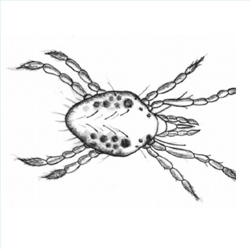
Agrodok-series No. 28

AGROMISA

Identification of crop damage

caused by diseases, pests or mineral deficiencies



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Agrodok 28 - Identification of crop damage

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caused by diseases, pests or mineral deficiencies

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First edition: 2004

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Printed by: Digigrafi, Wageningen, the Netherlands

ISBN Agromisa: 90-77073-31-0

Foreword

The purpose of this booklet is to help farmers in remote areas prevent and control diseases and plagues in their crops. These farmers may not have access to agricultural extension officers or other experts who could diagnose the cause of the crop damage and suggest immediate steps to control it, or advise the farmers on how to prevent it from recurring in the future.

Before applying any pesticide in such an emergency situation, the farmer will have to determine the nature of the damage that has been done, i.e. he will have to know what type of damage-causing agent caused the problem. Was it caused by an insect, a mite, a fungal, bacterial or viral disease, a nematode or a nutrient deficiency? This book therefore focuses on these various groups of pests and pathogens to help explain the possible causes of and solutions to crop damage.

The author would like to thank Professor A. van Diest for his contribution on nutrient deficiencies, Irene Koomen for her contribution on plant diseases, and Jan Schreurs and Jeroen Boland for contributing to the structure and editing of this publication. Acknowledgements go also to the KNPV (the Dutch Plant Pathological Society) for their support, which made the publication of this Agrodok possible.

Joep van Lidth de Jeude, Wageningen, 2004

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1 Introduction

Sometimes even experienced farmers are faced with serious crop damage that they cannot explain. Without a clear understanding of what caused the damage, they will not know how to treat it. In many developed countries agricultural extension officers can come to the field to analyse the symptoms and advise the farmer on how to prevent and control the problem. If such assistance is not available, however, the farmer will have to depend on the experience and insights of his colleagues. Unfortunately, they may also lack the knowledge required to accurately diagnose the cause of the problem. This publication is intended to serve as a tool to help farmers determine what steps can be taken to save their crops in such emergency situations.

Approach per group of damage-causing agents (pests and diseases)

Crop damage can be caused by various biological groups: plant diseases (caused by fungi, bacteria or viruses), insects, nematodes, mites, or others. Pesticides used to control these pathogens are usually highly specific to each group. A fungicide, for example, will usually not have any effect on insects or any other group of pathogens. To decide what emergency measures should be taken, it is usually not necessary to know the exact identity of the damage-causing agent, as long as the group to which it belongs can be determined.

Unfortunately, determining which group or category the agent belongs to is not that simple: the symptoms do not always clearly point to one specific group. The characteristic symptoms of a nematode infestation, for example, are very similar to those of a viral disease or a nutrient deficiency. By providing ample descriptions of the similarities and differences between the symptoms of the various groups of pathogens, the author has attempted to make it possible for an individual farmer to identify the cause of crop damage. Appendices I and II also provide additional keys to identifying damage-causing agents.

For each group a short description of possible control measures is given. The author would like to stress the importance of an integrated approach to pest management (IPM). Only as a last resort is the use of pesticides advised. More detailed information can be found in Agrodok 30 – Integrated Pest Management.

Expert assistance

This publication covers primarily the prevention, spread and control of the various causes of crop damage. If after reading this information a farmer is still not able to identify the cause and specific type of damage threatening his crop, we would advise him to consult an advisory institution or the Internet, if at all possible. For best results, the questionnaire in Appendix IV can be completed and sent to such an institution (usually an agricultural research station). With clear and complete data, experts can usually determine the cause of the problem, and give advice on specific measures to be taken.

Economic importance

For the purposes of this booklet, crop damage is defined as being severe enough to make control measures an economic necessity. Of course the difference in yield that can be achieved through these measures must greatly outweigh the costs involved. Damage that decreases the yield only slightly or not at all is thus not considered in this booklet. Neither chemical nor integrated control measures are needed in that case, and they may even be undesirable if their use would necessitate an avoidable investment.

2 The causes

2.1 An overview

Crop damage can be caused by:

- Insects and mites
- Diseases caused by fungi, bacteria or viruses
- Nematodes
- Snails, rats and other animals

In addition, there are also non-parisitic causes:

- Shortage or surplus of certain nutrients
- Extreme weather conditions, burning, depletion of the soil, etc.

Appendix 1 gives a general overview of what groups of agents could be responsible for specific types of crop damage.

2.2 How is crop damage discovered?

Severe crop damage has to be prevented by inspecting the crop regularly. The following figures illustrate how to do this, but keep in mind that it is also important to watch for any insects that fly away as you approach the crop.

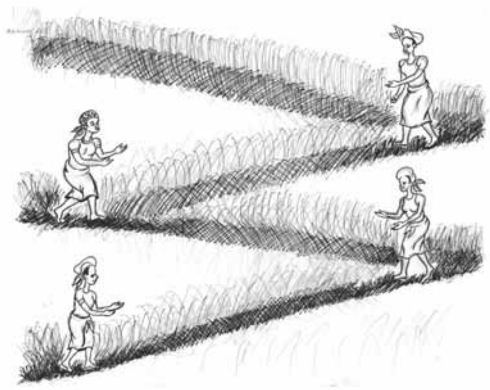


Figure 1: The whole field has to be inspected, not just a small area. This can be done by walking in a zigzag pattern through the field.

Figure 2: Stop occasionally to thoroughly inspect a few plants. Sometimes symptoms can be found on lower parts of the plant.

Figure 3: Make sure to also inspect the underside of leaves, where insects could be located.

Figure 4: If any damage is found, it might be helpful to uproot the plant to see if the root system is also damaged.

Figure 5: Insect storage jar

If the damage has to be evaluated by a third party (an expert, laboratory, etc.), the following steps are recommended:

For insect damage: collect several of the insects in a glass jar; add a few leaves and poke some air holes in the lid. Store the jar in a cool place.

For other types of damage: collect an ample amount of damaged plant material, including leaves, stems, and roots, and put them, together with moist tissue (toilet paper or newspaper), in a closed plastic bag. Store in a cool place until the material can be inspected.

Figure 6: Storage bag for plant material

If a soil sample has to be analysed, gather sample material from the top 20 cm of the soil. Make a composite sample by walking in a zigzag pattern through the field and taking a sub-sample every few metres.

2.3 Initial identification

To help identify problems in the field, two keys have been included in the appendixes. The objective of appendix I is to help a farmer identify the general type of crop damage that has been found. Appendix II will help the farmer determine a possible cause of the damage based on the symptoms observed on the various plant parts.

2.4 The use of pesticides for identification

Most pesticides are effective against only one specific group of pathogens. Insecticides, for example, generally only work for insects, and will not affect mites. Fungicides will kill fungi, but usually not bacteria, insects, mites, nematodes or other organisms. Only in a few select cases will certain pesticides attack more than one group of organisms. Aside from enabling the pesticides to effectively control the various types of harmful organisms for which they were intended, this specificity characteristic can make pesticides useful tools in identifying the group of pathogens to which a damage-causing agent belongs. This can be especially helpful in cases where the same kinds of damage can be caused by more than one type of pathogen. For example, as explained later in this booklet, the symptoms of a nematode infestation closely resemble those of a viral disease. However, if the plant's condition clearly improves after application of a nematicide, it can be thus concluded that the damage was caused by nematodes and not a virus.
Similarly, leaf damage caused by fungi can look the same as that caused by pathogenic bacteria. If the plant reacts positively to the application of a combination of benomyl and ethridiazol, which is effective against all fungi but not against bacteria, it can be assumed that the damage was caused by a fungus and not a bacteria.

Other examples of the use of pesticide applications as well as mineral supplements to help identify damage-causing agents will be given later in this booklet. More details on the specificity of pesticides, with respect to possible commercial applications, can be found in Agrodok 30 - Integrated Pest Management, and Agrodok 29 – Pesticides: Use and Hazards.

3 Insects

Insects are small organisms that are distinguishable, among other things, by having six legs. Their mouthparts, which can vary widely among orders, allow the insects to either bite (chew), sting or suck. Insects can cause damage to the roots, leaves, stems, flowers, and/or fruit of a plant. The type of mouth an insect has determines the type of damage it causes.

Biting insects chew the leaves, stems, seeds and fruits of a plant, or bore tunnels into it. The plant tissues around the affected areas will usually partially or completely rot, mostly due to bacteria from the insect's excrement. Many sucking insects transfer viruses through their mouthparts when they pierce the plant, which can then become infected. Plant insects can inject fungi and bacteria into fruit, which results in rotting or discolouration in the effected area on the fruit. If they pierce the main vein of a leaf, this may cause the leaf to become deformed. If insect damage decreases the surface area of the leaves, the plant's production capacity will decline. This will result in a smaller yield or lower quality of the agricultural product.

Symptoms

Damage caused by insects is usually clearly distinguishable from damage caused by disease or nutrient deficiency. The ragged edges of chewed leaves are an obvious indication. Also, the area around the damage is usually free of necrotic (dead) tissue, which is characteristic of fungal or bacterial damage. Chewing damage is caused by the larvae of butterflies (caterpillars), beetles (grubs), and sawflies; adult beetles and sawflies also have biting/ chewing mouth parts and can thus also cause this type of damage. These insects are usually located somewhere on or near the plant. Look carefully for these insects and their often dry, powdery or granular excrement on or close to the plant. Pay particular attention to the underside of leaves.

To get a good look at the insect you will probably need a magnifying glass. Whether a particular insect is the cause of the damage or just a chance visitor will have to be determined based on experience and good judgment. If the plant's symptoms are unfamiliar, it is advisable to pull a few damaged plants out of the ground to inspect their roots for the presence of root borers or other insects.

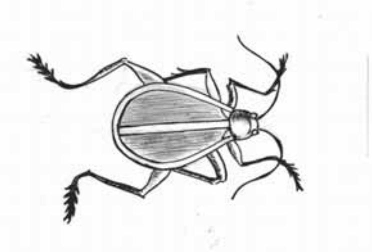


Figure 7: Beetle (3x)

In the final stage of their development, chewing caterpillars can pupate in the plant, but more often this will occur in the soil under the plant, between cracks in the parched ground or beneath clods of earth. Therefore, if harmful insects cannot be found, make sure to loosen the earth beneath the plant with a knife to a depth of about 6 cm to look for cocoons or caterpillars. Remember that caterpillars sometimes only chew the plant at night, and return during the day to the soil, where it is cooler.

Before larvae in the order of butterflies, beetles, wasps, etc., take on their adult forms, they produce a leathery covering or pupa, within which they metamorphize over a period of one to three weeks into an adult insect.

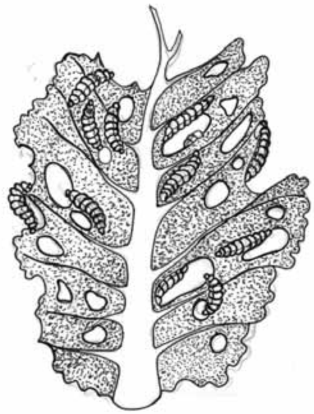


Figure 8: Caterpillars and their damage

Figure 9: Moth (4x)

Areas that wilt or die off suggest that an insect has chewed into the stem (of rice for example). Often a hole can be found on the surface of the stem. To see whether entrance holes have also been chewed into the roots, the plant will have to be pulled out of the ground. If the insect is still in the plant, it can be found by cutting the stem, roots or fruit open with a knife – first lengthwise and then in other directions if necessary. Some kinds of leaf-eating caterpillars (e.g. *Sylepta* sp., in cotton) make a roll out of a leaf by spinning it together with fine threads. They then often use this roll to hide and pupate in.

The presence of leaf miners is visible on the surface through the curved tunnels chewed into the mesophyll. If you hold the leaf up to the light, you can often find the insect or pupa at the end of one of the tunnels. The leaf tissue close to the tunnels often dies off.

Figure 10: Typical damage caused by leaf miners

Plant bugs and aphids cannot cause these types of symptoms because they do not have biting mouthparts. They can only pierce and suck. If they pierce young, not yet fully opened shoots and buds (such as *Lygus* sp., in cotton), the damage will not be visible until the plant is in a later stage of growth. The fully developed leaves can look more or less torn.

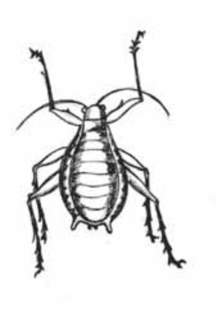


Figure 11: Aphid (wingless)(15x)

Figure 12: Winged Aphid (20x)

Other insects (aphids, jassids, plant hoppers) weaken the plant by extracting large amounts of the plant's sap. Especially when there are many insects on the plant at once, this can lead to a considerable drop in production. Piercing damage made by insects can cause the leaves to curl downward (aphids), or become otherwise deformed if the main vein is affected (*Helopeltis* sp., in cotton). In the latter case, the surrounding leaf tissue grows faster than the damaged vein. An aphid population can be wiped out by predation from their natural enemies. Curled leaves, moulted skins and the empty shells of aphids that have been sucked dry are then the only evidence left of their presence.

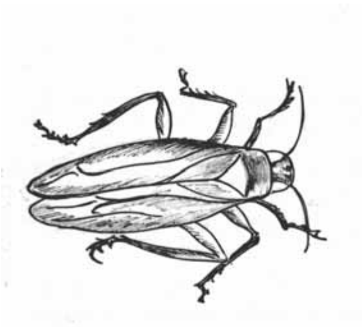


Figure 13: Jassid (10x)

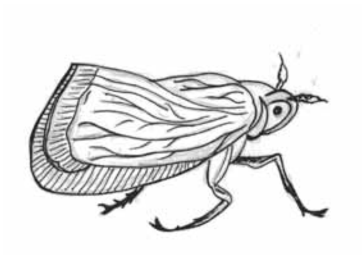


Figure 14: Plant hopper (12x)

Sucking insects can spread viral diseases through their piercing organs. The damage inflicted by these diseases is much greater than the mechanical damage insects themselves can cause (see section 5.3). They can also inject rot-causing micro-organisms into the plant or fruit. For example, after being pierced by cotton stainers, cotton tissues become discoloured and thereby lose much of their value.

Figure 15: Damage caused by a cotton stainer

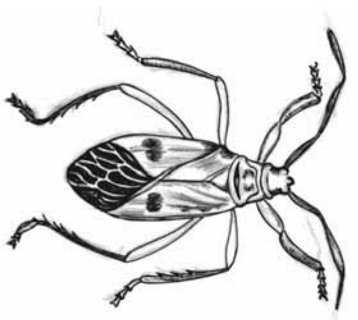


Figure 16: Cotton stainer (3x)

Some very small insects, such as thrips (1 to 2 mm in length), and also mites, can cause leaf or fruit scarring, or a coating that looks like a localized smooth, silver-coloured outer skin on the surface or underside of a leaf.

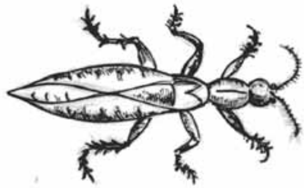


Figure 17: Thrips (25x)

Scale insects can also cause damage, in citrus and olive trees among others. Although they may not look like it, because they are legless for most of their lives, they are indeed insects. They live under dry, round or mussel-shaped scales (shields) that are a few millimetres in diameter. The scales appear to be glued to the plant's leaves and stems. You can confirm the presence of the insect by poking the point of a pencil through its shield. If it is still alive, its body fluid will seep out through the hole.

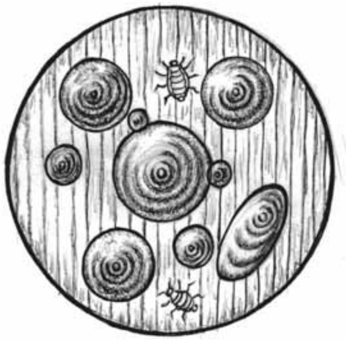


Figure 18: Scale insects

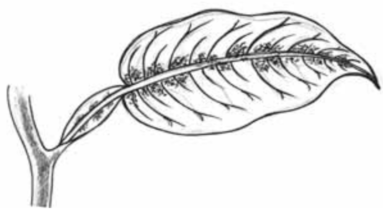


Figure 19: Typical damage caused by scale insects

Just like aphids, these insects secrete a honey-like substance that drips onto the leaves. Eventually a damaging soot-coloured fungus will develop on this fluid. This 'sooty-mould' hinders the plant's productive capacity.

Some insects are very skittish. They flee at the slightest sign of danger and are therefore impossible to see. Their presence is only noticeable because of the visible, and sometimes severe, crop damage they cause. In such cases it is advisable to catch them by walking through the rows of plants while waving a hand-held net across the tops of the plants. The damage-causing insects will most likely be found among the insects caught in the net.

To identify possibly harmful insects, they first have to be caught. A hand-held net can be used as described above to catch skittish insects, or to catch larger insects that are easy to spot during their flight. To catch smaller insects, an insect suction bottle can be used as illustrated in Figure 20. It consists of a glass or plastic bottle with a volume of about 100 m that is filled 1/3 to 1/2 full with ethyl-alcohol. By holding the diagonally cut end of one tube close to the insect and sucking forcefully with your mouth on the other tube, the insect will be sucked into the bottle and land in the alcohol, where it will die. It can later be examined closely under a magnifying glass or microscope.

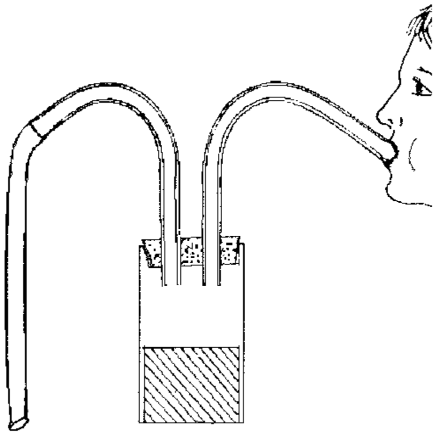


Figure 20: Insect suction bottle

The origin and spread of insects

The first insects to attack a crop can come from anywhere. Some, like the brown plant hoppers (in rice) and plant aphids, can be transported as far as 1000 km by rising air currents that can reach very high elevations. The insects can thus be found, in small numbers, a great distance from their origin. More often than not, however, the first infestation comes from the same crop (or crop residues from the previous harvest) or from other host plants, including weeds, in the direct vicinity. In newly planted fields, a population of harmful insects usually begins with a very small number of individuals. However, if the insects have landed on their preferred crop, where they have access to an ideal source of food, their population can increase very rapidly: at a growth rate of 80-150 times per month. Thus just two to three months after sowing, the farmer can suddenly be faced with a serious insect infestation. Once a field has been harvested, the insects move as a group to other fields of the same crop in the vicinity that were sown later and have therefore not yet been harvested. As a result, these fields usually become more heavily infested than the field that was sown earlier.

Control

The control of insects can best be done within the framework of integrated pest management (Agrodok No. 30). Preference should always be given to all possible and imaginable measures to reduce and prevent insect infestations that do not involve the use of synthetic chemical pesticides. Such pesticides should only be used as a last resort, if all other measures have not produced sufficient results. To keep the initial population as small as possible, crop residues should be destroyed after harvest, and both weeds and other host plants should be completely removed.

The use of synthetic chemical pesticides is usually not recommended, because they pose grave dangers to the consumer, the environment and the farmers who work with them. There are, however, situations in which their use is unavoidable. Poor farmers who own only a small area of land have to use pesticides in order to harvest their land more than once per year, which is the only way for them to produce enough food and income for their families. Unfortunately, for these farmers there is no alternative.

Remember that some insecticides have a disastrous effect on the natural enemies of harmful insects. It is of course never a good idea to attack one's allies, so try to choose pesticides that are the least poisonous to natural enemies. This information should be readily available. Unfortunately, the pesticides that are the most toxic are usually also the ones that work the best. But keep in mind that the less toxic ones are often also quite effective.

When using pesticides, it is important to consider their effectiveness, costs and possible negative impacts on public health and the environment. Relatively good and inexpensive pesticides are available on the market, but sellers usually promote the more expensive and most effective products, because the profit margins for these products are also greater.

Not all pesticides are equally toxic and harmful to public health and the environment. The advantage of the most toxic kinds is that they often have a very short residual effect on the plant (2-3 days), which makes them safer for consumers. However, the pre-harvest intervals during which these pesticides cannot be applied must be strictly adhered to. Highly toxic insecticides are too dangerous to be used by farmers with little knowledge or experience in this area. Farmers who nevertheless want to use these pesticides will have to ask for professional advice and possibly practical assistance. Of course less toxic pesticides are always preferable. Unfortunately, many farmers, especially in remote areas, often have no choice. They are dependent on the limited number of products local dealers can offer them.

4 Mites

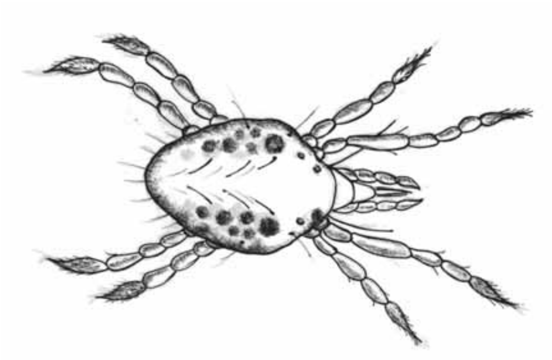


Figure 21: Mite (45x)

Mites are small, usually oval-shaped animals that are 0.1-0.8 mm in length. They are barely visible with the naked eye. They can be yellow to reddish, or milk-coloured. They move around freely, usually on the underside of leaves. Occasionally they produce web-like threads along the underside of the leaf, from which they can hang or glide and thus spread to another host. Since mites have eight legs, they are not considered to be insects, which all have six legs. Insects and mites belong to different biological classes.

As their name suggests, gall and bud mites can be found in galls and buds, in contrast to the free-moving mites described above. The galls are easily spotted, but the mites hidden within them are barely visible. These mites are much smaller than the free-moving type, and they have a different appearance: they look like short worms with what appears to be only two pairs of legs located in front near their heads. These mites and their galls usually cause little economic damage.

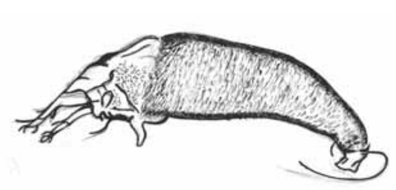


Figure 22: Gal and bud mite (60x)

Figure 23: Typical damage caused by a gall mite on an orange

A population of plant mites may also contain some useful predatory mites. These often stand out because they are larger and move faster than their prey. They are usually also fewer in number than their prey. It is therefore very important to look closely at the population.

Symptoms

The so-called free-moving mites cannot fly and usually stay on the underside of leaves, preferably close to the leaf's stalk and between its main veins, where they slowly move between their countless larvae and eggs. Look closely at the underside of each leaf, preferably with a magnifying glass. Mites cause damage by piercing and sucking. The leaf often turns yellow, which is also noticeable on its surface. Long-term damage can cause the entire leaf to die off and dry up.

Origin and spread of mites

Since mites cannot fly, the initial infestation of a field usually originates from a population in the direct vicinity. Mites located on nearby host plants, including weeds, can walk or be transported by the wind, while hanging on their threads, to the new crop plants. On perennial plants the mites can overwinter in the buds.

Control

Most chemical pesticides that are effective against insects are not effective against mites. Since mites are usually located on the underside of leaves or in buds, a systematic miticide is often more effective than a simple contact miticide.

Severe mite damage often occurs after the use of an insecticide that kills the mite's natural enemies (which usually belong to the biological class of insects) but not the mites themselves, which allows the mite population to grow even faster. For this reason, be very careful when applying insecticides! Using one of the few insecticides that is also a miticide will usually prevent the mite population from building up after the pesticide is applied.

5 Plant diseases

Plants can become diseased due to fungi, bacteria and viruses. Fungi cause leaves to die off, or fruit or other parts of the plant to rot. A virus infection often leads to dwarfed growth and decreased production. Damage caused by diseases can result in a considerable reduction of yield for a farmer.

5.1 Fungal diseases

Fungi are organisms that usually consist of barely discernible filaments (hyphae). Loose clusters of hyphae (mycelium) are clearly visible with the naked eye and look like very fine cotton wool. These are usually whitish in colour. Closer to the fungal fruiting body, the hyphal tissues can be more tightly ‘woven’ and look like sturdy plant tissue. Spore clusters and fruiting bodies (mushrooms) are often brightly coloured. The green spore clusters that form on old and rotten bread are a familiar example.

A fungal infection is often caused by fungal spores that land on leaves, germinate there and penetrate the plant tissue through its stomata (small openings in the epidermis [skin]), wounds, or sometimes even directly through the plant’s epidermis. The filaments develop at an increasing rate in the affected plant tissue, from which they extract nutrients and into which they may excrete substances that are toxic for the plant. The affected plant tissue eventually dies off. The harmful effects of the fungus are usually limited to the affected area, but there are some types of fungi that enter the plant through its vascular tissues (xylem) and are then spread by the vascular system throughout the plant. If a lot of plant tissue dies off, this can have serious economic consequences for the farmer.

Fungi can damage all parts of the plant. Fungal disease can have a primary (in most cases) or secondary cause. Direct infection or damage to healthy plant tissue is a primary cause of disease. When the infection occurs in plant tissue that was already weakened, damaged or killed in some other way, such as by a mechanical injury or an insect infestation, this is called a secondary infection. It is important to keep this distinction in mind when trying to determine the cause of damage.

Fungi are responsible for most damage to agricultural crops, as they lead to the massive loss of crop leaves or rotting fruit. In perennial plants, root fungi can also cause considerable damage. To diagnose the cause of damage, it is useful to know more about the various diseases that can be found on plants. Informative publications with colour illustrations of the symptoms can usually be obtained from the ministry of agriculture or seed companies and other suppliers of agricultural products.

Symptoms

To identify a pathogen, all parts of the diseased plant have to be inspected, including its roots. The symptoms of fungal disease are normally not restricted to just a few plants or a particular area within a field, but are spread over the entire cultivated area. (This is also true for bacterial diseases.) Damage caused by nematodes, viruses or a nutrient deficiency, in contrast, are more often found in limited areas. The most obvious symptom of fungal disease is spots on the **leaves**. These spots are normally round or oval, but they can also be rectangular or spindle-shaped (with pointed ends). They are usually located somewhere on the leaf's surface, but seldom limited to the area near its edges. In an early stage of infection, moist areas may be noticeable on the leaf (e.g. *Phytophthora infestans* on potatoes), where the leaf will later die off. In a later stage of infection, the leaf spots have a dead (brown) centre and are surrounded by a light or dark-coloured halo. Concentric rings of different shades of brown or

Figure 24: Typical damage caused by a fungal disease

grey also form around the centre (this is also true of stem cankers). These symptoms point to a fungal or bacterial infection. You can be sure that the disease is caused by fungus if (usually light-coloured) fungal tissue (hyphae) can be found close to the spots, usually on the underside of the leaf. Fungal disease is also indicated if fruiting bodies are present on the surface or underside of the leaf in the form of pustules or thin rod-like areas, which contain a powdery substance. These are clusters of fungal spores, which come in various colours including white, yellowish-brown or black.

Sometimes after round spots form on the surface of leaves, of plum trees for example, the tissue of the affected areas dies off and disintegrates, leaving holes where the spots were. It can then appear as if insects have been chewing the leaves, or as if the leaves were punctured by hailstones. In this case, the damage-causing agent is not insects, but a fungus. The name 'shot hole disease' is thus a fitting description.

Decay of the root collar and the lowest leaves that touch the ground (e.g. of lettuce), or decay just above ground in the stems of young seedlings, is usually caused by a soil fungus. If a plant wilts partially or entirely, starting between the veins of the leaves, it could be that the xylem have become blocked due to a fungus (e.g. *Fusarium, Verticillium* spp. in tomato), while the symptoms seem to point to a lack of water. Another possibility is that the stem has been eaten from within by insects, which damages the vascular system and thus also restricts the flow of water to the upper parts of the plant.

Symptoms of a fungal disease usually appear above ground first on the leaves, and only much later on other parts of the plant. During or just after germination of sown seeds, however, damping-off can occur in which a dry-rot wound develops in the stem just above ground and the seedling collapses. The damage in this case is also caused by a soil fungus (e.g. *Pythium, Phytophthora* spp.).

In perennials, such as mature citrus trees, soil fungi can infect stems or trunks near the ground when raindrops splash up against the trunk.

The fungus then forms stem cankers, after which the whole plant, shrub or tree can become diseased. The upper parts of a plant or tree can become infected with fungus transported through the air, after which local damage can develop in the form of stem or branch cankers (which can also develop as a result of bacteria or frost!).

Tip and top die-back can also be caused by a fungus (e.g. *Colleto-trichum* spp. and *Rhizoctonia* spp. in coffee and citrus). The youngest parts of a twig have a thinner top layer of epidermis than the older parts and are therefore more susceptible to invasion by fungus. The first sign of damage is often the formation of sunken spots on the tops of the young shoots (or on the fruit). The dying-off continues in the direction of the stem for usually just a short distance and then stops on its own. The bark then dies off and splits open. Gummosis can then also occur.

Root fungi can cause severe damage to perennial crops such as coffee, tea, rubber and cocoa. The leaves of infected plants become limp, then turn brown, wilt and eventually fall off. Because these fungi attack the plants' **roots**, their growth is retarded and rotten spots may develop; sometimes the whole root is black and rotten or it resembles a rat's tail. In a less serious case, fungal tissue (mycelium) can be seen in or between the wood and bark, usually in the form of white, red, brown or black rhizomorphs (strands of fungal tissue as thick as a shoelace). Sometimes sunken spots are visible on the bark at the base of the stem or on the roots, or the bark is split and 1.5-2.5 mm perithecia (fruiting bodies that contain spores) can be seen. As a result of the fungus, the roots sometimes turn brown or black and become dry and brittle. Only when the tree or shrub is almost dead do larger fruiting bodies develop on the roots, trunk and branches, often in the form of mushrooms. Sometimes these consist of nothing more than a thin crust of tightly woven fungal tissue that can engirdle a branch over a few centimetres. Within this crust are thin tubes containing spores, which will later be released and dispersed.

Thus in addition to the leaves, the lower parts of the plant can also be affected (e.g. *Phytophthora* in potatoes). Rot can develop or a type of scabs can form on the tubers. Only a few fungi (*Synchytrium* and *Spongospora* spp.) can cause corky warts and scabs to form on the base of the stem or on the roots. (These are thus not caused by *Azotobacter* spp. or a nematode infestation!)

Fungal infection of the **seeds** while they are still in the field is not common. Smut and bunt fungi can transform (usually just a limited number of) grain seeds into a mass of powdery black or green waxy spores. The economic loss is usually very limited, but in some cases, such as with covered smut in grain in the middle east, losses can be as high as 80%.

Directly after sowing, seeds can become infected by soil fungi. The damage in this case can be considerable. The seedling often dies even before it grows above the soil. Fungal tissue, in this case, should be visible on the germinated seed.

Stored seeds can be damaged by fungi, usually as a result of too much moisture. The storage area then smells musty and some fungal tissue can be seen among the seeds. The germination capacity of the seeds usually declines drastically, not so much due to the fungus but due to the presence of moisture, and the biochemical conversions that take place in the seeds as a result.

If all of the plants in only limited parts of the cultivated area are sick, and none in other parts of the field, it is possible that the damage is caused by a soil fungus (or an infestation of nematodes).

The symptoms of a fungal infection can be very similar to those of a bacterial infection. To be sure which pathogen has caused the damage, specific pesticides can be applied. One plant can be treated with the fungicides benomyl + etridiazol. This combination is effective for all fungi. (If these fungicides are not available, use mancozeb, maneb or dithane.) If the plant’s condition does not improve, then the damage was probably not caused by a fungus, but by bacteria. To effectively use fungicides in this way as an analytical tool, it is essential that they be applied early on (thus actually preventatively); and due to the constant threat of infection from the plant's environment, the fungicides should be applied a number of times in succession. In this way you can ensure that the plant will grow for a designated time free of fungal diseases and their symptoms.

If no fungal tissue can be found near the affected area, the presence of a fungus may still be revealed in a laboratory by cutting a 3-15 cm strip from the affected part of the plant and placing it in a plastic bag, similar to the method described in figure 2.2. This can also be a simple cardboard or plastic shoebox, lined with a layer of cotton wool, which has to be kept damp with water. The plastic bag or box top can only be slightly open, so that it stays very damp inside the box or bag. If a fungus is present on the plant tissue, it will manifest itself within a week by developing a significant amount of fungal tissue. This can then be identified under a microscope. Keep in mind that the fungus could be a secondary infection that developed on previously damaged (or dead) tissue. The fungus itself may not necessarily have been the cause of the tissue's death.

Origin and spread of fungal diseases

Fungi produce spore clusters on cultivars and weeds. The spores are disseminated by the wind, water (rain, irrigation), insects and other animals that come in contact with the plant. A disease can also be spread by people, when they use diseased plant material to start a new crop. Infections can thus easily occur.

Climate is an important factor in the development of fungal diseases. Most fungal infections are the result of excessive humidity in the soil, the air, or both. One exception to this rule is powdery mildew that grows in dry periods on apples and grapes. Too much rain leads primarily to leaf diseases (e.g. blister blight in tea, *Phytophthora* in potatoes), while poor drainage promotes the growth of soil fungus.

Chewing or piercing damage by insects gives fungi an extra opportunity to penetrate the plant, where it can then cause rot, especially in fruits. Rot can also be caused by the excrement of caterpillars (borers), such as in the emerging inflorescence at the top of the rice stem. Soil fungi can also penetrate the roots through lesions caused by nematodes.

Soil fungi can be spread through the soil that sticks to the bottom of people's shoes or animals' legs. Root fungi, such as those found in coffee, tea, rubber and cocoa plantations, spread slowly underground via living or dead roots and other dead organic material. These fungi are usually very damaging.

Control

Fungal diseases can be effectively controlled through cultural measures, and, if absolutely necessary, through the application of chemical pesticides. Cultural measures include using disease-tolerant varieties, removal (or pruning) of damaged plant parts, and rotation with crops that are not susceptible to a certain disease. In general, the most successful method is cultivating disease-tolerant crop varieties. Fortunately many resistant crop varieties are already available on the market.

Since fungal tissue and spores are usually located on and not in the plant, the infection and spread of disease can usually be sufficiently prevented by spraying the surface of the leaves and stems with a coating of water-diluted fungicide. Keep in mind, however, that frequent rain storms can quickly wash the fungicide off the leaves. The most effective and cost-efficient way to protect young seedlings is to treat the sowing seed with a (preferably systemic) fungicide. In this way, very little fungicide is needed to protect the seeds. Similarly, disinfecting the soil of germination and propagation beds is also cost-effective because their limited surface area requires only a small application of fungicide.

5.2 Bacterial diseases

Bacteria are one-celled organisms that are only thousands of millimetres in size. They are visible under a microscope, but not with the naked eye. Bacteria do not cause plant diseases as often as fungi, but they can cause severe damage to certain crops. Just as with fungal diseases, bacterial diseases manifest themselves on the leaves, stems, underground parts of the plant and in and on its fruit. There are many kinds of bacteria, but only a few (*Erwinia, Pseudomonas, Xanthomonas* and *Corynebacterium*) are responsible for the most common bacterial diseases in plants.

Figure 25: Damage caused by a bacterial disease

Symptoms

The symptoms of bacterial diseases on plants can look very much like the symptoms of fungal diseases. Stem cankers caused by a bacterial infection, for example, are indistinguishable from those caused by a fungal infection. The lesions are sometimes surrounded by a light-coloured halo, as is the case with fungal damage. However, pustules, rods (spore clusters) or other fruiting bodies, which are characteristic of a fungal infection, are not present with a bacterial infection. Dead spots in the leaf tissue caused by a bacterial infection also often have a more angular outline than those caused by a fungal infection. If at an early stage of infection, angular, dark, oily or damp spots begin to form, especially on the underside of the leaves, there is a good chance that the damage is being caused by bacteria. Later these spots will die off, the whole leaf may eventually turn yellow and then die off completely. Unfortunately, a bacterial infection does not always produce these characteristic leaf spots. The disease may also manifest itself in a different way that also leads to the yellowing, wilting and eventually dying off of leaves and twigs.

Bacterial cancer (*Corynebacterium michiganense*) produces brown streaks on the stem of a tomato plant and 'eyes' on its fruit. These 'eyes' consist of slightly raised round spots with a red centre surrounded by a white ring.

The leaf spots caused by bacterial diseases (as well as fungal diseases) usually begin to develop somewhere on the surface of the leaves, but may also occasionally appear at the edges where damaged tissue is dying off. Bacteria also often fester in the vascular system of stems, roots and leaves, making it more likely for them to spread throughout the plant than for most pathogenic fungi. This results, among other things, in rot within the roots and stems, where the vascular strands become dark in colour. If you cut the diseased parts off, you can almost always squeeze out a creamy white, yellow, orange or dark-coloured slime.

Fruits and stems can be seriously damaged by rot. In general, wet rot, which coincides with the production of a slimy substance, is caused by bacteria, whereas dry rot is caused by fungi. One exception is the dry, cracked warts and cankers found on citrus fruits that are caused by the bacteria *Phytomonas*.

Another symptom of a bacterial infection is long, smooth, parallel, yellowish-white streaks (which are abnormal colour patterns and not spore clusters!) on the leaves of monocotyledonous crops such as rice.

Bacterial infections can also lead to the development of galls on branches and stems of annual and perennial crops; in apple and oak trees (both perennial crops) these growths can even become several decimetres thick. These cause very little damage, however, and generally do not require any control measures.

To determine whether a disease is caused by bacteria, you can soak a sizeable piece of affected leaf or stem material in clear water in a transparent bottle or jar (do not use too much water). If the water becomes cloudy after about an hour due to exuding slime, the plant most likely has a bacterial infection.

Another way to distinguish between fungal and bacterial diseases is to apply a specific pesticide. If symptoms do not disappear after treatment with a combination of the fungicides benomyl and etridiazol, the infection is probably caused by bacteria.

Origin and spread of bacterial diseases

Bacteria have one or more flagella (hair-like appendages) with which they can propel themselves, as long as they are located in a thin layer of water. Unlike fungi, whose spores germinate and can then penetrate the plant's intact skin, bacteria almost exclusively infect the plant through weak spots, such as leaf scars, stomata and lenticels (small pores on the surface of stems and roots), and wounds. These can be caused, among other things, by insects, scratches made by thorns, nematodes, human handling of the plant (e.g. pruning) or other mechanical injuries. Bacteria in the soil can penetrate the plant through root lesions, caused for example by nematodes.

Bacteria are everywhere in the air and on objects. They are transported by human activity, shoes, the legs of insects, or the movement of dust. In many cases, such as with *Xanthomonas* sp. in cotton, bacteria and their diseases are spread (aside from through the introduction of contaminated seeds) in the field through the splash of raindrops and irrigation. Since plant-pathogenic bacteria often move through the whole plant via its vascular system, they can also infect the seeds. Once sown, infected seeds can introduce the disease into a new crop.

Control

The control of bacterial diseases consists primarily of taking preventative sanitary measures: disinfection of the seeds and cutting tools, with Lysol for example, removal of weeds that can serve as hosts, covering pruning injuries and disinfection of the soil. Disease control is also aimed at controlling insects that could carry a disease to the new crop.

If Moko disease is discovered in bananas, the only effective control measure is to remove the entire plants, including their roots. Before planting a new crop, it is best to disinfect the soil with methylbromide. Soil that has been contaminated with bacteria can also be restored through crop rotation. A different crop that is not susceptible to that particular bacterial disease, which is generally one that belongs to a different botanical family, will have to be cultivated on that piece of land for at least seven years. Another way to disinfect the soil, aside from the application of chemicals, is solarization.

If there is a high risk of bacterial disease, the seeds should be treated with a chemical agent before being planted. In the past, mercury compounds were used for this purpose. These are now outlawed in most countries because of their toxicity, and only copper-based agents are used, although these are not always effective. To prevent black arm disease (*Xanthomonas malvacearum*) in cotton, the cotton seeds are soaked in sulphuric acid, which also effectively disinfects the seeds. To prevent bacterial diseases in tomato and paprika, the seeds are soaked for 30 minutes in water that has been heated to a temperature of 50-56° C (see Agrodok No. 17).

Bacterial infections on plants can be controlled to some extent by spraying them with chemical agents, in the manner described for fungal diseases. Keep in mind, however, that most fungicides have no effect on bacteria. The copper compounds mentioned above are the only exception to this rule. Spraying with these compounds affects not only fungi, but also bacteria, at least to the extent that they suppress the bacteria's growth. Considering the usually 'systemic' presence of pathogenic bacteria inside of plants, it is not surprising that an exclusively external application of a disinfectant cannot possibly be 100% effective.

The most effective and simplest way to avoid problems is to buy only bacteria-free plant material from a trustworthy supplier, and to grow only disease-tolerant varieties (which are now available for many crops).

5.3 Viral diseases

Figure 26: Typical damage caused by a viral disease

A virus is a sub-microscopic pathogen with a protein structure that is not visible with the naked eye. By rapidly multiplying itself in living plant cells, the virus can damage the host plant and considerably reduce its production, to the great detriment of the farmer or gardener. A virus infection is often spread by insects that pierce and suck. The damage caused by the virus is then usually much greater than the mechanical injury caused by the insect.

Symptoms

Normally plant tissue damaged by a viral disease does not die off immediately. It therefore does not display any necrotic spots or areas. The most important symptom of viral infections is the light (white or yellow) colour of the leaves or a mosaic pattern of light and darker shades of green on the leaves. Larger spots (sometimes in an oak-leaf pattern) can also appear within which a 'rain-stripe' pattern (with multiple yellow or pale green, narrow, parallel lines and bands) is visible. The spots that form the mosaic pattern can be angular (bordered by the leaf's veins), or rounded and sometimes even ring-shaped. The latter example usually involves a soil virus. The leaf veins often also become lighter in colour, appear waxy and have a thin, darker-coloured streak on either side (i.e. 'vein-clearing'). The Psorosis virus in citrus trees causes their bark to die off and separate above the bud union with the lower trunk. Gummossis then often occurs as well.

In many cases, viral disease leads to dwarfed growth, rosette formation or other strange stem and leaf abnormalities. Rice, for example, can take on a grassy appearance as its leaves become small and thin. Cocoa can develop a type of 'witches' broom' appearance, in which many small branches grow closely together. Leaf curl in cotton causes deformation of the edges of the leaves, which become curled, wavy or contorted as some parts of the leaf grow faster than others. The same effect can be seen on fruits (e.g. citrus fruits), which develop shallow grooves, bulges, or other irregularities on their surface.

The symptoms of viral infections are often not found everywhere in a cultivated field as is usually the case with fungal or bacterial diseases. It is almost always possible to find a number of plants that show no signs of the disease. Surprisingly, even a plant that is thoroughly infected with a viral disease may only show symptoms on one part, such as one half of a leaf.

Abnormal (lighter) leaf colour, abnormal leaf and stem shape, dwarfed growth and mosaic patterns on leaves can, however, be signs of a nutrient deficiency as well as a viral infection or nematode infestation. A viral disease cannot be diagnosed with any certainty at first glance or without laboratory tests. The best approach in this case is probably to conduct a few simple tests to determine whether the anomaly could be caused by a nutrient deficiency or nematode infestation. This can be done by spraying a nutrient solution of micro- and macro-elements on the affected plant and applying a nematicide to see if this brings about any improvement in the plant's condition. If not, then it is indeed likely that the damage is caused by a viral infection.

Origin and spread of viral diseases

Viruses are usually spread to crops by insects (vectors) that have sucking mouth parts, especially aphids, plant hoppers and white flies, but other insect orders and families can also be responsible. These insects can come from the direct vicinity or from far away. The infamous tristeza virus in citrus trees is spread by an aphid that can be

Figure 27: White fly (25x)

carried hundreds of kilometres by air currents. The infection can thus come from distant places, especially places where typhoons occur. Viruses can also be spread by human hands that have come in contact with an infected crop or product. The tobacco mosaic virus is an example of a disease that can be spread in this way. This can sometimes be spread to tobacco plantations through the hands of workers who have rolled cigarettes with infected tobacco. Vegetatively propagated plant material can also spread viruses. Soil viruses can be spread by nematodes and certain soil fungi.

Some varieties of a crop can carry a virus without being significantly damaged by it. The farmer may not even notice that the disease is present until it spreads to a different, more susceptible variety, where it does cause serious damage. Only then is the presence of the virus clearly evident.

Control

Plants that show symptoms of a viral disease have to be removed from the crop and destroyed as soon as possible. If a virus is spread through seeds, it can sometimes be neutralized by soaking the seeds in warm water. Viruses cannot be treated with chemical agents. The most important way to prevent a viral infection is to use virus-free seeds and plant material. It is possible, however, to control the vectors (insects, nematodes) by applying chemicals, or often by adhering to strict periods during which a susceptible crop, or another botanically related crop, is not allowed to be cultivated on a particular field or during a particular period.

It is very difficult to disinfect soil that has been infected by a virus. The best approach is to cultivate crops that are not susceptible to that particular virus, or to initiate a fallow period during which the soil can receive a great deal of sun exposure. Improved, virus-resistant varieties are often available on the market. Using these varieties is the easiest way to prevent viral infections.

6 Nematodes

Nematodes are very thin eelworms that are no more than 2 millimetres long and therefore barely visible with the naked eye. They live in the ground, and spread from there to plants. A nematode infestation is extremely difficult to control.

There are many types of nematodes that parasitize hundreds of different crops. They damage these crops from the outside, via the roots, or they penetrate the plant and damage it on the inside. Based on how far they penetrate into the plant, nematodes can be divided into two groups: those that only push their heads into the plant's roots, and those that enter the plant through its roots and penetrate all the way up to the stems and leaves.

Nematodes have piercing mouth parts with which they suck the plant's sap. This can lead to a significant decrease in the plant's productive capacity; but even greater damage can result if viruses or fungi enter the plant through the injuries caused by the nematodes and then proceed to make the plant sick. Root knot nematodes produce galls on the roots that are 1-20 mm in diameter, and thus visible with the naked eye. Mature females are pear-shaped, white and 0.5-1.0 mm long, and are either embedded in the galls or protrude from the roots.

Nematodes multiply faster as the temperature increases. Reproduction increases substantially above 20°C and reaches its peak at 28-30°C. One female can lay hundreds of eggs. Nematodes are more at home in humid than dry soil, but they are not fond of anaerobic soil conditions, resulting for example from floods or irrigation. They also prefer sandy soils over clay soils.

Symptoms

If you discover an area in a cultivated field where part of the crop is clearly lagging behind in growth, the plants are lighter in colour, and their leaves are abnormally shaped, but do not show signs of a mosaic pattern, you should suspect a nematode infestation.

The decaying process caused by nematodes progresses slower in trees and shrubs than in annual plants. But even in perennials the infestation is soon visible in the leaves: they grow slower, are lighter and yellowish in colour, and fall off sooner (premature leaf drop). Twig dieback may also be evident in the branches. Infected fruit trees will also produce inferior fruit.

Most nematodes are found in roots and stems, but a less common type is also found on leaves. These can cause necrotic spots in the leaves, which are usually bordered by the leaves' veins and therefore may look more like symptoms of a fungal or bacterial disease than a nematode infestation.

A nematode infestation of the roots can be recognized by the numerous rotten spots on the roots caused by secondary fungi that have penetrated the plant via injuries caused by the nematodes. These rotten spots develop initially only in the bark, but eventually the whole root can become rotten. Plants affected by nematodes show signs of water stress (wilting) earlier than healthy plants. Nematodes can kill annual plants.

How can you determine whether a plant is affected by a nematode infestation or a disease? You could treat the damaged plants with a systemic nematicide. If the symptoms disappear, you can assume that nematodes were responsible, although secondary infection by other pathogens might have occurred. Another method is also used in laboratories to detect nematodes. Pieces of roots, stems or leaves from an affected plant are placed in a glass tube filled with water. Any nematodes present will come out of the plant material and can then be viewed and identified under a microscope.

Origin and spread of nematodes

Many plantations and gardens are already contaminated with nematodes. They spread to uninfected terrain usually through the introduction of infected plant material, dumping or loss during transportation of infected plant residues, or the transfer of soil carried on the shoes of people or the legs of animals from an infected parcel. Nematodes can also be spread by rainwater run-off. On their own, nematodes can move only very slowly through the soil, no more than a few metres per year. The infestation and its symptoms thus usually begin in a small, limited part of the cultivated area.

Control

Once a nematode population has established itself in a certain area, it is very difficult to eradicate. All possible measures have to be taken to prevent the infestation from growing and from spreading to newly planted crops. Nematode-free plant material has to be bought from trustworthy suppliers, and any plant material originating from another source has to be carefully examined (by professionals if possible) to detect any symptoms of nematode infestation before it is planted or grafted in a new crop. Nematode-resistant varieties and resistant root stocks of trees and shrubs are available on the market.

Efficient crop rotation of annual crops is an important preventative measure, as well as controlling weeds that can serve as host plants for the nematodes. A nematode-susceptible crop should only be cultivated once every three years on the same field.

Seed beds and nurseries for perennial crops are often sterilized with steam or chemical pesticides (many of which also kill insects and fungi in addition to nematodes). Nematicides are often injected by machine into the soil. However, some nematicides are water soluble and therefore easier to use. A solution of water and nematicide poured over the soil under a tree or shrub will be carried further by irrigation or rainwater into the root zone where it can have an effect. This can be done either before or after planting. As long as the correct type of nematicide is applied, it should not have any harmful effects on the tree or shrub.

Infected plant material in a banana tree (which develops in the form of a large bulb) can be freed of nematodes by soaking it in water that has been heated to 55 °C or that contains nematicide.

7 Nutrient deficiencies

7.1 Deficiency symptoms

If growth abnormalities are discovered that do not appear to be related to one of the pathogenic organisms described above, they could have been caused by a shortage of one or more of the 13 chemical elements that plants absorb from their root medium, which is usually soil. Since these elements are indispensable for normal plant growth, they are called nutrients. A shortage of one or more of these nutrients can seriously hamper the plant's development and substantially decrease its production.

Nutrients are almost always absorbed by the plant in ion-form (as cations or anions). Plants are not capable of absorbing organic compounds, aside from the simplest compounds, such as urea. For any particular crop, the symptoms caused by a deficiency of one element are usually clearly different from the symptoms caused by a deficiency of any of the other 12 elements. A shortage of nitrogen (N), for example, shows up as a yellowing of the leaf (chlorosis), a shortage of potassium (K) by a dying off of the leaf edges, and of magnesium (Mg) by a yellowing of the leaf tissue between the lateral veins. A complicating factor is that the symptoms of deficiency for some of the other elements can vary in different types of plants. For example, the symptoms of a manganese (Mn) deficiency in cotton are different from those of the same deficiency in citrus or peanut crops.

Once an observer has concluded that the symptoms found on affected plants are due to a nutrient deficiency, the next step is to determine which of the 13 nutrients is lacking and thus responsible for the growth anomaly. It is important to know that the deficiency symptoms of some nutrients are limited to the older leaves of a plant, whereas those of other nutrients are found primarily on the younger leaves. This difference is caused by the differences in mobility of the nutrients within the plant. A mobile nutrient, such as potassium (K), can be easily transported within the plant from older to younger tissue. If a plant is growing in soil that cannot supply a sufficient amount of K for the entire growing season, the plant will not suffer very much at first. However, as the plant grows, the available potassium in the soil will eventually be depleted. To continue the growth process in the younger parts of the plant, the growing points will withdraw K from the older leaves. As a result, the older leaves start to show signs of potassium deficiency, while the young leaves look healthy. Premature dying off of older leaves usually leads to a reduction of crop yield.

If the soil contains an insufficient supply of a less mobile nutrient, such as zinc (Zn), the young plant will again not suffer initially. However, as the plant continues to grow, the younger parts of the plant will not be supplied with a sufficient amount of zinc. Since zinc cannot be transported easily within the plant, the newly formed leaves cannot withdraw zinc from the older leaves. As a result the younger plant parts begin to show symptoms of zinc deficiency.

Deficiency symptoms are not always visible in only the younger or only the older parts of the plant. In the case of an N deficiency, for example, the symptoms are visible throughout the plant. If the deficiency is severe, all of the plant’s leaves will become light-green to yellow in colour. However, in general, deficiency symptoms are more common on older than on younger leaves.

If the deficiency is slight, the symptoms may only be recognizable to someone who has a lot of experience with that particular crop. However, even if the discolouration of the leaves is barely visible, the process of photosynthesis will be less than optimal, resulting in a reduced yield.

Normal symptoms of senescence on leaves can look similar to the symptoms of certain nutrient deficiencies, even if the plant had a sufficient supply of these nutrients during its entire active growing period. This is especially true for magnesium (Mg). Research on nutrient deficiencies should therefore be conducted during the middle of a growing season and not at the end.

Proper identification of a nutrient deficiency often requires a lot of experience with the crop in question. Leaf discolouration and deformation can be normal for certain plants, even if they have had an appropriate and sufficient supply of nutrients. Since these are not signs of a deficiency, they will not result in a reduced yield. If the plant is one of the crops that are widely cultivated around the world, a handbook may be available with colour photographs of its various deficiency symptoms, which can be very helpful to farmers. The most common deficiency symptoms for the various nutrients are described in Appendix III.

7.2 Causes

Absolute deficiency

We speak of an 'absolute deficiency' when the supply of a nutrient present in the direct vicinity of the roots (usually in the soil) is insufficient to allow the plant to develop optimally. Deficiency symptoms are usually discolouration and dying off of leaves or parts of the leaves. In less severe cases, the leaves are only smaller than normal, which will nevertheless also lead to yield loss.

Absolute nutrient deficiencies commonly occur in poor tropical soils, which often lack the capacity to retain nutrients and thus to prevent them from being washed out due to run-off caused by heavy rains. In this case it is preferable to use water-soluble fertilizers in split applications, rather than all at once. This reduces the risk that a large portion of the fertilizer will be lost due to leaching shortly after it is applied.

Induced deficiency

It is also possible that sufficient amounts of nutrients are present in the soil, but that the plants are not able to absorb them due to unfavourable chemical or physical soil characteristics. This situation is called an induced shortage. The most common factor responsible for an induced deficiency is an unfavourable soil-pH. A pH value higher than 7 indicates an alkaline soil reaction, in which some nutrients, such as phosphorus (P), iron (Fe) and manganese (Mn), are relatively insoluble and are therefore unavailable to plants. At a pH value of 4, for example, the soil has an acidic reaction, which makes molybdenum (Mo) insoluble and therefore unavailable to plants. If such acidic soils happen to also be rich in iron (Fe) and/ or aluminum (Al), soil or fertilizer phosphates can be tied up by these metals, thus making them unavailable to plants.

In such cases, the deficiency is not caused by an absence of the nutrient in question, but by a physical condition of the soil. A sufficient amount of the nutrient is present in the soil, but it cannot be absorbed by the plant. Adding more of the nutrient in the form of fertilizer will not produce desired results if the restricting effect of the pH factor that induces the deficiency is not alleviated first. This can be done by altering the pH of the soil in the desired direction. A pH value of 5-7 is the most favourable for plants. To increase the pH value of acidic soils, liming materials are needed. Adding calcium to acidic soils is often enough to relieve problems in plants related to the supply of molybdenum (Mo) and/ or phosphorus (P).

It is more difficult to lower the pH value of soils that are too alkaline. In such cases, it can be useful to add an acidifying nitrogen fertilizer, such as ammonium sulfate. Making the root environment less alkaline by adding this fertilizer can improve the solubility and thus the availability of nutrients, such as iron (Fe) and manganese (Mn). For optimal plant nutrition, the problem of an unfavourable soil pH can be circumvented by spraying the deficient nutrients in a water-soluble form directly on the leaves. This technique is known as ‘foliar fertilization’. More information on this technique is given in the following sub-sections.

A nutrient deficiency in a plant can also be caused by the application of an excessive amount of another nutrient. An excessive application of a K-fertilizer, for example, can lead to symptoms of Mg deficiency in the plant, even if sufficient Mg is available in the soil moisture in the root zone. This phenomenon is know as ‘K-induced Mg deficiency’. It could be that K and Mg penetrate the roots of the plant with the help of common carriers. If too much space on the carriers is taken up by K, this can restrict the absorption of Mg. Another form of induced nutrient deficiency can occur in highly organic soils. In peaty soils, copper (Cu) is unavailable as it is strongly bound to organic matter.

Finally, it is also possible that the addition of a high (and possibly excessive) dosage of an N-fertilizer stimulates the vegetative growth of a crop, to such an extent that the soil cannot supply sufficient amounts of the other nutrients needed to support the extra growth. This is known as an N-induced deficiency.

7.3 Treatment

If symptoms are observed on plants that indicate a possible nutrient deficiency, it is best to take representative soil samples from the affected field and have these analysed by a soil testing laboratory. The results of the soil tests will indicate which nutrients are lacking in the soil, and which should be added to achieve optimal growth of the crop.

If this procedure cannot be followed, or if the farmer has a strong idea which nutrient is lacking, he or she can add that element directly by applying the right fertilizer. The fertilizer has to be spread evenly and in the correct dosage over the entire field. If there is good reason to expect that the nutrient will be immobilized in the soil, the farmer can try to prevent this by applying the fertilizer in a row in or on the soil close to and along the row of plants. In a rainy climate, it is advisable to apply the fertilizer in split applications as mentioned above. The total dosage is then divided into two or three parts that are applied during different growth stages of the plant. In this way the farmer can reduce the risk that a large portion of the fertilizer will leach through the soil too soon and be lost due to heavy rains.

If a shortage of trace elements (i.e. micro-nutrients) occurs as a result of high or low soil-pH levels, it is normally not effective to apply these trace elements to the soil. The nutrients would be tied up in the soil. In such a case, it is preferable to spray the nutrients in liquid form as a mist over the crop. It is important that it does not rain soon afterwards, because this would wash the nutrients from the leaves. To prevent the leaves from scorching, the concentration of the nutrient in the liquid must not be too high. For the same reason, application in full sunlight must be avoided. In such cases it could also be advantageous to split the fertilizer application.

More information on increasing or decreasing the soil-pH to improve the availability of certain nutrients is given in section 7.2: induced deficiencies.

7.4 Surplus of certain elements

A surplus of nutrients, usually metals, can also cause growth anomalies and damage in plants. Low soil-pH values (< 4.2) can make Mn, Al, Fe and Cu so soluble that plants take up too much of them and begin to show signs of poisoning. The leaves can turn grey and start to wilt. These symptoms are less characteristic than the symptoms of nutrient deficiencies. The best way to remedy such a situation is usually to apply calcium to the soil.

Ferralsols (poor clay soils) are common in the tropics. They naturally contain a high amount of (poorly soluble) iron (Fe^{3+}). The first time the soil is inundated for the cultivation of lowland rice, a portion of the trivalent iron is reduced to the more soluble divalent iron (Fe^{2+}). The concentration of Fe^{2+} in the soil then becomes too high, which leads to obvious symptoms of poisoning in the young rice plants. However, the symptoms disappear after a few weeks as the Fe^{2+} is flushed through the root zone by the percolating water.

8 Other, non-parasitic, causes of crop damage

In addition to pests and diseases, crop damage can also be caused by burning, lightning strikes, drought, too much water, extreme humidity, wind, a shortage of light or air, or exhaustion. The symptoms can be similar to those caused by a fungal or bacterial infection or a nutrient deficiency.

Burning can be caused by the sun or a large fire in the vicinity, but it can also be caused by the application of too-high concentrations of chemical pesticides or the leaking of ammonia onto the leaves. Plants, shrubs or trees can look weak, or even die, if they become exhausted due to an over-production of fruit or if they are transplanted at the wrong time. This is particularly dangerous in the spring, when the plants have used all of their reserves to produce shoots and fruits. Pruning at that time can also cause irretrievable damage. Coffee shrubs planted without shade at an altitude too close to sea level will produce too much fruit. They become weak, susceptible to root fungi, and eventually die after a few years unless extra fertilizer is applied on time. Direct and intense sun exposure can also cause branch cankers and damage to fruits. For example, on tomatoes a hard green or yellow crust can develop on the side that has been exposed to the sun. Cracks can also develop on ripe tomatoes and bell peppers if the soil moisture fluctuates too much. Some leaf discolouration caused by a shortage of light may only be recognizable to someone who has had extensive personal experience with that particular crop. But even if the discolouration is only barely visible, the process of photosynthesis in the leaves will be less than optimal, resulting in a reduced yield. In a very dense tree canopy, for example, branches can become weak and die off, because of a shortage of sunlight. This problem can be easily remedied by appropriate pruning.

If in a certain area only part of the crop has been damaged, while the rest is still healthy, you can probably assume that the damage was not caused by a parasite. You can be even more certain of this conclusion if nearby plants belonging to different botanical families and orders show the same symptoms. Identifying the cause of crop damage requires good judgment: the gathered data have to be combined to form a logical picture that will often point to one or another specific cause.

A few examples will help illustrate this idea. When looking at leaf abnormalities in a cotton crop, the author of this booklet initially suspected that the damage was caused by a viral disease. But the fact that these abnormalities were only found in a part of the cultivated area, where field workers had begun to spray an insecticide, made him think twice. Further research revealed that the spray plane still had an extremely small amount of 2,4-D hormone weed killer from a previous spraying in its piping system when it released the first load of insecticide. This was the cause of the leaf abnormalities, which eventually disappeared on their own.

In another cotton field, the plants had pale, light-green leaves, which looked like symptoms of a nutrient deficiency. The same symptoms could not be found in an adjacent, higher field. After questioning the field workers, the author learned that the affected field had been irrigated too often. As a result, insufficient oxygen was present in the soil to ensure healthy nitrification of the applied ammonia fertilizer. The problem was therefore not related to the uptake of nitrogen, and it was easily solved by introducing longer irrigation intervals.

A third example has to do with a cotton field sown on ridges. Through furrow irrigation, the ridges became completely submerged in water. By the time the water had receded, a crust had formed in the soil on top of the ridges. The young seedlings were restricted in their growth by a lack of air and they were yellow and red in colour. They recovered after the ground on the ridges was raked loose so that the plants could breathe again.

9 Exercises

This booklet deals with the identification of crop damage and thus also the proper interpretation of the symptoms. Identifying crop damage is not an easy task. Study, experience and practice are all required before anyone can become an expert in this field. The cases presented below can be used as a practical exercise and as a way to test your own insight. The keys in the appendices can be used to help answer some of the questions. The answers are provided below.

Which pathogens caused the damage to the plants in the following examples?

1 A plant has a yellowish, mosaic-like discolouration. It is smaller than other adjacent plants that do not have these symptoms, and its leaves are somewhat deformed. No necrotic spots are evident.

2 Holes with ragged edges are present in the leaves. No dead tissue is visible. The rest of the plant looks healthy.

3 The leaves of a plant curl downwards and they look somewhat shriveled. The plants and the leaves are otherwise normal in size.

4 More or less round spots are visible on the leaves. The leaf tissue is dead inside the spots. Between the spots and the healthy leaf tissue, concentric rings of varying shades of brown can be seen.

5 A plant looks pale and is lagging behind in growth, along with about ten other plants in its vicinity. The plant's roots show many rotten spots and small nodules.

6 The leaves on a type of cabbage have increasingly large dark-brown, angular spots. From the underside of the leaves, these spots look oily or water soaked. The leaves eventually turn yel-

low and fall off. The disease is spreading to other plants located downwind during a rain shower.

7 A tomato plant has wet rot in its stem. The leaves are wilting and dying.

8 Rot is evident on the base of a vegetable and some whitish fungal tissue is visible.

9 The leaves of lettuce plants that touch the ground are turning brown and dying.

10 A turnip has wet rot. Moisture is oozing from the tuber.

11 Cabbage leaves have dry, brown, necrotic edges.

12 Scab is present on potatoes and apples.

13 A tree has large woody galls on its bark.

14 A cabbage plant had large galls on its roots.

15 A tree branch has a dead area on which pustules with violet-pink powder can be seen.

16 A plant has dwarfed growth in its vegetative parts. The leaves do not look damaged, but they are greenish-purple to bronze-coloured.

17 In germination beds, some of the seedlings are bent over close to the ground. The stems had become very thin and dark brown at the points at which they snapped.

18 The same symptoms are found as in number 17, but the stems appear to have been bitten off.

19 The leaves are relatively small but undamaged; they are uniformly pale, and yellow to purplish in colour. The symptoms appear first on the older leaves and then spread upwards in the plant.

20 A twig with leaves wilts and later dies off. No spots are evident on the leaves. If the twig is cut off, a dark slime oozes from the cutting edge.

Answers to the exercises:

1 A virus.
2 The plant has most likely been chewed by an insect.
3 An infestation of insects (usually sucking insects such as aphids or jassids) on the underside of the leaf.
4 A fungal disease.
5 Nematodes.
6 A bacterial disease.
7 Bacterial rot.
8 A fungal disease (probably caused by a soil fungus).
9 A soil fungus.
10 Bacterial rot.
11 Bacterial or fungal rot
12 A fungal disease
13 Crown gall caused by a bacteria: *Agrobacterium tumefaciens*.
14 A fungal disease (*Plasmodiophora brassicae*).
15 A fungal disease.
16 Phosphorus (P) deficiency.
17 A soil fungus.
18 Cutworm (butterfly or beetle larvae, which can be found in the soil around seedlings)
19 Nitrogen (N) deficiency.
20 Bacterial infection.

Further reading

The Diagnosis of Plant Diseases, by R.B. Streets; 1972; University of Arizona, Tuscon. ISBN 0-8165-0350-8.

Handbook of Tropical and Sub-tropical Horticulture, by E. Mortensen & E.T. Bullard; 1970; USPGO, Washington.

Pests and Diseases in Tropical Crops Vol. 2 - Handbook of Pests and Diseases, by D.S. Hill & J.M. Waller; 1988; Longman, London; ISBN 0-582-60615-2

Complete Guide to Pest Control, With and Without Chemicals, by George W.Ware; 1988; Thomson Publications, Fresno. ISBN 0-913702.

Controlling Crop Pests and Diseases, by Roslyn Rappaport; 1992; 106 p.; Macmillan, London. ISBN 0-333-57216-5.

Pests, Diseases and Disorders of Garden Plants, by Stefan Buczacki & Keith Harris; 2000; Photo guide. Harper Collins Publishers, London. ISBN 0 00 22 0063 5.

Practical lessons. Crop protection teaching in warm climatic zones; 2000, published by STOAS, P.O.Box 78, 6700 AB, Wageningen, The Netherlands.

Pests, diseases and nutritional disorders of the common bean in Africa, A field guide, by D.J. Allen, J.K.O. Ampoto and C.S. Wortmann; 1996; CIAT, CTA, ISBN 958-9439-55-1.

Fundamentals of plant pathology, by D.A. Roberts and C.W. Boothroyd, 1984; W.H. Freeman and Company, USA; ISBN 0-7167-1505-8.

Agrodok No. 29. **Pesticides: compounds, use and hazards**. Agromisa/CTA.

Natural crop protection in the tropics; letting information come to life, 2001, by Dr. Gaby Stoll, CTA, No. 1005, ISBN 3-8236-1317-0.

Useful addresses

HDRA
Henry Doubleday Research Association, Ryton Organic Gardens, Coventry, Warwickshire CV8 3LG, United Kingdom.
www.hdra.org.uk (advice on organic production of vegetables)

CABI Bio-sciences
Bakeham lane, Egham, Surrey, TW20 9TY, UK
www.cabi-bioscience.org, plant.clinic@cabi.org
Offers a free identification service.

CABI Africa Regional Centre
PO Box 633, ICRAF Complex, Village Market, Nairobi, Kenya
arc@cabi.org

CABI South-East Asia Regional Centre
PO Box 210, 43409 UPM Serdang, Malaysia, searc@cabi.org

Natural History Museum
Cromwell Road, London, SW7 5BD, UK
www.nhm.ac.uk/Science (Insect identification service)

IITA
International Institute of Tropical Agriculture
P.O.Box 5320, Ibadan, Nigeria

IBPGR
International Board for Plant Genetic Resources
Crop Ecology and Genetic Resources Unit
Food and Agriculture Organisation of the United Nations
Via delle Terme de Caracalla, 00100 Rome, Italy

CIAT
Centro Internacional de Agricultura Tropical
Apartado Aereo 6713, Cali, Colombia

ICRISAT
International Crops Research Institute for the Semi-Arid Tropics
Patancheru 502324, Andhra Pradesh, India

Glossary

Anaerobic	Describes the absence of oxygen, usually due to an absence of air.
Chelates	Organic compounds, usually containing iron or copper.
Cotton bacteriosis	Bacterial disease in cotton plants.
Ferralsols	Soils that have been severely washed out by rain and that contain almost nothing more than iron and aluminium hydroxide.
Fructification	The formation of fruits, fruiting bodies, seeds or spores.
Furrow irrigation	An irrigation method in which water is made to flow between the rows of a crop. The ridges upon which the crop was sown are supposed to remain dry.
Galls	Round or irregular-shaped growths of plant tissue, usually caused by a small insect within the gall, or by bacteria.
Infestation	Initial infection by disease pathogens, or the entrance of the first insects or other pests, which then rapidly multiply.
Leaf miners	1-2 mm long worms that bore tunnels in the leaf tissue.
Monocotyledon crops	Crops, such as grasses, characterized among other things by narrow leaves that have parallel veins. These are distinguishable from dicotyledon or 'broad-leafed' crops, which usually have net-like veins.
Necrotic	Dead, died off.
Pathogenic	Disease-causing.
Predation	Killing by animal organisms that feed on their prey.
Reduction	The loss of oxygen or the addition of hydrogen.
Residual effect	Effect of the residue of an applied pesticide.
Solarization	Exposure to the effects of sunrays.

Systemic	Spread throughout the plant by the plant’s sap circulation.
Vector	Usually an insect that, because of its mobility, spreads a disease (usually a virus).
Host plants	Plants, other than the cultivated crop, upon which insects or diseases can thrive.

Glossary of chemical abbreviations:

Al = aluminium
Ca = calcium
Co = cobalt
Cu = copper
Fe = iron
K = potassium
Mg = magnesium
Mn = manganese
Mo = molybdenum
N = nitrogen
P = phosphorus
Zn = zinc

Appendix 1: Identification based on general symptoms

Table 1: Identification of group of damage-causing agents based on general symptoms

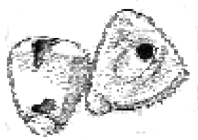
		Symptoms	Damage-causing agents
1	A	Irregular-shaped areas of plant tissue that have been chewed off of a plant part.	Chewing by insects, snails or other animals.
	B	No chewed areas, just spots on the leaves.	Go to 2
2	A	Spots containing dead leaf tissue.	Fungus, bacteria or nutrient deficiency. Go to 3
	B	Spots that do not contain dead leaf tissue.	Virus or mineral deficiency. Go to 4
	C	Pale discolouration of leaves.	Mineral deficiency or nematodes. Go to 5
3	A	Spots, occasionally surrounded by concentric rings. Mycelium or spore clusters are visible. Uniform damage throughout the crop.	Leaf fungus. (Yellow spots between leaf veins and darker vascular bundles = vascular disease). Rhyzomorphs present if root is affected.
	B	No improvement after application of fungicide. A sample placed in clear water causes the water to become cloudy.	Bacteria
	C	Tissue die back on leaf edges. Appears only in later growth stage of crop.	Mineral deficiency
4	A	Dwarfed growth; crooked growth and curling of stem and leaves; often mosaic pattern on leaves; some individual plants in the crop may have no symptoms. No improvement is visible after application of nematicide or nutrient solution.	Virus
	B	White or yellow leaf spots, often between the veins and in a mosaic pattern. Leaf veins are often light-coloured. Improvement is visible after application of a nutrient solution.	Mineral deficiency
5	A	Limited growth; leaf distortion may be visible; leaf discolouration (to light-coloured); plant reacts positively to application of nematicide.	Nematodes
	B	No improvement after application of nematicide, but an improvement is visible after application of an N-fertilizer.	N deficiency
The numbers in the far right column refer to those in the first col-umn			

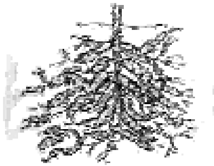
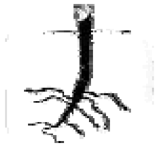
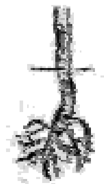
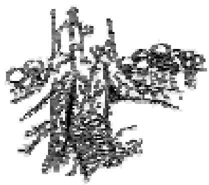
Appendix 2: Identification based on affected plant parts

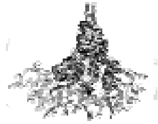
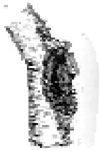
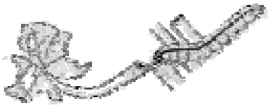
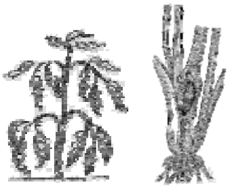
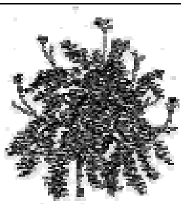
Where is the problem located? Go to:

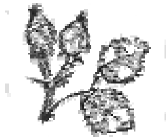
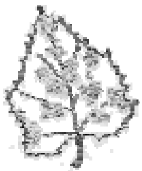
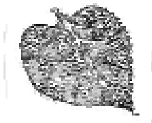
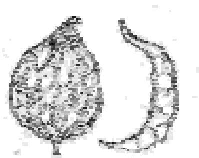
1 Seed
2 Roots
3 Stem
4 Leaves
5 Flowers
6 Fruit
7 Post harvest
8 Growth anomalies

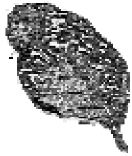
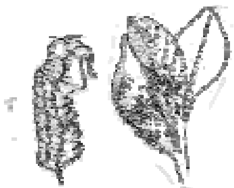
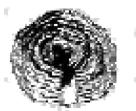
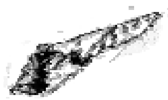
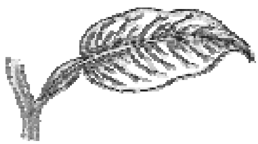
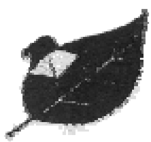
Table 2: Determination of the causes of crop damage based on the affected plant part

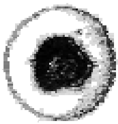
Symptoms	Illustration	Possible causes & remarks
1 Seed		
Discolouration		Seed-borne infection by fungi, bacteria or viruses. – Do not use discoloured seed.
Chewed or holes in seed/grain		Weevils, grain borers or rodents. – Dry seed until it contain only 10% moisture.
Poor or no germination		Seed too old, soil-borne diseases, conditions during germination not optimal (too wet or too dry) or herbicide damage. – Perform germination test on clean sand to test viability of seed before sowing.
Seed rot in soil		Post-emergence damping off (soil-borne disease). – Avoid sowing in wet conditions and improve drainage.

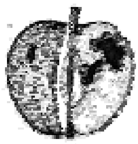
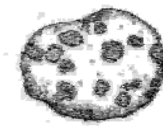
Symptoms	Illustration	Possible causes & remarks
2 Roots		
Root knots/nodules on roots		Nematodes or beneficial nitrogen-fixing nodules. – Nodules are recognised by a pink colour inside.
Black, often thread-like roots		Soil fungi, water logging. – Improve drainage.
Chewing damage visible on roots		Insects, centipedes, other animals. – Check for presence of insects, etc.
Lesions on roots		Nematodes, soil fungi
Mycelium (web of fungal threads) visible on roots, or between bark and wood		Root rot caused by fungi. – In perennial crops the plants can be made more resistant by applying fertilizers or providing shade.

Symptoms	Illustration	Possible causes & remarks
3 Stem		
Galls on stem		Insects, bacteria. – Slice gall open, sometimes the larvae of insects are visible.
Canker		Fungi, bacteria. – If bacterial canker, oozing might be present.
Breaking of stem		Caterpillars, ants or other insects. – Check for presence of insects.
Plant wilting and drooping leaves		Fungal or bacterial wilt (soil borne), stem borers. – Slice stem longitudinally to examine the vascular bundles
Seedling falls over		Damping-off caused by soil fungi, insects (cutworm). – If caused by fungi, improve drainage; otherwise check for presence of insects.
Growing tip of plant damaged		Insects. – Check for presence of insects.
Multiple branching (also of twigs)		'Witches broom' which has various causes such as viral infection, mites.

Symptoms	Illustration	Possible causes & remarks
4 Leaves		
Leaf spots		Fungal, bacterial or environmental problem.
Edge of leaf brown		Blight caused by either: a fungal disease, downy mildew, a bacterial disease or K deficiency.
White powdery appearance of leaves		Powdery mildew.
Undersurface of leaves dewy		Downy mildew.
Brown, powdery spots on underside of leaves		Rust (a fungal disease).
Mosaic pattern		Virus, nutrient imbalances.
Vein clearing, banding		Virus, nutrient imbalances.

Symptoms	Illustration	Possible causes & remarks
Curved tunnelling on leaf		Leaf miner.
Holes in leaves		Insect damage, shot hole disease, snails & slugs.
Deformed leaves		Virus, environmental problem like pesticide damage, fungus (peach leaf curl), aphids, jassids, plant hoppers. – Check for presence of insects, especially on underside of leaves.
Leaves are 'slimy'		Soft rot.
Leaf roll		Caterpillars, virus.
Roughness on leaves		Thrips, mites, wind damage from rubbing.
Hard, flat insects on leaves and stems		Scale insects.
Black 'soot-like' layer on leaves		Sooty mould. – Sooty mould is a dark fungus that grows on honeydew left by aphids. – Control insect pests.

Symptoms	Illustration	Possible causes & remarks
5 Flowers		
Blossom rot		Fungal or bacterial disease.
Brown flowers		Frost.
Deformed flowers		Insects, virus, herbicide damage.
6 Fruit		
Cracking of fruit		Irregular water supply during fruit set.
Brown areas on shoulder of fruit		Sun scald.
Brown areas on end of fruit (tomato)		Blossom end rot. – Shortage of calcium.
Hard, flat insects on fruit		Scale insects.
Rough areas on fruit		Scab (bacterial or fungal), insect damage, environmental damage i.e. wind rub.

Symptoms	Illustration	Possible causes & remarks
Black where grain should be		Fungal disease (smut, ergot). – Use clean seed.
7 Post harvest		
Soft fruit/tubers		Soft rot caused by either bacterial or fungal infection. – Only store dry, clean produce.
Mouldy appearance		Fungal infection. – Carefully handle harvested produce; ensure correct storage temperature.
Tunnels in fruit (visible on outside by hole in surface)		Fruitfly, codling moth.
Rough areas on surface		Scab (bacterial or fungal), insect damage, environmental damage, i.e. wind rub. – Damage occurred in field.
8 Growth anomalies		
Dwarfing		Nematodes, viruses.
Only some plants growing poorly		Nematodes, viruses, nutrient imbalances, missed spray, i.e. at end of row.

Appendix 3: Symptoms of nutrient deficiencies

Macro-nutrients

Macro-nutrients are chemical elements that are needed in relatively high concentrations (30-200 kg/ha) for the optimal nutrition and growth of crops. The most common symptoms of nutrient deficiencies are described below. It is important to remember that the symptoms are not identical in all plants. The names of various fertilizers available to eliminate a deficiency of any particular nutrient in the soil are also given below.

Nitrogen (N) deficiency

Nitrogen deficiency in crops can be caused by an absolute or an induced N deficiency in soils. The symptoms are the same in both cases: all leaves, both young and old, are light-green to yellowish in colour. The discolouration is consistent over the whole surface of the leaf.

Extensive experience with a particular crop is needed before a farmer can know what the crop's normal colour is, and thus be able to detect a light form of nitrogen deficiency.

The mineral components of the soil are not a source of absorbable N for the plants. The potential supply of absorbable N in the soil is located only in the organic material. Induced N deficiency can occur when a large amount of organic material with a high carbon content (high C/N ratio) is added to the soil. Microbial growth is stimulated by the high level of carbon, and the resulting increased population of micro-organisms consumes not only the N present in the woody material, but also the N present in any other form in the soil. In the competitive struggle for sufficient nitrogen between the micro-organisms and the crop, the crop will lose.

However, this situation can change with time. Eventually, when the added nitrogen-rich material is finally depleted, the microbial population will slowly die off and return to its original level. During this decomposition process, a large part of the nitrogen that was tied up by the micro-organisms becomes again available for higher plants. Unfortunately, this release can come too late for the crop that was being cultivated when the N-sources were added.

The traditionally well-known N-fertilizer, ammonium sulphate, has an acidifying effect on the soil. This is advantageous for some crops, but not for others. The application of ammonium nitrate and urea has a less acidifying effect. Ammonium nitrate is explosive and must be handled with care. Calcium nitrate and calcium ammonium nitrate do not have an acidifying effect on the soil, but they are more expensive.

Phosphorus (P) deficiency

Leaves of plants suffering from a phosphorus deficiency have a dull-green to almost purplish colour. Such colour abnormalities result in sub-optimal photosynthesis, which decreases the plant's growth rate and its yield. The leaf discolouration is usually more pronounced in the older leaves.

A phosphorus deficiency can also be either absolute or induced. The salts that phosphorus ions form with iron and aluminium in acidic soils, and with calcium in alkaline soils, are poorly available to plants. This is why plants in acidic soils can suffer from Fe- and/ or Al-induced P- deficiencies, and plants in alkaline soils can suffer from a Ca-induced P deficiency. If the soil-pH is brought within the range of 5-7 (by adding calcium to acidic soils, or by adding acidifying N-fertilizers to alkaline soils), the availability to plants of both soil- and fertilizer-phosphorus will improve. Superphosphate {$Ca(H_2PO_4)2.CaSO_4$} and triple superphosphate {$Ca(H_2PO_4)2$} are the most commonly used phosphorus fertilizers. In tropical countries, where most soils are acidic, a positive effect can also be achieved by applying (less soluble and thus slower-acting) raw phosphates. Leguminous plants are especially able to make raw phosphates soluble and thus available.

Potassium (K) deficiency

As explained earlier, the high mobility of potassium in plants causes the symptoms of a K deficiency to appear mostly in the older leaves. The yellow discolouration (chlorosis) begins at the tips of the leaves and then spreads along their edges. In a later stage, this yellow discolouration turns brown, followed by dying-off of the leaves (necrosis). The necrotic leaf edges begin to curl up. Of course, premature dying-off of leaf tissue has a negative impact on the plant and leads to retarded growth and yield reduction.

The most commonly used potassium fertilizers are potassium chloride salts with a K_2O content of 40-60%. The K-40% fertilizer contains KCl as well as NaCl, which is important to certain crops, such as sugar beet, that benefit highly from the applied Na.

For other crops, such as potato, the presence of the chloride-anion is disadvantageous. Potassium sulphate is therefore a better fertilizer for these crops, but it is more expensive.

If it is known or suspected that both extra potassium and magnesium (Mg) are needed, the fertilizer called patentkali, which consists of a combination of K_2SO_4 and $MgSO_4$, can be the best choice.

Crops that are grown for the production of starch or sugar, such as sugar beet or banana, have a high K-requirement.

Magnesium (Mg) deficiency

Magnesium is also relatively mobile within a plant, and the symptoms of a Mg deficiency are therefore also found mostly in the older leaves. However, unlike a potassium deficiency, which causes the discolouration of leaf edges, a Mg deficiency manifests itself as yellow bands between the side veins of the leaf. In a later stage, the yellow discolouration turns brown, followed by a premature dying-off of the leaf tissue between the veins.

As mentioned above, Mg can be applied in the form of the fertilizer patentkali. If a Mg deficiency occurs in acidic soils, the problem can be resolved by applying calcium to increase the pH of the soil. The most suitable calcium fertilizer is dolomite, which is a combination of $CaCO_3$ and $MgCO_3$. Magnesium can also be added in combination with N-fertilizer. The trade name of this product is ‘magnesamon’.

Sulphur (S) deficiency

The symptoms of a sulphur deficiency resemble those of an N deficiency, but a sulphur deficiency is far less common because plants need much less sulphur than nitrogen.

Geographically, S deficiencies occur most often in soils located in the centre of continents rather than along their coastlines. This has to do with the supply of sulphur brought by ocean winds to plants located near the coast. Volcanoes and their emissions can also be an important source of sulphur.

Crops that belong to the family of crucifers, such as cabbages and rape seed, have a high sulphur requirement. Symptoms of a sulphur deficiency are thus particularly noticeable in these types of crops. Various fertilizers contain sulphur as a secondary nutrient, such as ammonium sulphate, superphosphate, potassium sulphate, and potassium magnesium sulphate (‘patentkali’).

Calcium (Ca) deficiency

Since calcium is relatively immobile within a plant, the symptoms of a calcium deficiency appear mostly in young plant tissues.

The symptoms can greatly differ among crops. Bulbs and fruits can develop corky spots. The young leaves of leafy crops can wilt and die off prematurely. The flowers of tomato plants can shrivel and dry up (‘blosson-end rot’). The plant’s shoots and the tips of young leaves can curl up and look frayed. Sometimes the symptoms of a calcium deficiency resemble those of a boron deficiency, or a viral infection.

Absolute calcium deficiencies often occur in plants growing in acidic soils derived from rock containing little or no calcium and/or that became exposed to heavy rainfall, and in acidic peat soils. Calcium deficiency in plants can also be induced by the application of excessive amounts of K-, Mg-, or ammonium-fertilizers.

A calcium deficiency can be remedied by applying limestone materials, or N- and P-fertilizers, for example those containing calcium as a secondary nutrient, such as calcium ammonium nitrate, calcium nitrate, superphosphate and rock phosphates. Calcium fertilizers (particularly dolomite) dissolve more slowly than many other fertilizers, except in extremely acidic soils. It can therefore take as long as a year before the effect of a calcium application can be noticeable in plants.

Micro-nutrients

To grow optimally, every plant requires, in addition to the six macro-nutrients discussed above, much smaller amounts of seven other essential micro-nutrients. The amount of each of these nutrients required by a crop varies from less than 100 grams to a few kilograms per hectare. Most soils contain many times the amounts of these nutrients annually absorbed by plants. But these amounts may be insufficiently available to the plants due to unfavourable soil-pH values, which can negatively influence the solubility of these nutrients.

These micro-nutrients can therefore best be sprayed in dissolved form directly onto the leaves of plants. To prevent salt damage from occurring on the leaves, the concentration of salts in the solution should not be too high. The plants should not be sprayed in direct sunlight or when humidity levels are low. However, if the micro-nutrients are applied in the form of chelates, the concentration can be higher.

Iron (Fe) deficiency

An iron deficiency is almost always caused by soil-pH values that are too high. The young leaves turn uniformly yellow or the veins stand out as green threads on an otherwise completely yellow leaf surface.

The diminished photosynthesis caused by this discolouration leads to growth retardation.

Manganese (Mn) deficiency

The symptoms of a manganese deficiency can resemble those of an iron deficiency, but there are some differences. If a plant is suffering from a manganese deficiency, the transition from green veins to yellow leaf tissue is less distinct, and the yellow colour of the tissue is darker than that caused by an iron deficiency. Moreover, the symptoms of Mn deficiency are not limited to the younger leaves, but can appear in older leaves as well.

Mn deficiencies are usually caused by high soil-pH values, but a high content of organic material in the soil can also be responsible.

Boron (B) deficiency

This deficiency is characterized by abnormal and/ or retarded development of both vegetative and generative growing points. The youngest leaves are often deformed and shrivelled, thicker than normal, and have a blue-green discolouration. In serious cases the plant fails to produce flowers or fruits. If any fruits are formed, they are often small and of poor quality. Other symptoms of boron deficiency are scaly surfaces and corky external and internal plant parts.

Zinc (Zn) deficiency

No nutrient has a larger variety of deficiency symptoms than zinc. The leaves of plants suffering from a zinc deficiency are too small, which is why this affliction used to be called ‘little-leaf disease’, when its actual cause was not yet known. Internodes are too short so the leaves are forced to grow closely together, in a rosette pattern. Hence the name rosette disease.

In addition to being too small, the leaves are also often irregularly spotted and deformed, making them look as if they have been infected by a virus. Chlorosis between the side veins is common, but the pattern is less consistent than that caused by a Mg deficiency. The leaves can also grow crookedly, when the two halves of a leaf grow at different rates. The leaf edges are often wavy. Shoots die and leaves drop prematurely. Bud formation is very limited, and the few buds that do form remain closed.

Zinc deficiency occurs often in potted plants that grow in almost exclusively organic potting soil. This problem can be alleviated by adding some zinc-containing clay soil to the potting soil.

Copper (Cu) deficiency

Just as with zinc, copper can be so strongly bound to the organic matter in soil that it becomes unavailable to plants. This is why copper deficiency often occurs in peaty soils.

Copper is relatively immobile in the plant and the deficiency symptoms are therefore usually visible in the younger plant parts. In grain, the leaf tips become white, and the leaves are twisted and narrower than usual. As with zinc deficiency, the internodes are too short, which causes the leaves to grow too closely together on the stem. Spike formation often does not occur at all.

In dicotyledonous plants and trees, the side branches are weak, which makes them bend downward.

Molybdenum (Mo) deficiency

Molybdenum availability is often insufficient in acidic soils. Adding calcium can alleviate the problem, if the total amount of Mo in the soil is high enough.

Plants that suffer from a Mo deficiency are often dwarfed. Their leaves are often too light-coloured and wilt prematurely. Flowers are frequently not formed at all.

In leguminous plants Mo deficiency resembles N deficiency. This is probably because Mo is needed for the mechanism by which leguminous plants fix nitrogen from the air in their root tubers. Without available Mo, this nitrogen fixation will not take place. This is why legumes growing in soils that are poor in soil nitrogen can suffer from a nitrogen deficiency despite their nitrogen-fixing capacity.

Chlorine (Cl) deficiency

A few more elements, such as chromium, selenium and cobalt, have been proven to be effective in stimulating the growth of some plants when added in miniscule amounts to nutrition supplements. However, as long as it has not been proven that these elements are required by all plants, they should not yet be added to the list of essential elements. As yet, they can only be seen as 'useful elements'.

There appears, however, to be one exception to this rule. It has been shown that all plants do require a very small amount of chloride. Since the air above the coastal regions of continents, and thus near the oceans, always contains some chloride, it has been extremely difficult to guarantee in experiments using nutrition supplements for plants that the plants did not come in contact with any chlorine. Nevertheless, it has been shown that a miniscule amount of chlorine does have a positive effect on the growth of plants. However, symptoms of Cl deficiency have not yet been detected.

The growth of some crops, such as sugar beet, is not only stimulated by small, but more so by relatively high concentrations of Cl in their root environment.

Appendix IV: Sample Form

For submission of a sample to a Plant Research Station or extension officer the following form can be used. Answer the questions below in as much detail as possible. It will help an expert identify the cause of the problem observed in the crop. See Chapter 2 for instructions on the submission of samples.

Date sample was collected:

Name of grower:

Location of farm:

Altitude:

Soil type: clay/sand/loam/other:

Soil colour:

Fertility: poor / moderate / good

Rainfall: dry / low / moderate / high

Drainage: good / fair / poor

Slope: flat/slight/steep

Crop: Variety:

Area: Date planted:

Planting: field / nursery / orchard / greenhouse / yard / indoor / forest

Affected parts: roots / stems / leaves / flowers / fruit / other:

Symptoms: wilting / yellowing / galls / dieback / rot / marginal burns / leaf drop / leaf spots / streak / mosaic / blight / chewing damage / other :

Distribution: entire field / edge of field / random / single plant / clusters of plants

Exposure: high areas / low areas / wet areas / dry areas / sunny areas / shaded areas / other:

Irrigation: no / yes

What fertilizers have been applied to the crop:

At what rate per hectare?

What pesticides have been applied to the crop:

At what rate per hectare?

Detailed description of the problem: