Agrodok-series No. 30

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Non-chemical crop protection

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Agrodok 30 - Non-chemical crop protection

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This publication is sponsored by: ICCO (the Netherlands inter-church organisation for development co-funding) and the Royal Netherlands Society of Plant Pathology (KNPV)

First edition: 2007

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Printed by: Digigrafi, Wageningen, the Netherlands

ISBN Agromisa: 978-90-8573-074-3
ISBN CTA: 978-92-9081-363-7

Foreword

Recommendation

Farmers often do not realize that their unsprayed fields are full of beneficial insects (parasitoids and predators) which keep pest numbers under control. However, these natural enemies are much more vulnerable to pesticides than the targeted pests. So when pesticides are used, natural enemies are killed and pests can develop unchecked. It is therefore essential to use non-chemical crop protection methods instead of pesticides. This booklet describes a number of tactics that can be used. It demonstrates how to work with nature to keep pests at tolerable levels. The booklet also draws attention to the Farmer Field Schools that have been set up world-wide. In these field schools, farmers learn to become active, self-reliant practitioners of non-chemical crop protection. This booklet, written by very experienced scientists, is highly recommended to farmers, extension officers and pest management practitioners.

Prof.Dr.Ir. Arnold van Huis, Tropical entomologist
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Acknowledgements

We acknowledge the following persons for their enthusiastic and fruitful contributions to discussions and for presenting cases for this booklet: Carol Waddington, Gerard Pesch, Francis Arulappan, William Barbier, Huub Stoetzer, Gerrit van der Klashorst, Joep van Lidth de Jeude, Moise Tchomguia and Roy Keijzer. We also thank Cambridge University Press for permission to reproduce figure 2 of this booklet, the Gatsby Charitable Foundation for permission to reproduce figure 11 and Dr. Aad van Ast of Wageningen University for permission to reproduce figure 23. Further thanks go to Barbera Oranje, for making most of the drawings.

Piet Scheepens and Rik Hoevers, Wageningen 2007

Contents

1 Introduction

1.1 What is this booklet about?

As a farmer of arable crops or vegetables, you strive to achieve the highest yield and the best quality product possible. Of course you would prefer to do this with a minimum investment of energy and resources, but you are continuously bothered by all kinds of harmful organisms (pests) that threaten to reduce the quality and yield of your crops. Protecting your crops from these pests is extremely important, but it is difficult to achieve maximum results with a minimum of effort. You have to look not only at a measure's immediate effect, but also at its long-term effect.

This booklet gives an overview of the main non-chemical measures you can take to protect your crops from pests. Most of these measures are preventive: they involve planning and farming practices that will help you to keep pest numbers down and limit the damage they do.

1.2 Why publish a booklet about non-chemical crop protection?

Non-chemical methods of crop protection have always been practised, but the introduction of chemical pesticides a few decades ago seemed to make crop protection a lot easier. As a farmer, you suddenly only needed to know which particular pests you were dealing with, which pesticides were available to control them, and how to apply these products safely. These products were so effective that it looked at first as though all pests could be eradicated in this way. In practice, however, the pests were not actually eradicated, because they came back every growing season. Many natural enemies were temporarily wiped out along with the pests, which gave the pests the opportunity to multiply even more explosively than before (see case 1 for an example).

To ensure a healthy crop, it was often necessary to spray several times per season just to control one type of pest. Eventually, some pesticides did not even work anymore because the pests just became resistant to them. This happened first with pesticides used against insects and mites (insecticides), but eventually pesticides used to control diseases (fungicides and bactericides) and weeds (herbicides) also became ineffective. And since pests became resistant to frequently used chemicals, there was a continuous need for new chemicals, chemical compounds and mixtures.

Case 1: Killing predators of pest insects makes farmers more dependent on pesticides (see also case 7)

Brown Plant Hopper, *Nilaparvata lugens*, occurs in lowland rice in Asia. Before the introduction of insecticides it was hardly noticed in the crop because of its size of less than 3 mm. Its numbers were kept low by natural enemies, particularly the spider *Lycosa pseudoannulata*. One spider eats up to 20 Brown Plant Hoppers per day. Spraying insecticides early in the growing season kills most of the Brown Plant Hoppers, but the spiders are even more sensitive to the chemical. In the absence of its natural enemies, Brown Plant Hopper can recover and damage the crop. Since the introduction of pesticides, Brown Plant Hopper has become one of the most damaging insect pests in rice.

Some pesticides are also extremely poisonous for people (see case 2). Farmers are expected to know how to handle these chemicals safely, but in practice many accidents have occurred.

Case 2: Pesticides can threaten a farmer’s health

A questionnaire among 100 cotton farmers in Mozambique revealed that half of them had suffered from insecticide poisoning (Javid et al., 1998. Insect Science and its Application 18, 251-255.).

More than any other factor, these disadvantages of pesticides have sparked renewed interest worldwide in non-chemical methods of crop protection. Fortunately, small-scale farms in the tropics never completely abandoned the use of various non-chemical methods. Based on what we know about the biology of pests, this booklet attempts to explain:

- how these non-chemical pest management methods work and
- how various types of methods reinforce each other.

We hope this will enable you, as a farmer, to apply these methods more effectively and to use your own observations to optimise them.

1.3 Consequences of changing to non-chemical crop protection

It is not easy to compare the profitability of chemical and non-chemical crop protection. Especially if they look at one crop or one year, many people tend to under-estimate the costs of chemical control and over-estimate the costs (especially the labour costs) of non-chemical control. The costs of chemical control include not only the pesticides, but also equipment, protective clothing, safe storage and depreciation costs. And don't forget the doctor's bill if there is an accident. In remote areas the price that the crop will get on the local market may not cover the costs of the pesticides.

Chemical pesticides are often very effective against the target pests, but sometimes they do not work at all because the pest has become resistant to the pesticide or because of unfavourable weather conditions. In that case, costs have been incurred and there is no crop yield to pay for them.

Non-chemical crop protection is often less effective than chemical crop protection, but it is usually less expensive and is based on locally available inputs and interventions.

The undesired side effects of chemical pesticides make it difficult to combine them with many non-chemical methods. We present one example in case 3.

Case 3: Combining chemical and non-chemical crop protection can be difficult

The results of the same questionnaire in Mozambique (case 2) show that the majority of the farmers started spraying too early after sowing the cotton crop. They were unaware that such sprays reduce natural enemies and may not lead to increased cotton yields.

This booklet explains how to keep your crops healthy without using any chemical products, and provides you with some examples. It suggests that you only consider using chemicals if all else fails, and then always choose the chemicals that have the least toxic effects on non-target organisms.

Another booklet in the Agrodok series, *Pesticides: compounds, use and hazards* (No. 29), may be useful if you want to apply pesticides.

1.4 Outline of the booklet

This booklet does not give ready-to-use formulas on how to respond to pest X in crop A or to pest Y in crop B. It provides a more flexible way of thinking and working, which you can adapt to the crops you cultivate and to local conditions.

Whether a farmer applies non-chemical crop protection methods or chemical pesticides, he or she must be able to recognise the most important pests that occur on the farm. It is also important to know more about their life cycles and how they are affected by local conditions. You may find Agrodok No. 28: *Identification of crop damage* helpful in identifying organisms that cause crop damage.

Chapter 2 summarises the most important characteristics of pests and explains how you can learn to control them in a responsible way. The intention is not to eradicate pests, but to minimise their harmful effects.

Chapter 3 describes how you can organise your farming activities in such a way that pests have less chance of multiplying at an explosive rate. Many of these measures are effective for several years and help to control more than one type of pest.

Many measures to protect crops from pests are taken before or during cultivation. These measures are usually directed towards keeping down the numbers of a specific type of pest or category of pest organisms. One example is the use of healthy seed to prevent a crop from becoming diseased in an early stage of growth. Another example is sowing a crop in rows so that weeds can be removed using a hand tool. Yet another example is planting a Neem tree, which keeps many pest insects at bay.

Since the effect of control measures depends to a large extent on a pest's life cycle, we treat pest management in this booklet per category of pest organism. In Chapter 4 we will look at the life cycle, prevention and control of insects and mites; in Chapter 5 we will look at disease-causing moulds, viruses and bacteria; and in Chapter 6 we will look at weeds. Chapter 7 is devoted to the parasitic weed *Striga*.

Strengthening knowledge in farmers' communities

This booklet discusses the general principles of non-chemical crop protection. To apply them effectively, you will need additional knowledge about the crops you are growing, the pests they may harbour and how they interact under local conditions. Farming communities often already have a lot of this valuable knowledge, but sometimes also have ideas and beliefs that are inaccurate or incomplete. For efficient production of healthy crops with little or no pesticide use, it is important to strengthen and upgrade the knowledge in farming communities. It is also important that farmers learn to make decisions based on this knowledge and on observing crops. Farmer Field Schools have proven to be an excellent means of applying and improving non-chemical crop protection. Successes have been reported from many parts of the world. For an example, see case 4 and figure 1.

Case 4: Farmers in Ghana benefit from Farmer Field School

250 farmers participated in the programme, and went on to increase their yields by an average of over 50% per hectare, raising seasonable profits by 30% and reducing pesticide use by 95%. With the increased income, they improved their housing conditions, paid school fees for their children, bought new clothes, and contributed to their churches. Some farmers expanded their farm and turned it into a more business-oriented enterprise. Participants from the savannah zone were able to produce enough crops to store food throughout the lean season. Farmers from more food-secure districts could afford more meat and fish in their diet.

Farmers especially valued the improvement to their health due to reduced pesticide poisoning. Female participants who were trained as farmers or extension staff members felt they had strengthened their organisational ability, leadership skills and self-esteem. Farmers working together also pushed local authorities and agricultural district offices to put more effort into community development.

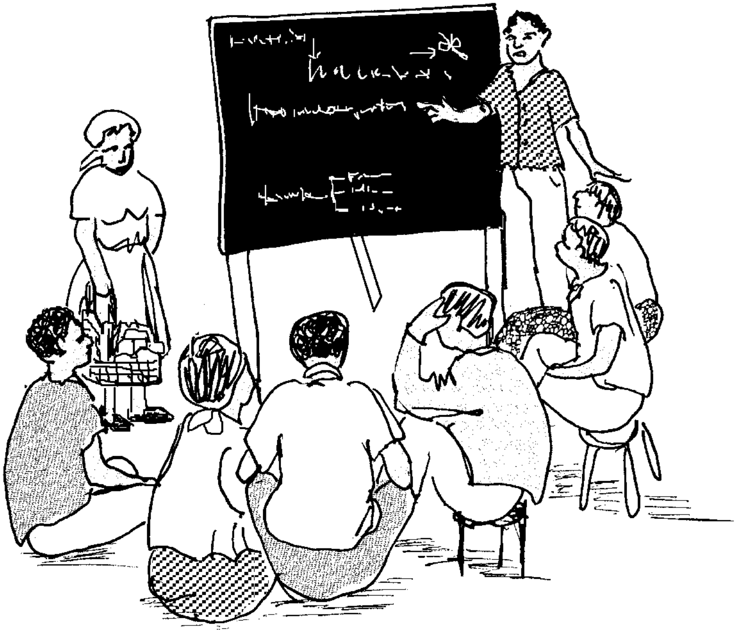


Figure 1: Participants of a Farmer Field School discussing their results

In Chapter 8 we will discuss Farmers Field Schools and how they can be used in a community to reinforce crop protection knowledge and experience.

2 Pests and pest management

2.1 Characteristics of pests

When we speak of crop pests, we mean all organisms that threaten the quality and yield of crops. These can be higher animals, such as rats, mice and birds, but they are more often lower animals, such as insects, mites, nematodes (microscopically small worms) or snails. Micro-organisms, such as fungi, bacteria and viruses, can also cause harmful plant diseases. Higher plants, acting as weeds, can be classified as pests as well. However, the mere presence of these organisms on your farm does not make them pests. In principle they are not pests until you and other farmers are bothered by them. Plants can be especially bothersome in one situation, but quite useful in another. Plants growing wild on a field are often weeds, but in another situation they can be a useful source of animal feed or compost. Seeds, bulbs or roots left on a field after a crop is harvested can grow into bothersome weeds for the following crop.

Of course not all plants and animals found on your farm can develop into pests. All potential crop pests share the following characteristics:

- They can damage individual plants in a crop.
- Under favourable conditions, they can multiply very rapidly.
- They harm the farmer because the damage they cause reduces the yield or quality of the harvested product, or can only be controlled at great expense.

Pests damage individual plants in a crop

Pests differ in the way that they damage crop plants. Three groups of pests will be discussed in this booklet: insects, micro-organisms and weeds.

Insects

Insect pests either eat plants or plant parts (see case 5 for an example), or they pierce the plants and feed on their juices.

Case 5: Pink cotton bollworm, an example of an insect pest that eats plant parts

Pink cotton bollworm, *Pectinophora gossypiella*, belongs to the group of insects with a complete metamorphosis. This means that the larvae (caterpillars) are completely different from the adults (moths), as you can see in figure 2. The caterpillars live inside cotton bolls and they are responsible for the crop damage. We explain complete and incomplete metamorphosis further in figure 12, Chapter 4).

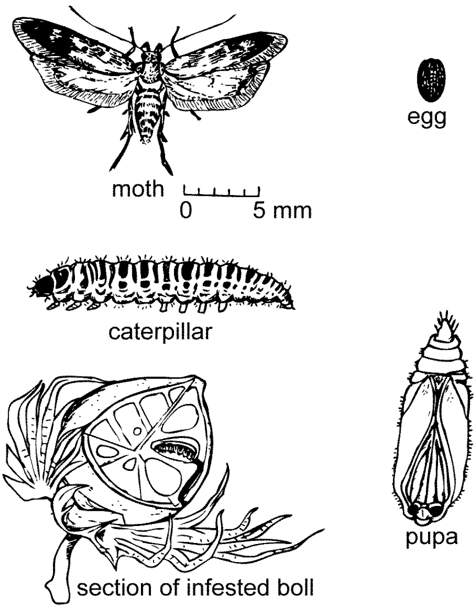


Figure 2: Development stages of pink cotton bollworm. For details, see case 5.

Micro-organisms

Micro-organisms can be a pest because they can make plants diseased. These are called disease-causing or pathogenic organisms. The symptoms of such diseases can include malformation, spots on the plants' leaves, or rotting stems, fruit or roots. In figure 3 (case 6) you can see several diseases on a tomato plant. In reality you will seldom see so many diseases on one plant.

Case 6: A tomato plant showing several diseases
The tomato plant is shown in figure 3. You do not see the micro-organisms that cause the diseases, but the reactions of the plant to the disease-causing micro-organisms. We discuss plant diseases further in Chapter 5.

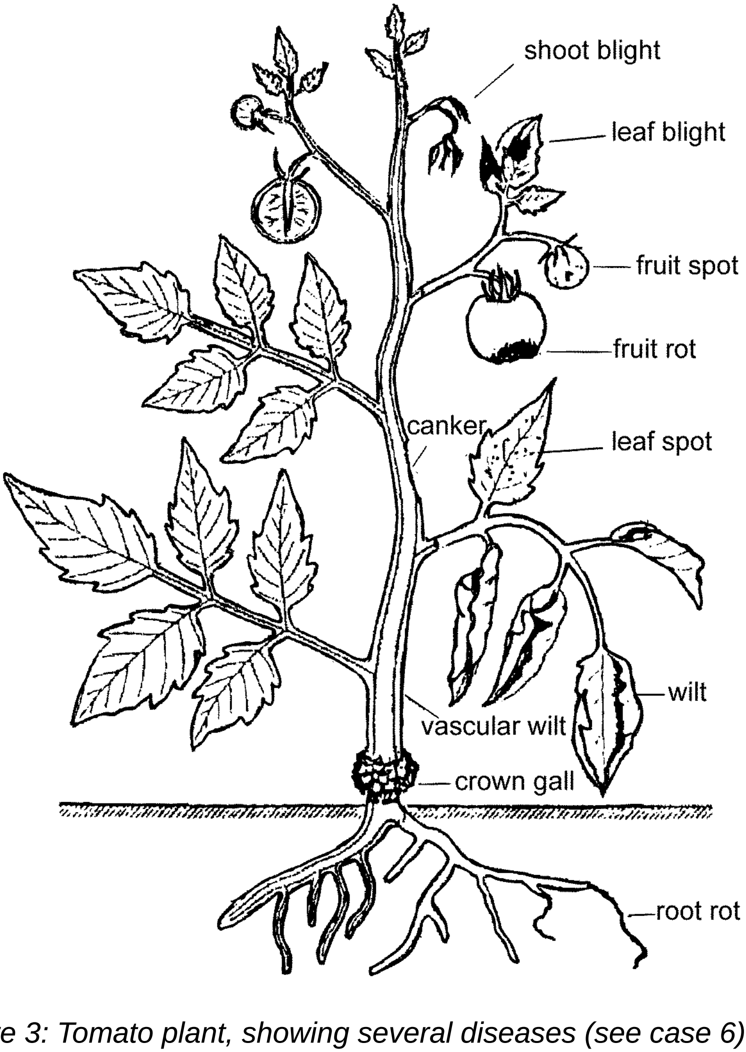


Figure 3: Tomato plant, showing several diseases (see case 6)

Weeds

Most weeds are harmful because they compete with the crop plants for light, water and nutrients. This slows down the crop's growth. Some plants are considered to be weeds because they are parasitic. This means that they live on the roots of plants and extract nutrients and water from the plant through direct contact. In figure 4 you see the parasitic weed *Striga* on the roots of a Sorghum crop. Other plants are weeds because they host pest insects or disease-causing micro-organisms.

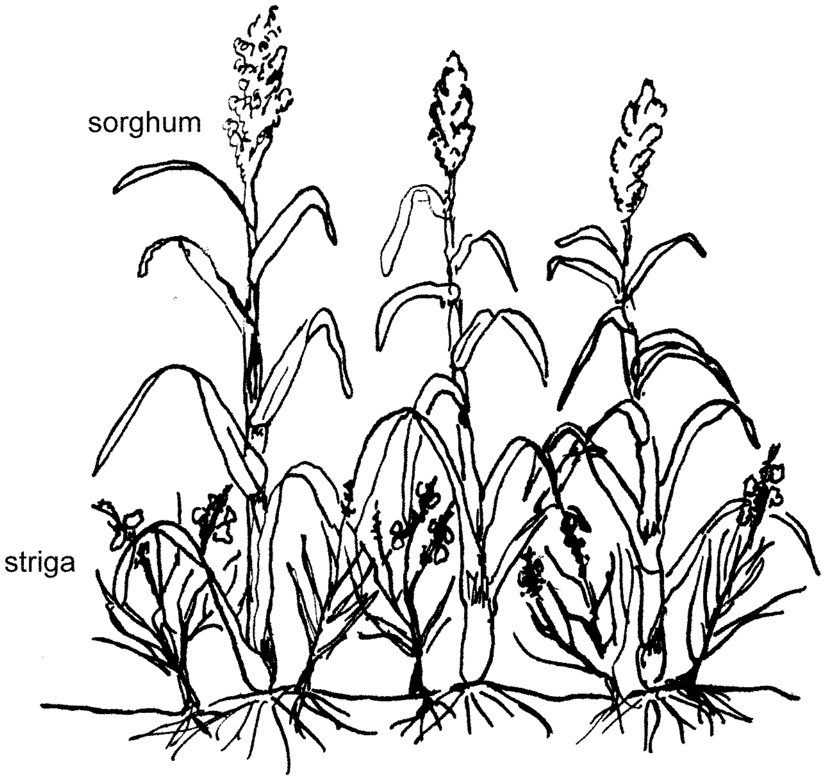


Figure 4: Striga parasites on Sorghum roots

Pests multiply very rapidly

The damage caused by one single pest organism is barely noticeable in a crop. But pests are often present in large numbers, because they can multiply very rapidly within one growing season. In the early stages of a pest infestation, very little appears to be happening because only a small number of individuals are multiplying. This initial stage is then followed by a stage during which they multiply at an explosive rate. This growth pattern is characteristic not only of insects, but to a certain extent of all living organisms.

At a certain point, the size of the population will level off and even start to decrease. This happens either because the food supply runs out or because the population is eaten by its own natural enemies, which also increase in numbers. Case 7 and figure 5 show the effects of insecticide on Brown Plant Hopper and its natural enemies.

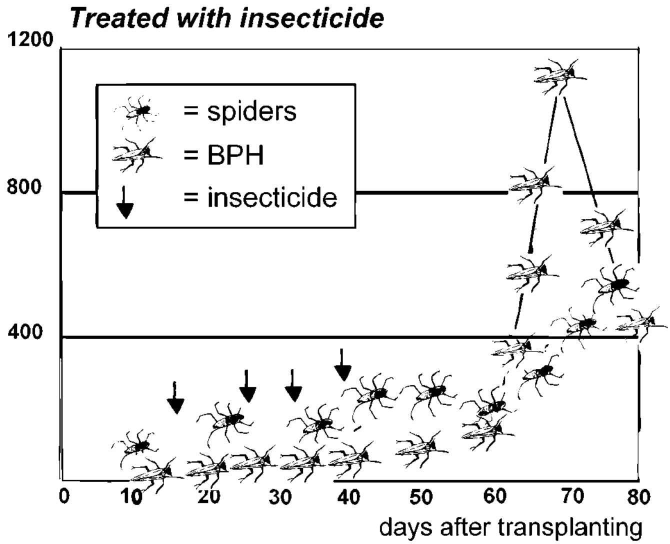
Case 7: Insecticides trigger explosive growth of Brown Plant Hopper (see also case 1)

Figure 5 shows the numbers of Brown Plant Hopper (BPH) and predatory spiders per square meter in an Indonesian farmer's field, and how these numbers vary over time (in days after transplanting of wetland rice).

The upper diagram shows the results from a plot that was sprayed four times with insecticides during the first 40 days after transplanting rice. The insecticide applications are shown as vertical arrows. The population of spider predators decreases to less than 75 per square meters. Although the population of Brown Plant Hopper also went down slightly, it recovered faster than the spiders. Its numbers reached a peak of more than 1000 animals per square meter after 75 days. In the presence of so many Brown Plant Hoppers, spiders also increase in numbers, but too late to prevent crop damage.

In the untreated plot, shown in the lower diagram, the farmer applied no insecticides. Before transplanting and in the early growth stages of the rice, spiders found enough alternative prey to multiply to 300 per square meter at 40 days after transplanting. With so many spiders, Brown Plant Hopper could not reach numbers that are damaging to the crop.

The greater damage caused by insecticides to the natural predator than to the target insect explains how Brown Plant Hopper could become a pest in Asia.



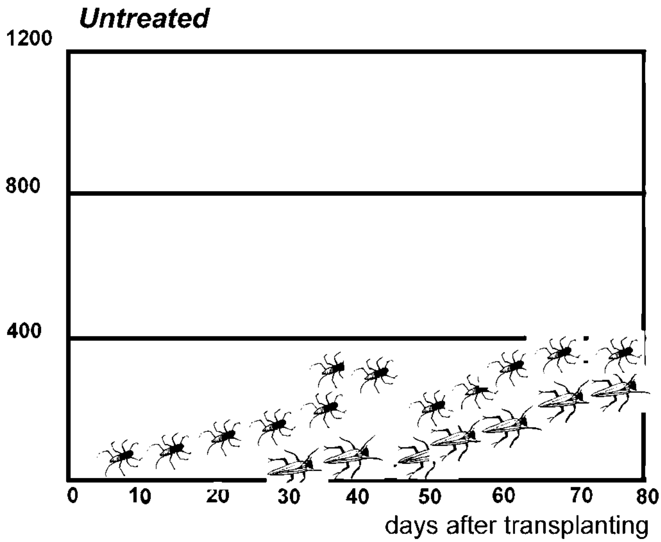


Figure 5: Development of numbers of Brown Plant Hopper (BPH) and spiders in rice plots during a growing season. The upper plot is treated with insecticides, the plot below is untreated. Details are explained in Case 7.

Crop damage

As a group, the pest organisms in an infestation can eventually have a big effect on the yield and quality of a crop. The damage is felt by a farmer in the form of a smaller crop yield or a lower-quality product that will have to be sold at a lower price.

To prevent such damage, the farmer can take measures to control pests. But these measures cost money, so it is not a good idea to implement them automatically. The decision as to whether or not to take action has to be based on regular inspections of the crop. Weekly inspections will be sufficient in most cases.

Case 9 shows how a field can be inspected. The purpose of the inspections is to identify which pests and how many are present in the crop, and to determine whether they are increasing in number.

2.2 Shifting to non-chemical methods

Crop protection using a lot of pesticides is primarily reactive. As soon as the first individuals of a pest are sighted, or when the population has reached a certain size, farmers (like you, probably) consider what pesticide they can use to reduce the number of pest organisms. The advantage of this method is that the desired result is achieved quickly and will continue for as long as the pesticide remains effective.

In the past few decades, more and more pests have become resistant to chemical products. Besides, chemical pesticides often have a very broad impact, which means they kill not only pests but also useful organisms, and they are sometimes poisonous to humans too. For all these reasons, protecting crops through regular applications of chemical pesticides has become less and less effective.

Protecting crops with little or no use of pesticides is possible, but it requires a way of thinking that takes into account the life cycle of pests. We will discuss life cycles of insects, diseases and weeds in chapters 4, 5 and 6, respectively. Rather than choosing to eradicate a pest as soon as you see a small number of individuals, you can also ask yourself why the pest comes back again every time you plant a new crop and why it reproduces so rapidly in that particular crop. It will soon become clear that pests take advantage of certain circumstances. These circumstances may be related to the pest, to the crop, to environmental conditions, or to a combination of the three.

This knowledge forms the basis for a more pro-active (preventive) approach to crop protection. You have undoubtedly gained a great deal of knowledge already through your own observations in the field. Being pro-active means that you accept the presence of pests on your farm, but that you have organised your farming activities and adjusted your cultivation techniques so that pest populations generally do not become too large and the damage they cause remains within acceptable limits. In the unusual event that the population of a particular pest threatens to reach an unacceptable level, pesticides with the least unwanted effects can still be applied as a last resort.

Recognising the most important pests

If you want to apply non-chemical crop protection, you must be able to recognise the pests that are the most harmful on your farm: the key pests. When you understand under which conditions they will cause most damage, you can take pro-active action to prevent that damage.

Once the pest management measures you choose to take are all in place, they will reinforce each other to provide sufficient protection from these key pests. Remember that the measures you take should not be too expensive or require more labour than you can spare.

Planning, implementation and experimentation

Pro-active pest management is not a recipe that works everywhere and at all times. It is a flexible approach that you will continue to adapt to the circumstances on your own farm. You will have to think ahead about which measures you have at your disposal and how you will implement them. Some measures are effective for several years and help control various types of pests. For example, you might want to make a planting schedule in which you indicate the type and order of crops to be cultivated per field (crop rotation). This is discussed further in Chapter 3.

In practice, you will continuously make small improvements. We recommend that you experiment on a limited scale, for example by planting a different variety or a different combination of crops on a small portion of a field. By comparing the damage caused by a certain pest to an individual variety, or combinations of varieties, you can determine under what conditions the pest causes the least damage. In case 8 we show how farmers in Cameroon test plant extracts against insect pests.

Case 8: How farmers in Cameroon evaluate new crop protection techniques

Farmers in Cameroon are organised in small groups, in which they discuss problems they have with pests, and traditional (local) methods to cure them. They also consult a specialist from a local Research Centre who knows about new methods of non-chemical crop protection. Together they set up experiments to see how the new techniques work in local practice.

If a new method turns out to be an improvement, it is adopted and used on a wider scale. Efforts are focused on the use of plant extracts against insect pests (for examples, see case 18).

Inspection

During the growing season, you will have to inspect your crop weekly to observe the main pests and get an idea of how quickly they develop. In case 9 we explain how you can inspect a crop systematically and thoroughly. We suggest that you make drawings of the crops and the pests you find several times in a year. You can then later see which pest you can expect at which development stage of a crop.

If you share the farm labour with your husband or wife, it is also important to make a schedule for the observations, so you know who will do what. See case 10 for the observations on *Striga*.

For insect pests, it is also important to know how their natural enemies develop. If the pest develops much faster than its enemies, you may still be able to take corrective action. At the end of the season you can evaluate the yield and quality of the crop.

Case 9: Crop inspection

The field is inspected systematically by walking across it in a zigzag pattern (see figure 6, picture above). It is inspected thoroughly by detailed observations of a few plants (see figure 6, picture below).

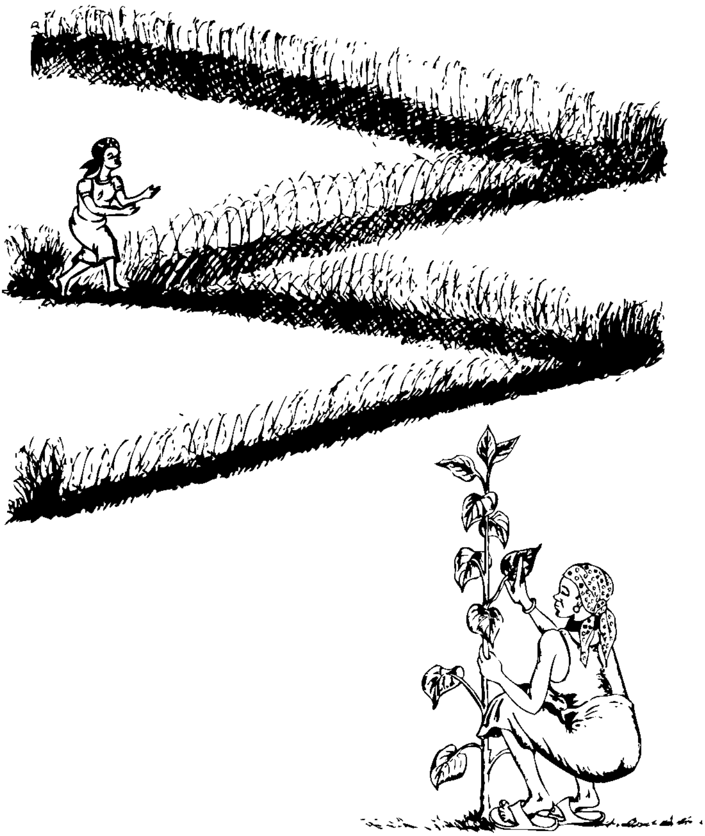


Figure 6: Inspection of a farmer's field for the presence of pests

Case 10: Who does the field observations?
Men and women often share the farm work, but not at the same time. Therefore it is important to work out who should do which observation. And it is important to share not only the work, but also the knowledge.

In Northern Ghana, field workers discussed germination of *Striga* and attachment to the host plant (see chapter 7) with a mixed group of men and women. The women are regularly in the field at this stage of crop development. Because they dig into the soil, they are able to observe the *Striga*-attachment. They distinguish two species of *Striga*. They used their hands to communicate this knowledge during a session of the group (see figure 7).

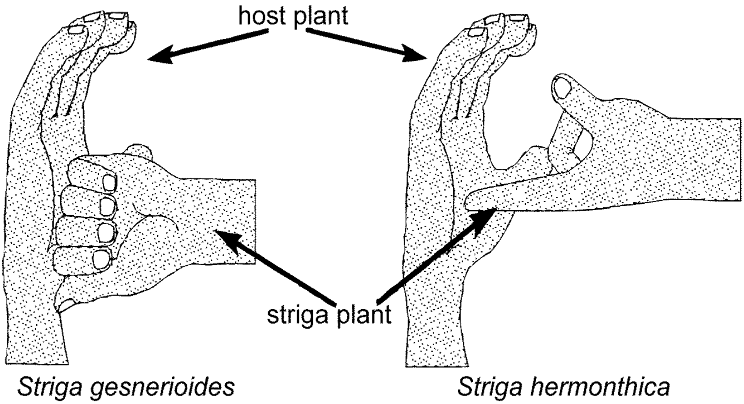


Figure 7: A Ghanaian farmer explains with her hands how two species of Striga differ (see case 10).

Every season you will have to evaluate how effective your total set of measures has been in controlling the key pests on your farm. For each crop and pest, look at what worked well and what could have worked better. Use your findings to adjust your plans for the coming season.

3 Making a farm less attractive to pests

Farming enterprises, especially large ones, often look monotonous, with large fields of the same crop. This uniformity makes it easier to perform various tasks in the fields, but it is also a major cause of the explosive growth of pest organisms. One large field of a single crop is a nearly inexhaustible source of food for pests. Often the same crop is cultivated year after year on the same field, and this enables soil-borne pathogens and certain weed species to multiply unchecked.

Small farms are usually more diverse, with various crops planted side-by-side in one field. Farmers have often developed their own methods to keep harmful pests, especially animals, away from their crops. These farms are also a lot less attractive to pests. So if you grow a variety of crops, then you already have a head start in pro-active pest management.

3.1 The role of biodiversity

One of the main pillars of pro-active pest management is making your farm less attractive to pests. A key requirement for this is that you create the greatest possible variety of plant and animal life above and below the ground. This variety of life forms is what scientists call biodiversity. Biodiversity severely hampers the growth of pests.

A number of measures you can take to improve the biodiversity on your farm are discussed in section 3.2. They affect not only one crop in one specific year, but all crops over many years. They do not target just one type of pest, but are effective for a broad range of animal pests, pathogens and weeds.

The main consequences of improving biodiversity are the following:

- Varied plant growth in and around the fields creates a favourable environment for the natural enemies of animal pests (insects and mites in particular). In many cases these natural enemies keep the pest populations from reaching a harmful level.

Case 11: Varied plant growth around crop fields is important for crop protection

Higher plants surrounding crop fields are important as windbreaks (figure 8). Live fences or other vegetation have several functions. They protect crops from large animals. They also shelter small animals that eat pest insects. An example from Sri Lanka is the Greater Coucal (figure 9), a bird which is or should be the farmer's best friend, because it eats a range of insects and snails.

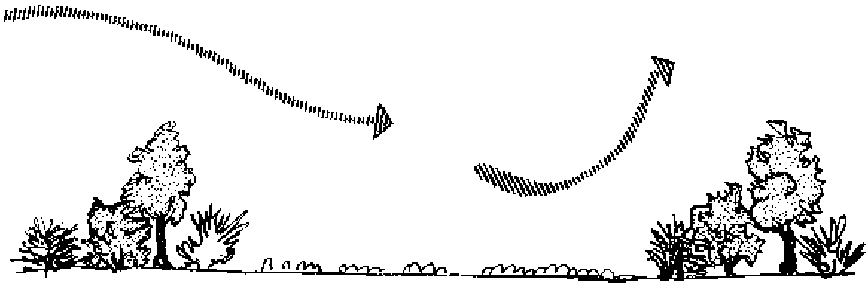


Figure 8: Higher plants surrounding crop fields are important as windbreaks (see case 11).

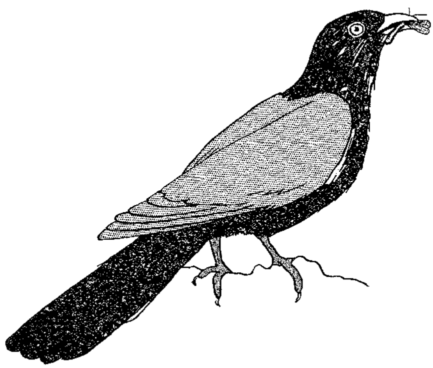


Figure 9: The Greater Coucal (Centropus sinensis) is an enemy of many pest insects and snails (see case 11).

- Varied plant growth in and around the fields limits the spread of pathogenic fungi, bacteria and viruses, but also the spread of insects and mites.
- Varied plant growth in the fields can provide faster-growing and more widespread ground cover, which prevents weeds from germinating and growing.
- Multiple crops, which are cultivated at the same time or in rotation, stimulate a rich and varied soil life. This helps control the growth of soil-borne pathogens and weeds.
- A varied soil life, created in part by varied plant growth, is also good for the soil structure. Good soil structure and balanced fertilisation ensure the optimal growth of crops that have a maximum resistance to diseases and animal pests and that can compete successfully with weeds.

The measures listed above not only help control pests, but often have other positive effects as well, which is all the more reason to implement them. Additional advantages can include the following:

- Ground cover crops protect the soil from rain and intense sunshine.
- Keeping the ground covered with plants prevents soil loss, or erosion, caused by heavy rains or strong winds. This is particularly important on hilly terrain.
- Combining leguminous crops with other crops allows both to profit from the nitrogen fixation of the leguminous crops. See in case 12 and figure 10 how maize and a legume can be grown together with optimal utilisation of sunlight.
- Combining a shallow-rooted crop with a deeper-rooted crop makes better use of the applied manure or fertilisers.
- A well-balanced crop rotation also ensures that the fertiliser applications incorporated in the planting schedule are optimally utilised.

Case 12: Innovation in traditional maize – legume intercropping

Farmers in Kenya have intercropped maize with beans for many years, as in the upper row of figure 10. Root nodules on the bean crop provide Nitrogen for both crops, and both crops suffer less from pest insects.

A problem of traditional systems is that the tall maize plants block out a lot of light, inhibiting the growth of the smaller legumes. The solution proved to be another arrangement of the two crops. You can see this in the lower row of figure 10. Instead of alternating single rows of maize and legumes, the two crops are planted in alternate double rows in the ‘Mbili’ (two) system.

Legumes that are used in this Mbili maize-legume intercropping system are common bean, mung bean, groundnut and soybean. The Mbili system also resulted in greater returns on fertiliser inputs and provides food security when the maize crop fails due to drought. The alternation of beans with other legumes instead of growing beans every year reduces the incidence of insect pests and diseases in the bean crops.

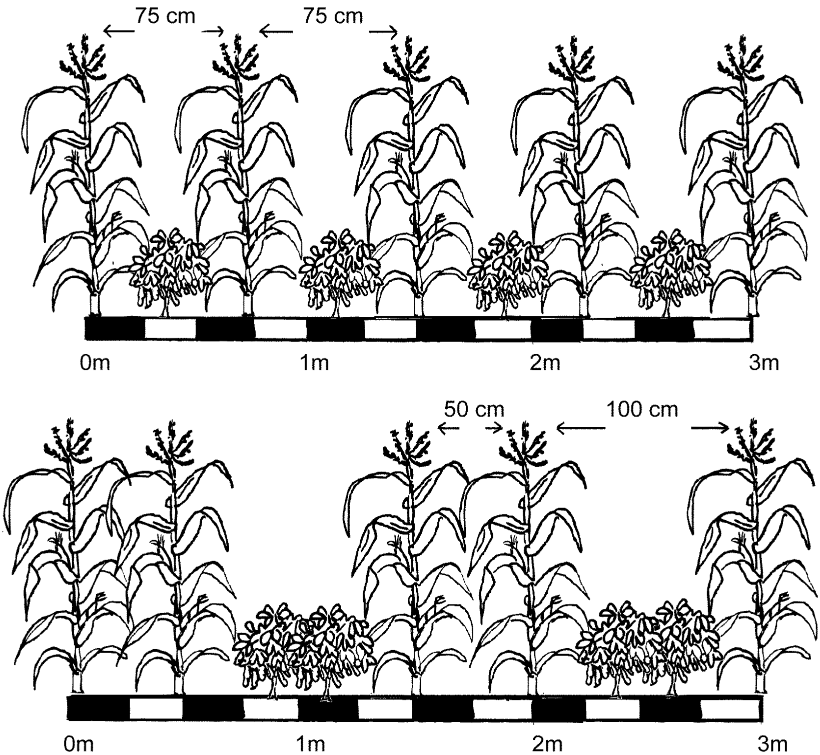


Figure 10: Growing maize and a legume together traditionally (upper row) and in a new way that makes better use of sunlight (lower row). For details, see case 12.

You won't need to implement all the measures that can improve the biodiversity on your farm, and certainly not all at the same time. You know yourself which pests are the biggest problem on your farm. If they are insects and mites, then the best thing is to stimulate their natural enemies. If they are pathogens that multiply above ground, then measures to control their spread will be most important. If they are soil-borne pathogens or soil-borne animal pests, then crop rotation is the most effective measure. Chapters 4, 5 and 6 will focus more on the effects of these measures on insects and mites, diseases, and weeds, respectively.

3.2 Improving biodiversity

Plant growth alongside fields and ditches

Vegetation borders along the edges of fields and ditches can serve to ward off pests arriving from elsewhere. A combination of tall-growing trees and bushes with an undergrowth of grasses and herbs is sufficient for this purpose. Since many pests are carried by the wind, it is particularly important to plant these borders along the edges of the fields that face the prevailing winds. Many natural enemies of insects depend for part of their life cycle on nectar and pollen. It is therefore also important to plant trees, bushes and herbs in your borders that are rich in flowers. Unfortunately, vegetation may also offer food and shelter for some crop pests, so you may need to adapt it to make it more attractive to the natural enemies and less attractive to pests.

It is best to use plant species that grow well under local conditions, because you can be sure that they will thrive. You may create a permanent border by using a mixture of grass seeds with annual and perennial herbs. You will probably have to maintain the border by cutting it once or twice a year for the first two to three years, primarily to suppress the growth of undesirable plants. Mow the border after the annuals have produced seeds. Do not fertilise the border because this will stimulate the growth of grasses, which will eventually take over. If you want to include annual herbs, or herbs that are not native to the area, you will have to weed them in the early growth stages, just as you do with your crops.

Cultivating multiple crops on one field

The simultaneous cultivation of two or more crops on one field is called intercropping or mixed cropping. Mixed cultivation enables you to make optimal use of the available space in the field, and also offers advantages for the prevention of pests. Unfortunately, it is often not done because it hampers the use of mechanical equipment.

There are three ways to cultivate two crops on one field:

- Companion planting is a system in which two or more crops are sown or planted together randomly in a bed or in a row;
- Row intercropping is a system in which individual rows of one crop are alternated with individual rows of another (The upper row in figure 10 is an example of row intercropping);
- In strip cropping a number of rows of one crop are alternated with a number of rows of another. (The lower row in figure 10 is an example of strip cropping).

In theory, companion planting produces the highest yield per square metre and the greatest benefits, as long as care is taken to ensure that the crops do not compete too much with each other. These benefits are somewhat less pronounced with the other two systems, but the crops are easier to manage and to weed. With strip cropping the two crops can be managed completely independently.

Case 13: The push-pull effect protects maize in Kenya from Stem borers and *Striga*

Stem borers (caterpillars of moths) are the major insect pests of cereal crops in eastern and southern Africa. Losses can reach as high as 80%, while those due to *Striga* range from 30 to 100% in most areas.

Researchers in Kenya found a way to grow maize together with two other crops. One attracts stem borers. This is the pull effect. The other intercrop repels the stem borers, causing the push effect. Together they effectively protect the maize crop from stem borers. In figure 11 you can see how the three crops are arranged in the field.

Both domestic and wild grasses can cause the pull effect. Napier grass is the most effective. It is planted in the border around the maize fields where invading adult moths are attracted to it. Instead of landing on the maize plants, the insects are attracted to what appears to be a tastier meal. Napier grass has a particularly clever way of defending itself against the pest onslaught: once attacked by a borer larva, it secretes a sticky substance that physically traps the pest and effectively limits its damage. And so the natural enemies lurking among the grasses go into action.

The legume *Desmodium* repels stem borer moths and 'pushes' them away from the main crop (maize or sorghum). *Desmodium* is planted in between the rows of maize or sorghum. Being a low-growing plant, it does not interfere with the crops' growth and has the further advantage of maintaining soil stability and improving soil fertility through nitrogen fixation. It also serves as a highly nutritious animal feed. Other legumes have this effect as well, but *Desmodium* also effectively suppresses *Striga*.

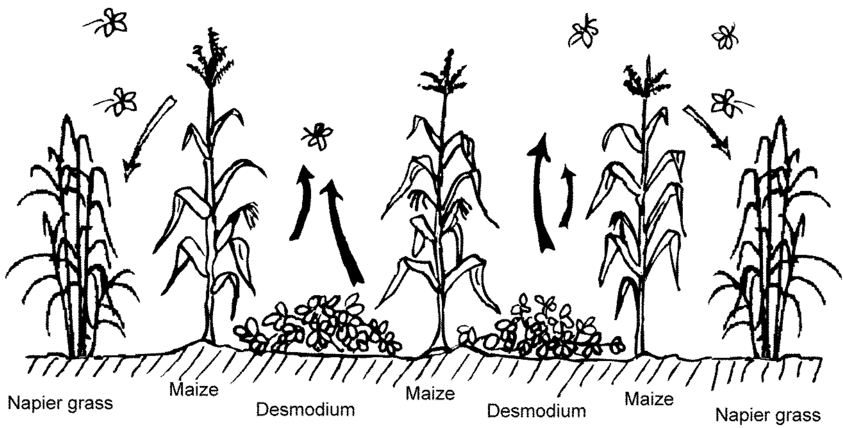


Figure 11: Intercropping maize with Napier grass and Desmodium to protect maize from stem borers. For details, see case 13.

Crop rotation

Crop rotation means that various crops are cultivated in successive planting seasons. Crop rotation is important for soil fertility, but also for controlling various pests such as soil-borne diseases and perennial weeds.

Ideally, you should rotate grain crops with vegetables and root crops. Be careful not to grow two crops from the same family (such as potato and tomato or celery and carrot) right after each other. It is possible, however, to grow a grain crop more frequently than others in a rotation, because soil-borne diseases do not thrive in grain crops. Of course your regular crops have to be taken into consideration when planning a rotation. If you need 70% of your land to grow cereals, the possibilities for crop rotation will be limited. In this case, you could try to plant the crops that are most readily affected by soil-borne diseases or by particular weeds on ‘new' ground every year.

Case 14: Organic farmers in Benin successfully grow cotton without pesticides

Cotton attracts a large number of insect pest species. That is why conventional cotton growing is associated with intensive spraying with insecticides. Benin cotton farmers, associated in the NGO OBEPAB (Organisation Béninoise pour la Promotion de l’Agriculture Biologique) have switched to a system of organic cotton production. They use no synthetic pesticides and no inorganic fertilisers. Another difference with conventional farming is that crop residues are recycled instead of burnt, to increase soil fertility. In most years they attain lower yields than 'conventional' cotton farmers. But for the year 2006 yield levels comparable to conventional cotton have been recorded. Additional advantages are that organic farmers don't need to buy pesticides, and they get a better price for their cotton.

The basis for organic cotton is a three year crop rotation. The cotton crop in the first year is fertilised with cottonseed press cake and is grown on ridges of decomposing crop residues on the contour line. The cotton crop is followed by grain (maize, millet, sorghum) and oil plants (peanuts, sesame or safflower). Other possibilities include spices and vegetables like chilli or onion. In the third year, pulses like pigeon pea, mung bean, chick pea and cowpea are grown. The following cotton crop (in year 4) profits from the Nitrogen provided. In longer periods between two growing seasons, the soil is not left bare, but cover crops are grown instead, to prevent soil erosion, to suppress weeds and to supply food and shelter for beneficial insects that control cotton pest insects. Popular cover crops include alfalfa, sweet clover, red clover, white clover, vetch, cowpea, buckwheat and mustard.

In addition, trap crops are grown on the edges of cotton fields. They attract pest insects from the cotton crop. Trap crops include sunflower, cowpea, alfalfa, okra and early sown cotton.

Crop growth and soil quality

The top 10-20 cm of the soil are the most important for crops. This top soil has a relatively loose structure, which makes it easier for plant roots to grow and provides them with air and water. Nutrients that the plant needs to grow are taken up through the water. The soil also contains many animals such as worms, and micro-organisms. Among other things, they are responsible for fertilising the soil by releasing the nutrients stored in plant residues and minerals. The soil is an important ally in pest management. Some of the soil micro-organisms and other natural enemies directly attack the pests. Besides, good soil quality ensures optimal plant growth, which maximises the plants' resistance to pest attacks.

The crops you cultivate have a big impact on soil quality. The roots hold on to the soil, thus protecting the soil from being washed away by heavy rains. Above-ground plant growth ensures that soil particles are not blown away by the wind. Above-ground plant growth or a ground cover made of mowed plants and plant residues (mulch) also protects the soil from becoming overheated by the sun and keeps it porous after heavy rains. These factors ensure that the growing conditions for the plant's roots and other soil life remain optimal.

Depending on local conditions, it may be necessary to take extra steps to protect the soil from water or wind erosion and to maintain the soil's structure and fertility. As noted above, these measures will ensure optimal crop growth, thus increasing the crop's resistance to pests. If it rains often and hard in your area, you may have to dig a system of water ditches to minimise surface runoff. This method of erosion control can best be carried out in collaboration with the village community.

- During the rainy season, make sure that the soil is covered as much as possible with plants or residue from the previous crop. If the main crop is still small and a lot of surface area is exposed, you can consider cultivating a second crop that is sown earlier or that covers the ground quicker.

- Add as many plant residues to the soil as possible. They improve the soil structure, soil life and soil fertility.

If you add extra nutrients in the form of a fertiliser, be careful not to add too much nitrogen (N), because it makes the crop grow too quickly and become less resistant to pests. Phosphate (P) and potassium (K), on the other hand, increase the crop's resistance to diseases. (See Agrodok 11 on *Erosion control* and Agrodok 2 on *Soil Fertility Management* for simple non-chemical techniques).

4 Insects and mites

4.1 The life cycle of insects and mites

Insects

Almost every insect starts its life as an egg, out of which comes a larva. The larva progresses through 3-6 development stages and grows a bit larger with each stage. The insect becomes an adult after the final larval stage. This change in appearance is called metamorphosis. In one group of insects, the adults look very much like the larvae. They are called insects with an incomplete metamorphosis. Their larvae are also called nymphs. Only the adults have wings and can reproduce. Brown Plant Hopper belongs to this group. We show its life cycle in figure 12, on the left. The nymphs (larvae) usually consume the same food. For instance, the nymphs and adults of Brown Plant Hopper both feed on rice plants.

Another group of insects goes through a complete metamorphosis; their larvae look a lot different from the adults. Their last larva stage is followed by a dormant stage, after which the adult crawls out of its pupa. On the right of figure 12 we show the life cycle of a lady beetle, which is an example of an insect with a complete metamorphosis. In the case of the lady beetle, both the larvae and the adult beetles eat insects. However, in most other cases, the larvae consume more and different food than the adults. Examples are cotton pink bollworm (case 5) and maize stem borer (case 13). In both these cases, only the larvae (caterpillars) are damaging to their host plant, while the adult moths feed on nectar and pollen.

Adult insects are responsible for the reproduction of the species. If they have wings, they can fly from field to field and spread the population over longer distances. Plant-eating insects normally lay their eggs directly on a host plant on which the larvae can feed. The larvae stay on this plant or on neighbouring plants. Predator insects like lady beetles lay their eggs on plants with many prey insects.

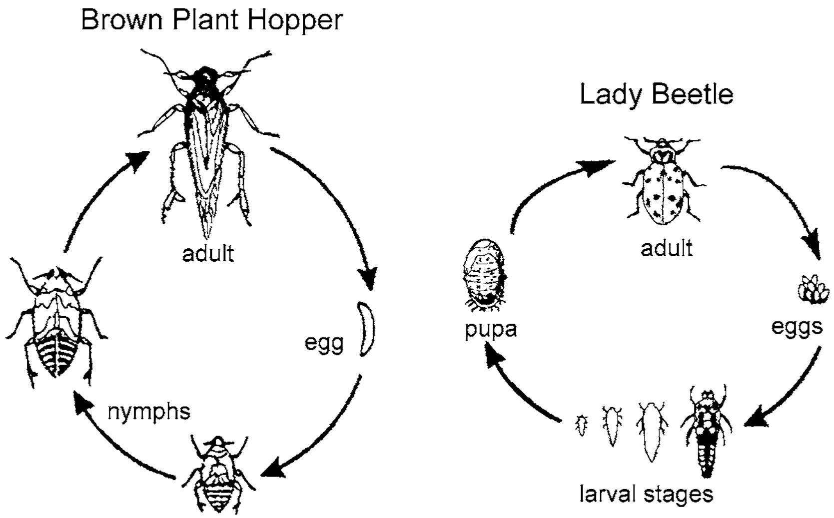


Figure 12: Life cycle of Brown Plant Hopper (left) and a lady beetle (right). Brown plant hopper is an insect with an incomplete metamorphosis; the lady beetle has a complete metamorphosis. For details, see text.

The mouthparts of insects are adapted to their food preferences. Plant-sucking insects have pointed mouthparts with which they can pierce the plant and suck its juice. Biting and chewing insects have hard jaws with which they can cut and grind their food. Some insects eat many species of plants, but most of the insects that harm crops are specialised for one plant species or just a few related ones. The form the insects take through the period between two crops when no food is available (whether it be as an adult, egg, larva or pupa) varies according to its species.

Mites

Mites are more closely related to spiders than to insects. They are smaller than 1 mm, so you would need a magnifying glass to see them. For a picture, see Figure 13. Just like insects, mites begin their life as an egg. They progress through several development stages before they become adults and can reproduce. A group of individuals on a plant often forms a kind of silk web to protect them.

Mites have mouthparts that are adapted to pierce individual plant cells and suck them dry. If there are many sucking spots next to each other, the leaf will lose colour and will often drop off prematurely. Seriously affected plants will remain small or may even die. Mites often survive the period between crops as eggs, but in some species they survive this period as adults.

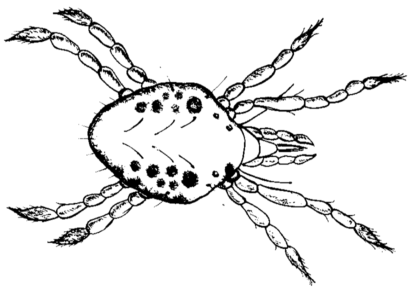


Figure 13: Mite (0.1 - 0.8 mm)

Mites do not have wings. They travel on the plant and between plants by walking. They can be carried over greater distances by the wind.

4.2 Prevention of damage

Promoting natural enemies

The natural enemies of crop-damaging insects and mites are also your allies. There are two groups of natural enemies: predators and parasites. Predators eat their prey. The most important predators are harmless to crops and people. Well-known predators include spiders, predatory mites, lady beetles, ground beetles and hoverflies. The advantage of these predators is that they can multiply just as rapidly as their prey.

The most common parasites are wasps and flies. They lay eggs in the pest insect’s larvae and their larvae then eat the host from the inside out. Predators eat many different species of insects or mites, but parasites are often specialised for one type of pest insect. As adults their diet consists entirely of pollen and nectar of (often wild) flowers.

If there is a sufficient number of natural enemies present at the start of the growing season, they will normally keep the pest insects and mites under an acceptable level, so that the crop can remain healthy. See in cases 3 and 7 how this is true for Brown Plant Hopper.

The farmer can take measures to help the natural enemies out a bit. Diverse vegetation around pieces of land offers shelter where they can survive between growing periods. You can stimulate their growth even more by sowing plenty of flowering herbs around and in the fields where your crops grow. You can also build additional housing for predator insects or parasites, as we demonstrate in case 15 and figure 14.

Case 15: Simple housing for predator wasps to provide shelter for their hatchlings

Predator wasps are present all over the world and they are particularly abundant in the tropics. They are very efficient predators, attacking a wide range of insects, but they especially target caterpillars to feed their offspring.

A novel technique has been developed in Vietnam, enhancing the control of the cotton leaf roller, *Sylepta derogata,* by trap-nesting wasps. Leaf roller is a major pest for cotton crops in Vietnam. These solitary wasps hunt caterpillars, and enclose them in their nest as living food reserve for their hatchlings.

The idea is to multiply nesting sites close to the fields where predatory wasps are needed. Artificial nesting devices vary in design, but the principle remains the same, as we have illustrated in figure 14. Cylinders of 6 to 12 mm diameter are plugged with mud at one end to enable wasps to build their nests. They can be made of bamboo, reeds, drilled wood board or even cardboard.

Several traps are then tied together in a sheet of plastic or metal and placed close by the fields. One efficient method is to hang them in small trees. It is important to put some kind of glue on the string in order to deter ants and termites that might damage the nests.

Besides being reliable and simple, this technique is also effective against leaf rollers. Assessments made in South Vietnam showed a trap colonisation rate of 30%, and an average of 570 caterpillars removed from the field per 100 nests installed.

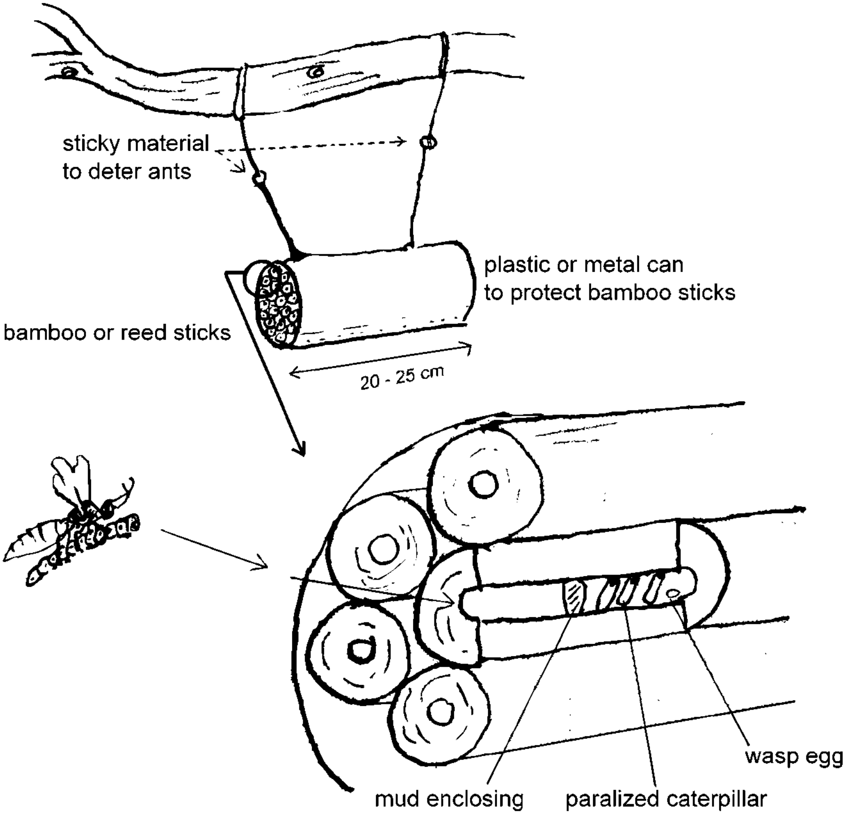


Figure 14: Man-made housing, providing shelter for predator wasps (see case 15).

Preventing the spread of pests

Vegetation in and around crops does more than just supply shelter for natural enemies. High vegetation around fields keeps flying insects away, as well as mites that are transported by the wind. A second crop in a field can also serve as a physical barrier, in addition to the advantages mentioned in Chapter 3.2. Rows of specific crops can deter or attract pest insects with their smell: these are known as repellent crops and trap crops. We have seen this before in case 13 and figure 11 in section 3.2

Crop rotation

In a crop rotation, you can alternate crops that are eaten by a certain pest with crops that are not eaten by that pest. Crop rotation is part of a multi-annual strategy to minimise the number of pest insects on a farm.

Short growing season

If you are mainly growing one crop, and crop rotation is not a viable option, it is especially important to extend the period between crops as long as possible. The number of pest insects will decrease during the crop-free period. You can also enhance this decline by working the plant residues containing the pest insects deep into the soil, or by bringing the pests to the surface where they are vulnerable to attack from their natural enemies. You can keep the growing season short by sowing or planting over as short a period as possible. The same is true for harvesting. It may also be better not to wait until the last plant can be harvested or the last fruit is ripe, because the longer you wait to harvest, the more surviving pest insects there will be when you plant the next crop.

Removing crop residues

If there are many pest insects left after harvesting the crop, it is better to remove the crop residues together with the pest insect than to leave the residue in the field. However, if there are relatively few pest insects present on the crop residues and many natural enemies, it may be useful to leave the crop residue in the field.

Fertilising

It is important that you fertilise in a balanced way, with enough P and K and not too much N. Too much N makes the crop appetizing for insects, and leads to a dense crop, in which it is more difficult for pest insects' natural enemies to find them.

4.3 Control

Even with all the preventive measures mentioned above, the number of pest insects could become too high and threaten to cause unacceptable damage to your crops. It is important to inspect the crops every week to see whether critical levels are being reached. Information on critical levels (such as the number of pests per square metre or per metre of a row) should be available for your area. As soon as the number of pest organisms is too high, you can consider taking corrective action.

Catching by hand

If their population is not large, relatively big insects can be caught by hand and squashed between your thumb and forefinger, or in another way.

Catching in traps

It is of course less labour intensive and less tedious to control these pests by luring them into traps. The most common types of traps either give off light to attract night insects, are made of yellow strips covered with glue, or contain some kind of bait.

Biological control with beneficial insects and micro-organisms

If it appears that the natural enemies of the pest insects and mites are staying in the margins of the field rather than moving into the centre, you can carry them by hand into the field. We present an elegant example in case 16 and figure 15.

Case 16: Vietnamese farmers help predator ants to conquer new territory

Weaver ants, *Oecophylla smaragdina*, build their nests in trees. From there they hunt insects. Vietnamese growers of citrus and other fruit trees know that trees with weaver ant nests are well protected against pest insects. The establishment of new weaver ant colonies is hampered by the presence of black ants, because weaver ants and black ants fight each other. Figure 15 shows how farmers can help weaver ants to establish new colonies.

Farmers lure Soldier weaver ants by putting a rope from a tree with nests to a container with food such as shrimps (a). The farmer then puts a bag over the container, carries it to a tree with black ants, climbs to the top of the tree and releases the weaver ant soldiers (b). When the soldier ants have defeated their enemies, the farmer collects a whole nest of weaver ants and attaches it to the newly conquered tree (c).

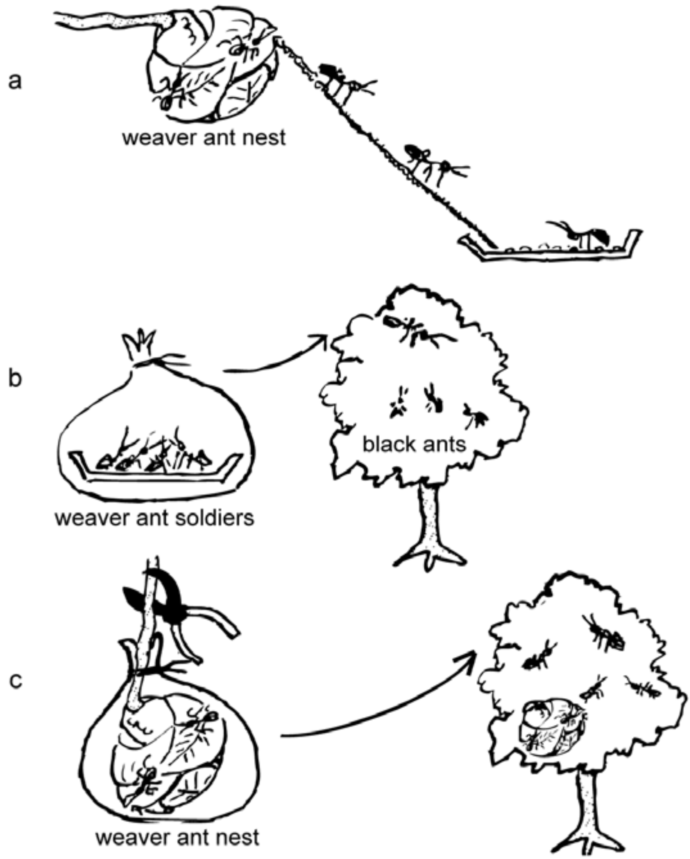


Figure 15: Farmers help weaver ants to establish new colonies

Sometimes natural enemies that are bred elsewhere are offered for sale. These can be predators or parasites, but also nematodes or disease-causing fungi, bacteria or viruses.

Nematodes are primarily used to combat soil insects. Viruses, bacteria and fungi are sprayed over the entire crop and work against the pest insects that are present on the plants. In case 17 we present an example how farmers can control a pest insect by introducing and enhancing the growth conditions of a disease-causing fungus.

Case 17: Farmers in The Philippines fight palm beetle with a disease

The Rhinoceros beetle, *Oryctes rhinoceros* is one of the most damaging insects to coconut and oil palm crops. After mating, the female lays her eggs in decaying organic materials like rotting stumps, compost and sawdust heaps. Farmers chop up such materials and bring them together in open boxes (about 0.5 m high). They then introduce the insect-killing fungus *Metarhizium anisopliae* into the boxes. As soon as the beetle's eggs hatch, they become infected by the fungus and subsequently die. It is a remarkably simple technique, and the fungus only has to be introduced once. The composting fibre that has been inoculated with infected larvae is the basis for establishing new boxes.

Control using plant extracts

Many plant species, both cultivated and wild, contain substances that can kill insects. You can easily make a spraying liquid out of these plants yourself. Plant extracts have both advantages and disadvantages compared to chemical pesticides. The most important advantages are:

- They are inexpensive.
- They decompose faster, so no residue is left on the crop.

Case 18: Farmers in Cameroon select plant extracts with insecticidal properties

Various non-chemical crop protection methods and products have been tested under local conditions in Cameroon. First, an inventory of traditional methods of pest control was conducted with small-scale farmers in the North-West, South-West and West provinces of Cameroon. Information was gathered from their answers and from literature, and a booklet was prepared for distribution. At the rural training centre, Mfonta, groups of farmers were trained in non-chemical crop protection methods for controlling pests on their own farms. The training methodology was based on a participatory approach and Farmer Field Schools. Farmer Field Schools are discussed in Chapter 7.

One of the promising preparations subjected to field-testing after this inventory was castor oil (*Ricinus communis*). The preparation is as follows: 0.5 kg shelled or 0.75 kg fresh unshelled seeds are mashed and then heated for 10 minutes in 2 litres of water. 2 teaspoons of kerosene and a bit of soap are added. The solution is sifted (through a cloth) and diluted with 10 litres of cold water. The preparation is then ready for application on the leaves, to control leaf-eating caterpillars, aphids and true bugs on vegetable crops.

Beware: Castor oil is poisonous for humans as well as for the natural enemies of pests.

Extracts from the Neem tree, *Azadirachta indica*, are also widely used. Neem extracts have an effect on nearly 400 species of insects, including major pests (moths, weevils, beetles and leaf miners). They do not kill insects directly, but effectively prevent their reproduction. Neem extracts can be prepared from leaves, but the seeds contain higher concentrations of insecticidal components. 75g of seeds (including the seed coat) should be used per litre of water. The seeds should be at least 3 months old but no older than 8-10 months. The pounded kernel powder is gathered in a muslin pouch and soaked overnight in water. The pouch is then squeezed and the extract is filtered. Some soap is added to the filtrate (1 ml per litre of water) to help the extract to stick to the leaf surface of crop plants.

Papaya leaves can also be used: Pick 1 kg of fresh leaves, shred and soak in 10 litres of water, add 2 teaspoons of kerosene and a bit of soap, and leave it overnight. Sift the decoction through a cloth, and the spray is ready for application on the leaves of vegetables, against leaf-eating caterpillars, aphids and true bugs.

The main disadvantages of plant extracts are:

- They often have a weaker effect than synthetic insecticides. This could mean that many insects survive or that the insects just become ill and then recover.
- The required dosage differs per insect species. Because you manufacture the spray yourself, you will have to determine the optimal dosage through experimentation.
- Some extracts (such as tobacco juice that contains nicotine) are very poisonous to humans and their pets. Just as with chemical pesticides, you have to handle these extracts with extreme care.
- Most plant extracts are toxic to natural predators or parasites of pest insects, so the ‘natural balance’ will be disturbed when using these bio-insecticides.

5 Diseases caused by micro-organisms

Some micro-organisms among the many fungi, bacteria and viruses can cause disease in plants. These micro-organisms are not visible with the naked eye. What you see with the naked eye is not the micro-organism itself, but the reaction of the plant to the micro-organisms.

In dealing with plant diseases, it is important to understand that a huge number of very small organisms (pathogens) are responsible for making a plant diseased and that they spread throughout the plant and from plant to plant. Once a plant is infected, it is nearly impossible to cure it. It may sometimes be possible to halt the disease, but only by removing the affected parts of the plant. It is much better to do everything in your power to prevent plants from becoming infected by these pathogens. Even though you cannot see the pathogens, it is important to realise that they are there so that you can understand how to prevent diseases effectively. We distinguish between two groups of diseases: those that spread above ground (air-borne diseases) and those that live at or below the soil surface (soil-borne diseases).

5.1 Air-borne diseases

Air-borne diseases are often not very noticeable, and may even be invisible early in the growing season, but they can become serious very quickly. This slow start has to do with the following three conditions, which all have to be met for a crop to become diseased:

1. The plant has to be susceptible, which means that it will react with disease symptoms once it is infected by a bacterium, fungus or virus.
2. There must be an infection source present that contains pathogens.
3. The conditions must be favourable for the disease to spread.

Susceptible plants

Every plant species can be affected by only a limited number of diseases caused by specific micro-organisms; no other micro-organisms cause plant diseases. Moreover, micro-organisms capable of making plants diseased can usually only do this to one species, a group of related species, or varieties of one species. Susceptibility of individuals within one species to a particular disease can also vary considerably – one may be highly susceptible while another is only mildly so.

Source of infection

At the start of the growing season, there are usually a few sources of infection present from which a disease can spread. Seed or planting material is often an important source of infection. The pathogens are located in or on the outer surface of seeds, tubers or other organs that are planted in the field. The plants that grow from these sources will be diseased rather than healthy. Crop residues from the previous growing season can also be a source of disease. A third possibility is that a disease survives the period between two crops on living crop plants or weeds that remain in the field after the harvest.

Conditions for the spread of diseases from plant to plant

A disease can be spread from one plant to another in a number of ways. Bacteria and some fungi can be spread over a small area of no more than half a metre through the splashing of raindrops. Other fungi can be carried by the wind over distances of up to hundreds of metres. Air-borne diseases that are transported by raindrops or wind can spread quickly within a crop during a long period of wet weather. A crop that is very susceptible to the disease can be completely destroyed in a short period of time.

Many diseases can also spread through a crop by means of plant juices. In this way, insects with piercing mouthparts can carry many viruses, but also bacteria and fungi. They suck up the juice of a diseased plant and then infect the next plant that they feed on. You can unwittingly become a carrier yourself if you come in contact with a diseased plant and then transfer the pathogens to the next healthy plants you come in contact with. Diseases that are transferred exclusively through plant juice are generally not very dependent on wet weather conditions.

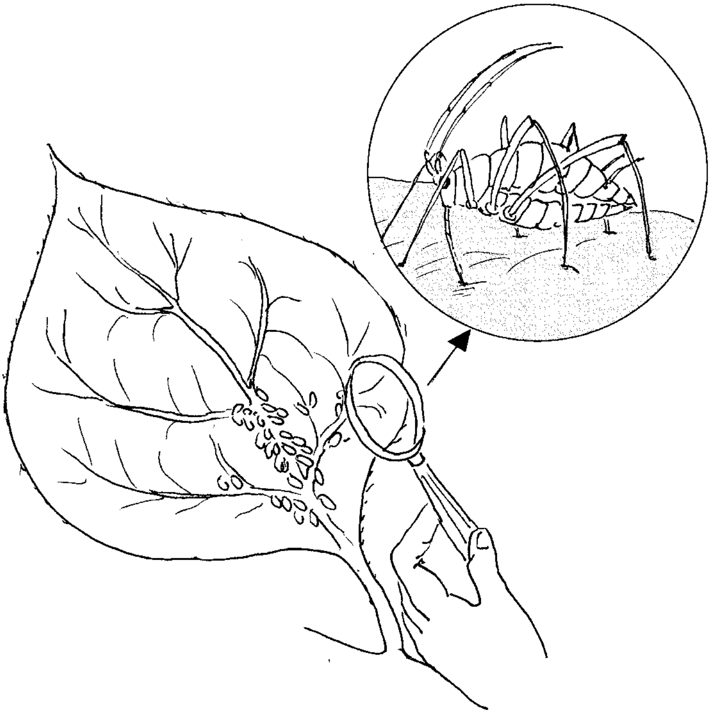


Figure 16: Diseases spread through plant juices carried by lice

5.2 Prevention of air-borne diseases

In the previous section we said that air-borne diseases can develop if three conditions are met simultaneously: the presence of a susceptible plant, pathogens and favourable conditions. To prevent these diseases you have to ensure that at least one of these conditions is not met. In this section we discuss the possibilities for doing this (1) by increasing crop resistance, (2) by decreasing the number of infection sources, and (3) by influencing external conditions.

(1) Crop resistance

Cultivation of resistant crop varieties

The crop varieties cultivated nowadays often produce a higher yield than traditional varieties. This is because all the plants have the same genetic characteristics that lead to higher yields.

Unfortunately, all the plants are usually also uniformly susceptible to diseases. Through selective breeding, new varieties can be created that produce a higher yield and are resistant to a certain disease. In practice, however, we often see that the pathogen then adapts itself and can make the new variety diseased as well, which necessitates the creation of another new resistant variety. The farmer is then forced to regularly buy seed or planting material of new varieties in order to continue to grow healthy plants.

Cultivation of varietal mixtures that are not uniformly susceptible

Traditionally cultivated indigenous crops are not usually uniformly susceptible to diseases. There are two advantages to simultaneously cultivating varieties that have varying resistance characteristics. Firstly, individual plants that are moderately or highly resistant will develop few or no disease symptoms. Secondly, just like plants from an entirely different species, they will catch spores spread from diseased plants, thus keeping them away from more susceptible plants. We present an example of this principle in case 19. The other advantage of this method is that new strains of the pathogen do not arise as quickly. It also makes it possible for you to select your own seed and planting material rather than having to buy them regularly. If you collect your own seeding seed, it is important to collect it only from healthy plants.

Case 19: Asian farmers prevent rice blast by several preventive measures

Rice blast is a plant disease caused by the fungus *Pyricularia grisea*. The fungus kills plant tissue. This is visible as darkened spots and stripes on leaves and flowers. Under humid conditions it can be very destructive and cause great losses in crop yield.

Chinese farmers have rice varieties that are resistant to rice blast, but these varieties are not much appreciated by local consumers. They value the local 'sticky' rice much higher. However, 'sticky' rice is very susceptible to rice blast. Farmers protect the susceptible rice by surrounding each row by 4 rows of a resistant variety. In this way, the disease develops much slower, and farmers are able to produce enough sticky rice for the local market without using fungicide or with one application at the most.

Vietnamese farmers also suffer great yield losses caused by rice blast. Farmers who participated in Farmer Field Schools learned how the disease develops and how to manage it without using fungicides. (We explain Farmer Field Schools further in Chapter 7.) The best solution to protect their rice crops is a combination of resistant varieties with lower seeding rates and less Nitrogen fertilisation. These practices slow down the development of the disease within the crop field.

(2) Reducing sources of infection

- Make sure you use healthy seed and planting material. This is always important, because diseases arising through infected seed and planting material will develop early in the season and can cause considerable damage by the end of the season. The best method is to select seed and planting material from fields with few diseased plants or fields from which diseased plants have been carefully removed.
- Remove crop residues. This is especially important for highly contagious pathogens that are known to cause infections early in the season through crop residues.
- Continue to remove diseased plant parts as long as the level of disease is still low.
- Keep levels of insects or other animals that carry a disease at low levels. An insect or animal that can carry a disease from one plant to another is called a vector. We give an example in Case 20.

Case 20: Farmers in Sudan prevent virus infection in tomato by repelling the carrier insect

Tomato Yellow Leaf Curl virus has many host plants, but it is particularly damaging for young tomato. Infected plants become severely stunted and produce small, distorted leaves. They do not produce marketable fruit. The disease is transmitted from one plant to another by the whitefly, *Bemisia tabaci*. The disease can be kept within limits by controlling the whitefly.

In Sudan, not many farmers use insecticides. Instead they plant coriander as a companion crop with tomato. Coriander acts as a repellent; it keeps the whitefly away from the tomato plants. Tomato yields are even higher than those achieved using insecticides.

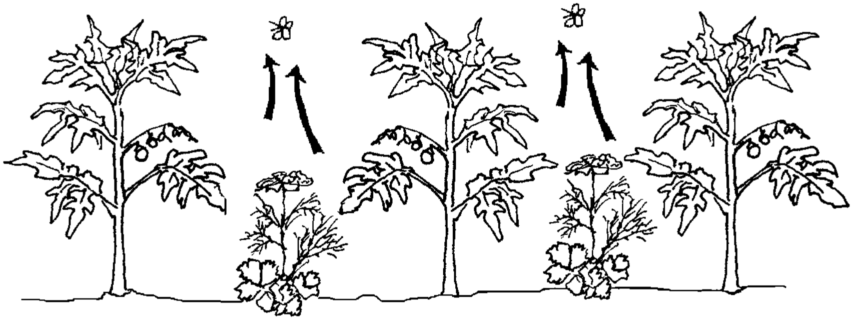


Figure 17: Coriander acts as a repellent: it keeps the whitefly away from tomato plants (see case 20).

(3) Influencing external conditions

- Good soil quality ensures optimal crop growth. Good drainage and soil structure play an important role in this. A crop that is growing optimally is less susceptible to many pathogens.
- Balanced fertilisation (not too much N, and sufficient P and K) fulfils two objectives. It ensures that the crop plants are more resistant to disease and that leafy crops do not become too dense.
- You can also create a less dense crop with fewer plants per square meter. The humidity of the air in a dense crop is often high, which promotes the development of diseases.
- Vegetation around a field protects the crop from fungi spores carried by the wind and from flying insects that spread viruses. The higher the vegetation is, the more effective this barrier will be.
- A second crop cultivated in the field (mixed cropping) is even more effective than vegetation planted around the field in catching fungal spores from the air.

5.3 Soil-borne diseases

Soil-borne diseases penetrate plant roots or the base of the plant's stem. By remaining in the soil, they survive the period when there are no susceptible crops in the field. Not many pathogens are capable of doing this. Most soils contain various small animals, but also many micro-organisms that are in a constant life or death struggle with each other. Soil-borne diseases have special inactive (dormant) forms, which allow them to survive in this hostile environment. These dormant forms can become active and penetrate the roots of susceptible plants in their direct environment as soon as they start to grow.

Depending on the disease, the resulting symptoms can include death of seedlings (damping off), root rot, wilting and death of the entire plant. New dormant forms are produced on the diseased plants and these eventually reach the soil.

Soil-borne diseases spread slowly over a field. At first the disease remains limited to individual plants or to small areas of affected plants in a field. These areas grow only slightly larger as the growing season progresses. However, if the same crop, or another susceptible crop, is cultivated on the same field in subsequent years, the number of pathogens will increase each year or crop season. The number of diseased plants will also increase. You may inadvertently speed up the spread of the disease yourself by carrying around soil particles and plant material.

5.4 Prevention of soil-borne diseases

Soil-borne diseases are much less influenced by humid weather conditions than air-borne diseases. The emphasis in preventing these diseases is largely on cultivating crops that are not (or are only slightly) susceptible to them. There are two advantages to cultivating resistant crops: The resistant crop stays healthy despite the presence of pathogens in the soil, and the number of pathogens in the soil will decrease while the resistant crops are growing. So a more susceptible species can be planted again after one or two growing seasons.

Applying more crops in a rotation

Soil-borne diseases become more serious if you cultivate a susceptible crop or related varieties on the same field in consecutive seasons. The more often you include resistant crops in a crop rotation, the faster the number of pathogens in the soil will decrease and the less chance there will be for diseases to develop. Bacterial wilt (case 21) is a typical example of a soil-borne disease for which crop rotation is an important component of disease prevention.

Case 21: Managing Bacterial Wilt of potato and tomato

Bacterial Wilt is a soil-borne disease caused by *Ralstonia solanacearum* (formerly called *Pseudomonas solanacearum*). It attacks a broad range of plant species, and is particularly damaging to tomato and potato. On tomato, the first symptoms are a sudden wilt of the youngest leaves (as shown in figure 2) and a slight yellowing of older leaves. As the disease progresses, the plants wilt permanently and die. To confirm that the disease is Bacterial Wilt, farmers cut a piece of stem 2-3 cm long from the base, and put it in clear water in a glass container. Within a few minutes, smoke-like milky threads exude from the cut stem (see Figure 18).

Resistant varieties of tomato and potato are not common. Resistant varieties that also have a good food quality are not available at all. Therefore, Bacterial Wilt is difficult to eradicate, but farmers in Asia and South America have found ways to suppress it. Crop rotation is one of the most effective measures for managing this disease. Rotation of tomato or potato with at least two (and preferably three) non-susceptible crops is recommended. Thereafter, if available, a tolerant or moderately resistant variety of potato or tomato should be planted. Avoid crops of the same family as tomato and potato, such as eggplant, pepper and tobacco. Also avoid banana, ginger and groundnut. Suitable crops to rotate with tomato or potato are: pastures or cereals; onion, garlic, leek; cauliflower, broccoli, mustard and other members of the cabbage family; most legumes, including pea and bean, but not groundnuts; pumpkin, cucumber, zucchini.

Because Bacterial Wilt is easily carried over from field to field and from one season to the next one, additional care should be taken to prevent the disease from spreading:

- During harvest and prior to rotating, harvest remains must be removed and buried outside the plot far from irrigation channels.
- During crop rotation, removing weeds and volunteer plants of tomato and potato is important.

- Likewise, irrigation or rainfall water flow from an infested field into neighbouring fields must be prevented. For this purpose, drainage ditches can be built.
- Tools, shoes and animal hooves must be cleaned.

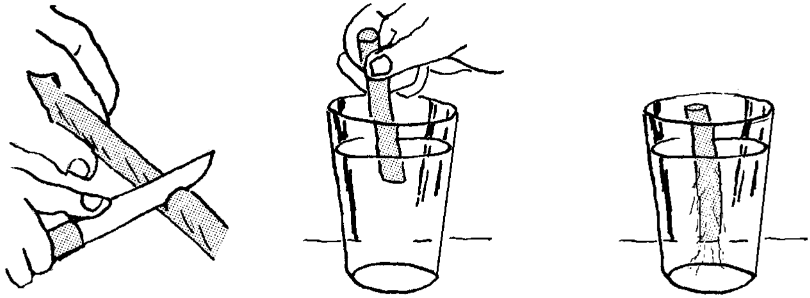


Figure 18: A method to detect Bacterial Wilt in the field. For details, see Case 21

Cultivating resistant varieties

Less resistant varieties do not become diseased as often as varieties that are highly susceptible. They also slow down the growth of the disease in the soil or even reduce its level. One alternative is to graft a susceptible variety to a resistant root system.

Healthy seed and planting material

If a disease is already present in the soil, it will not make much difference if a small number of the same pathogens are added through seed or planting material. Using only healthy seed and planting material is still important, however, in order to prevent the disease from spreading to clean fields.

Biological control of seeds and planting material

Seed and planting material can be protected by treating them on the outside with a bacterial or fungal preparation. The fungi or bacteria produce substances that protect the plant against soil-borne diseases in its seedling stage. We give an example in Case 22, where a fungus is added to planting material or directly to the soil.

Case 22: Trichoderma fungus helps to control soil borne diseases in Cuba

Trichoderma is present all over the world in the soil and decomposing plant material. It does not attack and kill living plants. In fact it is beneficial for farmers. It helps to decompose organic matter, releasing fertiliser for the crops. It also protects crop plants from soil-borne diseases and animals that attack plant roots. It does so by living close to plant roots, where it attacks – or strangles – these crop pests. It also produces chemicals (antibiotics) that are toxic to other micro-organisms.

Trichoderma is not just one strain or one species. In fact it consists of many strains, and each one is more or less adapted to certain temperatures or a certain task, such as protecting plants from disease or decomposing dead plants.

In Cuba, some strains of *Trichoderma* with good properties are selected. They are then grown in large quantities in tanks in a laboratory. Farmers spray the fungus directly on the soil where crops have been planted. Sometimes, they mix it with manure, compost or other organic fertiliser.

Trichoderma is used in several other countries besides Cuba. In most cases, selected strains are grown in tanks and distributed to farmers.

This case study shows that naturally occurring fungi can be a great help in controlling diseases. For most farmers, no *Trichoderma* from the lab is available. But they can experiment with their own *Trichoderma* from a well-decomposed compost heap. They can put the compost directly onto the soil or they can put it in water for some hours and spray the water on the soil containing a disease.

Improving the soil structure

If you take steps to ensure that the soil structure is good, your crops will be more resistant to diseases. This also stimulates the soil life so that the pathogens' natural enemies will have a better chance of controlling them.

Solarisation

Solarisation is labour intensive, so it is only useful for small cultivation areas such as in nurseries. The ground is loosened to a depth of 15-25 cm (the entire top soil), well watered and covered with plastic sheets. Heat from the sun warms the top layer of soil up to a temperature at which most organisms will die. This method works against disease-causing bacteria and fungi, and also against weeds.

6 Weeds

6.1 Life cycle and effects

Before or during the sowing or planting of a crop, you often prepare a sowing bed by loosening the top layer of soil and removing plant growth. This creates the right conditions for the crop to germinate and grow. These conditions are also ideal, however, for the germination and growth of weeds. Weeds compete with the crop, because they share the same space and make use of the same light, nutrients and water. This competition leads to stunted crop growth. Weeds can also be harmful because they host diseases and animal pests that threaten the crop. Like pathogens, some parasitic weeds, including *Striga*, infect the crop's roots and extract water, nutrients and sugars from them.

Weeds can be annual or perennial plants. Annual weeds (such as Barnyard grass, *Echinochloa crus-galli*: figure 19 on the right) produce seeds within one year and then die. They are well adapted to survive in unstable conditions, such as on a field used for the cultivation of annual crops whose soil is therefore tilled more often. Annual weeds multiply exclusively by means of their seeds, and almost all of the seeds fall directly on the ground around the mother plant. The seeds of a few species have appendages, which allow them to adhere to the fur of animals or get carried by the wind over distances of hundreds of metres. Ripe seeds that fall from the plant do not germinate immediately, but lay dormant for at least a few weeks. Following this dormant period, and if the conditions are favourable, they will germinate. Germination almost always takes place in the top 2 cm of the soil. After the sowing bed is prepared, a large percentage of the weed seeds present in the soil will germinate.

Perennial weeds also produce seeds, but usually far fewer than annual species. An example of a perennial weed is Cogon grass (*Imperata cylindrica*), shown in figure 19 on the left side. Perennial weeds survive the dry season by storing food in vegetative organs, such as roots, rhizomes, tubers or bulbs. This food is produced in the above-ground shoots in the rainy season. They can continue to survive for quite a while even after these shoots have been removed. New shoots will emerge from these organs at the beginning of the new growing season. Because of their food reserves, these plants usually grow more vigorously than annual plants. They can even sprout new shoots from depths of 10-20 cm. Once they have sprouted, these young shoots also grow faster than annual plants in their seedling stage.

Figure 19: Cogon grass (a perennial weed) and Barnyard grass (an annual weed): see the text for more details.

If you do not take any measures to control weeds, the crop and weeds will (at best) mature together. The weeds will always grow at the expense of the crop, however, so the crop's yield at the end of the growing season will be reduced. Another possibility is that the weeds completely overgrow the crop plants at the start of the season, thereby destroying the entire crop.

6.2 Control

In practice, you will almost always have to remove most of the weeds at an early stage to prevent serious damage. Non-chemical weed control is labour intensive but necessary. Preventive measures are intended to ensure that less manual labour will be required to control weeds later for the same crop or for subsequent crops.

The most important non-chemical weed control method on small farms is pulling the weeds out by hand or cutting them off using simple hand tools (for examples, see Case 23 and figure 20). You can only use tools if there is enough space between the crop plants. Once the crop is planted, it is important to disturb the soil as little as possible when pulling and cutting weeds. Most of the germinated weed seeds are located in the uppermost layer of soil; if deeper soil is brought closer to the surface the as yet ungerminated seeds located there will also be given the opportunity to germinate.

Case 23: Human-powered weeding equipment

Different tools are available for different tasks. Here we present 4 groups of hand tools.

- The cutlass or machete is used to slash or cut off aboveground parts of tall weeds.
- Digging hoes are well suited to soil cultivation and ridging; they are less suited to weeding because they stimulate weed germination.
- Pushing and pulling hoes are useful for cutting the weeds just under the soil surface. They are less suited to harder soils.
- Wheeled hoes can only be used in row-planted crops. They can come with a range of attachments.

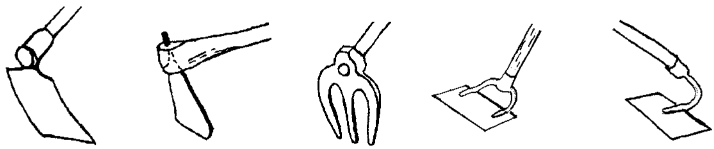


Figure 20: From left to right: 3 digging hoes, a pushing hoe and a pulling hoe

You will have to continue weed control until the crop's canopy closes. The resulting lack of light will prevent many annual weed species from germinating. Some species will still be able to germinate, but the plants will remain small and will not be strong enough to compete with the crop.

It is more difficult to control perennial weeds than annual species. After the shoots have been pulled out or cut off, the plant can sprout again from the same source, or reproductive organs at greater depths will begin to sprout. These plants will have to be controlled a number of times per season until their reproductive organs are exhausted and they are no longer able to sprout.

6.3 Prevention

Preventive measures will never be enough to keep a crop completely free of weeds. It is possible, however, to reduce the time required to control weeds in the crop. Some measures are directed toward all plants that can potentially cause problems, and others specifically target one or more species that often cause problems. In either case, four general principles should be applied:

- Exhaust the seed supply of annuals and the remaining organs of perennial species present in the soil.
- Prevent new weed seed supplies from entering the soil.
- Minimise the space available for weeds to germinate and grow.
- Plant crops in a way that makes it easier to use weed control equipment.

In case 24 we show an example from Mexico of how several weed prevention methods can be combined.

Exhausting the weed supply

Provide shelter for seed-eating animals

Vegetation around fields offers shelter to seed-eating mammals, birds and insects. Growing more than one crop on the same field at the same time will also increase the population of seed-eating animals. The effects on later weed growth vary and cannot be accurately predicted.

Improving biodiversity of the soil

If measures are taken to improve biological activity in the soil (see Chapter 3) more seeds will be eaten by soil-dwelling animals and killed by micro-organisms.

Ploughing

The topsoil of fields that are planted or sown with a new crop without first being ploughed is always rich in weed seeds. Mixing the upper layer of soil with deeper soil reduces the number of seeds that can germinate. A ploughing method that turns the entire upper layer of soil and replaces it with deeper soil is therefore the most effective way of combating annual weeds. The weed seeds will of course be brought back up to the surface in the following season, but their number will be significantly reduced by then through natural dying off, consumption by animals and damage by micro-organisms.

False seedbed

If the crop is sown directly after preparing the sowing bed by loosening the top few centimetres of soil, the weeds will start to grow before or at the same time as the crop. An alternative is to make a false seedbed, by preparing the soil but not sowing the crop right away. Most of the weed seeds located in the upper layer of soil will germinate and can then be removed with a hoe. If enough time is available, this process can be repeated before the crop is actually sown.

Crop rotation

A well thought-out crop rotation ensures not only that the existing weed seed supplies are exhausted, but also that fewer seeds are added to the soil. It is best to alternate between crops that quickly develop a closed canopy and crops that can be hoed for a longer period of time. If perennial weeds are increasing in spite of your control measures, crop rotation is one of the few options available for reducing the number of weed plants.

Case 24: How Mexican vegetable growers win the war against weeds

Simultaneous cultivation of a variety of vegetable crops is an ancient agricultural practice in Mexico. Farmers use flattened cardboard to cover the bare soil between crop plots, In the crop plots they remove weeds by hand and with simple tools for digging. Once the crop canopy is closed, its shade slows or stops the growth of weeds.

When temperatures become too high in summer for vegetable growth, they clear the plots of vegetation. Then they stretch out pieces of used plastic on the soil to facilitate solarisation. Black plastic is ideal, but any waste plastic works. Adding moisture to the solarised area allows weeds to germinate; these will then perish in the scorching temperatures under the plastic.

As the temperature cools down, faba beans are planted. This cover crop allows remaining weed seeds to germinate. The crop becomes so dense that weed plants remain very small and do not produce new seeds. The beans are harvested and consumed locally. The plants are allowed to grow until early spring, when they are cut down and allowed to decay, providing nutrients for subsequent vegetable crops.

Keeping the weed supply down

Preventing the production of seeds and other reproductive organs

During the growing season, a certain number of weeds can grow without seriously harming the crop. It is advisable, however, to do as much as possible to prevent these weeds from producing seeds or other reproductive organs. This is especially true for species that often cause problems for other crops.

After a crop has been harvested, there may be a period during which plant growth is possible but no other crop is being cultivated on that field. You can take advantage of this fallow period to control perennial weeds – and of course you can control annuals at the same time to prevent them from producing seeds. You could also choose to plant an extra crop that quickly covers the ground. This ground cover will suppress the growth and production of the weeds' reproductive organs.

Weed-free seed and planting material

Cleaning seeds and planting material to ensure that they are free of weeds is an important part of farming hygiene, especially because seed can be highly contaminated with weed seeds. Even though the number of weed seeds is usually small compared to what is already present in the soil, thorough cleaning of the seed is still important. Remember that most of the weed seeds in the seed come from species that are optimally adapted to cultivation of that crop. If the seed comes from elsewhere, it may also introduce new weed species onto the farm that you are not familiar with. In case 25 we give an example of how not only seeds but also young plants from a nursery can be contaminated with weeds.

Case 25: Benefit of cleaning crop seeds and nursery plants in the Philippines

Barnyard grass (*Echinochloa crus-galli*) is a serious problem in rice and other cereal crops. This grass weed competes for light with the crop. It also prevents rice plants from tillering, which is the production of new shoots from the stem base. In the early growth stages, Barnyard grass is often mistaken for rice. It may even be transplanted together with young rice plants. To remove Barnyard grass from rice nurseries you need to learn the differences between a rice plant and a Barnyard grass plant. A rice leaf has a pronounced ligule, which is a thin outgrowth at the junction of leaf and leaf stalk. It also has small but pronounced auricles, which are ear-like outgrowths at the junction of the leaf blade and the leaf sheath. Barnyard grass has neither ligule nor auricles, as you can see in figure 21. Furthermore, a Barnyard grass leaf has a smooth blade whereas that of rice is toothed and can be as sharp as a razor.

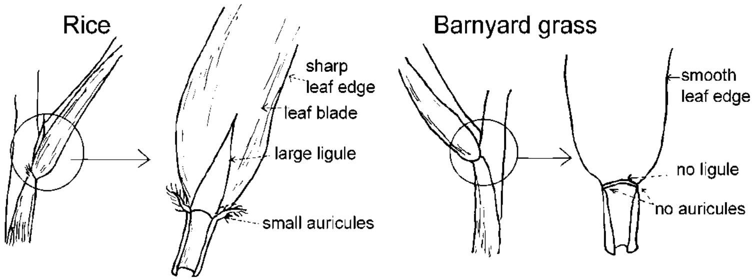


Figure 21: Leaves of Rice (left) and Barnyard grass (right)

Limiting growth possibilities for weeds

Living ground covers and mulch

If a crop with a lot of space between the plants is cultivated together with a second crop (mixed cropping), then the ground will be covered more quickly, and less effort will be needed to control weeds. Another possibility is to combine a tall-growing crop with one that remains much lower. The second crop's growth will be stunted at first, but as soon as the first crop begins to ripen or is harvested, leaving more space for weed growth, the second crop will begin to suppress the weeds. Plant residues, used as mulch, can also be used to cover the soil and prevent weed growth.

Creating and exploiting an advantage for the crop

We present two examples in case 26 and case 27.

Case 26: Means to suppress the growth of Barnyard grass in rice in The Phillipines

Rice roots contain air pores through which oxygen can diffuse to the roots. Through this capacity, it can grow under anaerobic, muddy and flooded conditions. The roots of Barnyard grass lack this characteristic. So transplanting Rice into a well prepared muddy or flooded field prevents the development of an abundant weed population. In direct seeding, rice is given an advantage by using pre-germinated seed.

Many farmers grow Rice by direct seeding. To give the crop a competitive advantage over the weed, they can use pre-germinated rice seeds. They can also increase the seeding rate. In the Philippines, this would mean increasing the seed rate by 50%. A third option is to place fertiliser below the rice seeds, so that the crop benefits from it more than the weed does.

Case 27: *Striga* management in Cameroon

In sub-Saharan Africa, rainfall is often growth-limiting. For that reason, farmers apply a system of double ridging to grow their cereal and legume crops. They make ridges with the top few centimetres of the soil, which contains most of the *Striga* seeds. Then they sow the cereal and legume crop below the ridge, where the moisture conditions are much better than on the top. As a consequence, most of the *Striga* seeds do not germinate or attach themselves to the crop roots.

Fertilising
If the soil is not well fertilised, the crop's canopy will not close and the crop will be very susceptible to weeds for a long time. If a crop is grown in rows, fertiliser can be applied exclusively to the crop rows, so that only the crop benefits from it.

Making it easier to use weeding tools

Planting pattern and plant distance
Through experimentation, experts have determined the optimal distance between the plants of every crop in order to maximise yield. However, for weed control, it may be desirable to adjust this distance slightly. Crops that are distributed uniformly over a field can be sown a little closer together so that weeds will have less chance to germinate. If this does not suppress weed growth enough, the crop can also be sown in rows with small spaces between the plants in a row and larger spaces between the rows. This makes it possible to remove the weeds between the rows with a hoe or other tool.

7 Life cycle of *Striga* and options for control

7.1 Introduction

Striga is an enormous problem in cereal and grain legume production throughout Africa and South-Asia. The estimated average yield reduction due to Striga is about 40%, and on infested fields, complete crop loss can occur. *Striga*, also known as Witchweed, is a common name for a family of plants that parasitize on the roots of cereals and grain legumes and survive at the expense of the crop to which they are attached.

7.2 Life cycle

In figure 22 you see the life cycle of *Striga*. (The letters in the explanation below refer to the letters in the figure).

A. Conditioning: *Striga* needs to be preconditioned through favourable climatic conditions, brought about by the start of the rainy season. Under unfavourable conditions it does not germinate.
B. Germination: *Striga* only germinates in the presence of, in particular, young seedling plants of a crop.
C. Attachment and Penetration: *Striga* attaches itself to the roots of the crop with specific parasitic roots (haustoria). It feeds on the water and nutrients of the host crop, which therefore shows symptoms similar to those of a viral disease and severe water stress.
D. Underground development: In the next phase of its life cycle, *Striga* grows underground, and its presence can only be determined by uprooting the plants with the symptoms mentioned under C. The haustoria easily become detached, so even when the crop is uprooted, the presence of *Striga* may go unnoticed.
E. Emergence: Reddish *Striga* plants surround the crop. They have no roots and poorly developed leaves, demonstrating that the parasite de-

pends totally on the host plant for its survival. The crop generally remains small and weak.

F. Flowering: The prevailing *Striga* species produce pink or purplish flowers.

G. Seed production: One *Striga* plant produces many very small seeds, often over 10,000, and sometimes up to 500,000.

H. Seed bank: Because of the enormous number of seeds produced by *Striga*, the top soil contains a tremendous stock of *Striga* seeds, waiting for the next cropping cycle to start.

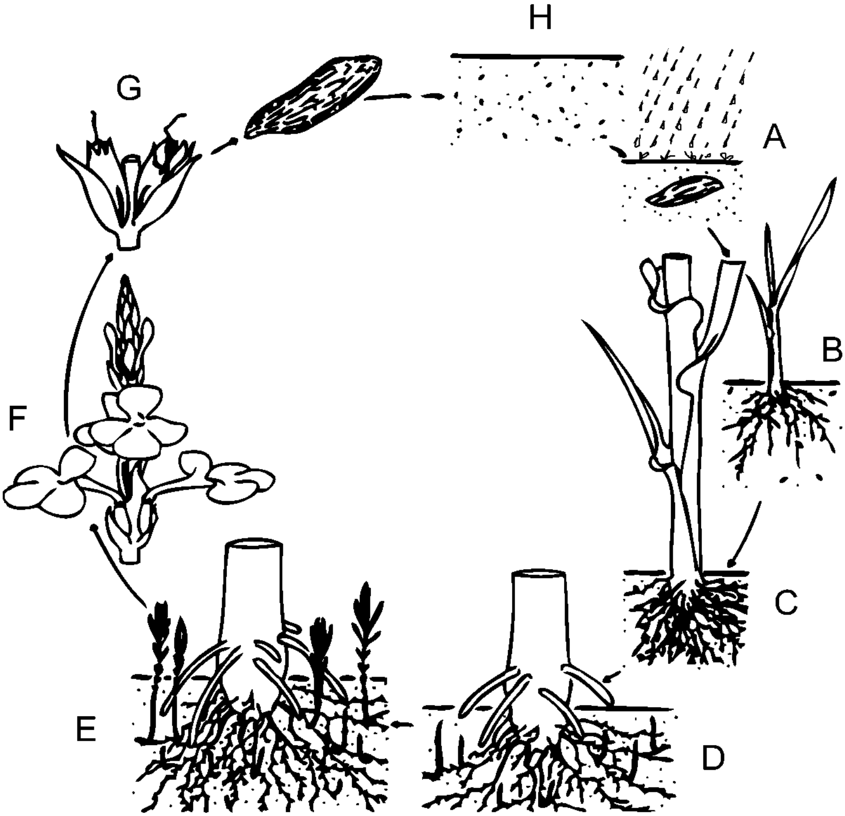


Figure 22: The life cycle of Striga. For an explanation, see text.

7.3 Control measures

Overview

Striga control depends on a combination of measures taken throughout the season, including:

- Exhausting the stock of seed in the soil through planting trap crops in crop rotation, and by developing 'living' soil.
- Choosing crop varieties that are tolerant or resistant to *Striga*.
- Adopting cultivation and planting practices which diminish the effect of *Striga*.
- Weeding out as many plants as possible before *Striga* sets seed.
- Preventing contamination of next year's seed with *Striga*.

In the next paragraph we will further discuss these measures in relation to the life cycle of *Striga*.

Crop rotation and using less susceptible crop varieties

Crop rotation and using less susceptible crop varieties are helpful because:

- *Striga* species are specific to certain crops, and do not develop on some others;
- Susceptibility to parasitism by *Striga* varies according to crop varieties: Some are more tolerant or resistant to than others;
- Continuously growing susceptible crops and crop varieties leads to a rapid build-up of the seed stock.

Reducing survival of *Striga* seed in the soil

The *Striga* problem is biggest in areas with low rainfall and soils with low fertility. In these areas the *Striga* seed in the soil survives relatively well. In wetter and richer soils, natural enemies of *Striga* survive and reduce the viable seed stock in the soil by destroying or damaging the seeds. These natural enemies of *Striga* are various nematodes and fungi. It is therefore particularly important to improve the organic matter content, even though that will be hard to achieve in sub-humid and semi-arid areas. Moreover, improved soil conditions will increase crop vigour. In the absence of a suitable host crop, the number of living *Striga* seeds slowly decreases. This gives fallowing and crop rotation with resistant crops a role in exhausting the seed stock in the soil.

Manipulating germination

When the crop plants are germinating, their roots release substances into the soil which stimulate *Striga* to germinate, and other substances which enable *Striga* to attach to the roots of the host plant. The *Striga* seed thus germinates and the seedling then will become attached to the root of the host plant.

To reduce *Striga* infestation, crops may be grown that are more or less resistant. Certain crops even induce germination of *Striga* seeds, but *Striga* cannot become attached to their roots. Having germinated, the *Striga* plant dies. This is called ‘suicidal germination’ and the crop causing it, is called a trap crop. Many grain legumes are trap crops for *Striga* that affects cereals and vica versa. *Desmodium*, mentioned in case 13 and figure 11, is a plant that induces ‘suicidal germination’ of Striga that affects cereals.

Striga seeds are usually present in the upper 2-3 cm of the soil. Ploughing a soil with a large seed stock results in the redistribution of *Striga* seeds in the whole top soil layer of 7 to 10 cm. If the seeds are concentrated in the top few cm, one way of avoiding early infection of the crop with *Striga* is to plant the crop in holes of about 15 cm deep, dug with a planting stick or a traditional hoe. See figure 23. Another option is described in case 27, in chapter 6.

Erratic rainfall, especially in the first 2 months after seeding, worsens the drought stress caused by *Striga*. Severe drought stress may then be visible early in the planting season. This is therefore often a symptom of *Striga* infestation, even if the *Striga* plants are not yet visible above ground.

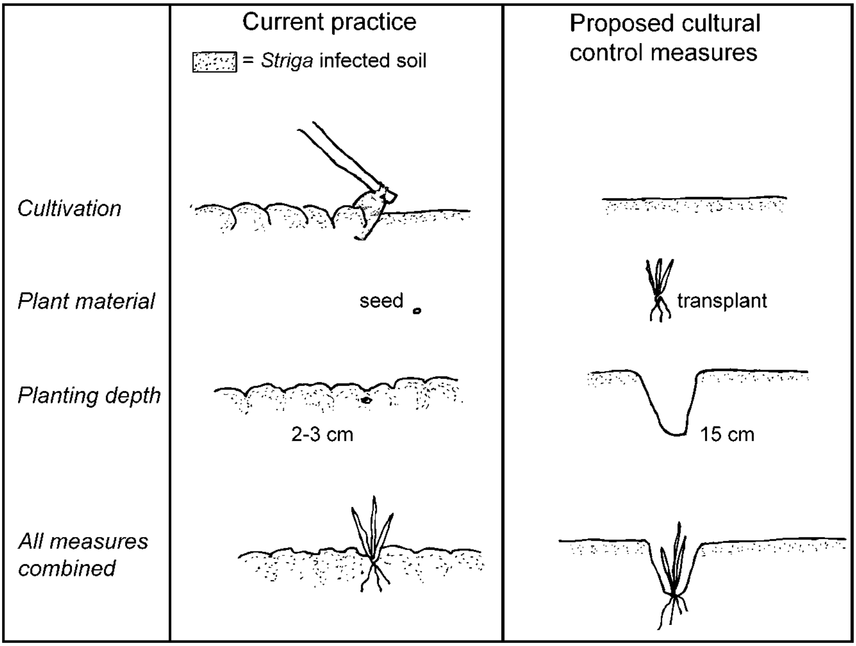


Figure 23: Avoiding Striga infection by using different cultural control measures

Crop growth and weeding

After the *Striga* plant surfaces from the soil, it can be weeded out to a certain extent. Farmers should remove the aboveground plant parts as often as they can to prevent *Striga* from producing seed.

Many organisms feed on *Striga*, preventing it from producing seeds. Certain caterpillars completely defoliate the plants, while other organisms damage the flowers, preventing seed production. As both the *Striga* and the grains that are affected are indigenous, there may be a lot of local understanding of how to encourage the enemies of *Striga*. The use of insecticides proves counterproductive in *Striga* control, since they kill the natural enemies of *Striga*.

Clean seed

Striga produces its own flowers and these produce many seeds, sometimes up to 500,000 per plant. The seeds are so tiny that people find them difficult to identify as seeds (see figure 24).

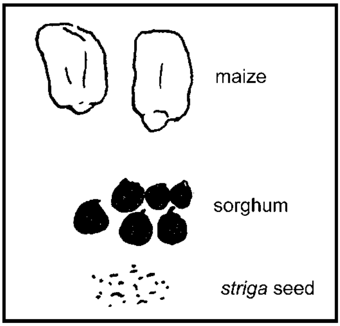


Figure 24: Seed sizes of Maize, Sorghum and Striga compared

Striga seeds easily attach to crop seeds. So, if you don't take measures to stop it, *Striga* spreads with the contaminated seed from one field to the other.

The contamination of crop seed with *Striga* seed is the main means of spreading the weed to new areas. Contrary to common belief, wind and rain hardly play a role in the dissemination of these parasitic plants. Contamination of crop seeds with *Striga* often occurs at harvest time, especially if the *Striga* plants are not removed before harvesting: the ears of the cereal touch the weed capsules or the top-soil containing the weed seeds (see figure 25).

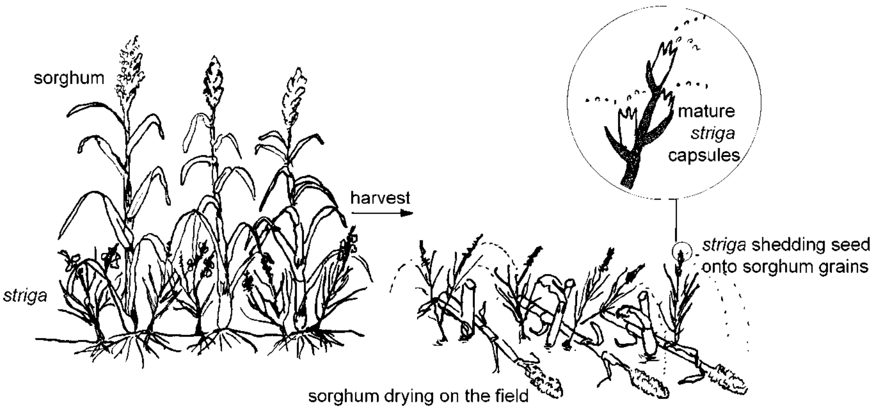


Figure 25: Striga seed can attach itself to next year's crop seed

Crop seed can be cleaned by steadily shaking the seed in a large pan. Due to differences in size and weight, the *Striga* seed will detach itself and ‘sink’ to the bottom, while clean crop seed is left on the top. If it is not shaken off, the *Striga* seed stays attached to the crop seed.

Combine different measures, efforts and experiences
All the measures mentioned above reinforce each other. The measures targeting the depletion of the seed bank are preventive measures for improving the sustainability of cropping systems through rotation and intercropping, and by improving soil conditions.

Many control programmes are seriously hampered by lack of access to reliable information and to local knowledge systems. Yet there is a lot of information on *Striga* control, both in research centres and in villages. Contrary to common belief again, experience has shown that many communities as a whole have a thorough understanding of *Striga* and opportunities for its control (see figure 7). The *Striga* problem is an indigenous problem, and there is a wealth of knowledge about it hidden in local communities. However, due to the division of tasks in crop production, the relevant knowledge is often scattered across gender and age groups. Bringing these groups together is an important step towards applying local knowledge in local interventions for a more sustainable production.

8 Farmer Field Schools and non-chemical crop protection

To use non-chemical crop protection methods effectively, you need to take preventive measures in good time. On the other hand, measures such as spraying with chemical pesticides or ‘biosprays’ must be delayed as long as possible, to allow natural enemies to build up and perform their role. So timing is all-important.

Farmers have knowledge and experience regarding crops, pests, and local conditions. But they can also learn to

- observe crop growth better;
- distinguish between causes and effects of pests;
- distinguish between pests, which are ‘enemies’ of farmers and natural enemies of pests, which are ‘friends’ of farmers.

By learning ‘on the job’, farmers can improve their crop protection.

Non-chemical, sustainable crop protection methods depend very much on local conditions. It is therefore impossible to provide simple solutions that work always and everywhere. Instead farmers must learn to observe how pests develop and behave on their farm. Based on their observations and possible solutions, they must make an independent decision on how to act. To decide between various possible solutions, they learn to set up simple experiments. Their ultimate goal is not to learn mere facts, but to become skilled in deciding which methods or measures to apply at which growth stage of the crop. Farmer Field Schools have proven to be very effective for improving these skills.

8.1 What is a Farmer Field School (FFS)

In a Crop Protection Farmer Field School, a group of 20 farmers in one location meet almost every week throughout the cropping season. As a rule, each weekly FFS session is designed to cover eight activities. We will explain these activities in section 8.3.

In the FFS, learning-by-doing, observing and discussing are always combined with the central question: 'What measures need to be taken now, if any?'

Not a classroom, but a school in a crop field

FFS are a means of education for groups of adults. They assume that farmers already have a wealth of experience and knowledge. They also assume that some of this knowledge may be based on misconceptions, and that some essential knowledge may be missing. There is not a teacher like in primary school, who tells the pupils everything they should know. Instead, the facilitator aims to use a participatory approach to integrate the farmers' knowledge into the programme. For example, when observing in the field, facilitators will ask farmers what something is (e.g. a natural enemy) and ask: 'Who knows what it might eat?' Farmers give their response, and the facilitator adds his/her own knowledge. If there is a disagreement, the facilitator and participants will set up simple studies to find the correct answer.

> **Case 28: Investigate what food an insect eats**
> In one Field School, farmers were discussing whether a certain lady beetle was a predator of pests or a pest of the plant. Two farmers laid bets on their opinions. The facilitator showed the farmers how to put two of the lady beetles in jars - one with pest insects and the other with crop leaves. The result was that the lady beetle ate the insects and the loser had to carry the winner around the village on his back!

The activities of the FFS are guided by a facilitator, who is a specially trained FFS extension worker. The extension worker knows how to measure and judge the numbers of pests or of plants with pest symptoms. She or he can inform the group what would be the expected damage if the group decided not to intervene, and to calculate whether measures like spraying would pay off.

The facilitator should be willing to lead the actual field work, showing both symptoms of diseases or pests and the predators present in the farmers' fields. The facilitator should be able to steer the group process so that the farmers participate and contribute their observations and experience. And she or he must keep the discussion focussed on crop protection issues.

Background of the Farmer Field Schools

The term Farmer Field Schools (FFS) was first used in Indonesia in 1989 for training rice farmers to manage rice pests (mainly insects) with fewer pesticide sprayings. FFS were a success from the beginning, because farmers discovered that they could often rely on the activity of natural enemies instead of pesticides (See case 3: BPH). By carefully spraying on the basis of field observations, they reduced pesticide inputs and saved money. With some variations, FFS have since been introduced in other parts of the world. Many of them are concerned with sustainable crop production and crop protection methods that are less dependent on external inputs.

In order to effectively link existing and new knowledge, FFS are physically situated in the farmers' community, and the facilitator joins the group at every session. They include a field where the usual crops are grown during the course. One course lasts for at least one cropping cycle.

8.2 How to set up and run a successful FFS

Taking the initiative

Most FFS are initiated by the government or a Non-Governmental Organisation (NGO), and they usually engage and train the facilitators. Facilitators should have good educational skills. They should also have the knowledge and skills needed to grow the crops involved in the programme. A season-long training is the best preparation for them, since they need to have experience of growing the crops and of observing, testing and teaching about crop protection 'in the field'. Generally a FFS consists of farmers from one village, because they know each other and often share the same interests and problems. Ideally, a request for a field school should come from a farming community. Farmers who request training themselves are usually better motivated than those recruited by some authority. To trigger such requests, FFS can be promoted by conducting a field day where farmers can observe the process and the achievements of a previous FFS. Farmers are more likely to ask for field schools if they see the benefits other farmer communities are reaping. In areas where FFS are a complete novelty, interest can be elicited by working through a convinced local leader. He or she can help arrange one or more preliminary meetings for interested farmers.

Participant selection and participatory planning

In an informative initial meeting in the village, the Extension Worker introduces non-chemical crop protection and the FFS process, raising interest in participation. The timing of such a meeting is important. It should be convenient for potential participants to attend. It is useful to identify and analyse agricultural problems the community is facing, provide information about the objectives and activities of the FFS, and give farmers the opportunity to ask questions. To get things clear, it may help to draw a map of the village, including crop fields, other vegetation and housing.

Figure 26: Mapping the village, the agro-ecology and the problems experienced by farmers

Either in the same meeting or in a subsequent one, FFS participants are selected by the community itself. The participants are invited to prioritise the activities proposed for the FFS. They can also discuss problem-solving ideas and compare these with potential solutions originating outside the village. This process should result in the preparation of a realistic work plan for conducting a Crop Protection FFS in the village.

The work plan should specify:
- the date and time of the weekly FFS meeting
- the location of the field study site
- the list of FFS participants
- a schedule of weekly activities for the entire season
- designs for field experiments to compare currently used methods with new ones

It depends on local habits, and can best be decided by the village leaders, whether men and women participate as one group or two subgroups of the same gender.

8.3 A typical FFS session

Each of the weekly sessions includes the following 8 activities:
- field observation (about 30 minutes)
- charting the growth and development of the crop (5 minutes)
- agro-ecosystem analysis (30 minutes)
- presentation of results and discussion (30 minutes)
- economic analysis (10 minutes)
- observing insect behaviour (10 minutes)
- group dynamics exercise (10-30 minutes)
- special topic (30-60 minutes)

We can illustrate this schedule with reference to a FFS on Sweet Potato held on Java, in Indonesia, in 1997. Beforehand, farmers and researchers had worked together to analyse the problems in Sweet Potato cultivation within the context of the whole farm enterprise. They concluded that pests caused considerable losses in some seasons. Lack of fertilisation guidelines was seen as a bigger problem than crop damage by pests, and this issue was included in the FFS programme. The FFS had 25 participants as a maximum. They were divided into workgroups of 4-5 people each.

Field observation

Each workgroup evaluated 10 locations at each session. Observations consisted of: Soil conditions, symptoms of nutrient deficiency in the crop, symptoms of diseases and insect damage, number and types of insect pests and natural enemies. The age of the crop was noted, together with general observations on weather conditions, weeds in the field and vegetation around the field. Unknown insects and plant parts with unknown symptoms were collected in containers for further observation and identification.

Charting crop growth and development

The lengths of stems (vines) and storage roots were measured weekly and charted. At the end of the course, the data were used to demonstrate how dry matter is distributed between aboveground and underground plant parts during the season.

Agro-Ecosystem Analysis

The Agro-Ecosystem Analysis (AESA) is the FFS's core activity, and other activities are designed to support it. In the Sweet Potato FFS, all data from the field observations were pooled per group. Samples or elements that were supposed to have a positive effect on the crop were pinned on the left side of a triplex board, and elements with a negative effect on the right. Participants were further encouraged to draw a Sweet Potato plant in the middle, showing the development stage of the foliage and storage roots. The drawing should also show whether the plants had stress symptoms or looked healthy.

Presentations and discussions

Each workgroup in turn presented and explained their agro-ecosystem analysis to the whole FFS (see figure 27 for an example). After the workgroups had finished, the facilitator guided the group in summarising the overall plant and soil conditions, drawing conclusions and making recommendations.

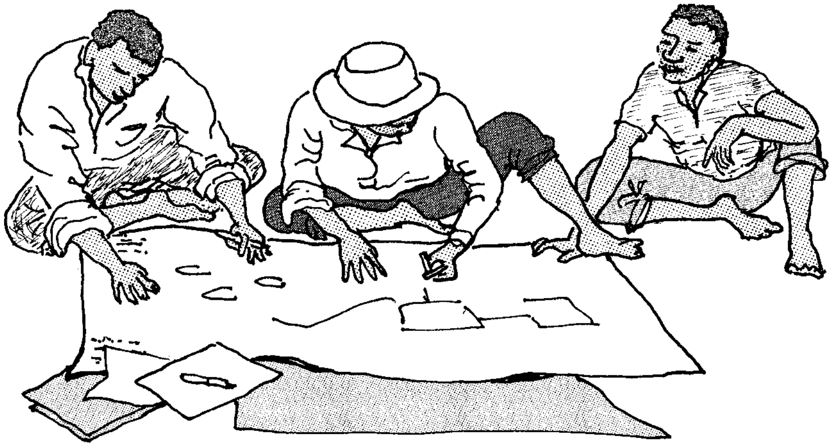


Figure 27: Farmers' workgroup preparing their presentation

Economic analysis

An economic analysis is used to develop the analytical skills of the participants. Once the Sweet Potato farmers had recognised the factors that determine the profitability of their Potato enterprise, they were better placed to choose between individual management options.

Observing insect behaviour

The purpose of this exercise is to discover the role of insects, especially the behaviour of crop-eating insects and their natural enemies. Workgroups put insects in a jar together with what is believed to be their preferred food. We show an example in figure 28.

Group dynamics

Group dynamic exercises develop group cohesiveness and problem-solving skills. They also encourage collaboration and creativity. Usually, the exercise begins with an introduction by the facilitator, who sets up a problem or challenge for the FFS to solve. Many are physical and active, while some are real brain teasers.

Special topic

The special topic is chosen from a list of suggestions from the participants. The topic should support the agro-ecosystem analysis, and should include carrying out experiments.

Figure 28: Observing insect and predator behaviour

Further reading

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1 IPM Priniciples, ISBN 9988-0-1085-0;
2 Cereals and Pulses, ISBN 9988-0-1086-9;
3 Root and Tuber Crops and Plantains, ISBN 9988-0-1087-7;
4 Vegetables, ISBN 9988-0-1088-5.

Useful addresses

CAB International Caribbean and Latin America
CAB International is a not for profit organization, specialising in scientific publishing, research and communication.
Gordon Street, Curepe, Trinidad & Tobago, West Indies
T: +1 868 645 7628, F: +1 868 663 2859
E: crc@cabi.org and bioscience-trinidad@cabi.org
W: www.cabi-bioscience.org/html/clarc.htm

FAO Global IPM facility
Improves and implements programmes to put Integrated Pest Management practices within the reach of farmers through farmer networks, extension services and research institutions (English).
Contact: Peter E. Kenmore, Co-ordinator Global IPM Facility
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Viale delle Terme di Caracalla, 00100 Rome, Italy.
T: +39 065705-2907, F: +39 065705-6227, E: Global-IPM@fao.org,
W: www.fao.org/ag/AGP/AGPP/IPM/gipmf/index.htm

HDRA, the Organic Association
The International Development Programme of HDRA promotes and facilitates organic agriculture in Africa, Asia and Latin America. It offers a range of booklets and leaflets on various techniques related to natural crop protection (free downloadable):
Contact: Ryton Organic Gardens
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E: enquiry@hdra.org.uk, W: www.gardenorganic.org.uk

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ILEIA
Centre for Information on Low External Input and Sustainable Agriculture. Promotes exchange of information for small scale farmers in the South through identifying promising technologies. Information about these technologies is exchanged mainly through the LEISA Magazine. All articles accessible on-line.
Contact: ILEIA, Zuidsingel 16, 3811 HA Amersfoort, The Netherlands
T: +31(0)33-4673870, F: +31(0)33-4632410
E: ileia@ileia.nl, W: www.leisa.info

OISAT (PAN Germany)
Online-information service for non-chemical pest management in the Tropics with specific methods for each crop and pest
T: +49 (0)40 399 19 10-0 , F: +49 (0)40 390 75 20
E: info@pan-germany.org, W: www.pan-germany.org / www.oisat.org

Pesticide Action Network (PAN) – Africa
Location Nº 15, Rue 1x J Castors/Derkle, Dakar Senegal
BP: 15938 Dakar-Fann, Dakar, Senegal
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E: panafrica@pan-afrique.org, W: www.pan-afrique.org

Global Farmer Field School Network and Resource Centre
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T: +31 317 451727, F: +31 84 7500302
W: www.farmerfieldschool.info

Glossary

Numbers given after terms refer to the chapter or section where the term is used for the first time.

agro-ecosystem	the interaction of all life forms and physical circumstances in an agricultural landscape (8.3)
air-borne	(of a disease) carried by air or raindrops above the soil surface (as opposed to soil-borne, 5.1)
annual	a plant that completes its life cycle and dies within one year; the opposite of perennial (3.2)
arable	fit for cultivation for agriculture (1)
biodiversity	the variety of life forms at a certain place (3.1)
complete metamorphosis	the development of certain insects in which the adults completely differ from the larvae; the opposite of insects with an incomplete metamorphosis (2.1)
crop rotation	the successive planting of different crop species, often used to reduce pest problems (1)
damping-off	death of a seedling before or shortly after emergence due to decomposition of the root and/or lower stem (5.3)
disease	(of a plant) abnormal functioning of a plant caused by an other organism (1)
dormant	(literally: sleeping) state of an organism lacking activity, used as a survival mechanism (4.1)
false seedbed	(technique) to cultivate a seedbed as if for planting and then allow a flush of weeds to grow that is removed before seeding the crop (6.3)
host plant	living plant attacked by or harbouring a parasite or pathogen and from which the invader obtains part or all of its nourishment (2.2)
incomplete metamorphosis	development of certain insects in which the adults still look very much like the larvae (2.1)
infection source	initial site of infection, generally with reference to a population of plants (5.1)

infection	process in which an organism enters, invades, or penetrates, and establishes a parasitic relationship with a host plant (5.2)
infestation	the presence of a large number of pest organisms in an area or field, on the surface of a host or anything that might contact a host, or in the soil
intercrop	to grow two or more crops simultaneously on the same area of land (synonymous with mixed cropping, 3.2)
life cycle	the cyclical stages in the growth and development of an organism (1)
mixed cropping	see intercrop
mulch	layer of material, such as organic matter or plastic, applied to the surface of the soil for purposes such as retention of water and inhibition of weeds (3.2)
parasitic	(of an organism) living in intimate association with another organism on which it depends for its nutrition (2.1)
pathogenic	(of an organism) producing a disease (2.1)
perennial	plant that survives for a number of years (3.2)
pest control	any measure or set of measures aimed at reducing the numbers of a pest or pest complex in an area; it often refers to measures that have an immediate effect on a pest or pest complex (4.3)
pest management	means the same as pest control, but it includes both preventive measures and measures that have an immediate effect (2.2)
pest	any organism that damages plants or plant products (1)
pesticide	a chemical used to control pests. The term also applies to a biological control agent, normally a pathogen or micro-organism, formulated and applied in a way similar to a chemical pesticide (1)
population	total number of a species living in an area (2.1)
pro-active pest management	instead of waiting for a pest problem to develop or to become widespread, there is a

	planned and designed process in place to enable early detection or prevention (2.2)
resistant	(of a plant) possessing properties that prevent or impede disease development (the opposite of susceptible, 3.2). The term is also used for pests that have become insensitive to the action of a pesticide (1)
soil-borne	(of a disease) present on or beneath the soil surface (as opposed to air-borne, 5.3)
solarisation	disease or weed control practice in which soil is covered with polyethylene sheeting and exposed to sunlight, thereby heating the soil and controlling soil-borne plant pathogens and weeds (5.4)
strain	a variant of a plant or micro-organism, used for a certain purpose (5.2)
strip cropping	the growing of two or more crops in alternating strips (3.2)
susceptible	(of a plant) can become diseased after contact with a pathogen (the opposite of resistant, 5.1)
trap crop	crop planted around a field to protect the inner crop from diseases transmitted by certain pest insects or a parasitic plant (3..2)
variety	a plant type within a species, resulting from deliberate manipulation, which has recognisable characteristics (colour, shape of flowers, fruits, seeds, height and form); synonymous with cultivar (2.2)
vector	a living organism (e.g., insect, mite, bird, higher animal, nematode, parasitic plant, human) able to carry and transmit a pathogen and disseminate disease (5.2)
vegetative	referring to asexual parts of a plant, which are not involved in sexual reproduction (6.1)
wind break	a row or other grouping of trees or shrubs used to provide protection against the effects of high velocity winds (3.1)