it is attached by a silken girdle. The pupa usually color-match the surroundings: pupae found on actively growing plants are deep green whereas pupae found on dead plant material are usually dull gray and speckled to match the background. Completion of the pupal stage ranges from one to two weeks.

Caterpillar of *Pieris brassicae* are pale green in color at first, but they rapidly become mottled blue-green, with many black markings. When fully grown, each caterpillar is 25-40 mm long and has three yellow-colored lines down the back, and yellow along the sides of the body. Each has groups of short, stiff, white hairs along the body. Caterpillars tend to stay together in small groups.
Life cycle

Life cycles of *Pieris rapae* and *Pieris brassicae* are slightly different, and are described separately below.

*Pieris brassicae* :

The females lay their yellow, flask-shaped eggs in batches of 20 to 100 on a cruciferous plant, usually on the underside of leaves. The eggs hatch in about 14 days and the young caterpillars first eat their eggshells and then feed on the leaves. They stay together in a small colony. After the third moult, the caterpillars disperse, many moving onto new leaves. Usually, most of the caterpillars feed on only one plant. They are easily seen feeding on both surfaces of the leaf. When populations are large it is common to see plants completely defoliated with just leaf stalks and some midribs remaining. After feeding for about 30 days, the caterpillars leave the host plant and search for sheltered pupation sites on vertical or overhanging surfaces on trees, walls, fences or similar objects. Each larva spins a silken pad to which it attaches itself in an upright position. It then makes a silken girdle around its waist to hold it in position. The pupa is gray-green in color with yellow and black marks. After about 15 days, the adults emerge. Their wings are crumpled at first but within hours they expand and dry.

*Pieris rapae* :

Eggs are often laid on many different plants within a field. The eggs are laid individually on the underside of leaves. The pale-yellow colored, bottle-shaped eggs hatch in about 3-15 days, depending on the temperature. Caterpillars feed solitary, usually in the heart or around the growing point of the plant. Later instars rest openly along the mid-ribs of the leaves. Although dark green in appearance, the presence of the larvae is easy to find by the damaged leaves with accompanying frass.

Plant damage and plant compensation

The caterpillars eat the leaves and defoliate the plants and contaminate them with large quantities of feces. In heavy infestations leaves are reduced to the midribs and the plants are killed. The larvae feed on the first formed outer leaves of their host plants, which often appear riddled with irregularly shaped holes. As the caterpillars become mature, they feed in the center of the plant. Their excretions can be found between the leaves.

Caterpillars of *Pieris rapae* are feeding more solitary than larvae of *Pieris brassicae* so individual plant damage is usually less severe but more plants may be damaged.

*Pieris* species are sometimes considered to be a pest, not because of the amount of crop it destroys, but because of the amount of frass contamination which can make cabbages of a lower quality grade. The frass is particularly troublesome in cabbage crops near harvest as the pungent-smelling frass is located between the wrapper leaves and the cabbage head.

Natural enemies

*Pieris* larvae are commonly parasitized by a wasp, *Cotesia (Apanteles) glomerata*, and pupae by another wasp, *Pteromalus puparum*. *Meteorus versicolor* is also reported as natural enemy of *Pieris rapae*. Often, natural occurrence of these parasitoids makes additional control unnecessary. In fact, control action can be damaging as insecticides can easily kill parasitoids, resulting in more damage from the caterpillars.

The parasitoid *Cotesia (Apanteles) glomerata* can achieve very effective control of caterpillars. The small, bright-yellow colored cocoons of *Cotesia glomerata* can be seen alongside the dead and dying caterpillar.
Major Cabbage Insect Pests

from which the parasitoids have emerged. See also section 6.2.3 for details on *Cotesia glomerata*. In Vietnam, this parasitoid has been brought to Dalat, a highland area, for *Pieris* control (FAO-ICP progress report '96 – ‘99). The Hung Yen rearing unit in the area is establishing mass-production facilities for the natural enemy *Cotesia glomerata*. Once this has been established, field releases combined with farmer training will be set up (FAO Dalat report, 1998).

Commercial preparations of *Bacillus thuringiensis* (Bt) are available as biological insecticides and are effective in some areas but not in others. In Dalat, south Vietnam, for example, farmers reported that Bt was not effective against *Pieris*. This is why the parasitoid *Cotesia glomerata* was imported.

A Granulosis Virus (GV) can be an important mortality factor. This GV can possibly spread through the parasitoid *Cotesia* (ref. www16). See sections 6.2.3 and 6.3.3.

Chickens and ducks like to eat these caterpillars when they roam around in the field. Often however, they only eat the caterpillars that have dropped on the ground. They are therefore not very effective in controlling these caterpillars but do contribute a little. Caterpillars are also eaten by some other birds and predatory ground beetles.

Management and control practices

Prevention activities:

- Some prevention is obtained when crop residues are removed from the field after harvest. These residues may be sources of infestation when they contain eggs or young larvae. The larvae can easily spread to the new crop. The crop residues can be buried into the soil, fed to farm animals, added to a compost pile or collected, dried slightly and burnt. Removing crop left-overs is also very valuable for prevention of other insect pests and diseases.

Once the cabbage white butterfly is present in the field:

- Hand-picking of egg masses and young larvae is recommended when cabbage is grown in small plots. Also when only a few plants are attacked, handpicking of caterpillars is useful. Effective control can be achieved with this.

- Monitor field for signs of natural control by parasitoids. Natural control percentages can be very high and no additional chemical control is necessary in that case.

- Chemical control of this caterpillar with insecticides is difficult because once the caterpillars have entered the hearts of cabbage plants, they are protected by leaves and sprays are not effective. Consider spot applications when insecticide spray is still found necessary.

- When large numbers of caterpillars are attacking many plants in the field, consider applying a preparation of *Bacillus thuringiensis* (Bt). Efficacy of Bt preparations may also be tested in insect zoos before applying to main field. See section 6.3.1.

Points to remember about *Pieris* species:

1. *Pieris* species can be a problem in cabbage fields because caterpillars defoliate plants, and contaminate the crop with frass, which can make cabbages of a lower quality

2. Where available, the parasitoid *Cotesia glomerata* can give effective control of *Pieris* larvae, when pesticides are not used.

3. Bt spray may be effective for *Pieris* sp.control.
5.10 Whitefly – *Bemisia tabaci*

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

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

Whitefly currently is 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.

In Cebu, in the Philippines, serious damage on cabbages by the whitefly *Bemisia tabaci* occurred during the dry season. Injudicious use of pesticides and favorable temperature led to whitefly outbreak in the area (Ref. FAO-ICP progress report April 1996 – Feb 1999).

**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.

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

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1. Egg (actual size about 0.24 mm long)
2. & 3. Top and side view of 1st stage nymph
4. 4th stage nymph (actual size about 0.75 mm long)
the adult can be seen through its transparent back. The total nymphaal 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 silver leaf of squash and irregular ripening of tomato. Plant viruses also can be transmitted by whiteflies, but for cabbage this is not a serious problem.

**Natural enemies**

Whiteflies are controlled by predatory insects such as green lacewing or coccinellid larvae (lady beetles); 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!

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**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)
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).

In Cebu, the Philippines, field parasitism of whitefly by the parasitoid *Encarsia* sp. ranged from 75 to 90%! (Ref. FAO-ICP progress report April 1996 – Feb 1999).

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 reach 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 called *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. In Cebu, Philippines, *Paecilomyces* sp. was found native in the field (Ref. FAO-ICP progress report April 1996 – Feb 1999).

### 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, which is the case in most cabbage growing areas, other methods such as biological control can be more effective.

**Prevention activities:**

- **Plant resistant cabbage 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 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.
- **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.

- 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, floating row covers (generally made out of a light fiber mesh and placed over newly planted crops) that exclude whiteflies during the vegetative growth of the crop, and trap crops.

- 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).

> 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 techniques.

Once whiteflies are present in the field:

- Chemical control of whiteflies is both expensive and increasingly difficult. Many systemic and contact insecticides have been tested for control of whiteflies, but few give effective control. Besides the cost of treatment, other factors involved in chemical control decisions are:
  
  - the need for thorough coverage: whiteflies are located on the undersides of leaves where they are protected from overhead applications, and the immature stages (except for the first one) are immobile and do not increase their exposure to insecticides by moving around the plant,
  
  - the risk of secondary pest outbreaks (due to elimination of natural enemies),
  
  - the risk of whiteflies developing insecticide resistance (a very serious threat!), and
  
  - the regulatory restrictions on the use of insecticides.

Points to remember about whitefly:

1. Whitefly populations in cabbage can be high, but infestation seldom leads to severe crop losses.
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 on sucking insects in insect zoo
4-D.2 Cage exclusion of natural enemies in the field
4-D.7 Parasitism of whitefly

5.11 Stemborer – *Melanagromyza cleomae*

During IPM training exercises in Lao PDR (1997) and northern and central Thailand (1999, 2000), the stemborer *Melanagromyza cleomae* was found in stems of cabbage seedlings and petioles of older plants. Very little is known about this stemborer fly.

*M. cleomae* appears to attack only crops in the crucifer family. It must be considered a potential pest on important crops on a wider scale than so far reported in literature (CABI ID report, 2000). Much of the documented information on *M. cleomae* in below section is based on innovative action-research by farmers, IPM trainers and field-based researchers, during above mentioned IPM training exercises (pers. comm. J. W. Ketelaar, 1999/2000).

**Description and life cycle**

The adult is a fly, approximately 2 mm long, mostly black with red eyes and a slight blue-green cast on the back of the thorax and abdomen. Eggs are inserted into plant tissue. Larvae are small white maggots with no legs. Pupation occurs inside the tunnels formed by the larvae in plant tissue.

In northern Thailand, IPM trainers reared aromyzid stem borers and their parasitoids from weeds (composite family) surrounding the cabbage fields. These stemborers were identified as *Melanagromyza metallica*. This means that the cabbage stemborer is probably not using the prevalent composite weeds as alternative hosts. Further ecological studies are needed to study alternative hosts (pers. comm. Dr. M. Schmaedick, 2000)

**Plant damage and plant compensation**

The larvae (maggots) of this stemborer fly, bore into the main stems of cabbage plants, often young cabbage transplants. The main symptom is plant stunting. The transplants usually survive but show very weak growth, discoloration of leaves and do not form heads. In older plants the larvae are ofund boring in the petioles of older leaves. It is not certain what effect, if any, this damage to the older petioles may have on cabbage yield. Fields infested at this stage may, however, produce large numbers of flies that could infest nearby fields.

Damage symptoms caused by the stemborer is often confused by farmers with stunting due to lack of water or fertilizers.

Serious crop damage occurred in young cabbage transplants during a training activity in Chiangrai province, northern Thailand. Interestingly, it seemed that there was a difference in stemborer occurrence in the plot that was fertilized according to Farmer Practice (high level of infestation) as compared to the IPM plot which received fertilizer according to recommended rate after soil analysis (low infestation). The main difference in fertilizer treatment was that the IPM plot received a high input of organic fertilizer, and the FP plot received only chemical fertilizers.
This could indicate that better fertilizer management (that includes organic material) made plants grow quicker and therefore shorten the borer susceptible stage, or that IPM fertilizer treatment resulted in healthier plants which were less susceptible to the stemborer. The higher organic matter in the IPM plots might have helped in population build ups of predators (including predatory fly Coenosa sp. (see below)). However, such hypothetical relations should be further studied. (Chiangrai TOT report, 1999)

**Natural enemies**

Two species of parasitoids, *Eurytome* sp. and *Syntomopus* sp. were reared from stemborer immature stages from fields in Chiangrai, northern Thailand. Identification of these parasitoids was not yet done upon printing of this guide.

The predatory fly, *Coenosa* sp. may be a natural enemy for this stemborer. *Coenosa* is being used in German greenhouses for control of cabbage maggot (*Delia* sp.) Both the larvae in the soil and adults above ground are predatory. There is a strong link between population of *Coenosa* and earthworm and thus a likely link to organic matter content in the soil. Thus higher organic matter in the soil, such as in fields where lots of compost is used, may help increase the population of predators (pers. comm. M. Schmaedick and J.W. Ketelaar, 1999/2000).

However, such links should be further studied.

**Management and control practices**

- Selecting only healthy seedlings for transplanting.
- Proper soil fertility management and using organic material, such as compost, may help increase crop vigor and may help population build-up of predators.
- Good sanitation, including weeding out and destruction of visibly damaged plants and remaining stubbles in the field, may help to prevent population build-up.

**Points to remember about stemborer:**

- The stemborer *Melanagromyza cleomae* can severely damage young transplants of cabbage, resulting in stunted plants and no head development.
- Adding organic material possibly lowers infestation by stemborer but this needs to be confirmed with more experiments.
- Some parasitoids of stemborer were found, but identification and efficacy is not yet clear.

**Related exercises from CABI Bioscience/FAO manual:**

4-C.1 Sanitation to control shoot borers
SUMMARY

Predators, parasitoids and pathogens are the main groups of natural enemies that can control large numbers of cabbage 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 an insect. Parasitoids such as Diadegma sp. and Cotesia sp. are the most important natural enemies for diamondback moth control and possibly for Pieris sp. Diadegma and Cotesia sp. are now (commercially) available in SE Asia for field releases.

Pathogens: are usually host specific 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. NPV and some fungal pathogens can be produced at farm level, after basic farmer training. Nematodes such as Steinernema sp. also increasingly available for insect control.

Natural enemies:
- Are easily killed by (broad-spectrum) pesticides
- (Indigenous) natural enemies 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).
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 cabbage 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 cabbage 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. Adults 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 debris 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.
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.

Shelterbelts 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 in 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 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**

These 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.

Predation efficacy hoverfly: a study example

To check how effective one hoverfly larva is, you can count how many prey it eats in a day. Collect a few hoverfly larvae from the field (use wetted hair brush to handle them). Put one larva per potted plant with a known number of prey e.g. aphids on an cabbage leaf. Count how many prey is left after 24 hours. Place the same number of aphids in a jar without the predator to check how quick the aphid population grows when no predator is around. Use hoverfly larvae of different sizes (there are 3 larval stages) and compare the appetites of each stage. Discuss if hoverflies can keep up with aphid population growth.

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 - Mantidae

Also called praying mantis.

Primary prey: flies, bees, moths and small spiders.

Predatory stages: nymphs and adults are predators.

Description and life cycle

Both adult and nymphs have large front legs that they hold 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.

Effectiveness

Mantids are very active predators of many insects and they serve a beneficial role in destroying many pest insects. They are indiscriminate hunters and can eat many large insects per day.

However, mantids are usually not considered to be important in regulating insect pest populations.

Conservation

As for almost all 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 cabbage field. The young nymphs may start feeding on pest insects of cabbage.
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.

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 of 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, (e.g. Diadegma) only one parasitoid will develop in or on each pest while, in others (e.g. Cotesia glomerata), hundreds of young larvae may develop within a single host.
Recognizing parasitoid activities

Parasitoids are difficult to spot because they are very small and they are fast flyers. However, they leave evidence of their activities. In the case of diamondback moth (DBM) parasitoids for example, dead caterpillars or, more commonly, cocoons can be found. Often, these cocoons are wrongly thought to be eggs of insect pests. A good way to study parasitoids is to collect sick insects, cocoons, round or egg-shaped masses of spiders and even insects caught in spiders webs in the field. These can be observed in jars or clear plastic bottles. If cocoons are found next to a dead or dying caterpillar, the connection between cocoon and caterpillar can be shown. For example, a white cocoon of *Cotesia plutellae* is usually found next to a dead caterpillar with a large hole indicating where the parasitoid larva emerged. After emergence, the larva spins a cocoon.

Many insect pest larvae of similar age could be collected to confirm if the parasitoid is coming out of the caterpillar, and witness the process of emerging. Showing this will help farmers understand the importance of the cocoons.

Placing cocoons inside clear plastic bottles helps to observe what emerges from the cocoon. Draw the cocoons, the dead caterpillar and the type of adults that emerge, using color pencils (Ooi, 1999). See also box below.

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

An easy method to rear parasitoids, for example of cabbage aphids, is the following:

- Collect a number of cabbage leaves with large colonies of aphids on the underside.
- Check, if possible with hand lens, if there are any “mummies” (swollen, dead aphids that have been tanned (often brownish) and hardened).
- When mummies are found, place the leaf with aphids in a jar (insect zoo), together with a piece of tissue to avoid condensation. Close the jar with a fine netting.
- Monitor changes in aphids and mummies over the next few days.
- Other aphids that have been parasitized, will transform into mummies in the next few days. Adult parasitoids (possibly *Diaeretiella rapae*, see section 6.2.1) will emerge from the mummy. After emergence, you can see the exit hole towards the end of the aphid’s abdomen.

Leaves containing aphid mummies can be redistributed to help spread the parasitoids.
Major Natural Enemies of Cabbage Insect Pests

Related exercises from CABI Bioscience/FAO manual

1.6 Show effects of beneficials incl. natural enemies

6.2.1 Diaeretiella rapae

**Primary host:** aphids

**Description and life cycle**

*Diaeretiella rapae* is a small wasp that attacks only aphids. The adult wasps are very small, less than 3 mm, and dark with long antennae. Adult wasps are usually active on bright, clear days. They may not fly on very hot, windy or rainy days. Females lay up to several hundred eggs. They prefer to lay eggs in aphid nymphs rather than adults. One wasp larva develops within one aphid. Parasitized aphids look like “mummies”: swollen, dead aphids that are brownish in color and have a hardened, papery skin to form a protective case for the developing wasp pupa inside. The mummies may occur within an aphid colony or be found singly on leaves or stems. The larva inside the aphid either spins a cocoon under the dead aphid or pupates within the mummified aphid. The adult wasp emerges after cutting a circular hole in its cocoon. Adults live from 1 to 3 weeks and there can be many generations per year. They can occur in many vegetable crops with aphid populations.

**Effectiveness**

*Diaeretiella rapae* can have an effective impact on aphid infestations. Females of some species may parasitize hundreds of aphids in one day. If young aphids are parasitized, they will usually die before reproducing. Aphids parasitized as older nymphs or as adults may reproduce before dying but produce fewer young aphids than normal. The effectiveness of this wasp in cooler areas is not clear.

**Mummy monitoring**

Monitoring just the number of aphid mummies will not give the right estimation of the degree of parasitism by wasps. It does not account for the parasitized aphids that have not yet become mummies. Also, parasitized aphids may move away from the feeding site or fall off the plant. It does tell you if the parasitoid *Diaeretiella* is present and active and it gives an idea of the amount of parasitism.

In cases where aphids transmit virus diseases (that cause injury to plants), aphid parasitoids will generally not provide adequate control. Since the virus is transmitted within a few seconds after the aphid starts sucking the plant, this happens in a few seconds and whether or not that aphid is parasitized does not matter for the spread of virus.
Conservation
Leaves containing aphid mummies can be redistributed to help spread the parasitoids in the field. Check if the parasitoids are still inside the mummies: when you see a circular hole in the mummy or in the cocoon of the parasitoid, the adult has emerged and it is useless to redistribute that leaf.
Most parasitoids are even more susceptible to pesticides than predators. Adult parasitoids are usually also more susceptible to pesticides than their hosts. Immature parasitoids may sometimes be protected when they are inside the host or in their egg or cocoon, but when the host is killed, the immature parasitoid will also be killed.
Many adult wasps feed on insect honeydew, and nectar from flowers. When there is a lot of this food available for the adult wasps, they live longer and lay more eggs, resulting in a higher percentage of parasitism. Adult wasps are attracted to flowering plants near the field, such as mustard plants that can also be used as a trap crop (see section 3.10). They also benefit from a source of water nearby.

6.2.2 Diadegma species

Primary prey: larvae of diamondback moth.

Diadegma sp. belong to the family of Ichneumonid wasps. This family has many members that are natural enemies of vegetable insect pests. Some species of the genus Diadegma that are parasitoids of diamondback moth (DBM) are:

- Diadegma semiclausum (Hellen) (Hymenoptera: Ichneumonidae)
- Diadegma insulare (Hymenoptera: Ichneumonidae)
- Diadegma eucerophaga (Hymenoptera: Ichneumonidae)

D. semiclausum is very efficient in keeping DBM populations low at temperate conditions. It is mass-produced and released in highland cabbage growing areas in many countries, such as Philippines (see box below), Malaysia, Indonesia, and Vietnam. However, it does not perform well at temperatures above 25°C. As a result, DBM is still a problem in tropical lowland areas. D. insulare may have potential for DBM control in tropical lowland areas. Introduction of D. insulare is being considered, e.g. in Vietnam and Philippines.

Description and life cycle

Diadegma semiclausum is a small black wasp of about 5 - 7 mm long. Diadegma insulare looks very much like Diadegma semiclausum: it also is a small black wasp but it has reddish-brown legs and body.

Females of both Diadegma semiclausum and Diadegma insulare insert one egg into the host larva. All larval stages are accepted for parasitism except the first stage due to its mining activity. The parasitoid has a slight preference for the second and third instar.

Female wasps search holes in damaged cabbage leaves with their antennae, indicating where DBM may be present.

Larvae that are parasitized do not look and behave differently from the unparasitized larvae since the parasitoid larva synchronizes its development with the development of the DBM larva. Only when the host larva has completed its cocoon, the parasitoid larva inside will eat the host. It spins its own cocoon inside the webbing of the DBM cocoon. The cocoon can be recognized because it is a double cocoon which may have a pale-white waist band. Diamondback moth cocoons are white inside (green when the larvae first form the cocoon); Diadegma wasps are visible as dark bodies inside the cocoon, before the adult Diadegma emerges.
The life cycle from egg to adult *Diadegma semiclausum* takes about 3 weeks. Females start laying eggs one day after emerging from the cocoon. During the first 2 or 3 days, they lay only unfertilized eggs that result in male wasps.

**Effectiveness**

*Diadegma semiclausum* is well adapted to temperate conditions: a temperature of 23°C is considered to be the optimum whereas at temperatures above 30°C, the parasitoid will lose its effectiveness. Under temperate conditions, the female adults of *Diadegma semiclausum* have a lifespan of about 3 weeks and will parasitize 35 to 50 DBM larvae daily. That means every female can kill up to 1000 DBM larva in its life!

In Philippines for example, 75% DBM parasitization was obtained by field releases of *D. semiclausum* in farmers’ fields (Ref. V. Justo, workshop biocontrol agents).

Unfortunately, when the temperature rises, the lifespan and parasitism capacity decline rapidly. This means *Diadegma semiclausum* is not suitable for effective DBM control at lower altitudes.

*Diadegma insulare* may be more effective at lower altitudes. *Diadegma insulare* is the most important parasitoid of the diamondback moth in North America and Canada. Native populations of *D. insulare* have parasitized up to 70% of diamondback larvae in field trials in New York and from 50% to almost 90% in Wisconsin (Grafius, www15).

Studies in Asia to rear and test *Diadegma insulare* are ongoing, for example in Philippines.

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**Field releases of *Diadegma semiclausum* in the Philippines: how is it done?**

*Diadegma semiclausum* can be released in the field as cocoons or as adult wasps. Distributing cocoons is easy because they are stronger than adult wasps and can survive longer transportation between the rearing station and the field. In the field however, the pupae need protection from predators like ants. They should protected until emergence. Usually, releasing adult wasps is recommended. Even though for the transport a special cage is necessary, loss from predation in the field is avoided and in addition, the number of males and females can be decided before release (only females are parasitoids of DBM!)

As a general rule, about 200 - 300 females and 100 - 150 males are distributed over a 1 hectare area. If the wasps can be established on the release site, it will act as point of dispersal for neighboring fields. Usually, adults are released at the same site several times (4 - 6) at weekly intervals. This increases the chance of taking action at the right time for release, and speeds up the build-up of the field population by closing the gaps between generations.

(Koenig et al, 1993)

**Conservation**

*Diadegma* sp. can give very effective control of DBM if their populations are conserved through limiting use of chemical insecticides. This requires the cooperation of many farmers in an area. The first step in conserving *Diadegma* wasps (and other natural enemies) is to monitor fields, and observe and count the presence of pests and the degree of parasitism.

For those farmers who still want to use pesticides (despite the fact that DBM has become resistant to many chemical pesticides, and even to Bt – see box in section 5.1), they could be encouraged to use Bt preparations or to spot spray: only on the heart and later the head of specific plants, not on the whole
field. The head of cabbage is the marketable part and needs protection against feeding of pests. The outer leaves will be removed anyway and can serve as a reservoir for DBM to be parasitized by Diadegma wasps.

It should be noted that application of Bt kills DBM larvae, including the parasitized DBM larvae. That means the parasitoid larva inside the DBM is also killed! Adult parasitoids, however, survive a Bt application.

For the longer term establishment of Diadegma wasps, the area should provide enough cabbage fields (not only in terms of size but also in year-round cabbage production) to support survival of the parasitoid. Diadegma females require nectar sources to feed on. A nectar source can increase D. insulare female longevity from 2-5 days to more than 20 days (Grafius, www15). And the longer it lives, the more eggs it can lay.

Allowing wildflowers (especially cruciferous weeds) to grow around the fields, and allowing DBM to colonize those weeds, will increase the abundance and effectiveness of Diadegma wasps for management of DBM.

**FARMER TRAINING is essential for successful parasitoid introduction!**

When farmers…
- recognize that DBM is not effectively controlled by chemical pesticides,
- understand how parasitoids work,
- understand that parasitoids are killed by chemical pesticides,
- recognize parasitoid activity in the field, and know how to quantify it, …………………………they’ll appreciate the work of parasitoids in the control of insect pests!

**6.2.3 Cotesia species**

Previously called: Apanteles sp.

_Cotesia_ species belong to the family of Braconid wasps. The genus _Cotesia_ has many members that are natural enemies of vegetable insect pests. Some of the beneficial _Cotesia_ relevant to cabbage are:

- _Cotesia glomerata_: parasitoid of the cabbage white butterfly, _Pieris rapae_ and _Pieris brassicae_.
- _Cotesia plutellae_: parasitoid of diamondback moth, _Plutella xylostella_.
- _Cotesia marginiventrus_: parasitoid of the cabbage looper, _Trichoplusia ni_.
- _Cotesia rubecula_: parasitoid of the cabbage white butterfly _Pieris rapae_.

Characteristics of _Cotesia glomerata_ and _Cotesia plutellae_ are described below.

**Description and life cycle**

Adults of _Cotesia glomerata_ are small, dark colored wasps of about 7 mm length. Their antennae are long and curved. First and second instar larvae of _Pieris_ sp. are attacked and serve as the host for the young wasps. The female wasp lays 20 to 60 eggs inside the host caterpillar. This caterpillar may still live for some time while the larvae develop inside but eventually it dies. The parasitoid larvae will emerge
from the caterpillar after some time to spin their silken cocoons on or very near to the host caterpillar. The cocoons are usually found in an irregular mass next to the dead caterpillar.

Adults of *Cotesia plutellae* are also small black wasps. Females live only a short time: about 10 days, depending on environmental conditions. Total life cycle from egg to adult takes about 25 days.

*Cotesia plutellae* lays its egg inside a DBM larva. The parasitoid larva develops inside the DBM caterpillar. When fully grown, the parasitoid larva emerges from the side of the DBM body and it spins a silken cocoon for pupation. The cocoons are white and can usually be found attached to the under surface of the leaves.

### Effectiveness

*Cotesia glomerata* is reported to be a very effective control agent of cabbage butterflies *Pieris* sp. In the U.S.A., more than 80% of the caterpillars may be parasitized in fields unsprayed by chemical insecticides (ref. www16).

*Cotesia plutellae* can give effective control of diamondback moth. In studies (1995) in the highland area of Dalat, Vietnam, *Cotesia* was found soon after DBM occurred, and reached parasitism levels up to 90%. In the lowlands of Hanoi area (1994-1995), parasitism was not more than 22% on average. (FAO - Updates on Vietnam national IPM programme in vegetables, 1999)

Studies show that *Cotesia plutellae* can reach high parasitation levels when pest populations are already high, but is less effective at lower pest densities (FAO Dalat report (V.Justo), 1998).

*Cotesia* can be naturally present in fields. Several *Cotesia* parasitoids are commercially available, for example in the U.S.A. Mass-rearing houses have also been established in Philippines (FAO Dalat report (V.Justo), 1998) and will be established in Vietnam. In Lao PDR, *Cotesia* is being reared and released with assistance of the AVRDC.

In addition, *C. glomerata* may be a vector in the transmission of a granulosis virus in cabbageworm, *Pieris rapae* (ref. www16).
Conservation

Like almost all other predators and parasitoids, *Cotesia* sp. are quickly eliminated when spraying chemical insecticides. When *Cotesia* is active in the field, avoid using insecticides when possible. Insecticide application may actually lead to an increase of pest insect populations because the natural enemies are killed (see section 4.11.11 and box in section 5.1).

**6.2.4  Diadromus collaris**

*Host:* pupae of diamondback moth (DBM).

The wasp *Diadromus collaris* belongs to the family of Ichneumonidae.

Adult females are about 6 mm long with an obvious ovipositor.

This DBM parasitoid was originally from Europe and came to Asia via Australia. It was introduced to Vietnam in 1997. It is reared and has been released in the field in Dalat, a highland area in Vietnam. The release in Dalat is being carried out in conduction with monitoring and ecological studies by Farmer Field Schools and farmer study groups (FAO progress report '96 – ‘99). Initial results, however, show a low parasitism percentage.

In other studies, parasitism of pupae of 1 to 12% has been recorded (Hoffmann, 1993).

*Diadromus collaris* complements the action of the larval parasitoid, *Diaegema semieclausum*. Together with *D. semieclausum*, *Diadromus collaris* helps keep diamondback moth populations low, especially when there is low (or no) use of chemical 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. During the dry season for example, you will almost never see aphids killed by a fungus because that fungus needs a high humidity for survival and spread.
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, bioinsecticides 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 cabbage 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. aizawai**: Caterpillars, including diamondback moth
- **Bt var. kurstaki**: Caterpillars
- **Bt var. tenebrionis**: Colorado potato beetle, elm leaf beetle
- **Bt var. israelensis**: 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’s 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 DBM larvae 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 paralyses the stomach. Death by starving takes some time and, caterpillars will be dead after three days. Also see box below about testing Bt.

(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:

<table>
<thead>
<tr>
<th>A. Leaf damage</th>
<th>1 = low</th>
<th>2 = moderate</th>
<th>3 = high</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. Frass production</td>
<td>1 = none</td>
<td>2 = little</td>
<td>3 = much</td>
</tr>
<tr>
<td>C. State of DBM larvae</td>
<td>1 = dead</td>
<td>2 = dying</td>
<td>3 = active</td>
</tr>
</tbody>
</table>

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 needs warm, humid weather for spread and infection. Infected insect larvae eventually turn white or gray. This fungus has a broad host range: it can infect larvae of rice insects like black bugs and rice seed bugs but also pests of other crops like corn borer, Colorado potato beetle and Mexican bean beetle. It is being tested for use against many other pest insects. Unfortunately, some natural enemies such as 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.**: this fungus is fairly specific with regard to the groups of insects affected. Susceptible insects include aphids and several species of flies (in case of *Entomophthora muscae*). In Indonesia, an Entomophthorales (and the fungus *Nomuraea rileyi*) has been found on the cabbage heart caterpillar *Crocidoloma binotalis*. However, methods for production and distribution for these fungi have not been developed (FAO Dalat report, 1998).

- **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).

- **Nomuraea rileyi** has been found in Indonesia as a control agent for the cabbage heart caterpillar *Crocidoloma binotalis* (FAO Dalat report, 1998). Methods for production and distribution of this fungus have not been developed. More study is needed to evaluate the effectiveness of this fungus but there may be potential for development, especially because at present there are no other good biocontrol options for the cabbage heart caterpillar.

- 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.

- **Zoophthora radicans** has a wide host range. It has been found infecting cabbage aphid (*Brevicoryne brassicae*), and larvae, pupa and adults of diamondback moth (*Plutella xylostella*). This fungus forms a white to tan colored mat of hyphae (fungus threads) that covers the insect completely. Numerous spores are formed on this mat. Because *Z. radicans* is found is such a wide host range, it is suspected that this may actually be a complex of species, each with a more restricted host range (Shepard et al, 1999).

- **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!
Primary or secondary?

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. 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!

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.
Major Natural Enemies of Cabbage Insect Pests

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 cabbage butterflies, diamondback moth (*Plutella xylostella*), cabbage looper (*Plusia* sp.), armyworms (*Spodoptera* sp.), bollworm (*Helicoverpa armigera*), and European corn borer (*Ostrinia nubilalis*).

- **Granulosis virus (GV)**: have been found in several caterpillar species including diamondback moth (*Plutella xylostella*), cabbage butterflies (*Pieris* sp.), cabbage looper (*Plusia* sp.), cutworm (*Agrotis* sp.), armyworms (*Spodoptera* 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 *Spodoptera exigua*
- **SINPV**: NPV for control of armyworm *Spodoptera litura*
- **HaNPV**: NPV for control of bollworm *Helicoverpa armigera*

**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).
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.

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. www16).

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.

Advantages and disadvantages of NPV are indicated in table 6.3.3

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

(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.

**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, 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 microorganisms. 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 corn earworm (*Helicoverpa* sp.) 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 flea beetle *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. 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 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.

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 debris 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 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!
SUMMARY

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

Cabbage diseases are caused by pathogens such as fungi, bacteria, viruses and nematodes.

Most pathogens spread attached to or inside seeds, or infected plant material, or are carried with 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 cabbage diseases, especially during prolonged periods of wet weather. If at all 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. More biological agents may become available 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 microorganisms. Only very few microorganisms 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 microorganisms 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 (section 7.10.1).

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 black rot in cabbage: the veins turn black due to the bacterium infection). 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 debris or in the soil, or it may form resting spores that can survive adverse conditions such as drought. Clubroot in cabbage is a fungus which can produce resting spores that can remain active in the soil without plants for over 10 years!

**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 mildew (both powdery and downy mildew), *Alternaria* leaf spot, black leg (*Phoma lingam*). 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. Examples of water-carried pathogens are black rot bacterium (*Xanthomonas campestris*): the secondary spread from initial infection results largely from splashing during rains. Clubroot (*Plasmodiophora brassicae*) is spread by surface water. Water however is not as important as wind for long distance dissemination.
- **Soil**: soil can contain infected plant debris and it contains spores of fungi such as damping-off (e.g. *Pythium* sp.) and clubroot (*Plasmodiophora brassicae*) and bacteria such as black rot (*Xanthomonas campestris*). 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 (often important in case of virus diseases) 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.

### 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 leafspot 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 softrot: 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 - like leafspot on cabbage: it can reduce the yield but plants will survive.

### 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. leafspot in cabbage) 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 **bottom rot** (*Rhizoctonia solani*) in cabbage. The following management methods for bottom rot resulted from the discussions:

**PATHOGEN**
- Practicing proper field sanitation (X)
- Using compost (to improve soil structure, increase soil nutrients, reduce soil-borne pathogens, strengthening activities of beneficial organisms) (X)
- Using clean water resource
- Uprooting diseased plants for composting (X)
- Applying good irrigation methods
- Using *Trichoderma*
- Practicing crop rotation

**HOST PLANT**
- Using less susceptible variety (incl. non-diseased seedlings and healthy plants) (X)
- Applying fertilizer properly (X)
- Keeping sufficient moisture (X)
- Practicing proper crop timing (X)
- Practicing crop rotation (X)
- Prepare field carefully
- Make high beds for good drainage
- Buying varieties from reliable shop

**ENVIRONMENT**
- Practicing proper crop timing (X)
- Applying compost (X)
- Using proper transplanting density
- Not flooding furrows
- Proper weed control
- Applying lime (X)

(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 (ref. modified from www21).

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|
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 leaf spots is given below.

**Disease zoo for leaf spots:**

Select one or a few plants in the field that have disease-like symptoms. Mark the plants with a stick and label the leaves that show the symptoms (you can put a tag on the leaf or draw a big circle with a waterproof markerpen around the spot you want to study). With cabbage it is also possible to take some leaves off the plant and place them in a plastic bag, a glass jar, or in a vase filled with water. Draw the leaves with symptoms in detail (use hand lens) using color pencils (what color is the symptom, where is it located, do you see structures inside the symptom (e.g. black specks), what color is the plant tissue around the symptom, etc.). Measure the size of the symptom and note it down with your drawing. Also note down if it is a young or an old leaf and if the plant was located in the middle or more towards the border of the field.

Repeat the above after a few days: draw and measure the symptoms. If you find that the symptoms are growing, becoming bigger in size and maybe even have spores (you can sometimes find them as dusty powder or in small black pustules on the spot) it is very likely that you are looking at a disease. Check the symptoms found with the table in chapter 11, key tables and with details on some of the major diseases of cabbage to confirm diagnosis. Leaves taken off the plant do not last longer than about 5 days.

**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 or 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!

Diseases can never be completely eradicated - but populations can be reduced to low levels!

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 leafspots here and there 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 leafspot? Yes, you may be able to temporarily stop the spread of those leafspots 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 a few spotless cabbages? That is what counts in the end!

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 3.12).
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 cabbage diseases.

**Table 7.9 : A summary of some sources and carriers for important cabbage diseases**

<table>
<thead>
<tr>
<th>DISEASE</th>
<th>contaminated seeds</th>
<th>other infected plants</th>
<th>diseased crop residues</th>
<th>soil</th>
<th>contaminated water</th>
<th>carried by wind</th>
<th>contaminated tools, people, animals</th>
</tr>
</thead>
<tbody>
<tr>
<td>damping off</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>black rot</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>soft rot</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Alternaria leafspot</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>club root</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>downy mildew</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>black leg</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

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 : treat seeds before sowing (section 3.3),
other infected plants : uprooting diseased plants, pruning infected leaves, increasing plant spacing,
diseased crop residues : sanitation – removing all debris from previous crop from field,
soil : crop rotation, for small areas: soil sterilization (sections 3.12 and 3.7.1),
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 microorganisms 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.


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 cabbage diseases, especially during prolonged periods of wet weather. Fungicides (if at all 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. But against what diseases you should spray is often unclear and 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).

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 debris 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 microorganisms 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.

### 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.

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.

### 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 3.3.3), 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 son fungi are unclear. Milk is expensive for use on larger scale.
SUMMARY
Major diseases of cabbage in seedbeds are damping-off and downy mildew. In the main field, a number of other diseases can occur and cause yield loss which occasionally can be severe. Seldom will diseases in the main field cause total yield loss.

Some general disease management practices are given here. Specific practices are listed under individual disease sections.

- **Use of disease-resistant varieties.** Cabbage varieties may vary in susceptibility to diseases. Check with seed companies and local extension offices for information. Setting up variety trials to test how well 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.

- **Clean planting material.** Use of clean seed such as treated seed (section 3.3) or “certified” seed that has been inspected for pathogens at all stages of production. Clean planting material includes healthy, disease-free transplants, also when bought from elsewhere.

- **Grow a healthy crop.** A vigorous but balanced plant growth is the key! Fertilizer and water management are important factors here. Some examples:
  - **Fertilizer:** 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. Water management methods are listed in section 3.9.

- **Sanitation.** Removing diseased plants (or parts) will help prevent the spread of pathogens to healthy plants. Crop debris can be used to make compost. If temperatures during composting rise high enough and are uniformly achieved in the pile by mixing, most pathogens are destroyed. Sanitation also includes weed control and insect control because many pathogens persist in weed hosts or are spread by insects.

- **Crop rotation.** Rotate crops to disease-free fields to avoid buildup of pathogens in the field. Rotation to an entirely different plant family is most effective against diseases that attack only one crop. However, some pathogens, such as those causing damping-off 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 such as damping-off.
8.1 Damping-off in seedbeds (*Fusarium, Rhizoctonia, Pythium, Phytophthora sp.*)

Causal agents: fungi – *Fusarium, Rhizoctonia, Pythium, Phytophthora sp.*

A number of species of soil-dwelling fungi, including *Fusarium, Rhizoctonia, Pythium* and *Phytophthora* sp., infect vegetables, especially legumes, crucifers and solanaceous crops. Species of *Pythium* are more common than the others. If the infection occurs either before (pre-emergence) or just after emergence (post-emergence), and development of a spot (lesion) at the soil line results in collapse and shriveling of the plant, the disease is called ‘damping-off’.

**Signs and symptoms**

Infection occurs just around the soil line in young seedlings. Damping-off fungi rarely attack transplants in the field or established seedlings.

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

*Pre-emergence damping off*  
*Stem rot*

(from Kerruish, 1994)

**Source and spread**

The fungi are natural soil inhabitants but when circumstances are favorable and when susceptible host plants are present, the population can increase to damaging levels. It is difficult to predict when that will occur: it depends on temperature and humidity but also on the population of microorganisms in the soil. Sometimes, there are microorganisms (*antagonists*) that serve as natural enemies of the pathogens: they can keep the population of the pathogen under control.

Infection occurs through wounds or natural openings but *Pythium* can also actively penetrate the tender tissue near root tips.

In case of *Pythium* infection, dying seedlings contain the spore-carrying structures of the fungus. The spores can drop to the soil (and attack seed or young seedling roots), or be carried by wind or spread to another location by surface water or irrigation water. *Pythium* can be transported in soil attached to seedling roots during transplanting. And *Pythium* can form thick-walled spores (called oospores) that can survive during adverse conditions and persist for several years in the soil.
Role of environmental factors

Damping-off occurs in areas with poor drainage or areas with a previous history of the disease. Damping-off is often associated with high humidity and high temperature. The temperature range in which these fungi can live is quite broad, from about 12 to 35°C with an optimum (the temperature at which damping-off develops fastest) of 32°C. That is why you can find damping-off disease both in highlands with a temperate climate and in (sub)tropical lowlands.

Natural enemies/antagonists

Many successes have been reported with the use of *Trichoderma* sp. for the prevention of damping-off. *Trichoderma* outcompetes fungi that cause damping-off for nutrients and a place to grow around the roots ("rhizosphere dominance"). There are several species of *Trichoderma*. The species *Trichoderma harzianum* has been used successfully in tropical climates but *Trichoderma parceramosum* also gave good results in field trials in 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. Examples are listed in the table in section 8.4 on *Rhizoctonia*. To date, no information about use of these biocontrol products is available from Asia.

Damping-off can also be reduced in soils rich in compost. Compost contains many different microorganisms 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 microorganisms in the soil or compost outcompetes pathogens and will often prevent disease. See section 3.5.3.1 on compost. 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.

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 crop debris 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 microorganisms and it feeds microorganisms already in the soil. An active population of microorganisms in the soil outcompetes pathogens and will often prevent disease.
- **Crop rotation**: If you are raising cabbage seedlings every season, use fresh soil that has not been used for cabbage or other cruciferous crops for at least 2 years. Plant another crop (not a cruciferous crop) in the ‘old’ cabbage nursery.
- Use vigorous seed or seedlings. Slowly emerging seedlings are the most susceptible.
- Use seed that is coated with a fungicide layer. See section 3.3.
- 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 3.7.1.
- Consider using a layer of sub-soil (taken from a layer of soil below 30 cm) to prepare raised nursery beds. See section 3.7.1.3 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 new 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 3.5.3.1 on composting.
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 the water flow away. 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).
- 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 debris) are ways to prevent disease problems.
4. Good control of damping-off can be achieved by adding compost or other decomposed organic material to the soil regularly.
5. Additional prevention (mainly) and control can be obtained with use of the antagonistic fungi Trichoderma sp.

### 8.2 Black rot - Xanthomonas campestris

See plate 1 Fig. 3, 4 and 5

Causal agent: bacterium – Xanthomonas campestris

Worldwide, black rot is considered to be one of the most important disease of crucifers.

#### Signs and symptoms

The disease can affect both seedlings and mature plants. Leaves of affected seedlings turn yellow and drop off prematurely. On older plants, V-shaped yellow lesions appear at the leaf margins with the point of the V inwards. These lesions expand towards the center of the leaf. Affected areas turn brown and the plant tissue dies. The veins in affected areas are black in color. This can sometimes also be seen on cutting the stem of a leaf.

Heads are dwarfed and lower leaves may fall off. Symptoms can be more severe on one side of the head. Soft rot often develops on affected heads as a secondary infection.

Infection can occur in the seedbed, when seed leaves (cotyledons) and one or two lower leaves become infected and drop off prematurely. With unfavorable conditions for further dissemination, the external signs of the disease may disappear for several weeks, but bacteria are still there, progressing slowly within the vascular tissue of the plant. Symptoms may appear in the upper leaves some weeks after transplanting.

See section 7.7 on studying diseases in a “disease zoo”.
**Source and spread**

The black rot bacteria are carried over with infected seed and in the soil on diseased plant residues as long as they are not decomposed. In addition, many cruciferous weeds can harbor the black rot bacteria. The bacteria can persist in residue for up to two years.

When symptoms appear early in the season or even in the nursery, this may be a sign of the seed being infected with the bacterium. Infected seed will germinate and from their seed coats, the bacteria gain access to the cotyledon and into the young leaves. Leaf infection takes place through water pores (natural openings in the leaf) at the leaf margins, through stomata (another type of natural openings in leaves) and sometimes via wounds in the roots and leaves (for example due to insect feeding). The bacteria further spread through the veins of the plant.

Bacteria are spread by splashing or running water, wind-blown rain, by blowing of detached leaves, cultivating implements and infected seedlings. Insect transmission, for example by larvae of the cabbage worm, is known but not important. Overhead irrigation also spreads the bacteria, particularly in close-planted conditions such as in the seedbed.

**Role of environmental factors**

Hot, wet conditions favor disease development. Under warm, humid conditions, symptoms appear 10 to 14 days after infection. The optimum temperature for growth is 30-32°C, maximum is 38-39°C. Temperature seems to be more critical than moisture.

**Importance - plant compensation - physiological impact**

The damage to the yield and quality of the cabbage caused by black rot can be important when the infection occurs early in the season (it then probably started in the nursery) and when the weather is hot and wet. Poor head formation and reduced yields are a result of the black rot infection. In the absence of rain or overhead irrigation, which spread the disease, losses are much less. When infection occurs late in the season, usually no yield loss occurs.

Once entered the plant, the bacteria travel through the veins of the plant. When a plant is infected, the bacteria can be present in the whole plant, even in the parts that show no symptoms. It is therefore not effective to prune infected leaves to try to reduce the disease.

**Natural enemies/antagonists**

Unknown

**Management & control practices**

**Prevention activities :**

- Grow a resistant variety when you have had serious black rot problems before or know that black rot is a problem in your area. Some varietal resistance has been reported but it is advisable to test different varieties at local conditions.
- At least three years’ rotation of the seedbed and the transplanted field with non-cruciferous crops is advisable.
- It is advisable to sterilize seed in water at 50°C for 30 minutes before planting. That will kill bacteria that stick to the seed. See section 3.3.
**Major Diseases of Cabbage**

- Practices such as dipping or spraying transplants with water after digging may spread black rot disease and should be avoided.
- Use other irrigation methods than overhead irrigation and/or irrigate in the morning when the leaves of the plants will dry quickly. The bacteria can easily spread with splashing water and soil particles.
- **Avoid planting downstream from infected fields.** The bacteria may spread with the water running down from the infected field.
- **Control cruciferous weeds:** they may be a source of infection.

**Once an infection** is present in the field:

- When symptoms of black rot appear in the nursery: **do not transplant seedlings with symptoms.** When many seedlings already show symptoms, it would be advisable not to use any of the seedlings because probably all of them (also the ones that look healthy now) will be infected.
- When the plant is at the heading stage and only older leaves get infected, no action needs to be taken. The yield will not go down with a few black rot symptoms at old leaves. It is advisable not to grow crucifers for at least two years after harvest of this crop.
- **Sanitation:** after harvest, remove all infected plants with roots from the field and either place them on a compost pile, feed them to cattle, or burn them. This will reduce bacteria surviving in the field on infected crop debris.
- **Biological soil sterilization** or biofumigation could be options for testing. See sections 3.7.1.5 and 3.7.1.6.

**Points to remember about black rot:**

1. Black rot is a bacterium that causes V-shaped yellow lesions at the leaf margins of older plants.
2. Black rot survives on seed and residues of diseased plants and is spread mainly by water and on diseased seedlings.
3. Use of resistant varieties where available, seed treatment, crop rotation, proper water management and sanitation (removing infected plant material) are ways to prevent or reduce black rot infection.

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**8.3 Soft rot - ** *Erwinia carotovora*

See plate 1 Fig. 6 and plate 2 Fig. 7

Causal agent: bacterium – *Erwinia carotovora*

**Signs and symptoms**

The common name of this bacterial disease arises from the characteristic soft decay of the fleshy tissue of the plant. When soft rot affects a plant, the tissue softens, becomes watery and slimy. Cabbage plants give off an distinctive sulfurous odor. Affected heads decay rapidly and turn dark.
Source and spread

The bacteria survive in soil on decaying and dead plant debris. Wounds are the most common entry point for this bacterium. The infection can occur through surface areas like leaves injured by insects or mechanical means or through damaged roots or stems. Bacteria spread through the veins to other plant parts.

Some species of maggot fly are known to carry the soft rot bacteria. Eggs of the flies are laid in decaying cabbages and as the egg hatch, the larvae become contaminated with the soft rot bacteria. Infested adult flies lay eggs smeared with soft rot bacteria on maturing cabbage. The emerging larvae serve as vectors as they feed on the cabbage and create wounds that allow the bacteria to infect the plant tissue.

Role of environmental factors

Warm wet conditions promote disease development. Abundant moisture at the surface of the plant tissue, where wounds are present, is essential for invasion. After infection has taken place, fairly high relative humidity is needed for progress of the disease. When decaying cabbages are placed in a dry atmosphere, the rotted tissue dehydrates rapidly and further advance of the disease may be checked completely.

Soft rot can accompany mineral deficiency symptoms. Potassium deficiency or an unbalance of potassium and other essential nutrients may bring about leaf scorching which may be followed by a bacterial attack. Soft rots are also common where an excess of farmyard manure is applied on poorly drained soils, probably due to the maggots attracted by the manure, as explained above.

Importance - plant compensation - physiological impact

Soft rot is mostly a problem shortly before the harvest period, when cabbage heads near maturation. Usually, the disease is very localized, only a few heads here and there drop out due to soft rot. In warm, wet conditions, the bacteria progress inside the plant and eventually, the whole cabbage head will be rotten. Plant compensation does not take place at this stage. Often, farmers will quickly harvest heads with soft rot and peel off the outer affected leaves. The small remaining head may still be used for consumption.

Natural enemies/antagonists

Unknown.

Management & control practices

Prevention activities:

- **Sanitation** practices: make sure the field is clean from crop debris from a previous season. Also the borders of the field should be cleaned from crop debris.
- **Avoid injury** to the crop - the wounds can be entry points for the bacteria.
- **Monitor** field regularly and **remove** heavily infected heads from the field.
- **Crop rotation** is probably of limited value for *Erwinia* because it can survive in the soil for many years on dead plant tissue.

Once an infection is present in the field:

- Lightly infected **heads can be harvested** and the affected leaves peeled off. Those heads can still be sold or used for home consumption.
### Points to remember about soft rot:

1. Soft rot bacteria survive in soil on decaying and dead plant debris
2. Wounds in plant tissue are entry points for soft rot bacteria.
3. Avoiding crop injury and good sanitation practices (removing infected material) are ways to reduce spread of soft rot disease.

### 8.4 Bottom rot – *Rhizoctonia solani*

**See plate 2 Fig. 8**

Other names: wirestem (seedlings) and head rot.

**Causal agent:** fungus – *Rhizoctonia solani*

This fungus is also a common cause of damping-off in seedbeds (see section 8.1 above). This section describes the disease as it occurs in the main field.

Subspecies of *Rhizoctonia solani* can cause diseases in many crops: stem cancer and black scurf of potato, root rot of cotton and many others.

#### Signs and symptoms

Bottom rot develops on plants after they have been transplanted to the field. Dark slightly sunken spots develop on basal leaves near the soil. Affected plants are weak, produce small heads and sometimes wilt and die. In moist conditions and in storage, rot spreads to adjacent leaves and causes a head rot. The whole cabbage head may develop a dry rot, first restricted to the outer wrapping leaves. Tiny sclerotia (fungus reproductive structures) which are irregular and brown in color may form on the rot.

Diseased plants appear in patches in the field, with the location and size depending on weather and soil conditions. 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.

#### Source and spread

The fungus *Rhizoctonia solani* is a common inhabitant of field soils. It can survive on decaying and dead organic matter in the soil.

Bottom rot (and damping-off) occur in areas with poor drainage or areas with a previous history of the disease.

#### Role of environmental factors

Disease is promoted by moist conditions and high soil temperature. Root damage from salts and soil compaction can also lead to increased loss due to root rots.

#### Natural enemies/antagonists

Use of the beneficial fungus *Trichoderma* sp. has been reported to prevent or cure soil-borne diseases including root rots. 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). In Thailand and Indonesia, for example, *Trichoderma* is available for use by farmers. There are more details on *Trichoderma* in section 7.10.1.

There are several other antagonistic organisms, including bacteria (e.g. *Bacillus subtilis*, *Pseudomonas*...
fluorescens) and fungi (e.g. Streptomyces griseoviridis, Trichoderma sp. and Gliocladium catenulatum) that control Rhizoctonia sp. These antagonistic organisms are available as biocontrol products registered to control Rhizoctonia and related soil-borne disease in the United States. Some of these products may become available in Asia in the future. (www25; www29)

Management & control practices
See section 8.1, damping-off. The same practices apply for bottom rot.

Points to remember about bottom rot:
1. Bottom rot is caused by a soil-borne pathogen that survives on decaying and dead organic matter in the soil. The same fungus also causes damping-off in seedlings.
2. Bottom 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 transplants, crop rotation, and sanitation practices (removing crop debris) are ways to prevent disease problems.
4. Good control of bottom rot can be achieved with use of the antagonistic fungi Trichoderma sp. There are many other effective biocontrol products which may become available in Asia in the future.

8.5 Leaf spot
Causal agent: several fungi
Leaf spots on cabbage can be caused by several fungi. Each fungus can cause slightly different symptoms and the pathogen can sometimes only be distinguished with a microscope, which is usually not available in the field. The most common leaf spot fungus is Alternaria brassicae, which is described below. Other fungi causing leaf spot on cabbage include Mycosphaerella brassicicola, Phoma lingam (see section 8.8) and Cercospora sp.

In the field, the difference between the various fungal leaf spots is not always easy to make, especially with early symptoms. Note that for a proper decision on the management of fungal leaf spot, it is not always necessary to be able to distinguish the different causal organisms. Most fungal leaf spots will need the same management practice, mainly reduction of the source of infection by sanitation.

Alternaria leaf spot - Alternaria brassicae
See plate 2 Fig. 9
This fungal disease is also known as black mold, gray leaf mold or black spot.
Causal agent: fungus – Alternaria brassicae

Signs and symptoms
Symptoms of Alternaria leaf spot usually appear on the older leaves of the cabbage plant. The spots begin as black pinpoint-size spots and enlarge to distinct, brown-black leaf spots of 1 to 2 cm diameter with concentric rings and sometimes a yellow area around the spot. The concentric rings contain the
Major Diseases of Cabbage

spores with which the fungus spreads. These have a dark, dusty appearance. Spores develop on the leaf spots during moist periods. The fungus occasionally attacks seedlings in the nursery. The symptoms occur immediately after germination as dark spots on the seedling stem, which causes damping-off or a stunting of the young plant. *Alternaria* leaf spot also infects Brussels sprouts and causes brown rot of cauliflower.

**Source and spread**

*Alternaria* leaf spot can be transmitted on the seed and in plant debris. It also survives on cruciferous weeds. Infected crop residues are a major source of infection for the next crop, or a neighboring field. Even old leaves that are completely dead and dried, can still contain living spores of the fungus! Single spores cannot survive in the soil, except when they are on a lesion on a piece of old leaf. *Alternaria* spores are easily spread by wind, splashing rain, machinery or farm tools and workers when the plants are wet.

**Role of environmental factors**

Cool, wet weather favors disease development. This is why leafspot is usually not a problem during the dry season, but it can be severe in the wet season.

Rain and humid weather are favorable for spore development. Infection may occur when leaves are wet for more than 9 hours. This can also be caused by use of overhead irrigation or sprinklers, especially when used in the late afternoon. This results in wet leaves which will not dry up quickly. Overhead irrigation can best be used in the morning when the sun will dry the leaves of the plant. Even better is to use furrow irrigation.

In seedbeds, *Alternaria* leaf spot can be stimulated by high humidity due to overwatering, dense seeding and heavy dew.

**Importance - plant compensation - physiological impact**

Leaf spots reduce the area of leaf producing nutrients for the plant (photosynthesis). As the leaf spot fungus usually attacks the older leaves, in which the photosynthetic activity has gone down anyway, the effect on yield and quality of the cabbages will not be severe. When the leaf spot infection is not serious and only affects the older, dying leaves of mature cabbage plants, no control is necessary.

When the infestation of leaf spot is severe, e.g. when seedlings are already affected or when leaf spots are also found on the cabbage heads, control measures may be considered because yield and quality of the cabbages can be reduced.

**Leaf pruning to control leafspot...**

During a Training of Trainers (TOT) in the Philippines, a study was done with hand-picking of old infected leaves. The idea was that removing leaves with lesions would reduce the severity and spread of the disease. The disease severity and yield of the pruned field were compared with the unpruned field. Results varied from no effect (same disease incidence and same yield but labor costs for pruning higher) to a negative effect (lower yield in the pruned fields) (pers. comm. cabbage TOT participants Cordilleras, 1994/95). 😊

It may still be a good idea to test during the wet season, when disease incidence is high. 😊
Natural enemies/antagonists

There are fungi, such as *Aureobasidium pullulans* and *Epicoccum nigrum*, that have an antagonistic effect on *Alternaria* sp. To date however, none of these have developed into a product that can be applied as a control measure against leaf spot.

Management & control practices

**Preventive activities:**

- Use a **crop rotation** plan: do not grow any type of cruciferous crop for at least 2 years.
- Use **clean seed** that is coated with a fungicide or treated in hot water of 50°C for 30 minutes. This will kill spores that are attached to the seed. See section 3.3.
- Practice **sanitary measures** such as the use of clean seed beds away from other crucifer production and the destruction of cruciferous weeds. Plant seedlings in a field where crop debris is removed, even from the borders of the field. Even dead cabbage leaves may still contain living spores of the disease!
- Plant **resistant or tolerant varieties** where available to reduce disease incidence.
- Use a **planting site** and **plant spacing** pattern that expose plants to full sun throughout the day.
- When planting, **orient rows** in the direction of prevailing winds for better circulation of air through the foliage.
- **Avoid over-planting** or crowding plants as this increases the drying time.
- In order to **reduce disease spread** by hand or machinery, avoid working in fields while the plants are wet.

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**Fungicides for leafspot control, a study example from Vietnam:**

In Dalat, in the central highlands of Vietnam, a study was done (Feb-May 1995) to compare the effect of fungicide applications on yields and disease level. Fungicides were applied twice per week and control plot received no fungicides. It was found that disease levels did not differ in the sprayed and unsprayed plots and cabbage yields were the same. Economic benefits in the fungicide treatment were VND 1.6 million/ha lower! ☺

(FAO Updates on Vietnam National IPM programme in vegetables, 1999)

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**Once the disease** is present in the field:

- When only **older leaves** are affected, no control is necessary. After harvest however, it IS necessary to remove old leaves. These leaves should be taken off the field and either fed to cattle, buried in a pit or put on a compost pile away from the field.
- Some **fungicides** are effective in stopping spread of this fungus. Be careful for the effect of fungicides on the natural enemy population of insect pests! See box in section 4.9.
- **Plowing immediately after harvest** helps eliminate the sources of airborne *Alternaria* and encourages the rapid decomposition of crop residues.
**Major Diseases of Cabbage**

**8.6 Clubroot - *Plasmodiophora brassicae***

*See plate 2 Fig. 10 and 11*

**Causal agent:** fungus – *Plasmodiophora brassicae*

**Signs and symptoms**

Clubroot causes wilting and yellowing of the above-ground parts. Often mature plants wilt during hot days but may recover during the nights. Plants stay smaller in size and often develop no heads. The best diagnostic symptom is the presence of big spindle-shaped enlargements (the "clubs") on the roots. This may occur on fine roots, secondary roots and the main taproot. Sometimes, the fungus can enter through wounds in the stem at soil level - the clubs then appear there and just below soil level. The lowest leaves of the plant may turn yellow and drop off.

The fungus can attack both seedlings and mature plants. Symptoms of seedlings may only be detected when the plants are pulled.

The disease is often most severe in low-lying, poorly drained soils. Secondary invasion by other pathogens like soft rot bacteria may occur.

**Source and spread**

The fungus is soil-borne and enters the plant through fine hair roots or through wounds in secondary roots or in the stem. The disease is spread by soil particles (soil easily clings to shoes or slippers and to tools used in the field), by transplants and by drainage water. Clubroot is not seed-borne. Transplants are usually the main means of widespread distribution.

Every infected plant with clubs is a little timebomb. The clubs are full of fungus spores. These spores are released into the soil when the root decomposes. That happens when infected plants are not removed from the field. The spores of clubroot are very persistent and can stay alive in the soil for many years (from 7 to 20 years!). This is because the spores have a very thick skin that protects them from drying out and from high temperatures.
How to test your soil for presence of clubroot:
The easiest way is to uproot several cabbage roots at harvest and check them for clubs. If you find some roots with clubs, the soil is infected.

When you do not have that possibility, another option to check the soil for presence of clubroot is the following trial. This trial is however more time consuming (takes at least one month) and there is a risk that you will find a “false negative”: the soil is infected but you don’t find it in the trial.

Take some soil from different portions of the field. Put it in pots and sow some cabbage seed (can also be Chinese cabbage as this is very sensitive to clubroot) per pot. Keep the soil in the pots moist and look after the emerging seedlings for about 3 - 4 weeks. Seedlings with at least 3 true leaves can be uprooted, and washed to remove the sand from the roots. Carefully check the roots for small clubs. If you find clubs, the soil is infected.

Since clubroot can be very localized in a field, the more soil samples and pots you take for this test, the better your conclusion will be. That reduces the risk of missing an infection.

Role of environmental factors
The temperature range in which the fungus is active is 9 - 35°C with an optimum temperature for fungal development of 24°C. Infection is limited by low soil moisture. A common observation is that the disease is most severe in low-lying, poorly drained soils.

A soil pH of less than 7 favors disease development. When the pH is 7 or higher, the spores of the fungus germinate poorly or not at all.

Where potatoes are grown in rotation with cabbage:
While clubroot of crucifers is suppressed by a soil pH above 7, potato scab (Rhizoctonia solani) is known to be stimulated when the soil pH raises. This is particularly true in sandy soils, less in clay soils. A pH below 5.2 will reduce soil-borne scab in potato. That means that when soil pH is raised with lime to levels above 5.2, chances are that a following potato crop may develop symptoms of scab. In general, potatoes prefer a more acidic soil than cabbages. It depends on factors like severity of the diseases, economics, etc. what crop should have the priority of soil pH adjustment.

Importance - physiological impact - plant compensation
Given the fact that once the soil is infected with clubroot, the disease can stay in the soil for more than 7 years, even if no cabbages or other cruciferous crops are grown, the fungus is one of the most persistent diseases known in vegetable growing. In an infected field however, only seldom all plants are affected. Mostly the disease is localized, with groups of plants dropping out. Therefore, in an infected field, it is still possible to grow cabbage. The key is to keep the fungus from multiplying too much. See under prevention activities below. Severely infected fields however, become unfit for cabbage (and other crucifer) cultivation.

Once the fungus enters the fine roots of a cabbage plant, the plant reacts by making the clubs, cancer-like enlargements in the roots. Water and nutrient uptake are severely restricted by this and the plant cannot develop normally but it will not die immediately because there are still some roots left for water and nutrient uptake. In the middle of a warm, sunny day however, the plant may wilt.

Usually, symptoms are localized near the point of infection. The fungus does not move through the plant veins. When only a small part of the root system is infected with clubroot, a head can still be formed. New roots are generated that will compensate for the loss of part of the roots. Often, these plants and the heads will be small in size but still look relatively healthy. When a plant is suspected of having clubroot...
but does not look severely infected, it is possible to leave it in the field until the harvest. During harvest time, uproot the whole plant and if the roots of the plant are affected, take those plant parts aside for drying and burning afterwards. Don’t leave infected plants in the field. Severely infected plants will not form a head and should be removed from the field. See section below on management and control.

Natural enemies/antagonists

Biological control of clubroot with *Trichoderma* sp. may become an option in the future. In studies with Chinese cabbage in New Zealand for example, seventeen of the 25 isolates of *Trichoderma* sp. reduced clubroot severity compared to the untreated control. Field trial results with two *Trichoderma* isolates, applied as a root dip before transplanting, gave reduction of club weight on roots but did not increase the top weights of the plant. (Cheah et al, 1996, www28).

Management & control practices

Prevention activities:

- **Resistant varieties:** some differences in susceptibility between varieties has been reported but it is advisable to test varieties at local conditions, for example in varietal trials.
- **Select clubroot-free nursery soil** that is well drained. The preferred nursery has not grown crucifers for many years.
- Because clubroot is so long-lived, **crop rotation** is probably not effective. Fields once severely infected with the clubroot pathogen remain so indefinitely and become unfit for cultivation of brassicas.
- **Raising soil pH** to a neutral level of around pH 7 by broadcasting and incorporating hydrated lime into the soil offers some control/protection. This liming should not be done more than once every 3 years to keep the soil from becoming too alkaline, nor is it very effective on light, sandy soils. Guidelines to raise the pH are given in section 3.4.6.
- **Use healthy seedlings.** Do not transplant seedlings that have little clubs or swollen roots that do not look normal. In fact, no plants from a seedbed that has even a single clubroot seedling in it, should be transplanted into a disease-free field! If any transplants have clubroot symptoms, many others are certain to be infected, even though symptoms may not yet have appeared!
- **Remove weeds,** there are many cruciferous weeds that can be a host of clubroot and other cabbage diseases.
- Be careful with fields of other farmers that do have a clubroot infection. If you visit an infected field, make sure there is **no soil attached** to your slippers, shoes or farm tools when you return to your own field. You can easily transport the disease with the soil particles!

It was noted that some farmers, who had serious clubroot problems in their field, could easily recognize clubroot infected plants by the small plant size. But instead of roguing the plants, they applied foliar fertilizer to these small plants in an attempt to get at least a little head from these small plants. However, comparing the costs of a foliar fertilizer (quite expensive!) to the additional income of a few small, low quality heads AND the risk of giving the pathogen a chance to multiply, and spread into other parts of the field, make this practice not very attractive.

Remove infected plants: they will not give you much yield (and income) and infected plants in the field will lead to MORE disease!
Once there is an infection in the field:

- uproot infected plants including all roots and destroy them but.....:
  - do not throw the infected plants at the side of the field. From there, the spores will be released into the soil and may spread into the field again. The result: you have helped spread the disease!
  - do not put uprooted clubroot plants on a compost pile. When the temperature inside the compost pile is not high enough (above 60 °C), the spores will not be killed and may be spread into the field again with the compost. Temperatures above 60 °C should kill the spores inside a compost pile, but it is difficult to tell whether the temperature inside the pile reached that level for a sufficient period of time.
  - uprooted clubroot plants should not be fed to farm animals as the spores are so strong that they can survive passing through stomach and intestines. As a consequence, spores will be spread with the manure of the animals.
  - leave infected plants to dry for some time and burn them. It’s the safest way to be sure to have removed the spores.
  - unfortunately, by uprooting a diseased plant, the disease is not removed from the soil. The fungus is still present in the soil area around that infected plant. By removing the infected plant, you have only accomplished that the disease will not spread further.
  - Check the pH, if it’s too low, apply lime to raise it. Applying wood ashes also helps to raise pH. The infection will be less with a pH of around 7.
  - When the soil is very heavily infected with clubroot, consider growing another crop. Even after applying lime, it may still take several seasons before the pH has risen enough to suppress clubroot.
  - Soil sterilization: several trials were done, for example in the mountain areas of the Philippines, to test if solarization would control clubroot. High soil temperatures (over 60°C), due to heating up of the soil under the plastic sheets should kill spores of the fungus. The results of the trials varied considerably, therefore, no recommendation for use of this technique is given in this guide. It may however, be interesting to try in a small area of an infected field, but preferably combined with liming the soil. See section 3.7.1.2 and 3.4.6.
  - Applying fungicides is not effective to control this fungus. This is first of all because the spores are very strong and may still be inside the plant roots. Secondly, the fungus can be located deep in the soil and where pesticides may not reach.
  - Chitosan, a naturally derived component (polysaccharide) from the outer skeletons of crab, may have potential for clubroot control. Chitosan has been shown to be effective for control of Sclerotinia rot (caused by Sclerotinia sclerotiorum) of carrots (Cheah et al. 1997). In studies with Chinese cabbage in New Zealand, it significantly reduced the club weights.

Points to remember about clubroot:

1. Clubroot is a fungal disease that causes enlargements (the “clubs”) on the roots, resulting in wilting of the plant during warm days and small head sizes or none at all.
2. Clubroot is spread by soil particles, by transplants and by drainage water. Transplants are usually the main means of widespread distribution.
3. Resistant varieties, use of clean transplants, removing weeds, raising soil pH to 7 or above, and proper sanitation practices are ways to prevent or reduce clubroot infection. Soils (severely) infected become unfit for cultivation of crucifers. Trichoderma may become a biocontrol option in the future.
8.7 Downy mildew - *Peronospora parasitica*

See plate 2 Fig. 12 and plate 3 Fig. 13

Causal agent: fungus – *Peronospora parasitica*

This disease can be particularly damaging during the nursery stage or in a newly transplanted crop.

**Signs and symptoms**

Small yellow spots develop on the leaves and cotyledons of young plants in the seedbed. The spots later turn brown. In moist weather, a white downy mold develops on the underside of the spots. The mold are the spores structures of the fungus. The spores can sometimes stick to your finger as a white powder when you wipe the underside of the leaf. Dead leaf areas appear in the yellow zone on top of the leaves, which often have a speckled appearance. The young leaf or cotyledon, when yellow, may drop off.

Symptoms of the disease on mature plants are yellowish-brown areas between the main veins. Again, during moist weather, white downy patches of the fungus can be seen on the underside of the leaves. Severely infected leaves do not drop off and infected areas gradually enlarge, turn bright yellow, then become tan and papery. Occasionally, affected leaves will show hundreds of very small, darkened specks. On cabbage heads, the pathogen may cause numerous sunken black spots, varying in size from tiny dots to larger areas. Sometimes, a downy mildew infection can predispose plants to bacterial soft rot.

**Source and spread**

The fungus spreads with seed, and can stay over in roots and in decaying portions of diseased plants and on cruciferous weeds. In areas with a cold winter period, thick-walled resting spores may form in stems, cotyledons, and other parts of infected plants. On growing plants, the fungus produces large numbers of spores that are blown about by wind and splashed by rain.

Spores carried by wind can float long distances.

When the fungus is attached to seed, it is carried aboveground on new shoots. The mycelium (threads of the fungus) can penetrate leaves through stomata (natural openings in the leaves) and grows inside the plant tissue. The spore-carriers grow to the surface again, mostly on the underside of the leaf, to release the spores. If weather is favorable, spores germinate in only three to four hours, and infect new plant tissue and produce new spores in three to four days.

**Role of environmental factors**

Cool nights with moderate daytime temperatures (optimum temperature is 15 - 18°C) associated with high humidity are conditions that promote disease development. High humidity is likely to occur during the rainy season, during periods of heavy dew, when overhead irrigation is used and when plant density is close. Presence of a water film on the foliage from fog, drizzling rain, or dew allows spores to germinate, infect, and produce more spores on a susceptible host in as few as 4 days.

**Importance - plant compensation - physiological impact**

This disease is most serious on young seedlings; if cotyledons and the first true leaves are severely infected, the young plant may die. Damage to mature plants in the field is usually of minor importance. In Chinese cabbage, downy mildew may also cause severe losses in mature crops.

**Natural enemies/antagonists**

Unknown.
Major Diseases of Cabbage

Study of spread of downy mildew:

Take a number of leaves with white downy mold on the underside. Put these leaves in a small quantity of water and stir firmly. Remove the leaves from the water. The spores on the white mold will be released into the water. The water has now become a source of infection. Take a few pots containing a bundle of cabbage seedlings each and sprinkle the water over the plants. Treat a similar pot with seedlings with clean (uncontaminated) water as a control. Cover the pots with a plastic bag to keep a high humidity inside. Keep plants at a cool place for a few days. Depending on temperature and humidity, symptoms will appear on the leaves.

Management & control practices

Preventive activities:

- Use a crop rotation plan: do not grow any type of cruciferous crop for at least 2 years.
- Use a resistant/tolerant variety. Disease resistant varieties are not available for most cruciferous crops. However, differences in varietal susceptibility have been reported. Some hybrid varieties of broccoli are resistant or tolerant to downy mildew. It is advisable to test varieties under local conditions. See section 3.2.2.
- Use clean seed that has been hot-water treated and/or coated. See section 3.3.
- Practice sanitary measures such as the use of clean seed beds away from other crucifer production and the destruction of plant debris and cruciferous weeds.
- Use a planting site and plant spacing pattern that expose plants to full sun throughout the day.
- When planting, orient rows in the direction of prevailing winds for better circulation of air through the foliage.
- Thin out seedlings to about 2-3 cm apart. Closely planted seedlings will result in a high humidity and may stimulate infection.
- In order to reduce disease spread by hand or machinery, avoid working in fields while the plants are wet.

Once the disease is present in the field:

- When seedlings show symptoms of downy mildew, try applying some extra nitrogen. Seedlings tend to outgrow the disease if they are top dressed with a nitrogenous fertilizer.
- If severe disease pressure is expected, timely application of a registered fungicide before the onset or at the very beginning of the disease may reduce the severity of the disease. This is usually only necessary to protect young seedlings. Repeated applications may be required, depending on weather. Consult local extension agencies for current fungicide recommendations.
- When symptoms appear on mature plants at a late growth stage, usually no control is necessary.
- Plowing immediately after harvest helps eliminate the sources of airborne downy mildew spores and encourages the rapid decomposition of crop residues.

Points to remember about downy mildew:

1. Downy mildew is destructive only in seedbeds and on young transplants during cool, rainy weather.
2. The pathogen survives between seasons in crucifer weeds, seed and crop residues. Spores are spread to new crops primarily by wind and splashing rain.
3. Any practice which promotes the rapid drying of foliage and soils will help minimize disease incidence.
8.8 Black leg - *Phoma lingam*

See plate 3 Fig 14

Causal agent: fungus – *Phoma lingam*

Another fungal pathogen causing similar symptoms is *Leptosphaeria maculans*.

**Signs and symptoms**

Symptoms begin as dark sunken spots at the base of the stem and may appear later on the leaves as light brown circular leafspots. Infected plants remain smaller in size. Stem spots enlarge and girdle the stems, mostly at the soil level, causing the plant to suddenly wilt and fall over. The stem can feel dry and woody and the tissue has turned black, sometimes with a purplish margin.

In an advanced stage of black leg, the leafspots carry distinct black dots on the diseased areas of the plant. These are fungus spore-carrying structures (*pycnidia*).

The disease can infect both seedlings and mature plants. The fungus can infect plants during germination of the seed. The first signs of the disease then occur on the seed leaves (cotyledons). The resulting falling over of the seedlings is difficult to distinguish from damping-off disease caused by other fungi. The fungus produces many spores on prematurely killed seedlings and these are able to cause many secondary infections in the seedbed.

The root system is gradually destroyed, although plants may survive in damp soil when new roots develop above diseased parts. Infected plants will eventually die. Weather conditions determine how fast the plants will fall over.

**Source and spread**

The fungus can persist on seed and in residue from diseased plants. It can persist in residue for about 3 years. If infected plants are not removed from the field, the fungus can easily spread to neighboring plants. The fungus can be carried on seed and on transplants. Spread in the field can be due to splashing and running contaminated water or by workers and implements that move through fields that include diseased plants. Wind can carry spores over long distances.

Wounds can facilitate the fungus entering into the plant. A few infected seedlings from the nursery can easily infect many other seedlings through small wounds in leaves and roots due to uprooting.

**Role of environmental factors**

The growth speed of the fungus in the plant depends on the temperature. Below 10°C and above 28°C, the fungus is not very active. The optimum temperature for *Phoma lingam* is around 15°C.

The fungus needs a high humidity for the release of the spores from the pycnidia, the spore-carrying structures. The spread of the spores is dependent on rain: splashing rain (or irrigation!) drops can carry the spores to other plants. High humidity or rain is also needed for the spores to germinate on cabbage plants.

Wind can carry spores quite long distances.

**Natural enemies/antagonists**

Unknown.
Management & control practices

**Preventive activities:**
Most preventive activities as described for clubroot and black rot also apply for black leg disease (except for the pH factors for clubroot). In summary:

- **Crop rotation:** rotate both cabbage nursery and production field by not growing cruciferous crops for at least 3 years.
- **Use of clean seed:** either certified by a reliable seed company, or treated seed. See section 3.3.
- **Use of clean transplants:** Seedlings should not be transplanted from seedbeds that show any diseased plants.
- **Avoid overhead irrigation.** The splashing water may spread the disease.
- **Ensure good air circulation, drainage and rapid evaporation of dew.** e.g. by wide spacing, orienting rows in the prevailing wind direction, choosing a sunny planting site, etc.
- **Sanitation:** clean the field of old leaves and other crop left-overs before transplanting seedlings.
- **Diseased leaves should not be fed to farm animals if manure is to be used on crucifer fields:** researchers report that manure from cattle fed on black leg debris is an important infection source!

**Once the disease** is present in the field:

- **Remove infected plant material.** Take it away from the field to a compost pile, or a place far from the production field.

**Points to remember about black leg:**

1. Black leg can cause “damping-off” type symptoms in seedlings and leaf spots in older plants.
2. The fungus can survive on seed and in residue from diseased plants. Splashing water, field workers, and wind can spread the disease.
3. Sanitation (removing and destroying) infected plant material) is the main management practice.

8.9  Physiological disorders

Physiological disorders are “diseases” caused by adverse environmental conditions. Major causes of these disorders are excessively high or low temperatures, soil-moisture disturbances, sun burn, pesticide burn (when the leaves of a plant turn brown-black when the dose of a pesticide is too high), nutritional disorders, and even air pollution.

Fertilizer deficiencies (sometimes due to too low a soil pH) are a common cause of physiological disorders. If a plant is not supplied with sufficient amounts of the fertilizer elements it needs for good growth it will develop symptoms of lack of nourishment. These symptoms are specific for a crop and for a fertilizer element. Deficiencies may often develop on light sandy soils that let rain water through easily and allow nutrients to leach away. On the other hand, over-fertilization may also cause severe growth distortions in plants.

Some of the most common physiological disorders for cabbage are listed below. See also section 3.5.7. on fertilization needs of cabbage and box on deficiency symptoms for macro and micro nutrients in section 7.6.
Nitrogen (N) deficiency
In cabbage plants, symptoms are usually a purple glow on the leaves. Symptoms are located throughout the plant, although the older leaves usually show symptoms most clearly. When nitrogen deficiency occurs early in the growing season, the plants may stay small in size and head formation may be distorted. In light, sandy soils, nitrogen deficiency can easily occur after heavy rainfall. The rain will wash the nitrogen out to deeper layer of the soil where it is inaccessible for the crop.

Adding nitrogen (chemical fertilizer) is usually sufficient to overcome nitrogen deficiency for the short term. Adding organic material to the soil improves nutrient holding capacity of the soil and it therefore a more permanent solution.

Nitrogen (N) excess
Too much nitrogen leads to tall, weak plants. Plants basically grow “too fast” and become weak and therefore more susceptible to diseases. Sometimes, no cabbage heads develop. In addition, too much nitrogen may result in a high concentration of nitrate in the leaves which is detrimental for human health.

Phosphorous (P) deficiency
Symptoms of phosphorous deficiency are plants that stay small in size. Leaves are dark green to bluish green in color. Sometimes, a purple color at the undersides of the leaves can be seen. Symptoms are located throughout the plant. It is difficult to correct deficiency symptoms with additional fertilizer application once the symptoms are there. Proper fertilization before the crop is transplanted and use of lots of (well-decomposed) organic material is the best prevention.

Potassium (K) deficiency
Symptoms of potassium deficiency are a bluish-green coloration followed by yellowing and scorching of the leaf margins, accompanied by poor heading. The symptoms are located mainly at the older leaves.

Potassium deficiency symptoms are liable to occur on land recently broken up from grass, on light soils, on heavy soil with deficient drainage and in land heavily manured with nitrogenous materials.

Boron deficiency
Cabbage heads may be small and yellow. The stems of cabbage may be cracked and corky. Leaves may become dry and papery. Light soils are more susceptible to boron deficiency, especially in very dry periods. Also, soils with high pH are more susceptible to boron deficiency.

Boron can be added to soils separately but a soil test is advisable to ensure that boron levels are not too high.

Magnesium (Mg) deficiency
The symptoms of magnesium deficiency are pale marbled areas between the veins (chlorosis), sometimes accompanied by a purple color of the leaves. The pale areas finally dry out into brown dead patches. The symptoms are located mainly at the older leaves.

Growth and maturity may be greatly checked and the plants may become badly affected with diseases like downy mildew.
Deficiency of magnesium may occur both on acid soils and on soils containing ample supplies of lime, especially where this has been added. It is most prevalent on light soils under conditions where the magnesium is readily leached away, like in wet seasons. The deficiency may become apparent after several years of routine manuring with inorganic fertilizers.

In acid soils, magnesium limestone may be applied to counteract the deficiency. Other magnesium containing fertilizers like magnesium sulfate can also be used, preferably before the seedlings are transplanted. The turning-in of green manures and the use of farmyard manure or compost also tend to preserve supplies of magnesium in the soil.

**List of related disease 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-B.1. Seed drenching/coating to manage damping-off
3-A.6., 3.B.2 and. 3.D.2. Use of subsoil to manage diseases in the nursery
3-D.5. Test effect of soil solarisation in the field
3-A.9. Test effect of infected crop debris in the field
3-E.4. Sanitation measures to manage cabbage soft rot
3-A.10. and 3-E.2. Effect of rain on the spread of diseases
3-A.11. and 3.E.1. Spread of diseases by farming tools
3-A.12. and 3-E.5. Test different cultivars for resistance to diseases
3-A.13. Pruning and plant compensation
3-E.3. Pruning of infected shoots versus fungicide application
3-A.14. Restricted fungicide use to manage leaf spots
3-A.16. Study of spread of a fungal leaf spot
3-D.1. Pot experiments to test whether root diseases are soil-borne
3-D.6. Effect of liming on clubroot of cabbage
3-F.9. Virus or nutrient deficiency?
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 cabbage production is generally in the first 3 to 4 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. Dependence upon herbicides alone does seldom provide 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.
Weeds are normal plants, but they are “weeds” because they grow where we do not want them.

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 3.5.3.2).

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 very common weed in Bangladesh, growing only where soil is very infertile. This gives valuable information on the status of the soil.

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.
Broadleaf weeds or grasses

1. **Broadleaf weeds**: germinating seedlings have two leaves. The leaves are usually wider than those of grasses. Broadleaf weeds are basically all weeds except grasses, sedges and bamboo.

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

The Seedbank

To check if there are weeds 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! Seeds of weed will germinate in the next days and you can check how many weeds come up and which species of weed 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. 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. For cabbage this period can be shorter: 3 to 4 weeks after transplanting.

(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 3.5.3.

- **Increase planting density** to shade weeds: When the crop is sown or transplanted densely, the canopy will close quickly. Shade will prevent many weeds from germinating. In a dense crop however, chances for disease infection are higher because the humidity inside the canopy can be high. Another problem is that if weeds germinate anyway, they will be difficult to control at tight spacing.

- **Compost manures to reduce weed seed**: animal manures may still contain 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 3.5.3.2 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 3.5.3.1 on compost.

<table>
<thead>
<tr>
<th>Botanical weed control…?!</th>
</tr>
</thead>
<tbody>
<tr>
<td>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, however. 😒 (Peet, www8).</td>
</tr>
</tbody>
</table>

### 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 section 3.8.4.

- 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, especially for a crop like cabbage which covers the soil fairly quick.

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 cabbage 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.

Note: 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 loose 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 dependents 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 manage 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 cabbage 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 gloeosporioide* 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
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.

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.
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 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.

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 (SO₂) 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.

Microorganisms:

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

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kills rats on a large scale at the same time.</td>
<td>Expensive.</td>
</tr>
<tr>
<td>Mostly safe for humans, other animals and the environment.</td>
<td>Short shelf life/storage period (the time it keeps its potency).</td>
</tr>
<tr>
<td>Considerably reduces rat populations and its damage over long periods of time</td>
<td>Does not cause immediate death (rats die from 4 - 14 days after eating) so farmers do not like to use.</td>
</tr>
<tr>
<td></td>
<td>Use in the field is very much affected by weather conditions</td>
</tr>
</tbody>
</table>

Use of preparations with microorganisms 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 *pachyrhizus, nux vomica* for poisons. Care must be taken when these are used because they are very poisonous for humans and animals.

## Key to Some Common Cabbage Insect Pests and Diseases

### 11 Key to Some Common Cabbage Problems

<table>
<thead>
<tr>
<th>Affected plant part</th>
<th>Symptoms/findings</th>
<th>Possible cause(s)</th>
<th>See section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seedling</td>
<td>Seedlings in nursery have small shot-holes in the seed-leaves (cotyledons) and young true leaves</td>
<td>Flea beetle (<em>Phyllotreta</em> sp.)</td>
<td>5.3</td>
</tr>
<tr>
<td>Seedling</td>
<td>Stems of seedlings in nursery or young plants in the field are cut through at soil level</td>
<td>Cutworms (<em>Agrotis</em> sp.)</td>
<td>5.4</td>
</tr>
<tr>
<td>Seedling</td>
<td>Seedlings or young transplants have a poor growth</td>
<td>Poor soil structure, Poor fertilization condition of the soil, Water logging, Stemborer (<em>Melanagromyza cleomae</em>)</td>
<td>3.4, 3.5, 3.9, 5.11</td>
</tr>
<tr>
<td>Seedling</td>
<td>Seedlings in nursery have damaged leaves and hearts (sometimes covered with caterpillars) and whole plants may die</td>
<td>Webworm (<em>Hellula undalis</em>), Diamondback moth (<em>Plutella xylostella</em>)</td>
<td>5.7, 5.1</td>
</tr>
<tr>
<td>Seedling</td>
<td>Stems are hollow at soil level or just below soil level</td>
<td>Cutworms (<em>Agrotis</em> sp.), Stemborer (<em>Melanagromyza cleomae</em>)</td>
<td>5.4, 5.11</td>
</tr>
<tr>
<td>Seedling</td>
<td>Seedlings in nursery wilt and fall over suddenly</td>
<td>Damping-off (<em>Pythium</em> sp.), Black rot (<em>Xanthomonas campestris</em>), Black leg (<em>Phoma lingam</em>)</td>
<td>8.1, 8.2, 8.8</td>
</tr>
<tr>
<td>Seedling</td>
<td>Seedlings in nursery have small yellow or brown spots on the leaves</td>
<td>Downy mildew (<em>Peronospora</em> sp.), Leaf spot (<em>Alternaria brassicae</em>)</td>
<td>8.7, 8.5</td>
</tr>
<tr>
<td>Seedling</td>
<td>Upon uprooting, seedlings have swollen roots and/or little galls on the roots</td>
<td>Clubroot (<em>Plasmodiophora brassicae</em>)</td>
<td>8.6</td>
</tr>
<tr>
<td>Seedling</td>
<td>Seedlings/transplants are stunted</td>
<td>Stemborer (<em>Melanagromyza cleomae</em>)</td>
<td>5.11</td>
</tr>
<tr>
<td>Growing point</td>
<td>Cabbage heart is deformed</td>
<td>Diamondback moth (<em>Plutella xylostella</em>), Webworm (<em>Hellula undalis</em>), Heart caterpillar (<em>Crocidolomia binotalis</em>)</td>
<td>5.1, 5.7, 5.6</td>
</tr>
<tr>
<td>Growing point</td>
<td>One cabbage plant develops more than one head</td>
<td>Diamondback moth (<em>Plutella xylostella</em>), Webworm (<em>Hellula undalis</em>), Heart caterpillar (<em>Crocidolomia binotalis</em>)</td>
<td>5.1, 5.7, 5.6</td>
</tr>
<tr>
<td>Head</td>
<td>Cabbage head develops brown, dry rot</td>
<td>Head rot (<em>Rhizoctonia solani</em>)</td>
<td>8.4</td>
</tr>
<tr>
<td>Head</td>
<td>Cabbage head starts to rot, is soft and slimy</td>
<td>Soft rot (<em>Erwinia carotovora</em>)</td>
<td>8.3</td>
</tr>
<tr>
<td>Leaf</td>
<td>Leaves are crumpled and turn yellow</td>
<td>Aphids (<em>Brevicoryne brassicae</em>), Whitefly (<em>Bemisia tabac</em>)</td>
<td>5.2, 5.10</td>
</tr>
<tr>
<td>Leaf</td>
<td>Leaves have little “windows” where the tissue is gone except for a transparent cuticle</td>
<td>Diamondback moth (<em>Plutella xylostella</em>), Webworm (<em>Hellula undalis</em>), Heart caterpillar (<em>Crocidolomia binotalis</em>)</td>
<td>5.1, 5.7, 5.6</td>
</tr>
<tr>
<td>Leaf</td>
<td>Leaves and head have large irregular shaped holes and a frass is visible on the damaged leaves</td>
<td>Diamondback moth (<em>Plutella xylostella</em>), Webworm (<em>Hellula undalis</em>), Looper (<em>Trichoplusia ni</em>), Cabbage white butterfly (<em>Pieris sp.</em>), Heart caterpillar (<em>Crocidolomia binotalis</em>)</td>
<td>5.1, 5.7, 5.8, 5.9, 5.6</td>
</tr>
<tr>
<td>Affected plant part</td>
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<tr>
<td>---------------------</td>
<td>-------------------</td>
<td>-------------------</td>
<td>------------</td>
</tr>
</tbody>
</table>
| Leaf                | Leaves are skeletonized: only the veins remain, the leaf tissue is all gone | Diamondback moth (*Plutella xylostella*)  
Armyworms (*Spodoptera* sp.)  
Looper (*Trichoplusia ni*)  
Cabbage white butterfly (*Pieris* sp.) | 5.1  
5.5  
5.8  
5.9 |
| Leaf                | Leaves have black or brown round spots | Insect damage  
Leaf spot (*Alternaria brassicae*)  
Black leg (*Phoma lingam*)  
Bottom rot (*Rhizoctonia solani*) | -  
8.5  
8.8  
8.4 |
| Leaf                | Leaves have black or brown, irregular shaped, spots or dead areas | Pesticide burn  
Sunburn  
Black rot (*Xanthomonas campestris*) | -  
-  
8.2 |
| Leaf                | Plant has a purple color on the leaves but otherwise looks normal | Varietal characteristic  
Nitrogen shortage | -  
8.9 |
| Leaf                | Leaves are bluish green in color | Varietal characteristic  
Phosphorous deficiency  
Potassium deficiency | -  
8.9  
8.9 |
| Petioles            | Maggots/pupae in large petioles of older cabbage leaves | Stemborer (*Melanagromyza cleomae*) | 5.11 |
| Stem               | Larvae and pupae inside stem | Stemborer (*Melanagromyza cleomae*)  
Webworm (*Hellula undalis*) | 5.11  
5.7 |
| Roots              | Deformed roots, 'clubs' on the roots | Clubroot (*Plasmodiophora brassicae*) | 8.6 |
| Whole plant        | Discolouring, wilting, roots start to rot | Water logging | 3.9 |
| Whole plant        | Plant wilts during warm days | Water shortage  
Clubroot (*Plasmodiophora brassicae*)  
Stemborer (*Melanagromyza cleomae*) | 3.9  
8.6  
5.11 |
| Whole plant        | Plants stay very small and no heads develop | Clubroot (*Plasmodiophora brassicae*)  
Bottom rot (*Rhizoctonia solani*)  
Poor soil structure - localized  
Stemborer (*Melanagromyza cleomae*) | 8.6  
8.4  
3.4  
5.11 |
| Whole plant        | Plant falls over, stem is rotten at the soil level | Black leg (*Phoma lingam*) | 8.8 |
| Caterpillars/larvae in the soil | Cutworms (*Agrotis* sp.)  
Flea beetle (*Phyllotreta* sp.) | 5.4  
5.3 |
| Pupae in the soil  | Cutworms(*Agrotis* sp.)  
Armyworms (*Spodoptera* sp.) | 5.4  
5.5 |
| Pupae on plants    | Diamondback moth (*Plutella xylostella*)  
Looper (*Trichoplusia ni*)  
Cabbage white butterfly (*Pieris* sp.) | 5.1  
5.8  
5.9 |
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PESTS & DISEASES COMMON TO CABBAGE

Plate 1

Fig. 1: Crocidolomia
(See section 5.6, page 94)
(Source: AICAF, 1995)

Fig. 2: Hellula undalis
(See section 5.6, page 96)
(Source: AICAF, 1995)

Fig. 3: Black rot on cauliflower:
The disease extends inwards from the leaf margins. Affected areas dry out and turn brown. Older leaves may drop from the plant.
(See section 8.2, page 155)
(Source: DPI, 1994)

Fig. 4: Black rot on broccoli:
Leaves show infection along the leaf margins with yellow, V-shaped areas and dark veins.
(See section 8.2, page 155)
(Source: DPI, 1994)

Fig. 5: Black rot on cabbage:
Note the typical infection through the water pores on the leaf margin.
(See section 8.2, page 155)
(Source: DPI, 1994)

Fig. 6: Cabbage field seriously affected with bacterial soft rot
(See section 8.3, page 157)
(Source: AICAF, 1995)
Fig. 7: Bacterial soft rot of cabbage. Water soaked soft rot lesions enlarge very rapidly
(See section 8.3, page 157)
(Source: AICAF, 1995)

Fig. 8: Rhizoctonia bottom rot
(See section 8.4, page 159)
(Source: MacNab et al, 1994)

Fig. 9: Alternaria leaf spot of cabbage - large circular lesions with concentric rings on an outer leaf
(See section 8.5, page 160)
(Source: Black)

Fig. 10: Field symptoms of club rot:
Infected plants are stunted and wilted, particularly during the warmer part of the day.
(See section 8.6, page 163)
(Source: DPI, 1994)

Fig. 11: Close-up of club root infection:
Spindle or club-shaped swellings develop on roots.
(See section 8.6, page 163)
(Source: DPI, 1994)

Fig. 12: Downy mildew symptoms on crucifer seedling leaves:
A white fungal growth develops rapidly under cool, moist conditions.
(See section 8.7, page 167)
(Source: DPI, 1994)
**Fig. 13 : Advanced symptoms of downy mildew:**
Older leaves take on a speckled appearance.
*(See section 8.7, page 167)*
(Source : DPI, 1994)

**Fig. 14 : Field symptoms of black leg:**
The disease damages the roots, causing plants to wilt and collapse.
*(See section 8.8, page 169)*
(Source : DPI, 1994)
KEYWORD INDEX

C

cabbage
origin ---------------------------------------  4
cabbage heart caterpillar --------------------  94
cabbage looper --------------------------------  88
cabbage white butterfly --------------------  100
calcium ----------------------------------------  143
calendar spraying ---------------------------  150
Chili ---------------------------------------------  67
Chrysopa carnea ----------------------------  112
Chrysopa rufilabris --------------------------  112
climate -------------------------------------------  11
Clubroot---------------------------------------  163
coccinellid beetle ----------------------------  110
corn -------------------------------------------  20
Coenosa  sp. ----------------------------------  108
compensation --------------------------------------  8, 55
Compost ----------------------------  17, 24, 154
advantages -------------------------------  24
decomposition time --------------------  27
disadvantages ---------------------------  25
disease control --------------------------  27
how to prepare--------------------------  25
how to use -------------------------------  29
temperature-------------------------------  26
thermometer -----------------------------  27
Cotesia glomerata   ------------------  101, 122
Cotesia marginiventrus ---------------------  122
Cotesia plutellae ------------------------  77, 122
Cotesia rubecula ----------------------------- 122
Cover crops ------------------------  21, 29, 177
critical weed-free period --------------  176
Crocidolomia binotalis -------------------  94, 128
crop defenders ------------------------  57
crop development ---------------------  5
Crop rotation ---------------------  48, 145, 176
crop visitors ----------------------  56
cropping calendar -----------------------  6
cutworm ------------------------------  159
cutworm calendar ------------------------  88

A

acid soil ---------------------------------------- 19
AESA ...........................................  64
agro-ecosystem analysis ------------------  63
calcium ----------------------------------------  143
Agronomic practices ----------------------  10
Agronomic practices .......................... 10
Agronomic practices in control of pests 10
Agrotis ipsilon ------------------------  122
Agrotis segetum --------------------------  88
Agrotis sp. ..................................  88
Alternaria brassicae ----------------------  160
Alternaria leaf spot ----------------------  139, 160
anatomy -------------------------------  52
antagonist ---------------------------  57, 137, 147
aphid lions --------------------------  113
aphids 82, 110, 112, 114, 119, 139
mummies --------------------------------------  119
armyworm -------------------------------------  91
ash ............................................  67

B

Bacillus thuringiensis -----  78, 93, 102, 125
Bactrovirus -----------------------  130
Baculoviruses --------------------------------  130
Beauveria bassiana 127, 179
Beauveria sp. ..................................  104
Bemisia tabaci --------------------------  103
beneficials ..................................  57
biocontrol agents ----------------------  57, 68
biofumigation ------------------------  38
biological pesticides -------------------  68
Biopesticides ------------------------  68
biorationals ------------------------  68
birds ----------------------------------------  134
Black leg -------------------------------  169
Black rot ................................... 155
boron ----------------------------------------  33, 143
Boron deficiency -----------------------  171
botanicals -------------------------------  64, 150
Bottom rot ----------------------------  159
boundary area planting ------------------  21
Brevicoryne brassicae ------------------  82, 128
broadleaf weeds ------------------------  175
Bt ............................................  125

D

damping-off --------------------------------------  152
decomposition -------------------------------  24
<table>
<thead>
<tr>
<th>Term</th>
<th>Page Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>deficiency symptoms</td>
<td>143</td>
</tr>
<tr>
<td>defoliation study</td>
<td>8</td>
</tr>
<tr>
<td>Diadegma insulare</td>
<td>77, 120</td>
</tr>
<tr>
<td>Diadegma semiclausum</td>
<td>76, 120</td>
</tr>
<tr>
<td>Diadegma sp.</td>
<td>59, 120</td>
</tr>
<tr>
<td>Diadromus collaris</td>
<td>77, 124</td>
</tr>
<tr>
<td>Diaeretiella rapae</td>
<td>83, 119</td>
</tr>
<tr>
<td>diagnosing problems</td>
<td>142</td>
</tr>
<tr>
<td>diamondback moth</td>
<td>75, 120, 122, 124, 128</td>
</tr>
<tr>
<td>disease culture</td>
<td>144</td>
</tr>
<tr>
<td>Disease ecology</td>
<td>136</td>
</tr>
<tr>
<td>disease management</td>
<td>136, 141, 145</td>
</tr>
<tr>
<td>Disease spread</td>
<td>139</td>
</tr>
<tr>
<td>disease triangle</td>
<td>140</td>
</tr>
<tr>
<td>disease zoo</td>
<td>144</td>
</tr>
<tr>
<td>Downy mildew</td>
<td>167</td>
</tr>
<tr>
<td>Drainage</td>
<td>45</td>
</tr>
</tbody>
</table>

**E**

<table>
<thead>
<tr>
<th>Term</th>
<th>Page Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>ecology</td>
<td>51</td>
</tr>
<tr>
<td>economic threshold level</td>
<td>63</td>
</tr>
<tr>
<td>Encarsia sp.</td>
<td>104</td>
</tr>
<tr>
<td>entomopathogenic fungi</td>
<td>127</td>
</tr>
<tr>
<td>Entomophthora sp.</td>
<td>128</td>
</tr>
<tr>
<td>Epilachna sp.</td>
<td>110</td>
</tr>
<tr>
<td>Erosion control</td>
<td>21</td>
</tr>
<tr>
<td>Erwinia carotovora</td>
<td>157, 158</td>
</tr>
<tr>
<td>ETL</td>
<td>63</td>
</tr>
</tbody>
</table>

**F**

<table>
<thead>
<tr>
<th>Term</th>
<th>Page Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilizer</td>
<td></td>
</tr>
<tr>
<td>chemical</td>
<td>21, 33</td>
</tr>
<tr>
<td>foliar</td>
<td>34</td>
</tr>
<tr>
<td>inorganic</td>
<td>33</td>
</tr>
<tr>
<td>recommendations for cabbage</td>
<td>35</td>
</tr>
<tr>
<td>Fertilizer deficiency</td>
<td>170</td>
</tr>
<tr>
<td>Fertilizer management</td>
<td>22</td>
</tr>
<tr>
<td>field preparation</td>
<td>41</td>
</tr>
<tr>
<td>flea beetle</td>
<td>85</td>
</tr>
<tr>
<td>flooding field</td>
<td>45</td>
</tr>
<tr>
<td>fuel oil</td>
<td>68</td>
</tr>
<tr>
<td>fungi</td>
<td>137, 138</td>
</tr>
<tr>
<td>fungicides</td>
<td>149</td>
</tr>
</tbody>
</table>

**G**

<table>
<thead>
<tr>
<th>Term</th>
<th>Page Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>garlic</td>
<td>67, 150</td>
</tr>
<tr>
<td>germination</td>
<td>13</td>
</tr>
<tr>
<td>Gliocladium virens</td>
<td>148</td>
</tr>
<tr>
<td>granulosis virus</td>
<td>130</td>
</tr>
<tr>
<td>Green manure</td>
<td>30</td>
</tr>
<tr>
<td>ground beetle</td>
<td>111</td>
</tr>
<tr>
<td>growth stage</td>
<td>56</td>
</tr>
</tbody>
</table>

**H**

<table>
<thead>
<tr>
<th>Term</th>
<th>Page Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>HaNPV</td>
<td>130</td>
</tr>
<tr>
<td>Harvest</td>
<td>48</td>
</tr>
<tr>
<td>health</td>
<td>71</td>
</tr>
<tr>
<td>Hellula undalis</td>
<td>96</td>
</tr>
<tr>
<td>herbicides</td>
<td>68, 178</td>
</tr>
<tr>
<td>herbivores</td>
<td>55</td>
</tr>
<tr>
<td>Heterorhabditis sp.</td>
<td>133</td>
</tr>
<tr>
<td>hover flies</td>
<td>59, 83, 114</td>
</tr>
<tr>
<td>Humus</td>
<td>19, 23</td>
</tr>
<tr>
<td>Hybrid variety</td>
<td>11</td>
</tr>
<tr>
<td>hyperparasitism</td>
<td>114</td>
</tr>
</tbody>
</table>

**I**

<table>
<thead>
<tr>
<th>Term</th>
<th>Page Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>insect cage</td>
<td>61</td>
</tr>
<tr>
<td>insect zoo</td>
<td>54, 56</td>
</tr>
<tr>
<td>insect-pathogenic fungi.</td>
<td>127</td>
</tr>
<tr>
<td>insecticidal soaps</td>
<td>68</td>
</tr>
<tr>
<td>Insecticides</td>
<td>69</td>
</tr>
<tr>
<td>Inter-Country Programme</td>
<td>3</td>
</tr>
<tr>
<td>Intercropping</td>
<td>46</td>
</tr>
<tr>
<td>IPM</td>
<td>2</td>
</tr>
<tr>
<td>Irrigation</td>
<td>45</td>
</tr>
</tbody>
</table>

**K**

<table>
<thead>
<tr>
<th>Term</th>
<th>Page Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>kerosene</td>
<td>68</td>
</tr>
</tbody>
</table>

**L**

<table>
<thead>
<tr>
<th>Term</th>
<th>Page Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>lacewing</td>
<td>104, 112</td>
</tr>
<tr>
<td>lady beetle</td>
<td>83, 104, 110</td>
</tr>
<tr>
<td>Leaf spot</td>
<td>160</td>
</tr>
<tr>
<td>Leptosphaeria maculens</td>
<td>169</td>
</tr>
<tr>
<td>life cycle</td>
<td></td>
</tr>
<tr>
<td>complete</td>
<td>53</td>
</tr>
<tr>
<td>incomplete</td>
<td>53</td>
</tr>
<tr>
<td>light trap</td>
<td>62</td>
</tr>
<tr>
<td>Lime</td>
<td>19</td>
</tr>
<tr>
<td>Living mulch</td>
<td>30</td>
</tr>
</tbody>
</table>

**M**

<table>
<thead>
<tr>
<th>Term</th>
<th>Page Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macronutrients</td>
<td>22</td>
</tr>
<tr>
<td>magnesium</td>
<td>143</td>
</tr>
<tr>
<td>magnesium deficiency</td>
<td>171</td>
</tr>
<tr>
<td>Manure</td>
<td>31</td>
</tr>
<tr>
<td>nutrient contents</td>
<td>31</td>
</tr>
<tr>
<td>Term</td>
<td>Page</td>
</tr>
<tr>
<td>---------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Marigold</td>
<td>66</td>
</tr>
<tr>
<td>Melanagromyza cleomeae</td>
<td>107</td>
</tr>
<tr>
<td>Metarhizium sp.</td>
<td>128</td>
</tr>
<tr>
<td>microbials</td>
<td>68</td>
</tr>
<tr>
<td>micronutrients</td>
<td>22</td>
</tr>
<tr>
<td>microorganisms</td>
<td>19, 21, 23, 24, 137</td>
</tr>
<tr>
<td>Microplitis sp.</td>
<td>93</td>
</tr>
<tr>
<td>milk</td>
<td>150</td>
</tr>
<tr>
<td>mineralization</td>
<td>24</td>
</tr>
<tr>
<td>Mixed cropping</td>
<td>46</td>
</tr>
<tr>
<td>monitoring</td>
<td>51</td>
</tr>
<tr>
<td>mouthparts</td>
<td>52</td>
</tr>
<tr>
<td>mulching</td>
<td>21, 40, 44, 106, 176</td>
</tr>
<tr>
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### N

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