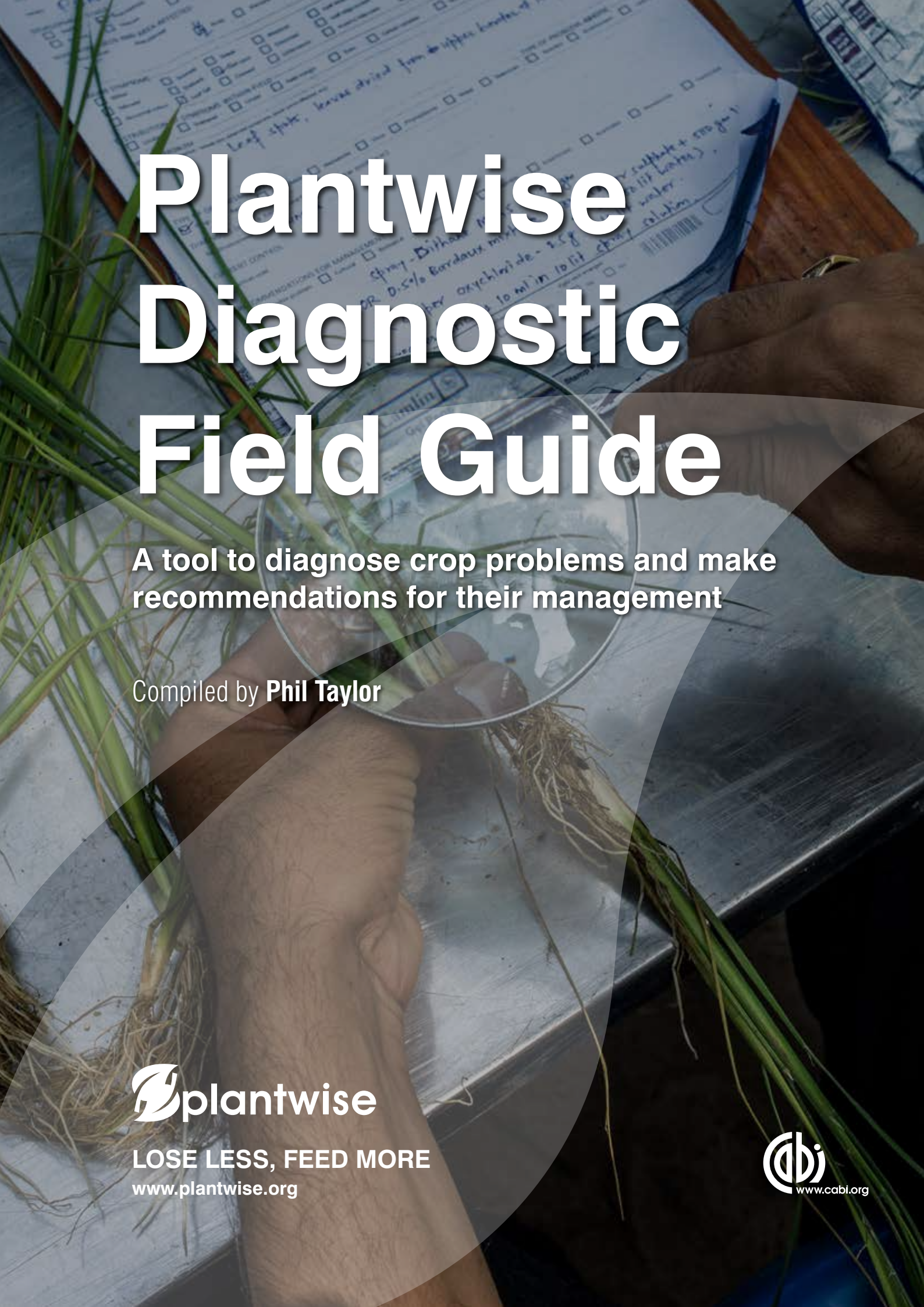

Plantwise Diagnostic Field Guide

A tool to diagnose crop problems and make recommendations for their management

Compiled by **Phil Taylor**

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- Click on a factsheet title to view the factsheet or click 'Home' to begin a new search
- Click back in your browser at any time to return to the previous list

For more information, please contact: plantwise@cabi.org

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Foreword

Continuous advances in global agricultural knowledge and technology have increased food production massively, but there are several factors that make it difficult for farmers to maintain yields and produce high-quality food. Plant health problems are an ongoing issue for farmers due to pest outbreaks (pathogens, insects, rodents, weeds, etc.), climate change (e.g. unpredictable rainfall), the decline of many natural resources (e.g. poor soils) and limited access to important inputs (e.g. plant protection products, water). When farmers encounter new or unfamiliar plant health problems they need support.

Plantwise is an innovative global programme, led by CABI, which aims to connect farmers to the services and information they need to maximise yields and improve the quality of their crops. Working in close partnership with relevant actors, Plantwise strengthens national plant health systems from within, enabling countries to more effectively develop sustainable solutions in agriculture. This approach initially focuses on establishing sustainable networks of local plant clinics, owned by national partners and run by trained plant doctors, where farmers can find practical plant health advice. Plant clinics are reinforced by the Plantwise knowledge bank, a gateway to online and offline actionable plant health information, including diagnostic resources, pest management advice and pest data for effective global vigilance.

The establishment of plant clinics with national partners improves the frequency and quality of interaction between advisory services (extension) and farmers. Plant doctors receive requests from farmers to diagnose diverse crop problems and to provide management recommendations. At the same time, plant doctors are gathering data from the field that can stimulate action by different members of the plant health system to investigate and solve the crop problems that farmers have.

As plant doctors play such a critical role in giving advice to farmers, it is important that they are selected from existing extension and/or plant protection services and have the right knowledge for the job. The Plantwise programme tries to ensure that they are equipped with the basic resources they need to run a simple, yet effective, plant clinic. Plantwise facilitates the training of plant doctors through two short courses that encourage the trainees to think about the general principles of diagnosing plant health problems and giving good advice. To support plant doctors in their work, a variety of information tools, such as the online Plantwise knowledge bank (freely available at www.plantwise.org) and offline documents, are produced through the programme to improve the quality of diagnoses and crop management advice given.

The *Plantwise Diagnostic Field Guide* is an important companion document for plant doctors running plant clinics. It provides images and short descriptions, which make it a useful resource for plant doctors at the plant clinic, but it also contains additional information that plant doctors can absorb during quieter moments. Furthermore this diagnostic field guide is a handy resource for anyone wanting to learn more about how to diagnose plant health problems and to explore the kinds of challenges with which plant doctors commonly have to deal.

The *Plantwise Diagnostic Field Guide* contains content that is the result of years of concept development and field testing, involving a number of CABI staff and partners around the world. The actual creation of this work was the result of tireless efforts by Dr Phil Taylor, with significant support from Dr Matthew Cock. It is important to also recognise the many others within CABI who provided content and feedback on earlier drafts of the document. Finally, this type of resource would not be possible without the strong support from the Plantwise donors.

Dr Ulrich Kuhlmann
Plantwise Programme Executive

Preface

The *Plantwise Diagnostic Field Guide* is intended for all plant doctors and other plant health advisors around the world. The job of being a plant doctor is not an easy one. Since farmers can bring any crop with any type of problem to a plant clinic, there are many different kinds of plant disorders that a plant doctor will be asked to diagnose and give advice on. It is not possible for a plant doctor, or anyone else for that matter, to be an expert on all crops and all plant health problems. This diagnostic field guide is designed to provide support to agricultural advisory staff as a field tool to assist in diagnosis of plant health problems prior to making management recommendations.

Since 2011, the Plantwise programme has been developing locally adapted information materials to support plant doctors, recognising that it is not always easy to obtain useful and up-to-date information about plant protection and production. These information materials are available both online (Plantwise knowledge bank) and offline (in the form of both digital and printed documents). Furthermore, Plantwise emphasises the importance of information networks to make sure that plant doctors and others involved in agriculture are connected to the right people to get the information and services they need. Much of the work that Plantwise does is based around strengthening linkages among plant health system stakeholders, such as extension, research (including diagnostics), policy, input supply and, of course, the farmers themselves.

Although the *Plantwise Diagnostic Field Guide* supplements training Modules 1 and 2 on 'How to become a plant doctor', it is not intended to be a manual for use in the plant doctor training courses, nor is it a substitute for taking the modules. The Plantwise plant doctor training courses have been designed with a discovery learning approach to get participants thinking about the broad principles of symptom diagnosis and giving good advice, as well as providing a detailed introduction to the operation of a plant clinic. Therefore, attendance at Modules 1 and 2 training is considered an important minimum requirement prior to operating a plant clinic as a plant doctor. Moreover, it is very important that candidates for plant doctor training should already have considerable experience and knowledge in plant health.

The plant doctor training modules contain only limited information on the biology of pest organisms because the aim of the training is to raise awareness of the diverse causes of plant disorders and to stimulate participants to think logically and critically when diagnosing plant health problems and giving appropriate advice. In contrast, this diagnostic field guide contains more information on the biology of the pest groups mentioned in the training. It is written so that most sections of it could be helpful to a plant doctor at a plant clinic. More information on diagnosing plant health problems and methods for maintaining healthy crops can be obtained through various knowledge resources that may be available, such as pest management decision guides, factsheets and other extension materials, text books, and Internet tools such as the Plantwise knowledge bank.

It is hoped that plant doctors[1] and others dealing with plant health problems will find this diagnostic field guide useful in the years to come.

Comments on the *Plantwise Diagnostic Field Guide* are welcome. To provide feedback, please send it in an e-mail to the following address: **plantwise@cabi.org**.

Dr Phil Taylor
Compiler, *Plantwise Diagnostic Field Guide*

[1] Plant doctors: the name plant doctor is widely used in many countries but not all. For those countries that have adopted Plantwise but use different terminology for the operators of plant clinics, please read this document mentally replacing 'plant doctor' with the chosen terminology of your country.

Acknowledgements

Any publication of this nature builds on the work of others. The Plantwise approach and some of its training materials grew from an earlier CABI-led project, the Global Plant Clinic, funded by DFID to provide a diagnostic and advisory service for crop protection in developing countries. Under Dr Eric Boa's leadership, the plant clinic concept was developed and tested from about 2002 with support from Jeffery Bentley, Solveig Danielsen, Rob Harling, Paula Kelly and Robert Reeder.

Dr Phil Taylor was responsible for developing the *Plantwise Diagnostic Field Guide* and he must be thanked for his enthusiasm and dedication to complete this book project. Special thanks must go to Dr Matthew Cock (editing and reviewing, entomology inputs), Dr Wade Jenner (editing and reviewing, plant clinic insights) and Dr Robert Reeder (reviewing, pathology inputs, pictures).

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Individuals who have made photographs available, either directly or via the Internet, include, Kalule Okello David (NaSARRI,Uganda), Yubak Dhoj (Department of Agriculture, Nepal), Paul Van Mele (Agro Insight) and Scot Nelson (University of Hawaii).

The diagnosis of mineral deficiencies has been enormously improved by the use of information and illustrations from Prakash Kumar and Manoj Kumar Sharma's *Nutrient Deficiencies of Field Crops: Guide to Diagnosis and Management* published by CABI in 2013.

Organisations that have made pictures available either directly or via Creative Commons license on the Internet include The Bugwood Network (www.bugwood.org), CIMMYT and Wikimedia Commons (http://commons.wikimedia.org/). Individual and corporate photographers are acknowledged with each photograph.

The Plantwise programme has been funded through a consortium of donors and their support has made it possible to prepare, print and distribute the *Plantwise Diagnostic Field Guide* to the plant doctors worldwide.

Many thanks to all who have injected energy and ideas into this publication.

Ulrich Kuhlmann
Plantwise Programme Executive

INTRODUCTION

One of the focal activities of the global Plantwise programme is to support local agricultural advisory services (extension and plant protection organisations) in establishing plant clinics. Based on the human health care system with doctors, medical clinics, prescriptions, etc., a plant clinic is a place where farmers can meet with local plant health advisors, called 'plant doctors', to get management advice for their crop problems. Farmers might ask for assistance on many different kinds of problems concerning the crops they grow, so plant clinics generally accept 'any problem on any crop'.

Plant clinic sessions are usually held in public places. Farmers attending a plant clinic are encouraged to bring samples of the affected crops from their farms for the plant doctor to inspect. While inspecting each plant sample brought, the plant doctor also interviews the farmer about the crop problem, which helps the plant doctor to understand the nature of the problem on the farm and make a 'diagnosis' (identify the cause). Once a diagnosis is made, the plant doctor can explain to the farmer what should be done to minimise yield loss, and a written recommendation ('prescription') is usually provided as well. It is important that a crop problem is diagnosed correctly because that diagnosis will determine the best plant health management advice to be given in the prescription. The *Plantwise Diagnostic Field Guide* is intended to support plant doctors to make diagnoses by showing relationships between common symptoms on plants and the various possible causes. It also provides a short overview of important principles for giving good advice, which is also underpinned by an integrated pest management (IPM) approach.

This document provides images and descriptions of many typical symptoms (indications that the plant is unhealthy) and signs (observations of pest organisms) associated with biotic and abiotic factors that harm plant health. Among the biotic factors, the major pest groups are represented. Please remember that throughout the *Plantwise Diagnostic Field Guide*, the term 'pests' will refer to all animals, microorganisms and weeds that damage plants. The most common abiotic factors of plant health decline are also highlighted. This diagnostic field guide does not attempt to show all possible symptoms or causes of plant disorders; therefore, it is important to understand the different types of symptoms caused by each factor and to use that knowledge to make a field diagnosis.

This diagnostic field guide consists of 'ready reckoners' (simple information tables for quick and easy reference) that serve as reminders of symptom–cause associations and therefore can assist in diagnosing plant health problems. While several biotic and abiotic factors create characteristic symptoms in plants, many others lead to very similar symptoms. There is also a table ('Potential sources of confusion') that identifies these areas of overlap and provides methods to differentiate between the possible causes.

The *Plantwise Diagnostic Field Guide* concludes with a short section on important points to remember when providing management advice to farmers for crop problems. These few, simple considerations will ensure that each farmer gets the best advice for him or her.

FIELD DIAGNOSIS: A PROCESS OF ELIMINATION

The process of diagnosing a plant health problem without any specialised laboratory equipment is called 'field diagnosis'. This is the situation at a plant clinic and when making a farm visit. Field diagnosis involves careful observation of the symptoms on a plant and linking those symptoms with possible causes. While some plant health problems are relatively easy to diagnose, others can be very difficult for a number of reasons. For instance, there may be multiple factors that cause similar symptoms or the sample provided by the farmer may not show very clear symptoms. As a result, it will often not be possible to make a highly specific field diagnosis, such as giving the name of a nutrient that is deficient or the pest species causing the problem. However, in many cases a very specific diagnosis is not necessary. A diagnosis of a pest group, such as fungus or stem-boring insect, will provide a lot of useful information for developing a good recommendation for the farmer. The precision and accuracy of the plant doctor's diagnosis ultimately depends on his or her knowledge of the crops and crop problems in the area, with additional support from tools like this diagnostic field guide.

> **Precise versus accurate**
>
> These two terms are often used interchangeably but they are different. A precise diagnosis is very specific, perhaps naming a pest species (as opposed to a pest group like virus or mite). An accurate diagnosis is one that is correct.
>
> If someone claimed she weighed 62.64932 kg, that would be very precise but hopelessly inaccurate if she actually weighed 67.5 kg. It is sometimes better to settle for lower precision (specificity) to ensure higher accuracy. In this example about body weight, it would have been far better for the person to have said she weighed about 65 kg.
>
> A field diagnosis of *Fusarium oxysporum* race 4 would be very precise but very inaccurate if the cause was nematode attack. Do not try to be precise unless you can be sure you are also accurate (correct).

The first step in narrowing down the cause of a plant health problem is to determine if the symptoms are caused by a living organism (biotic) or by a non-living factor (abiotic).

Abiotic factors usually affect the whole plant and often (but not always) there is not a defined line between healthy and affected tissue, although exceptions will be discussed later in the section on potential sources of confusion (Table 6). Many abiotic causes of poor plant health are associated with the soil environment (compaction, pH, nutritional deficiencies, etc.). These tend to affect all of the upper parts of the plant since they are all connected to the same root system. Other abiotic factors, such as heat, wind, cold, hail, etc. have direct effects on the above-ground parts of the plant and lead to symptoms that are often distributed symmetrically within the plant and within individual leaves.

The huge variety of pests that attack crops gives rise to a great variety of symptoms. Where the pest is active there may be a clear line between the healthy and the affected tissue, with more general symptoms of stress elsewhere on the plant. Much of the remainder of this field guide provides information on how to link symptoms with cause.

Once the cause of the crop problem has been narrowed down to either a biotic or abiotic factor, it will usually be possible to take the diagnosis to the next level of detail. For biotic causes this would mean identifying the pest group (virus, weed, mite, etc.), and for abiotic causes this would mean determining whether the problem is associated with water, nutrients, temperature or some other environmental factor. It may be possible to take the diagnosis even further, such as naming a specific nutrient that is deficient or naming a type of virus, weed or mite, or even giving a species name.

The more precise a diagnosis is, the better it is because it means that a more specific and effective recommendation can be given. However, making a very precise diagnosis is more difficult (for instance, many pest species look very similar) and the risk of making a mistake is higher compared to making a general diagnosis. Whenever you are unable to provide a full diagnosis to the pest species level or of the specific abiotic factor, make as precise a diagnosis as you can with confidence. As a diagnosis, 'insect' is useful but not particularly informative. 'Maize stem borer' is more helpful and 'Lepidoptera maize stem borer' is better still; however, avoid going further unless you know which stem borer it is because, depending on where you work, it could be one of several species that are difficult to distinguish.

Remember to ALWAYS eliminate all the alternative causes before pronouncing your final diagnosis. Even if you cannot determine the exact cause, a general diagnosis (e.g. pest group) may be enough to provide the farmer with some good advice and a recommendation that will help him or her overcome the problem.

Don't be in too much of a hurry. Slow down, cut open the plant and have a look inside. Use a hand lens to look for fungal fruiting bodies or small insects. Most importantly, talk to the farmer and ask questions relating to what you are looking at and the ideas that are forming in your mind.

It is better to tell a farmer that you are unfamiliar with the problem presented than to make a complete guess at the diagnosis (although be sure to tell them as much as you do know, e.g. what is NOT causing the problem). If you are too cautious you will never make a diagnosis, but equally you should not try to give a diagnosis for a plant health problem if there is not enough information to make the diagnosis. In many cases, the plant sample and information provided by the farmer may not be enough to make a diagnosis, in which case a visit to the farm may be required.

Example: Field diagnosis of spots on leaves

This cashew leaf has leaf spots, which are clearly defined and are all a similar size.

This clear delineation between healthy (green) and unhealthy (tan brown) tissue indicates that there is a biotic cause. If the cause were an abiotic one you would expect to see a much more general yellowing or browning of the leaf without the sharp divide between healthy and unhealthy plant material.

We can eliminate certain biotic causes through a mixture of experience and observation because the symptoms they generally produce do not fit in with the evidence presented.

Robert Reeder, CABI

- This symptom is not caused by insect or mite damage; there is no evidence of chewing, no webbing seen and no presence of insects or mites.
- This symptom is not caused by a nematode, virus or phytoplasma, as these organisms do not cause leaf spots.
- This symptom is not caused by a mammal or parasitic plants or weeds, as there is no evidence of it having been eaten (mammal) or of decline caused by competition by weeds or parasitisation by another plant.
- This symptom could be caused by a bacterial pathogen but you would expect the spots to have a water-soaked margin, to be bound between the leaf veins and generally associated with the edge of the leaf.
- This symptom could be caused by a water mould but the leaf spots are not spreading aggressively (they are all of a similar size), have a clearly defined border and show no evidence of fluffy sporulation. All of these characteristics together indicate that a water mould is not the causal agent.

By the process of elimination it can be concluded that this symptom has a fungal cause. They are known to cause leaf spots with these characteristics. More detailed examination of the material with a hand lens reveals fungal fruiting bodies (arrowed), making this diagnosis definitive.

Field visits

Extension workers often have a limited amount of information available to them, especially if the farmer brought the plant sample to the extensionist: they may have collected the wrong part of the plant or the sample may have deteriorated in transit. It may be necessary to visit the field to see fresh symptoms and to gain other information on the pest. If you intend to send a sample to a colleague or a formal diagnostic support service, it is usually a good idea to visit the field yourself and to select a fresh sample of your own.

The following is a summary of what to do when visiting a field to observe the symptoms in the context of the entire crop. (All of the information gathered would be of interest to a diagnostic support service if a sample were to be sent.)

STEP 1: GET IN CLOSE

- What parts are affected?
- Describe symptoms using the correct terminology.
- Observe changes in shape, colour and growth.
- Look for visible signs of insects, fungi or other pests.

STEP 2: LOOK AT THE WHOLE PLANT (INCLUDING ROOTS)

- Where are the symptoms within the plant?
- Which growth stages are affected?
- How do the symptoms progress from early to late stages?
- How severe is the attack?

STEP 3: EXAMINE GROUPS OF PLANTS

- Incidence: how many plants are affected?
- Distribution: random, edge of the plot only, in patches, pattern caused by use of machinery?
- Remember: consider plant variety, age and how it is grown.

STEP 4: SPEAK TO FARMERS AND OTHER LOCAL EXTENSION WORKERS

- When did the problem appear? Is this the first time?
- Record local name for the problem.
- Consider soil type and climate (patterns).
- Obtain information on the varieties used, recent history of chemical inputs used, etc.

READY RECKONERS FOR PEST IDENTIFICATION

The following tables (ready reckoners) provide a rapid method of linking plant symptoms and signs with possible causes. In order to use the ready reckoners effectively, some experience of diagnosing plant health problems is required by the observer. There is one table for insect and mite pests and one for pathogens, and the latter is then expanded to deal with each symptom group in more detail.

Insect and mite pests

The body shape and general appearance are often sufficient to identify many insects (Tables 1 and 2) to a group level, so no additional text is supplied in this diagnostic field guide.

Plant pathogen pests

As microorganisms are generally not visible, diagnosis is primarily based on symptoms, so additional information (Table 3) is provided focusing on the symptoms that different types of microorganisms can produce.

Mineral deficiencies

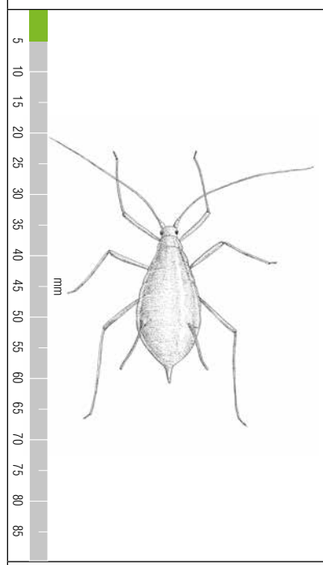
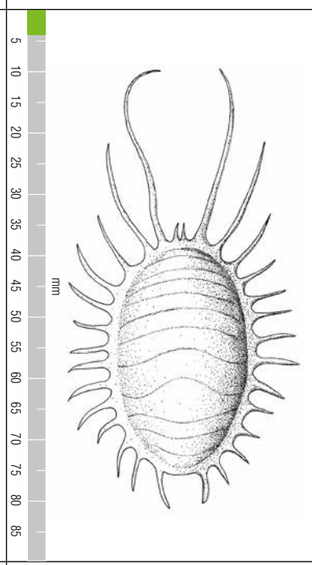
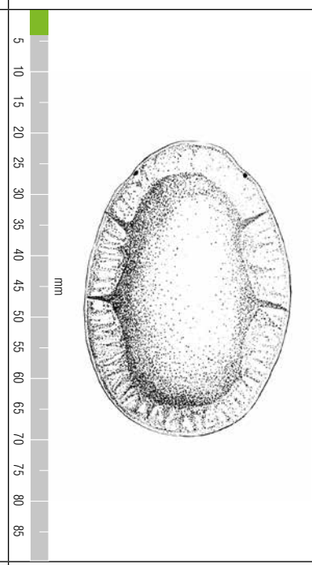
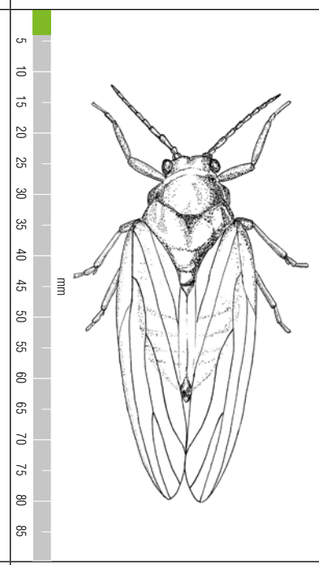
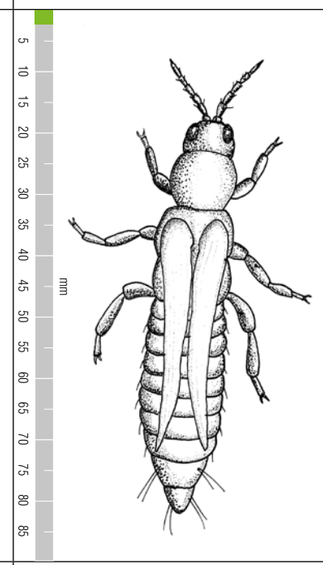
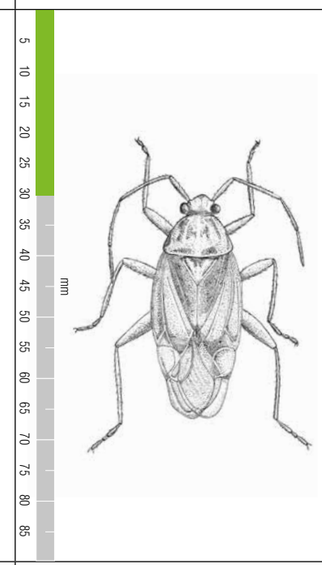
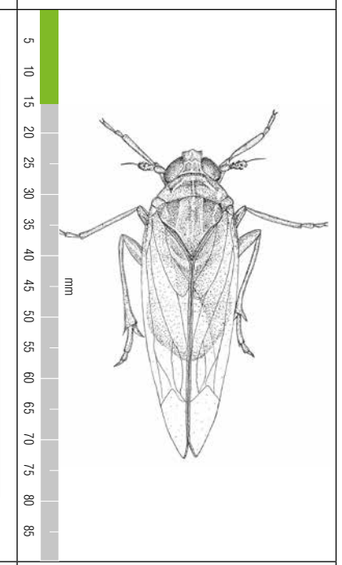
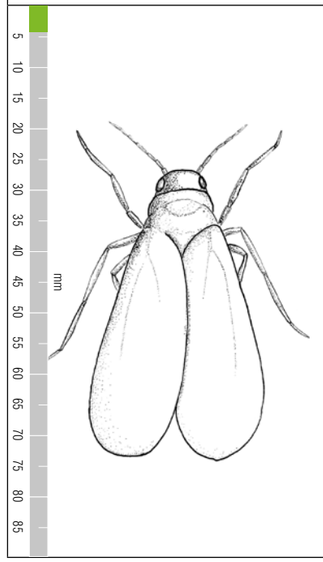
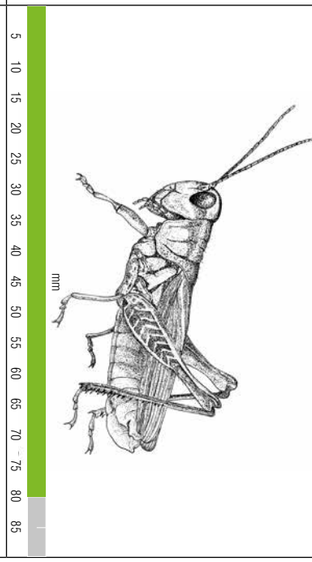
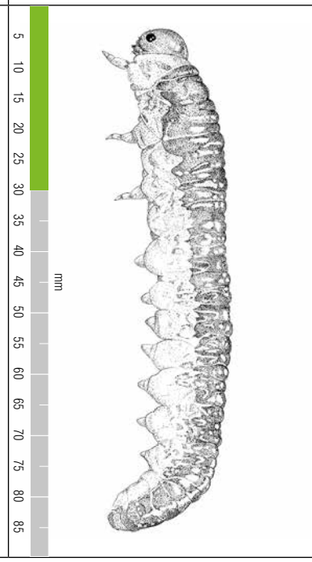
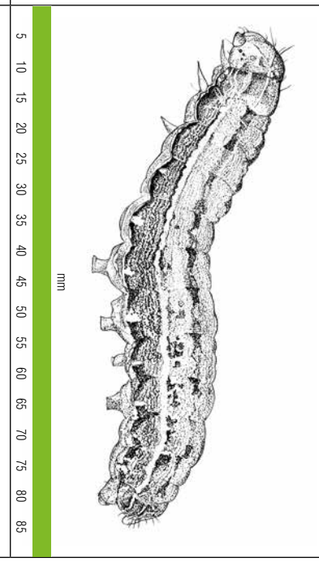
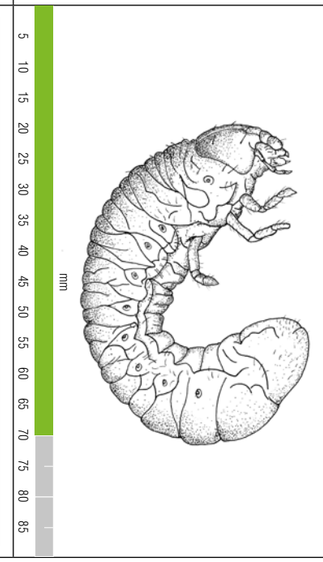
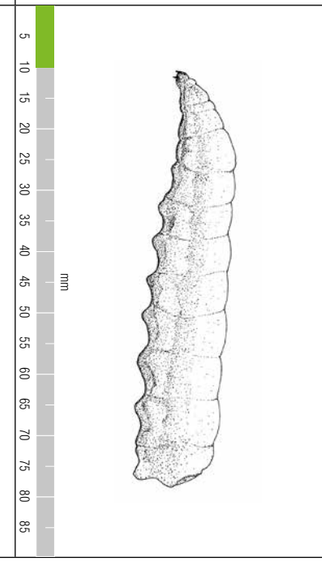
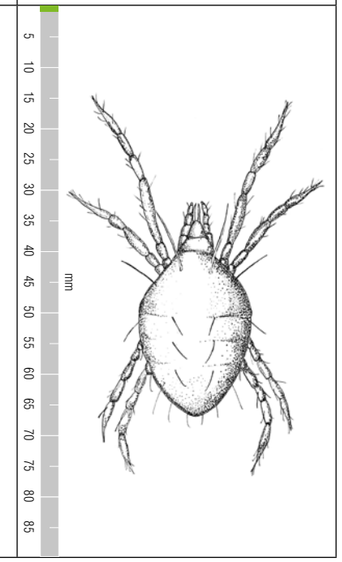
The ready reckoner (Table 4) summarises the major symptoms that many plants show when short (deficient) of a mineral. It provides only general information and shortage of a mineral is just one of many causes that can produce some of these symptoms. Not all crop plants display the same symptoms even when deficient in the same mineral (especially true for zinc). Some plants are more susceptible to shortage of minerals than others (e.g. molybdenum shortage in brassicas). Photographs of mineral deficient plants are provided in Table 5.

It is unlikely that the mineral deficiency will be so acute that the seedlings die (the seed carries limited amounts of mineral). In most cases the shortage is chronic and the plants will survive but show symptoms that can be severe or mild. Chronic symptoms generally include slow growth (possibly stunting) and poor flowering and fruit production (where relevant). Yields can be affected even when symptoms are not seen. The more commonly deficient minerals are listed on the left of the table and the less commonly deficient ones on the right. While field symptoms may be sufficient to provide an accurate diagnosis by an experienced agronomist who is familiar with local soil conditions, it is usually essential to have the field diagnosis confirmed with a laboratory soil analysis. This is especially important if the farmer is intending to spend a significant amount of money or effort on correcting the problem.

Table 1. **Ready reckoner for insect and mite pest diagnosis**

	APPROX SIZE	METAMORPHOSIS DO THE YOUNG LOOK DIFFERENT FROM ADULTS?	ADULTS WITH WINGS (TWO PAIRS EXCEPT AS INDICATED)	EXTERNAL FEEDERS?	LARVA/NYMPH OR ADULT CAUSES DAMAGE	PREDATORY OR PARASITIC GROUPS OCCUR	LEGS OBVIOUS?	BODY SHAPE
APHIDS	2-5mm	No	Some individuals	Yes, but often in curled leaves	Both	No	Yes	Pear-shaped
MEALYBUGS	2-4mm	No	No	Yes, but often in curled leaves	Both	No	No	Oval
SCALE INSECTS	2-4mm	No	No	Yes	Both	No	No	Oval or round
PSYLLIDS	2-5mm	Young look very different	Yes	Yes, except gall-formers	Both	No	Yes	Varied; adults elongate
THRIPS	1-2mm	Paler, but similar	Yes, limited flight	Yes, but often in curled leaves or gall-formers	Both	Yes	Yes, but very small	Elongate
PLANT BUGS	5-15mm	No, but nymphs have reduced or no wings	Yes, forewings more rigid, membranous hind wings underneath are for flying	Yes	Both	Yes	Yes	Varied
PLANT HOPPERS	3-15mm	No, but nymphs have reduced or no wings	Yes	Yes	Both	No	Yes	Tube-like
WHITEFLIES	2-3mm	Yes, similar but lack developed wings	Yes, limited flight mostly within crop	Yes	Both	No	Hidden beneath wings to some extent	Early stages oval; adults with (usually white) wings held at an angle
GRASSHOPPERS AND LOCUSTS	20-40mm	Young (nymphs) resemble adults without wings	Yes, may be strong fliers	Yes	Both	No	Yes	Adults are grasshoppers; young lack wings
WASPS (SAWFLIES)	3-15mm	Yes	Yes	Most wasp pests are gall-formers	Larva	Yes	Yes on adults; usually not on larvae except sawflies	Larvae grub-like
MOTHS (CATERPILLARS)	Larvae 2-35mm	Yes	Yes, strong fliers	Internal and external	Larva	Almost none	Yes on larvae and adult	Larvae are caterpillars
BEETLES (GRUBS)	Larvae 5-30mm	Yes	Yes, forewings form a rigid protective cover, membranous hind wings underneath are for flying; limited flight	Internal and external	Both	Yes	Yes on larvae and adult	Larvae are grubs; adults varied, but have hard forewings (wing-cases)
FLIES (MAGGOTS)	Larvae 2-12mm	Yes	One pair of wings only; can be strong fliers	Pests are internal	Larva	Yes	Yes on adult only	Larvae are maggots
MITES	1mm	No	No, but do parachute on threads	External except gall-formers	Both	Yes	Yes but small	Rounded

Table 2. **Line drawings of the major insect pest groups**

APHID	MEALYBUG	SCALE	PSYLLID	THRIPS	PLANT BUG	PLANT HOPPER
						
WHITEFLY	**GRASSHOPPER**	**WASPS (SAWFLY LARVA)**	**MOTH (LARVA)**	**BEETLE (GRUB)**	**FLY (MAGGOT)**	**MITE**
						

The size of the insect is indicated by the green scale on the left of each drawing. There can be great variation in the sizes between species. Upper limits are generally provided.

Table 3. **Ready reckoner of pest and detrimental environmental conditions based on symptoms**

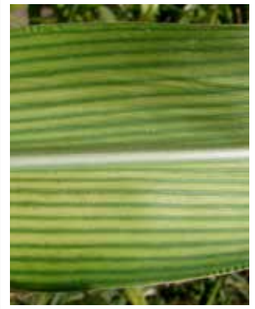
SYMPTOM	FUNGUS	WATER MOULDS	BACTERIA	VIRUS	PHYTOPLASMA	NEMATODE	INSECTS	MITES	MAMMALS & BIRDS	NUTRIENT DEFICIENCIES	PHYSICAL & HERBICIDE
Wilt	**YES** Very common. Usually *Fusarium* or *Verticillium* sp.	**YES** Common. Often caused by root-attacking phytophthoras. Water moulds are a common cause of damping off in seedlings	**YES** Common. Often seen in *Solanaceae,* e.g. *Ralstonia* on tomatoes and cucurbit crops	(NO) although some viruses of tomato, pineapple and broad bean cause wilting	(NO) except one example: Coconut lethal yellowing	**YES** Very common. Seen in a wide range of crops	**YES** Common. The larval stages of stem borers and the larvae and adults of root feeders commonly cause wilts. Not usually associated with sucking insects unless extremely severe	NO	(NO) although mammals and birds that damage the bark of trees or roots can produce this symptom	(NO) but copper deficiency can cause wilting in some plants. Extremely rare	**YES** Very common. Shortage of water (drought) and its excess (waterlogging) are a common cause of wilt as is physical damage to the roots, e.g. through weeding. Some herbicides can induce this effect too
Leaf spot	**YES** Very common, many types involved on a wide range of crops. Rust pustules are included as leaf spots here	**YES** Common. Generally rapidly spreading, may have water-soaked appearance and sporulation around edges. White rusts and downy mildews can produce pustules with little necrosis	**YES** Very common. On many types of crop	(NO) although there are exceptions. Ringspots are more common	(NO) although leaf markings can occur	(NO) but can occur on ornamental plants, do not occur on crop plants	**YES** Not common. Some sucking insects inject a toxin when they feed that can cause necrotic or yellow spotting	NO	NO	**YES** Not common. Necrotic spots on leaves can indicate nutrient deficiencies. Shortages of potassium, zinc, manganese and copper can all lead to this symptom if severe	**YES** Common. Careless spraying with contact herbicides such as diquat can lead to spots. Sunscald can lead to damaged patches often on fruit
Witches' broom (many branches)	**YES** Common. In woody plants only, not so in herbaceous plants	NO	NO	NO	**YES** Very common. Generally associated with little leaf	NO	NO	**YES** Very common. They are usually far too small to be seen even with a hand lens	NO	NO	**YES** Common. Only where plants have grown back after treatment with glyphosate
Canker	**YES** Very common	NO	**YES** Common	NO	NO	NO	NO	NO	NO	NO	NO
Mosaic	NO	NO	NO	**YES** Very common	NO	NO	(NO) although the feeding of tiny insects with piercing mouthparts such as thrips and whitefly can produce a mosaic-like effect	(NO) although as with insect feeding, mites can produce an effect that resembles a mosaic	NO	**YES** Common. The mottling caused by deficiencies of several minerals can produce a mosaic type of symptom	NO
Yellowing of leaves	**YES** Common. Often indicates symptoms or infection in other parts of plant e.g. roots, cankers on stem	**YES** Common. General stress caused by root death often the cause. Downy mildews may create defined yellow patches on leaves prior to the production of the downy spores masses	**YES** Common. A general or non-specific symptom indicating general decline of the plant	**YES** Not common. Mosaics are much more likely, unusual for the entire leaf to turn yellow	**YES** Common. Relatively rare pathogen BUT they do often cause yellowing when they do occur	**YES** Common. A general or non-specific symptom noting general decline of the plant due to root feeding	**YES** Common. A general or non-specific symptom caused by damage to the roots or a general decline in the plant	**YES** Common. Low populations of mites can cause many leaves to turn yellow	(NO) although mammals and birds that damage the bark of trees or roots can produce this symptom	**YES** Very common. Depending on the pattern of yellowing can give an indication of which mineral may be deficient but a definitive field diagnosis is difficult	**YES** Very common. Can be due to a variety of abiotic factors, some herbicides will generate yellow leaves on the treated plant
Distortion of leaves	(NO) although there is one spectacular example and a few others that can produce mild distortion	**YES** Not common. Downy mildews can cause unusually shaped leaves	NO	**YES** Very common	**YES** Not common. Usually associated with witches' broom and little leaf	NO	**YES** Very common. Can be due to feeding damage by sucking insects or leaves rolled by web formers	**YES** Common. Due to the mites damaging the developing leaves	NO	**YES** Not common. Cupping of leaves as well as reduced leaf lamina, can indicate mineral shortage	**YES** Common. Some herbicides induce unusual patterns of growth
Little leaf	(NO) reduced growth should not be mistaken for this symptom	**YES** Not common. Downy mildews can cause leaves to develop severely reduced in size	(NO) reduced growth should not be mistaken for this symptom	**YES** Not common	**YES** Very common. Often considered to be the classic symptom of this group	NO	(NO) reduced growth should not be mistaken for this symptom	**YES** Common. They are usually far too small to be seen even with a hand lens	NO	NO	**YES** Common. Only when plants have grown back after treatment with glyphosate
Galls	(NO) although on woody plants they can occur. Bunts and smuts could be considered galls	NO	**YES** Common. Often at the base of broadleaved plants (not grasses, banana or palms)	NO	NO	**YES** Very common. Swellings appear on root, as well as general distortion of root systems	**YES** Very common. Seen on many types of plant	**YES** Very common. Seen on many types of plant	NO	NO	NO
Drying/ necrosis/ blight	**YES** Very common. Associated with many types	**YES** Common symptom of foliar attacking phytophthoras	**YES** Very common. Associated with many types	(NO) although there are exceptions such as Maize lethal necrosis and Cassava brown streak	(NO) although there are exceptions, this is not a symptom commonly associated with phytoplasmas	**YES** Many types of nematode cause death and decay of the roots but not those that produce galls or cysts	**YES** Common. Stem boring and root eating larvae can cause these symptoms leading to death of the plant	NO	(NO) although mammals and birds that damage the bark of trees or roots can produce this symptom	**YES** Not common. In extreme cases the plants will dry and die prematurely	**YES** Not common on crops. Due to gross misuse of rapidly acting herbicide such as diquat or paraquat

Table 4. **Ready reckoner for common mineral deficiencies**

	Nitrogen (N)	Phosphate (P)	Potassium (K)	Magnesium (Mg)	Manganese (Mn)	Iron (Fe)	Zinc (Zn)	Sulphur (S)	Calcium (Ca)	Boron (B)	Copper (Cu)	Molybdenum (Mo)	Notes
Lower leaves	Pale and yellowing Often fall early	Dark green and dull with a bluish green tint	Light coloured necrotic patches	'Bronzing' and necrosis often with leaf fall	Not so affected	Not usually affected unless severe	Intermediate and mature leaves show symptoms Often seen early in the growth of plants	Affects upper and lower leaves Often more severe in the younger leaves	No effect	Hollowing and rotting of stems in brassicas	No effect	Generally mottled Yellowing cotyledons Remain dark green in brassicas	Lower leaves will naturally yellow and die as they get older due to age and shade
Upper leaves	Generally remain green except in severe cases	Dark green with purpling	Generally remain healthy	Not usually	Yellowing especially between veins White flecks can develop	Yellow at leaf base but remainder of leaf stays green			May fail to expand properly	Small	Small and misshapen May be darker green	Light green and with reduced lamina in brassicas	
Tip of plant	Green	Dark green	Green	No effect	No effect	Bleached yellow	No effect	Pale	Blackened and stunted	Shoot dieback and development of many side shoots Root tips swell	Small, misshapen, wilted Shoot dieback	Necrosis	Stem borers and cold damage
Leaf distortion	No effect	No effect	Leaf rolling in fruit trees	Leaf curling may occur	Frizzle top (stunted and deformed) in palms	No effect	In extreme cases fern leaf or little leaf Small, pointed leaves in fruit trees	No effect	New leaves may stick together and not expand properly Leaf hooking may occur	Leaf curling of young leaves Zig-zag leaf in palms	Leaf curling and cupping Lodging in cereals	Leaf cupping or rolling Appear thicker or whiptail in brassicas (no lamina)	Make sure that no insects or pathogens are at work
Reddening	Occasionally mostly as a sign of stress	Yes	Possible	Can occur especially in cotton if severe	No	Not usually	Possible	No	No	No	No	No	Reddening is common in response to many kinds of stress
Leaf veins	Not different from remainder of leaf	Dark green	Near midrib remain green	Mostly remain green especially close to midrib	Leaf veins remain green but not such a clear distinction as for iron deficiency	Remain green	Remain green/ prominent	Not different from remainder of leaf	No effect	May be more prominent than usual especially in trees	No effect	More prominent due to reduced lamina	
Interveinal regions	Not different from remainder of leaf	Dark green with a bluish green tint	Yellow/necrotic	Yellowing or necrosis		Producing a stark net of green on a yellow background	Yellow/necrotic	Not different from remainder of leaf	No effect	No effect	Yellowing and necrotic patches can develop	See leaf distortion above	
Leaf edges	No different from remainder of leaf	Reddening	Yellow/necrotic	Necrosis spreading from margins of leaf when severe	No different from remainder of leaf	Yellow	Occasionally crinkly or wavy	Not different from remainder of leaf	Necrosis on expanding leaf edges	Fail to expand and curl the leaf	Tips of young leaves withered and white in cereals	Can cause browning	Wind, chemical or salt damage
Plant size	Stunted	Severely stunted; looks like a miniature plant	Shortened internodes	Unlikely to be a major symptom	Small with slender stems	White if severe	Severe stunting can occur	Stunted	Unlikely to be a major symptom	Stunted, shortened internodes	Unlikely to be a major symptom	Stunted	Mineral deficiency will always slow down the growth of a plant but many other things can do this too
Fruit	Small and likely to fall	Generally poor flowering and fruiting Thick rinds in citrus if P/N fertiliser ratio wrong	Poor flowering and fruiting	Quality and quantity reduced	Necrosis with seeds such as ground nut and pea	No different from remainder of leaf	Formation of fruit bud inhibited Fruit is elongated, misshapen and cracked	Small and likely to fall	Necrotic patches within fruit or seeds Blossom end rot in tomatoes and cucurbits	Often do not develop but may be small, misshapen, lumpy, corky and cracked	Flavour, storage and sugar content all affected	Uneven development of grapes within the same bunch	Bitter pit of apple (Ca) and distortion of pawpaw (Bo) common
Necrotic patches	No	No	Light coloured fleck on leaves	Yes between veins often reddish	In severe cases	Unlikely to be a major symptom	Yes	No		Cracks and necrosis of stems Curd of cauliflower can appear brown at edges	Yes they can occur on leaves if severe	No	Typically symmetrical across the mid rib in the case of mineral deficiencies
pH effects pH 6.0-7.5	Not applicable	Not applicable	Not applicable	Less available at low pH and sandy soils	Less available at high pH	Quality and quantity reduced	Less available at high pH	Less available at low pH	Less available at low pH	Less available at high pH	Less available at high pH	Less available at low pH	Agricultural soil should be maintained between these ranges
Likelihood	Very common	Common	Common	Common	Common	No	Common	Common	Common	Rare	Not common	Rare	Locally these deficiencies can be important
Can be confused with	Many types of stress	Young plant	Wind scorch/drought/ leaf spots	Pathogen attack	Pathogen attack	Less available at high pH	Phytoplasma or glyphosate damage in fruit trees Manganese deficiency	Nitrogen deficiency	Fungal infection	Frost damage	Pathogen attack Herbicide damage Magnesium or manganese deficiency	Nitrogen deficiency in legumes	Mineral deficiencies are some of the most difficult symptoms to diagnose
Common in	All crops	Carrot, spinach, lettuce, maize	Potato, tomato, cabbage	Tomatoes	Onion, apple, peas, beans	Common	Citrus	Ground nut, amaranthus	Tomatoes, lettuce	Papaya, brassicas	Wheat, sugarbeet, legumes, sweet potato	Brassicas, legumes	

Note: this table provides general advice with regard to the kind of symptoms that mineral deficiencies produce. There are always exceptions to the rules; some of these are highlighted but there are others that are not mentioned. It is not meant to be a definitive guide but it should provide assistance in the field.

Table 5. **Photographic ready reckoner for the symptoms associated with lack of some common nutrients**

	Nitrogen	Phosphate	Potassium	Manganese	Magnesium	Iron	Sulphur	Zinc
Maize								
Rice								
Pigeon pea								
Castor bean								

These photos show the symptoms of the shortage of various minerals in four different crops. Compare the photographs for each mineral and try and spot the pattern, e.g. the pictures of iron deficiency all appear very different but in each case the leaf veins have remained green contrasting strongly with the yellow lamina. Similarly all of the photos of phosphate shortage show reddening and each of those of potassium shortage show the leaf edge is yellowing and turning brown at the edges. While field symptoms may be sufficient to provide a definitive diagnosis by an experienced agronomist, it is usually essential to have the field diagnosis confirmed with a laboratory soil analysis, especially if the farmer is intending to spend a significant amount of money or effort on correcting the problem. All photos are from Kumar and Sharma *Nutrient Deficiencies of Field Crops*, CABI, 2013, except for rice deficient in manganese and magnesium, which were supplied by IRRI.

The principal symptoms and their causes

The ready reckoners above are single page summaries of the types of insect and mite pests (Table 1) and the symptoms commonly associated with many pest groups and other plant health problems (Table 3). In the sections below we take the symptoms from Table 3, and treat each in turn, providing additional information on the symptoms and their causative agents.

Wilt

Wilt is a very common symptom of plants in distress. Plants rely on the water in leaves and stems to hold them up; without the water the plants will wilt, i.e. the green parts of the plant will hang down limply. Unless water is restored to a wilted plant it will die. The roots or stems or base of the stem may be the affected area of the plant although the symptom will mostly be seen in the leaves. Sometimes it can be just one region of the plant that is affected (indicating a problem in the stem) but more usually the whole plant will wilt. Wilts can be temporary whereby the plant will recover at night but wilt again the next day, this can be normal if the sun is strong and the ground dry but it may also indicate a problem.

SYMPTOM	**FUNGUS**
Wilt	**YES** Very common. Usually *Fusarium* or *Verticillium* sp.
	
Fusarium wilt on banana. Note the internal discolouration that is a common symptom associated with this pathogen. Scot Nelson, University of Hawaii	*Verticillium* wilt on sunflower. Leaves are severely short of water. Upper leaves are wilted and the lower ones are dead. Howard F. Schwartz, Colorado State University, Bugwood.org
Fungi commonly produce wilts in plants by preventing water from flowing up the tubes (xylem) in the stems, resulting in the leaves becoming starved of water. Wilt-inducing fungi are mostly soil borne pathogens and they attack the roots and the base of the stem. There is often discolouration of the xylem. The main fungal groups that produce wilts are *Fusarium* and *Verticillium*. Whereas *Fusarium* can produce a pink colouration inside the stem, *Verticillium* produces dark streaks. Cut the stem open and look for discolouration, making sure you compare it to a healthy plant.	

SYMPTOM	WATER MOULDS
Wilt	**YES** Common. Often caused by root-attacking phytophthoras. Water moulds are a common cause of damping off in seedlings.
 Base of dry bean seedlings having damped off after attack by *Pythium*. Howard F. Schwartz, Colorado State University, Bugwood.org	 *Phytopthora capsici* attacking the roots of capsicum pepper, the plant is severely wilted due to the damage to the roots. Gerald Holmes, California Polytechnic State University at San Luis Obispo, Bugwood.org
 *Phytopthora infestans* attacking the upper stem of tomato. Notice that that the plant is **not** wilting despite extensive damage to the stem. Phil Taylor, CABI	 *Phytophthora katsurae* causing yellowing and wilt. Heart rot of coconut. Scot Nelson, University of Hawaii
Wilt is associated with damping off of seedlings and root-attacking phytopthoras. Damping off occurs where the base of the seedling rots quickly and the plant wilts and dies. It can be caused by a variety of true fungi but *Pythium* (water mould) is often involved as well. Downy mildews and foliar-attacking phytophthoras do not generally wilt plants unless the attack is extremely severe.	

SYMPTOM	BACTERIA
Wilt	**YES** Common. Often seen in *Solanaceae*, e.g. *Ralstonia* on tomatoes and cucurbit crops
 *Ralstonia* on potato. This wilt has occurred suddenly as there are no symptoms other than the wilt. Phil Taylor, CABI	 Internal discolouration due to *Ralstonia* on capsicum pepper. Scot Nelson, University of Hawaii
 The papaya has turned yellow and is severely wilted due to *Pseudomonas solanacearum* infection. Scot Nelson, University of Hawaii	 Capsicum pepper with bacterial wilt. Note the complete collapse of the plant in the foreground relative to the healthy one at the rear. Phil Taylor, CABI
Bacteria are a common cause of wilting in plants. Unlike in the case of fungi (where the cause is usually localised in the base of the stem) bacteria occur throughout the stem and the prevention of water moving up the plant is due to the presence of the huge numbers of bacteria (and the gums they produce) in the water-carrying tubes.	

If you cut open a bacteria-infected stem, as you pull apart the cut ends it is sometimes possible to see strands of gum stretching between the two sides. It is also possible to put the cut stem into still water and observe bacterial streaming (see below). As for fungi they too can produce discolouration within the stem. Bacteria commonly associated with wilting are *Pseudomonas*, *Ralstonia* and *Xanthomonas*.

Bacterial streaming

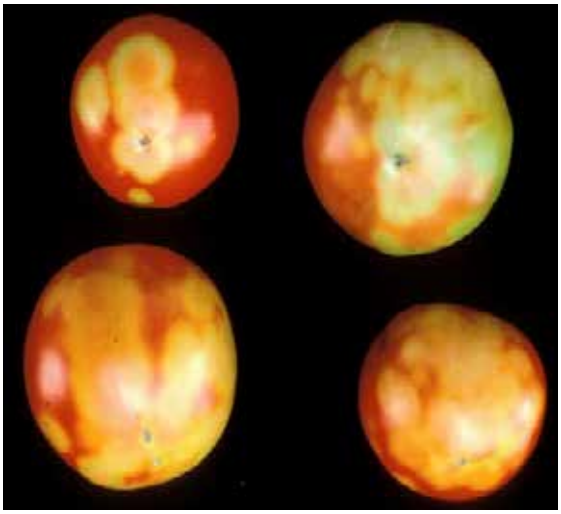
A plastic bottle, a sharp knife and a matchstick are all that are required for the bacterial streaming test. Fill the bottle with clean water and leave it in a place where it will be kept completely still but can be viewed. Cut a 15 cm section of stem with a sharp knife close to the base of the plant. Remove any leaves and put the lower end into the water as shown. Insert a matchstick through the top end so as to hang the cut stem portion in the bottle. Do not disturb the bottle or stem. Put a drop of water on the top cut section of the stem to prevent it from drying out. Observe for bacterial streaming after about 5 minutes against a dark background - you may see thin wisps of white fluid flowing from the cut end of the stem down into the water. These could be the millions of bacteria oozing from the cut stem. Make sure you test healthy stems as some plants produce latex that looks similar to bacterial streaming. Do not disturb the bottle or stem, otherwise the movement of the water will prevent a visible stream of bacteria appearing.

Bacterial streaming in field using a plastic bottle and matchstick.

Phil Taylor, CABI

Bacterial streaming from cut eggplant stem. Thin white wisps of bacterial ooze emerge from the cut stem. The container must be kept still and a black background helps visualise it as it can be difficult to see.

Robert Reeder, CABI

SYMPTOM	VIRUS
Wilt	(NO) although some viruses of tomato, pineapple and broad bean cause wilting.
 Don Ferrin, Louisiana State University Agricultural Center, Bugwood.org	 Scot Nelson, University of Hawaii
Notice the reduced size as well as the wilt of this tomato plant (left) infected with Tomato spotted wilt virus. Symptoms on fruit (right). It is extremely unusual for viruses to cause wilting. There are exceptions, the most common one being Tomato spotted wilt virus. Often the virus will produce other symptoms in addition to wilting.	

SYMPTOM	PHYTOPLASMA
Wilt	(NO) except one example: Coconut lethal yellowing.
This is not a symptom that is usually associated with phytoplasma infection but there is an exception: phytoplasmas reach such high numbers in coconut (Coconut lethal yellowing) that the water-carrying tubes become blocked, causing wilt in much the same way as bacteria do in other hosts. Witches' broom and little leaves are much more typical of this group of pathogens.	

SYMPTOM	NEMATODE
Wilt	**YES** Very common. Seen in a wide range of crops.
Root loss due to nematode feeding causes the plant to be more susceptible to water stress as they are simply unable to take up enough water to replace that lost through the leaves. Nematodes eat the fine root hairs which are responsible for the uptake of water so, even if the roots seem to be mostly intact, the water uptake part of the root system may be missing. Nematodes can be extremely damaging but produce only general symptoms above ground and unless the roots are examined it will be almost impossible to diagnose nematode infection.	

SYMPTOM	INSECTS
Wilt	**YES** Common. The larval stages of stem borers and the larvae and adults of root feeders commonly cause wilts. Not usually associated with sucking insects unless extremely severe.

European corn borer-induced wilt on cotton.

William Lambert, University of Georgia, Bugwood.org

Lepidoptera larvae: the damage caused is an access point for pathogens. Stem borers often have reduced legs and prolegs and may superficially appear like a fly larva (maggot).

IRRI Images

Stink bug damage on tobacco. The insect injects a toxin into the plant causing extensive damage. The leaf is wilted, yellow and showing signs of necrosis.

R.J. Reynolds Tobacco Company, Bugwood.org

Wilt induced by insects is common. It is often the larval stages that cause this symptom, and they may be present in the soil or in the stem. Consider which part of the plant is wilting – is it the whole plant or just a part of it? Split the stem open and look for stem borers. The insect may be providing access for pathogens which rot the plant so when you see a rot, consider whether it is associated with insect damage.

SYMPTOM	MAMMALS & BIRDS
Wilt	(NO) although mammals and birds that damage the bark of trees or roots can produce this symptom.

Many large bark-eating animals can gnaw the bark off trees. They may wilt immediately or this symptom may be seen with yellowing and drying as the plant dies.

SYMPTOM	NUTRIENT DEFICIENCIES
Wilt	(NO) but copper deficiency can cause wilting in some plants. Extremely rare.

Wheat showing wilting and leaf deformity due to copper deficiency.

Dr Prakash Kumar and Dr Manoj Kumar Sharma

SYMPTOM	PHYSICAL & HERBICIDE
Wilt	**YES** Very common. Shortage of water (drought) and its excess (waterlogging) are a common cause of wilt as is physical damage to the roots, e.g. through weeding. Some herbicides can induce this effect too.
Both a shortage of water and too much water (waterlogging) are abiotic causes of wilting. If the wilt is over a large area then consider whether this may be the cause. If wilted plants are close to healthy ones in well watered soil then there is probably a biotic cause.	

Leaf spot

Leaves are exposed to a great range of potentially damaging agents. Once a leaf is damaged a mark of some sort will always remain, not all of these marks are considered leaf spots. A true leaf spot is the site of an infection by a pathogen. It will start small and enlarge with time. It is an extemely common symptom and experience is required to identify the cause. In this section other spots on leaves are included as leaf spots.

SYMPTOM	FUNGUS
Leaf spot	**YES** Very common, many types involved on a wide range of crops. Rust pustules are included as leaf spots here.

Leaf spots of *Venturia inaequalis* on apple in Nepal.

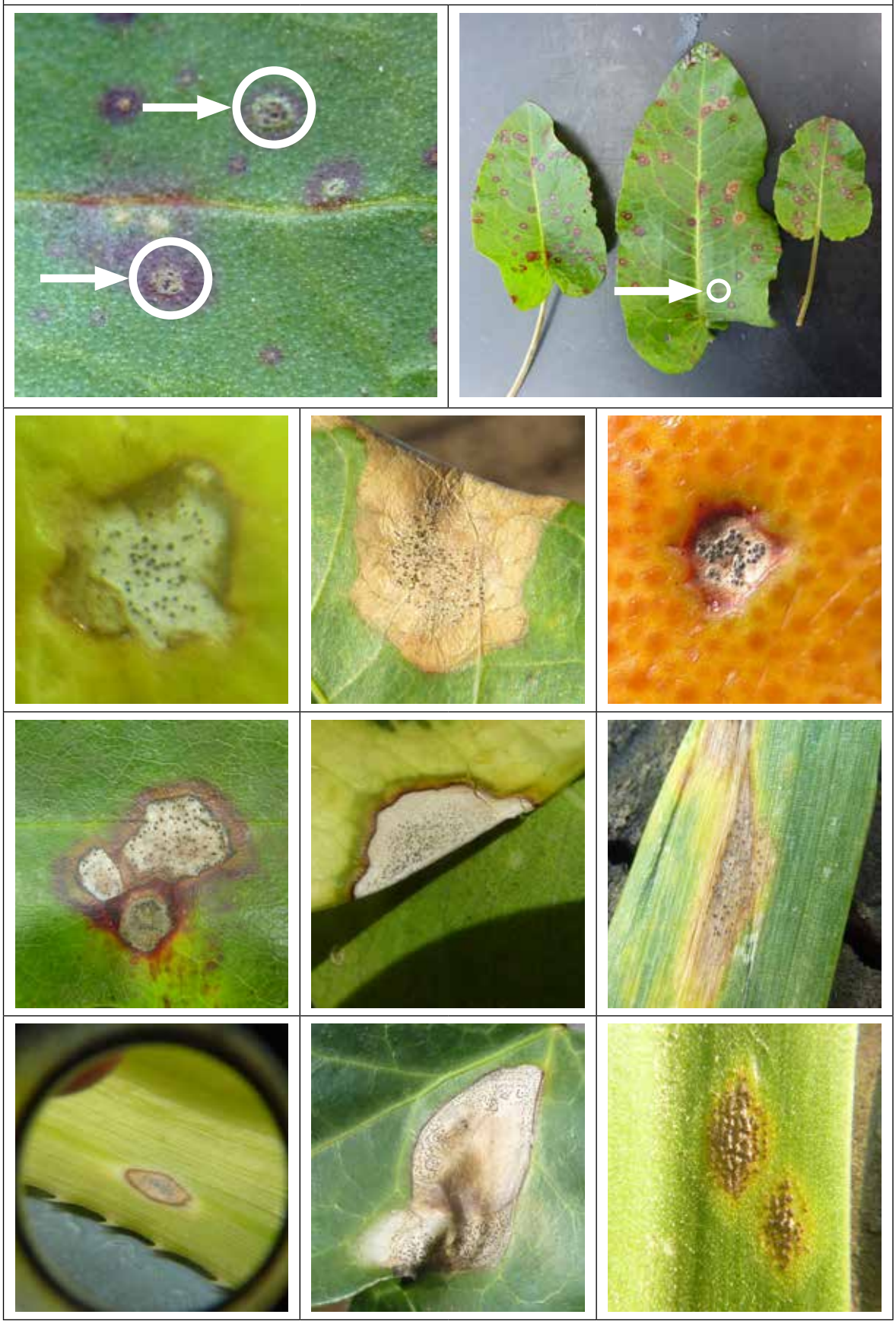
Yubak Dhoj, Department of Agriculture, Nepal

The leaf spot is a classic symptom of many groups of fungi. The leaf is generally unaffected except for the area of the leaf spot and immediate surrounding area. The margins of the leaf spot may be a different colour to the inside. Bacteria and water moulds (see below) can produce similar symptoms. Leaf spots on grasses often turn into streaks because of the geometry of the leaf, i.e. the leaf veins direct the pathogen along the length of the leaf. Fungal lesions will spread but will generally not consume the whole leaf. They appear to reach a certain size and then stop growing; this is not the case for some foliar pathogens, especially *Phytophthora* (a water mould) and bacteria, which can spread aggressively across the whole leaf. An indication that the leaf spots are caused by a true fungus is that they are all of similar size (or go on to grow to a similar size) and the older ones may have fungal fruiting bodies within them (see below). Visible fruiting bodies are not produced by bacteria or water moulds (although water moulds may produce fluffy spores). The fungal fruiting bodies are not always present (even in fungal infections) and are difficult to see with the naked eye but are often visible with a hand lens.

Correct use of a hand lens will enable you to see great detail within a leaf spot (as well as mites and other small pests). Hold the lens close to the eye and move the plant material back and forth until it is in focus (left). The same technique can be used to increase the magnification of a compact camera (right). All the photographs in this section were taken using this technique.

Phil Taylor, CABI

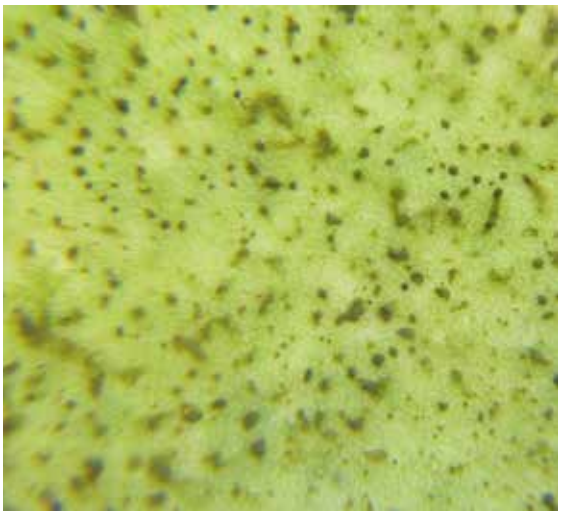
Pictures of fungal fruiting bodies in leaf spots. The presence of the fruiting bodies is a sure indication that the pathogen is a fungus, but if they cannot be found then this does not mean that it is not a fungus causing the problem. In the top pair of photographs only the two spots arrowed (right) contain fruiting bodies (left). Some fungi do not produce fruiting bodies in this form. All of these photographs were taken with a compact camera and a hand lens, so the magnification is no greater than that achievable in the field.



All images: Phil Taylor, CABI

Natural features of the leaf could be mistaken for fungal fruiting bodies.

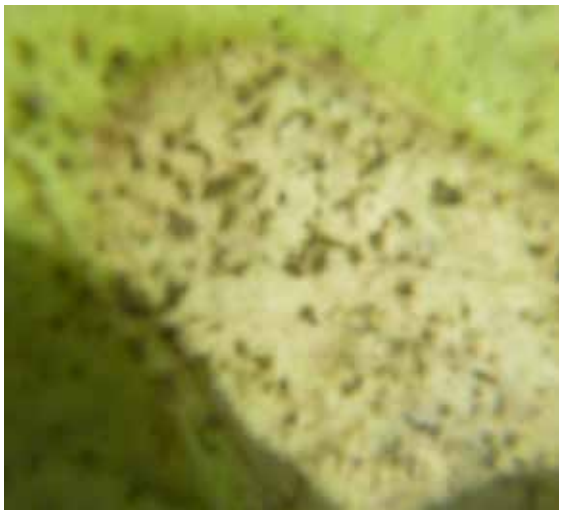
Phil Taylor, CABI



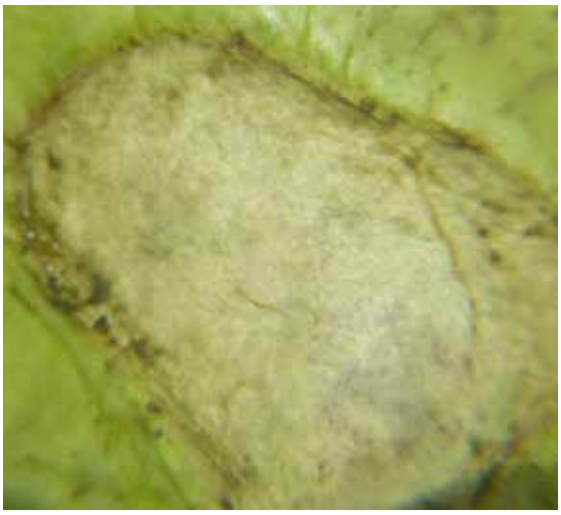
Insect frass can appear like fungal fruiting bodies but will appear both within and outside the leaf spot.

Phil Taylor, CABI

Ensure that the 'fruiting bodies' are not natural features of the leaf (left) or some artefact like insect frass (right). Older lesions may have been colonised by secondary microorganisms. These secondary invaders may produce fruiting bodies that could be mistaken for those of the disease-causing pathogen. When looking for fruiting bodies, try to find them in the younger lesions.



Phil Taylor, CABI



Phil Taylor, CABI

What appeared to be fungal fruiting bodies (left) were removed by wiping with a wet thumb (right) indicating that they were insect frass and not of fungal origin.

SYMPTOM	WATER MOULDS
Leaf spot	**YES** Common. Generally rapidly spreading, may have water-soaked appearance and sporulation around edges. White rusts and downy mildews can produce pustules with little necrosis.
 Leaf spot caused by *Phytophthora infestans* on tomato. Note the zone of lighter coloured leaf around the darker necrotic area: this is the area where spore production may be taking place. Phil Taylor, CABI	 Leaf spot caused by *Phytophthora capsici* on capsicum pepper. The symptoms are characterised by rapid death of the leaf material. Gerald Holmes, Bugwood.org
Leaf spots caused by water moulds are often rapidly spreading (especially in wet weather) and may not have a clearly defined border. They are usually not limited by the leaf veins and may have a water-soaked region around the spot, which may have fluffy white material (spores) on the surface.	

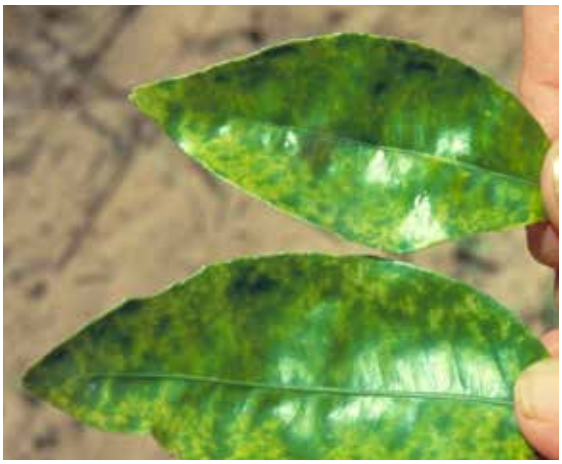
SYMPTOM	BACTERIA
Leaf spot	**YES** Very common. On many types of crop.

Bacterial infection of cabbage (left) and bean (right). Notice how in both cases the spots usually begin at the leaf edge.

Howard F. Schwartz, Colorado State University, Bugwood.org

Bacteria cannot penetrate a leaf in the same way as fungi and so bacterial leaf spots (in the early stages of attack) are often associated with the edge of the leaf or minor damage. As the bacterial numbers increase you will see the spots spread across the leaf. Bacterial leaf spots are more likely to be limited by the leaf veins in the initial stages but when the infection is growing rapidly, the expanding numbers of bacteria will push the infection past leaf veins. The edges of a bacterial leaf spot are often water-soaked, the plant tissue leaks material and the bacterial gums fill up the air spaces that are usually within the leaf. You will never see structures within a bacterial leaf spot as bacteria do not produce fruiting bodies which are characteristic of fungi. Bacteria often colonise stressed plants and the leaf spots will carry on spreading, especially if the leaf is under stress or is old.

SYMPTOM	VIRUS
Leaf spot	(NO) although there are exceptions. Ringspots are more common.



Citrus ringspot virus – not what would normally be called a true leaf spot.

Stephen M. Garnsey, USDA-ARS, South Atlantic Area, Bugwood.org

Spots caused by Tomato spotted wilt virus are not considered true leaf spots.

Scot Nelson, University of Hawaii

Viruses can produce a type of leaf spot on some occasions but they are usually in a ring or crescent pattern. Remember that viruses generally do not often cause the plant tissue to die, so a viral leaf spot will not usually have much dead tissue associated with it, but it will be a different colour (almost always yellow) from the remainder of the leaf.

SYMPTOM	PHYTOPLASMA
Leaf spot	(NO) although leaf markings can occur.

SYMPTOM	NEMATODE
Leaf spot	(NO) but can occur on ornamental plants; do not occur on crop plants.

SYMPTOM	INSECTS
Leaf spot	**YES** Not common. Some sucking insects inject a toxin when they feed that can cause necrotic or yellow spotting.
 Insect feeding can produce damage that looks like bacterial or fungal infection. This may be due to the physical action of feeding or due to toxins injected into the plant. Mirid damage on cacao. Robert Reeder, CABI	 Coconut plant bug damage on cashew. Robert Reeder, CABI
Feeding damage by insects that have sucking mouthparts can leave marks that look like fungal or bacterial spots and damage by biting insects that do not perforate the leaf can look similar.	

SYMPTOM	NUTRIENT DEFICIENCIES	
Leaf spot	**YES** Not common. Necrotic spots on leaves can indicate nutrient deficiencies. Shortages of potassium, zinc, manganese and copper can all lead to this symptom, if severe.	
 Potassium deficiency in lucerne: the marginal yellowing is associated with scattered white necrotic spots. Dr Prakash Kumar	 Zinc deficiency in wheat: a pale grey spot on the middle of the leaf. Dr Prakash Kumar and Dr Manoj Kumar Sharma	 Blossom end rot on tomato: this disorder is common on tomato and is seen when the fruits are rapidly expanding. It looks like a bacterial or fungal rot but is due to a shortage of calcium. Shamela Rambadan, CABI
A severe deficiency of any mineral will lead to poor growth but it is unusual for a plant to suffer such extreme shortage that would lead to cell death. The main exception is rapidly expanding tissue, such as the ends of tomatoes or courgettes. If calcium is in short supply the ends of the fruits will break down and appear like a fungal or bacterial rot (not 'leaf spot' but something similar on a fruit).		

SYMPTOM	PHYSICAL & HERBICIDE
Leaf spot	**YES** Common. Careless spraying with contact herbicides such as diquat can lead to spots. Sunscald can lead to damaged patches, often on fruit.

Strong sunlight can cause burnt patches on fruit (pepper).

University of Georgia Plant Pathology Archive, Bugwood.org

Strong sunlight can cause burnt patches on leaves (tobacco).

R.J. Reynolds Tobacco Company Slide Set, Bugwood.org

Paraquat damage on *Phaseolus* bean. Notice how the areas of damage are next to areas of healthy leaf with little transition between the two.

Howard F. Schwartz, Colorado State University, Bugwood.org

Bright sunshine can produce patches of dead tissue on leaves and fruit which may appear as spots. Wilted leaves exposed to bright sunshine and succulent fruits that are undergoing a period of rapid growth are the most susceptible. Shaded portions of wilted leaves exposed to the sun generally recover at night. Any type of stress that causes wilting will make plants more susceptible to sunscald.

Paraquat and diquat (and other less common herbicides) can cause what appear to be leaf spots: the otherwise healthy leaf is covered in small tan-coloured spots within which the tissue is dead. These symptoms are produced rapidly following herbicide application.

Witches' broom

In this condition, a biotic or abiotic factor causes the plant to lose control of the correct growth pattern and it grows in an uncontrolled way. The pathogen is either producing (or causing the plant to produce) the wrong balance of chemicals that regulate its growth. The clustered growth of many branches all emerging from a central point is not an especially common symptom: it usually occurs on woody plants and is often associated with 'little leaf'.

SYMPTOM	FUNGUS
Witches' broom (many branches)	**YES** Common. In woody plants only, not so in herbaceous plants.

Fungal witches' broom on silver birch. Extreme proliferation of branches from a single point creates a witches' broom.

Phil Taylor, CABI

SYMPTOM	PHYTOPLASMA
Witches' broom (many branches)	**YES** Very common. Generally associated with little leaf.

Witches' broom caused by a phytoplasma on lime.

J.M. Bové, INRA Centre de Recherches de Bordeaux, Bugwood.org

This is a classic symptom of phytoplasma. The dormancy of the side buds is broken and the cluster of tiny shoots all competing with each other is the result.

SYMPTOM	MITES
Witches' broom (many branches)	**YES** Very common. They are usually far too small to be seen even with a hand lens.
Mites can get into the growing point of the plant and cause witches' broom symptoms. The constant feeding on the material at the very tip of the plant causes it to produce multiple shoots. It is not possible to see the mites at the tip as the kind of mites that cause this symptom are too small to be seen, even with a hand lens.	

SYMPTOM	PHYSICAL AND HERBICIDE
Witches' broom (many branches)	**YES** Common. Only where plants have grown back after treatment with glyphosate.
	
If glyphosate does not kill a plant the regrowth can appear as witches' brooms (associated with little leaves). Nettle (left) and coffee (right), showing regrowth symptoms following glyphosate treatment. Eric Boa, CABI (nettle) and Scot Nelson, University of Hawaii (coffee).	
Glyphosate can produce witches' brooms in many plants. If you spray with glyphosate, much of the upper parts of the plant will appear dead, however sometimes, a while later, the lateral buds will break dormancy and small witches' brooms will develop.	

Canker

This refers to an open wound that does not heal readily. Usually, cankers are found on woody plants. The host plant is attempting to limit the pathogen by producing additional woody material to enclose it and the pathogen is attempting to grow into living tissue. This ongoing battle of host and pathogen produces raised sides to the wound which gives the canker its shape. It is not the same as a stem infection on green stems as they do not have the ability grow additional material around the infection site to limit the pathogen.

SYMPTOM	FUNGUS
Canker	YES Very common.

SYMPTOM	BACTERIA
Canker	YES Common.
 Phil Taylor, CABI	 Phil Taylor, CABI
 Eric Boa, CABI	 Phil Taylor, CABI
Fungal cankers on ash and Jatropha (top); a bacterial canker on ash (bottom left). Physical damage can produce a similar effect once the damage has healed (bottom right). Notice how the dead plant material is compensated for by additional growth around the edges of the canker.	

Mosaic

Many words can be used to describe the uneveness in the colour of a leaf and it can be difficult to convey the extent and severity of the unevenness. The word 'mosaic' is often used to describe such a symptom. It is a common symptom of viral infection (see below); however, other pests as well as nutrient deficiencies can produce similar symptoms.

SYMPTOM	VIRUS
Mosaic	YES Very common.
 Robert Reeder, CABI	 Scot Nelson, University of Hawaii
 Robert Reeder, CABI	 Phil Taylor, CABI

Mosaic caused by plant viruses. Note that the areas of green and yellow are distinct and do not blend to a great extent.

Viral symptoms of areas of green and yellow on leaves vary greatly - from a vague mottle through to a stark mosaic with extreme contrasts in colours in adjoining panels of leaf. This distinguishes it from 'yellowing' where the yellowed area of the leaf is continuous. The mosaic caused by viruses is often associated with rugosity (this is where the leaf does not lie flat between the veins).

SYMPTOM	INSECTS
Mosaic	(NO) although the feeding of tiny insects with piercing mouthparts such as thrips and whitefly can produce a mosaic-like effect.

SYMPTOM	MITES
Mosaic	(NO) although in the same way as insect feeding, mites can produce an effect that resembles a mosaic.

The superficial damage of mites can produce symptoms similar to viruses. This speckling on cassava could be mistaken for Cassava mosaic virus.

Robert Reeder, CABI

The superficial feeding by mites and thrips can resemble viral symptoms. The surface layer of cells have their contents sucked out and this creates a silvery appearance in some cases. This flecking of silver can give the impression of mosaic (viral infection), especially if leaf distortion (a symptom of mite, thrips and viral attack) is present.

SYMPTOM	NUTRIENT DEFICIENCIES
Mosaic	**YES** Common. The mottling caused by deficiencies of several minerals can produce a mosaic type of symptom.

Zinc-deficient maize plant with bands or streaks of yellow and green.

Dr Prakash Kumar

Iron-deficient pearl millet with faded veins in more advanced stage.

Dr Prakash Kumar and Dr Manoj Kumar Sharma

Manganese-deficient pearl millet plant showing stripes on the leaves.

Dr Prakash Kumar

There are many nutritional disorders of plants that can give rise to areas of leaves turning yellow adjacent to green areas, creating a kind of mosaic pattern. Experience is required to determine if the symptoms are those of a virus or mineral deficiency. Note that mineral deficiencies rarely distort leaves and cause mosaic/stripes symptoms at the same time whereas following virus infection, the two (distortion and mosaic) are often associated.

Yellowing of leaves

All pests weaken and stress plants and this often induces yellowing, however the pattern of yellowing can be important and indicate a cause. Plants can go into decline, where yellowing and reduced growth leads to further reduction in growth and so the problem continues. Even on a healthy plant the lower leaves will naturally grow old and will die; a yellowed leaf can be a normal sign of aging on a healthy plant and such leaves should not be considered a symptom.

SYMPTOM	FUNGUS
Yellowing of leaves	**YES** Common. Often indicates symptoms or infection in other parts of the plant, e.g. roots, cankers on stem.

SYMPTOM	WATER MOULDS
Yellowing of leaves	**YES** Common. General stress caused by root death often the cause. Downy mildews may create defined yellow patches on leaves prior to the production of the downy spores masses.

SYMPTOM	BACTERIA
Yellowing of leaves	**YES** Common. A general or non-specific symptom indicating general decline of the plant.

SYMPTOM	NEMATODE
Yellowing of leaves	**YES** Common. A general or non-specific symptom; general decline of the plant due to root feeding.

SYMPTOM	VIRUS
Yellowing of leaves	**YES** Not common. Mosaics are much more likely, unusual for the entire leaf to turn yellow.
It is unlikely that a viral infection will make the whole leaf turn generally yellowish. Yellow and green regions next to each other (see mosaic) is much more typical of virus infection.	

SYMPTOM	PHYTOPLASMA
Yellowing of leaves	**YES** Common. Relatively rare pathogen BUT they do often cause yellowing when they do occur.
Yellowing is a common symptom and may occur without other symptoms. Plants may be considerably smaller as well as yellowed (and sometimes red) when suffering from phytoplasmas. Usually much more striking features (witches' broom, little leaves) are present in addition to the yellowing.	

SYMPTOM	INSECTS
Yellowing of leaves	**YES** Common. A general or non-specific symptom caused by damage to the roots or a general decline in the plant.
Heavy infestation of sucking insects can weaken the plant sufficiently so that it turns yellow; the plant is unable to sustain the insect population and it goes into decline. The reduced growth of a plant under stress will prevent it from growing away from insect pest damage and the insect numbers will increase, which further increases the stress on the plant. Remember that insects attack the roots too and a yellowed plant may have insects attacking the roots.	

SYMPTOM	MITES	
Yellowing of leaves	**YES** Common. Low populations of mites can cause many leaves to turn yellow.	
 A. Elizabeth Johnson, CABI	 B. Phil Taylor, CABI	 C. Elizabeth Johnson, CABI
Male and female palm mites (A). Yellowing of palm leaflet associated with palm mite (B). The mites produce toxic saliva that causes the trees to go into decline and die. The numbers of mites may be relatively low but will do severe damage and ultimately kill a mature tree. Yellowing and decline associated with palm mite in mature coconut trees (C).		

SYMPTOM	MAMMALS & BIRDS
Yellowing of leaves	(NO) although mammals and birds that damage the bark of trees or roots can produce this symptom.
The removal of bark from trees will lead to the death of the tree; prior to death the leaves will turn yellow.	

SYMPTOM	NUTRIENT DEFICIENCIES
Yellowing of leaves	**YES** Very common. Depending on the pattern, yellowing can give an indication of which mineral may be deficient but a definitive field diagnosis is difficult.

Nitrogen-deficient pale green lentil leaflet.

Dr Prakash Kumar

Nitrogen-deficient maize: lower leaves are yellow.

Dr Prakash Kumar

Nitrogen-deficient wheat: yellowing of older leaves.

Dr Prakash Kumar and Dr Manoj Kumar Sharma

Nitrogen-deficient cluster bean: general yellowing.

Dr Prakash Kumar

Older leaves of nitrogen-deficient plants are yellow.

SYMPTOM	NUTRIENT DEFICIENCIES
Yellowing of leaves	Mineral deficiency commonly causes leaves to turn yellow. The position of those leaves and the colour of the leaf veins can give an indication as to which mineral is deficient.
 Iron deficiency in wheat: severe yellowing between veins. Dr Prakash Kumar and Dr Manoj Kumar Sharma	 Green veins contrast sharply against the yellowed iron-deficient sweet potato leaf. Dr Prakash Kumar and Dr Manoj Kumar Sharma
 Severely iron-deficient green gram: white leaf lamina while veins remain green. Dr Prakash Kumar and Dr Manoj Kumar Sharma	 Iron-deficient lentil plant: upper leaflets are yellow. Dr Prakash Kumar
Iron deficiency generally makes leaves turn yellow but characteristically the veins remain green.	

SYMPTOM	NUTRIENT DEFICIENCIES
Yellowing of leaves	Sulphur deficiency is shown in the upper leaves first because this element is less mobile within the plant than other nutrients and the plant is unable to remobilize it to the tip of the plant.
 Sulphur deficiency in pea: yellowing of upper leaves. Dr Manoj Kumar Sharma	 Sulphur deficiency in ground nut: uniformly pale young leaves. Dr Prakash Kumar
 Sulphur-deficient sugarcane plant. Dr Manoj Kumar Sharma	 Sulphur deficiency in potato: the pale yellow sulphur-deficient plant (left) compared with dark green normal plant (right). Dr Prakash Kumar
Symptoms of sulphur deficiency are similar to those of nitrogen deficiency but the younger leaves are the first to turn yellow.	

SYMPTOM	PHYSICAL AND HERBICIDE
Yellowing of leaves	**YES** Very common. Can be due to a variety of abiotic factors, some herbicides will generate yellow leaves on the treated plant.
 This oil seed rape plant was damaged by a herbicide used to control weeds. Phil Taylor, CABI	 This oil seed rape plant has temporarily yellowed due to sudden cold weather. Phil Taylor, CABI.
Herbicide damage often makes leaves lose their green colour and become yellow without other symptoms. The symptoms of herbicide on a crop could be drift from nearby spraying or from carryover from the previous crop. Many abiotic factors can cause plants to become stressed and turn yellow. If the environment changes so that the plant is in less than optimum conditions, it will stress the plant, which may turn yellow or pale green.	

Distortion of leaves

The leaves of all plants have a characteristic shape. Many kinds of problem can distort the shape of leaves; this can be a local effect where the distortion is only around the site of infection, or it could be a more general effect where the whole plant (or section of it) is affected. A general reduction in leaf size is not generally considered as distortion. Leaves can grow into a distorted shape as they develop or may become distorted after they have fully grown.

SYMPTOM	**FUNGUS**
Distortion of leaves	(NO) but there are exceptions and there is one spectacular example and a few others that can produce mild distortion.

The fungus that distorts leaves more so than any other is *Taphrina deformans*, the cause of peach leaf curl. This fungus distorts the leaves of peach and plum in a dramatic way that is difficult to miss; however for those who manage to overlook the hugely distorted leaves, it usually turns the leaves bright red too. It is difficult to imagine a plant pathogen with more dramatic and distinctive symptoms. Other fungi can distort leaves but this is not an especially common symptom.

Paul Bachi, University of Kentucky Research and Education Center, Bugwood.org

SYMPTOM	**WATER MOULD**
Distortion of leaves	**YES** Not common. Downy mildews can cause unusually shaped leaves.

Leaf distortion by blue mould on tobacco caused by *Peronospora tabacina*.

R.J. Reynolds Tobacco Company Slide Set, Bugwood.org

Plasmopara halstedii causing leaf distortion in sunflower.

Howard F. Schwartz, Colorado State University, Bugwood.org

If the downy mildew just causes a leaf spot there is little distortion of the leaves, but sometimes it can become systemic, in which case the whole of the leaf material is infected with the pathogen and leaves grow in a distorted manner (often with a waxy appearance).

SYMPTOM	VIRUS
Distortion of leaves	**YES** Very common.
 Leaf distortion in tomato. Contrast the infected leaf (left) to the healthy leaf (right). The infected one is smaller, twisted and blistered (rugose). Central Science Laboratory, Harpenden Archive, British Crown, Bugwood.org	 The lettuce has severe leaf distortion; in this case the leaf veins are unusually large, distorting the whole appearance of the leaf. Gerald Holmes, California Polytechnic State University at San Luis Obispo, Bugwood.org
Viruses can distort leaves into weird and peculiar shapes. They are often puckered (also called blistered or rugose) because the leaf lamina has grown at a different rate to the leaf veins or the leaf lamina may be severely reduced giving the appearance of a leaf that has been eaten. Beware that aphids and other sucking insects can distort leaves just by their feeding so do not assume the presence of a virus just because you see distorted leaves and insects (see below).	

SYMPTOM	PHYTOPLASMA
Distortion of leaves	**YES** Not common. Usually associated with witches' broom and little leaf.
They can distort leaves but by far more obvious is the small leaf size (see later) or the witches' broom usually associated with phytoplasma infection (see previously).	

SYMPTOM	INSECTS
Distortion of leaves	**YES** Very common. Can be due to feeding damage by sucking insects or leaves rolled by web formers.

Aphids, mealybugs and other sucking insects can distort leaves: the leaves are unable to expand properly as the sap is being sucked from them and this distorts the leaf. Notice that it is the developing leaves that are distorted: once produced, the leaves do not often become distorted.

Mealybugs causing damage to *Plumeria* leaves.

Scot Nelson, University of Hawaii

SYMPTOM	MITES
Distortion of leaves	**YES** Common. Due to the mites damaging the developing leaves.

Mites commonly cause leaf distortion.
Currant mites causing damage to currant.

Whitney Cranshaw, Colorado State University, Bugwood.org

SYMPTOM	NUTRIENT DEFICIENCIES
Distortion of leaves	**YES** Not common. Cupping of leaves as well as reduced leaf lamina can indicate mineral shortage.
	Pigeon pea showing leaf deformity due to copper deficiency. Dr Prakash Kumar

SYMPTOM	PHYSICAL & HERBICIDE
Distortion of leaves	**YES** Common. Some herbicides induce unusual patterns of growth.
	Tomato showing extreme leaf distortion due to herbicide exposure. Rebekah D. Wallace, University of Georgia, Bugwood.org

Little leaf

The point about this symptom is the **severe** reduction in leaf size, hence the name 'little leaf'. As for 'yellowing', there are many things that will cause the leaf size to be reduced: this can be a response to the stress the plant is under and is not directly a symptom. If a stressed plant is struggling to grow, the leaves it will produce will be smaller than those of a healthy plant. This is not the severe reduction of size seen in 'little leaf' that we are describing here. Little leaf here really means miniature leaf; the leaf is often perfectly formed but just on a miniature scale.

SYMPTOM	WATER MOULDS
Little leaf	**YES** Not common. Downy mildews can cause leaves to develop severely reduced in size.
When the downy mildews enter the 'systemic phase' the leaves that are produced are waxy and thick, and generally smaller than healthy leaves. See 'water mould distortion of leaves' on page 49.	

SYMPTOM	VIRUS
Little leaf	**YES** Not common.
 Potato leaf roll virus: the potato leaves are rolled and severely reduced in size on the infected plant on the right. Eugene E. Nelson, Bugwood.org	 Groundnut rosette virus. The ground nut plant is small partially due to the stem length but also because of the severe reduction in leaf size. Kalule Okello David, MoA Uganda
Not as common as infection by phytoplasmas, but viruses can cause something similar. The distortion caused by the virus can result in smaller leaves but the symptom is often associated with other types of distortion, such as rolling.	

SYMPTOM	PHYTOPLASMA
Little leaf	**YES** Very common. Often considered to be the classic symptom of this group.
	Infection by phytoplasma often causes a proliferation of small leaves. They can be in the form of a witches' broom with all the little shoots growing together with tiny leaves on them. This symptom may affect only a portion of the plant (sectoring) or it can affect the whole plant. Here we see phytoplasma infection on pigeon pea causing little leaf symptoms. Phil Taylor, CABI

SYMPTOM	MITES
Little leaf	**YES** Common. They are usually far to small to be seen even with a hand lens.
	Witches' broom of longan. The exact cause is not known but there appears to be a mite involved and possibly a microbial component. Notice how 'little leaf' can be a symptom with the witches' broom. Phil Taylor, CABI
Mites are often associated with little leaf and witches' broom but the kind of mites associated with these symptoms are too small to be seen, even with a hand lens. Little leaf symptoms often resemble witches' brooms because the leaves are clustered together; the two symptoms are often closely associated.	

SYMPTOM	PHYSICAL & HERBICIDE
Little leaf	**YES** Common. Only when plants have grown back after treatment with glyphosate.
As for witches' broom. The regrowth following a sublethal dose of glyphosate will often be a minature plant showing little leaf symptoms and reduced internode length.	

Galls

Any swelling that is produced by the plant in response to a pest or pathogen is considered a gall. They are common on woody plants but occur on annuals too.

SYMPTOM	FUNGUS
Galls	(NO) although they can occur on woody plants. Bunts and smuts could be considered galls.
Can be caused by fungi on woody plants but almost never on field crops.	

SYMPTOM	BACTERIA
Galls	**YES** Common. Often at the base of broadleaved plants (not grasses, banana or palms).
	
Crown gall disease on Jamaican sorrel (left) and sugarbeet (right). The bacterial pathogen has caused the plant tissue to grow in this unstructured and disorganised manner. Phil Taylor, CABI and Oliver T. Neher, University of Idaho, Bugwood.org	
There is one significant bacterium that causes galls on plants and it has a huge host range. *Agrobacterium* causes crown gall disease. The gall appears as a lumpy outgrowth often on the base of the stem. It does not infect monocotyledons such as cereal crops or bananas.	

SYMPTOM	NEMATODE
Galls	**YES** Very common. Swellings appear on the root, as well as general distortion of root systems.
 Nematode galls on roots of capsicum pepper. Phil Taylor, CABI	 Nitrogen fixing nodules on clover roots. Not nematode galls. Phil Taylor, CABI
Roots are the only place where nematodes produce galls. Nematode galls can be confused with nitrogen fixing nodules (in peas and beans). However one means of distinguishing them is that the root passes through the centre of a nematode gall whereas the nitrogen fixing nodule is usually displaced to one side and has a pinky colour.	

SYMPTOM	INSECTS
Galls	**YES** Very common. Seen on many types of plant.
SYMPTOM	**MITES**
Galls	**YES** Very common. Seen on many types of plant.

Eduardo E. Trujillo, Flickr

Tim Haye, CABI

Many different types of insect and mite can cause plants to produce galls. They produce substances that cause the plant cells to multiply so that a good habitat is produced for the adults or larvae to live in. In general a gall produced by an insect or a mite is smooth and appears structured whereas the galls of microbial origin are disorganised, unstructured and have a rough surface.

Contrast these galls (above) with those produced by microorganisms (below) which are generally more unstructured and indeterminate.

Phil Taylor, CABI

Phil Taylor, CABI

Drying/necrosis/blight

This is a very common symptom that has a variety of causes. The browning of plants when they lose their green colour is often called necrosis. This is often associated with a drying of the plant material. It is common for several leaf spots to join together to form an area of necrosis considered as blight. If a fruit is attacked, a wet rot may develop where the material loses its structure, becomes soft and disintegrates.

SYMPTOM	FUNGUS
Drying/necrosis/blight	**YES** Very common. Associated with many types.
	*Sclerotinia sclerotiorum* attacking cabbage. Note the extensive rotting spreading over the leaves. Gerald Holmes, California Polytechnic State University at San Luis Obispo, Bugwood.org

SYMPTOM	WATER MOULDS
Drying/necrosis/blight	**YES** Very common. Associated with many types.
	Taro leaf blight caused by *Phytophthora colocasiae*. The leaf spots have become so extensive that some areas of the leaf have been killed. Scot Nelson, University of Hawaii
The major water moulds that cause this symptom are species of *Phytophthora*. Many phytophthoras are root pathogens and only relatively few cause foliar symptoms of rotting and drying. However those that do cause these symptoms can be extremely destructive.	

SYMPTOM	BACTERIA
Drying/necrosis/blight	**YES** Very common. Associated with many types.

Xanthomonas axonopodis pv. *phaseoli* causing extensive drying and necrosis on dry bean leaf.

Howard F. Schwartz, Colorado State University, Bugwood.org

SYMPTOM	VIRUS
Drying/necrosis/blight	(NO) although there are exceptions such as Maize lethal necrosis and Cassava brown streak.

Joseph Mulema, CABI

Noah Phiri, CABI

Viruses very rarely cause necrosis and drying of the plant. The major exceptions are Maize lethal necrosis (left) and Cassava brown streak virus (right).

SYMPTOM	PHYTOPLASMA
Drying/necrosis/blight	(NO) although there are exceptions, this is not a symptom commonly associated with phytoplasmas.

SYMPTOM	NEMATODE
Drying/necrosis/blight	**YES** Many types of nematode cause death and decay of the roots but not those that produce galls or cysts.

The cut end of a banana root revealing necrosis and drying of the outside of the banana root caused by *Pratylenchus* spp. nematodes.

John Bridge, CABI

SYMPTOM	INSECTS
Drying/necrosis/blight	**YES** Common. Stem boring and root eating larvae can cause these symptoms leading to death of the plant.
Stem boring insect larvae often kill the branch or the whole plant they are in. The symptom is usually wholescale death of the leaves, which are often left hanging on the plant.	

SYMPTOM	MAMMALS & BIRDS
Drying/necrosis/blight	(NO) although mammals and birds that damage the bark of trees or roots can produce this symptom.
The removal of bark by large animals will lead to necrosis and death of the leaves.	

SYMPTOM	NUTRIENT DEFICIENCIES
Drying/necrosis/blight	**YES** Not common. In extreme cases the plants will dry and die prematurely.
Lack of nutrients frequently causes stunting but the death of large amounts of leaf tissue is much less common.	

SYMPTOM	PHYSICAL & HERBICIDE
Drying/necrosis/blight	**YES** Not common on crops. Due to gross misuse of rapidly acting herbicide such as diquat or paraquat.
A poorly cleaned sprayer, the use of the wrong pesticide, as well as severe drift can all lead to severe drying symptoms in crop plants.	

POTENTIAL SOURCES OF CONFUSION

The page shows the areas of likely confusion; cells are colour coded: red (confusion likely), purple (confusion possible), and blue (confusion unlikely); the empty cells represent combinations of pests rarely confused. The numbers within each colour coded cell indicate in which section in the remainder of the table the symptoms in common are explained and the possible means of differentiating them are provided.

Table 6. Potential sources of confusion

	Fungi	Water moulds	Bacteria	Viruses	Phytoplasma	Nematodes	Insects	Mites	Mammals & birds	Nutrients
Water moulds	**1** Confusion likely	*								
Bacteria	**2** Confusion likely	**10** Confusion likely	*							
Viruses	**3** Confusion unlikely	**11** Confusion unlikely	**17** Confusion unlikely	*						
Phytoplasma	**4** Confusion unlikely	**12** Confusion unlikely		**24** Confusion possible	*					
Nematodes	**5** Confusion possible	**13** Confusion possible	**18** Confusion possible	**25** Confusion unlikely		*				
Insects	**6** Confusion possible	**14** Confusion possible	**19** Confusion possible	**26** Confusion possible		**33** Confusion unlikely	*			
Mites	**7** Confusion unlikely		**20** Confusion unlikely	**27** Confusion possible	**30** Confusion likely		**36** Confusion possible	*		
Mammals & birds			**21** Confusion possible				**37** Confusion unlikely		*	
Nutrients	**8** Confusion unlikely	**15** Confusion unlikely	**22** Confusion possible	**28** Confusion likely	**31** Confusion unlikely	**34** Confusion possible	**38** Confusion unlikely	**40** Confusion possible		*
Physical & herbicides	**9** Confusion possible	**16** Confusion possible	**23** Confusion possible	**29** Confusion possible	**32** Confusion possible	**35** Confusion possible	**39** Confusion unlikely	**41** Confusion possible	**42** Confusion unlikely	**43** Confusion unlikely

PEST COMBINATION	SYMPTOMS IN COMMON	TECHNIQUES FOR DIFFERENTIAL DIAGNOSTICS
1 **FUNGI/WATER MOULD**	1. **Leaf spots and rots**. Common symptom of both pathogens. *Sclerotinia* (fungus) can produce a rot very like a water mould. Look out for large amounts of white thread-like hyphae and hardened sclerotia embedded within the rotting tissue in the case of *Sclerotinia* infection.	**Confusion likely** 1. *Phytophthora* leaf spots and rots are often aggressive and spread rapidly and are of an indeterminate size, whereas fungal ones usually reach a maximum size and have a well-defined border. In water mould leaf spots, there may also be white hairy growth (sporulation) produced, especially near the edge, which may be water-soaked. Downy mildews produce fluffy growth on the underside of the leaves and white rusts produce white pustules embedded within the leaf. No black fruiting bodies of fungi are found within water mould leaf spots.
	2. **Wilts**. Common symptom of both pathogens.	2. Split the stem: localisation within the xylem (staining of the water-carrying tubes) would indicate a fungal cause whereas a more general attack on the whole stem would indicate water moulds.
	3. **General yellowing**. Sign of stress caused by infection.	3. Yellowing is caused by both groups of pathogens and cannot be differentiated in the field.
2 **FUNGI/BACTERIA**	1. **Leaf spots and rots**. Common symptom of both pathogens. *Sclerotinia c*an produce a rot very like that caused by bacteria. Look out for masses of white thread-like hyphae and hardened sclerotia embedded within the rotting tissue in the case of *Sclerotinia* infection.	**Confusion likely** 1. Fungal infections may have fruiting bodies embedded within the tissues of the lesion. Fungal lesions may have a structure, e.g. concentric rings (target spot). Fungal leaf spots are more likely to be all of a similar maximum size. Bacterial infection is more likely to be limited by leaf veins in the initial stages, leading to spots that have straight edges and an angular shape, and are more likely to be associated with the edges of the leaf or minor damage. Bacterial leaf lesions may have water-soaked margins; these are most easily observed by holding them up to the light.
	2. **Wilts**. Common symptom of both pathogens.	2. Bacterial wilts may have bacterial ooze coming from inside the stems when they are cut. Perform the bacterial streaming test by placing the cut stems into water. Streaking and dark staining of tissues within the base of the stem is more common with fungal wilts.
	3. **General yellowing**. Sign of stress caused by infection.	3. Yellowing is caused by both groups of pathogens and cannot be differentiated in the field.

3 **FUNGI/VIRUSES**	1. **Mosaic/mottle**. Early infection by some fungi can look like a virus mottle.	**Confusion unlikely** 1. Look for more advanced symptoms. Fungal symptoms will develop from a general mottle into more striking symptoms such as leaf spots.
	2. **General yellowing**. This is a sign of general stress in the case of fungal infection whereas yellowing may occur as a true symptom in viral infections. Very few viruses produce symptoms similar to fungi on some crops, in these cases you just need to know the examples and become familiar with the symptoms.	2. The viral yellowed leaves may also be distorted, fungi rarely distort leaves and this is not a symptom associated with yellowing in this case.
4 **FUNGI/PHYTOPLASMAS**	1. **Witches' brooms** are very common symptoms of phytoplasma infection and are far less common for fungi.	**Confusion unlikely** 1. Phytoplasma-induced brooms occur on both green (herbaceous) and woody tissues whereas fungal brooms are almost always on woody tissue (mango malformation disease is a rare example on a crop plant).
	2. **Wilts**. Only confused in palms.	2. Phytoplasmas very rarely cause wilts (coconut lethal yellows is about the only example).
5 **FUNGI/NEMATODES**	1. **Wilt and yellowing**. A common symptom of both pests.	**Confusion possible** (especially when the plant is wilted) 1. Dig up the plant and look for galls or cysts on the roots; if these are found it is definitely a nematode cause. Split the base of the stem open lengthways and look for internal staining (strong indication of a fungal cause). Look for symptoms on the stem: nematodes rarely attack far above ground whereas fungi will spread up the stem. Nematodes that do not produce galls or cysts cause blackening and decay of the roots but this can be caused by fungi too.
6 **FUNGI/INSECTS**	1. **Wilts**. Insects that bore into twigs and stems or feed on roots can cause plants to wilt in a similar way to *Fusarium* and *Verticillium*.	**Confusion possible** 1. Split the stem and look for tunnels containing insects or frass. Look for insects eating the roots.
	2. **Leaf and fruit spots**. Capsids and other insects that inject toxins cause leaf and fruit spots similar to several fungal diseases.	2. Fruit spots caused by insects are relatively rare. They are often concentrated close to the stem of the fruit or on the side of the fruit that is closest to the plant, i.e. more protected. Insect-induced leaf spots are not common and may cause the leaf to curl around the insect.
	3. **Sooty mould**.This is a fungus but it is caused by insects excreting honey dew onto leaves on which the sooty mould fungus grows. The fungal problem is a secondary one, the insects are the primary cause.	3. Unlike true fungal diseases, sooty mould is easily wiped from the leaf surface.

PEST COMBINATION	SYMPTOMS IN COMMON	TECHNIQUES FOR DIFFERENTIAL DIAGNOSTICS
7 **FUNGI/MITES**	1. **Witches' broom**. The mites that cause witches' brooms are often too small to be seen even with a hand lens.	**Confusion unlikely** 1. Fungi generally produce witches' brooms on woody material and not green tissues, e.g. mango malformation disease has a fungal cause.
8 **FUNGI/NUTRIENTS**	1. **Leaf spots**. Severe lack of potassium (K) can look like fungal leaf spots. 2. **Rots**. Nutrient deficiency rarely causes rot-like symptoms, but blossom end rot caused by calcium deficiency and tip dieback due to boron deficiency can be confused with fungal infection.	**Confusion unlikely** 1. Look for fungal fruiting bodies. If neighbouring plants have similar symptoms then this may indicate a mineral deficiency issue. If the symptoms are symmetrical or if all the plants show the symptoms at the same growth stage (e.g. only on old or young leaves) it is more likely to be a mineral deficiency issue. 2. Look for foliar symptoms as well as symptoms on the end of the fruit or tip of the plant.
9 **FUNGI/PHYSICAL & HERBICIDES**	1. **Leaf spots**. Incomplete paraquat (herbicide) coverage can look like fungal leaf spots.	**Confusion possible** 1. Look for the pattern of spread. Herbicide damage is usually seen as a gradient away from the site of application, from severe to mild symptoms.
	2. **Wilts**. Drought stress can look like a fungus-induced wilt.	2. Look for unrelated plants wilting nearby. If they are found there may be a general shortage of water.
	3. **Canker**. Healing wounds caused by mechanical damage (e.g. farm implements) or fire damage can look like fungal cankers.	3. Enquire about fire or mechanical damage that the plant may have endured.
10 **WATER MOULDS/ BACTERIA**	1. **Leaf spots and rots**. Common symptom of both pathogens.	**Confusion likely** 1. Water moulds may sporulate in high humidity. Look for sporulation, particularly on the underside of the leaf, either dense mats of fluffy/downy material or white wispy material on the edge of the leaf spot. If necessary, place in a plastic bag overnight to encourage this. Bacterial infection is more likely to be limited by leaf veins in the initial stages, leading to spots that have straight edges and an angular shape.
	2. **Wilts**. Common symptom of both pathogens.	2. Bacterial wilts may have bacterial ooze visible from the stems when they are cut. Perform the bacterial streaming test by placing the cut stems into water. A water mould-induced wilt will often show extensive symptoms on the outside of the stem whereas bacterial infection often shows no external symptoms on the stem.
	3. **General yellowing**. Sign of stress caused by infection.	3. Yellowing is caused by both groups of pathogens and cannot be differentiated in the field.

11 **WATER MOULDS/ VIRUSES**	1. **Mosaic/mottle**. Early infection by some downy mildews can look like viral infection.	**Confusion unlikely** 1. Prior to downy mildew sporulation, leaves may develop yellow patches whereas viral symptoms are usually across the entire leaf. Look for more advanced symptoms (sporulation elsewhere). Extremely few viruses can cause leaf spots and extensive death of the tissue similar to a severe *Phytophthora* infection (e.g. Maize lethal necrosis virus).
	2. **General yellowing**. This is a sign of general stress in the case of water mould infection whereas yellowing may occur as a true symptom in viral infections. Very few viruses produce symptoms similar to water moulds on some crops, in these cases you just need to know the examples and become familiar with the symptoms.	2. The viral yellowed leaves may also be distorted, water moulds can distort leaves but this is not a symptom associated with yellowing.
12 **WATER MOULDS/ PHYTOPLASMAS**	1. **Wilts**. Only confused in palms.	**Confusion unlikely** (except in palms) 1. Phytoplasmas very rarely cause wilts (coconut lethal yellows is about the only example).
13 **WATER MOULDS/ NEMATODES**	1. **Wilt and yellowing**. Root-attacking water moulds often cause wilting. Phytophthoras that attack the above ground parts of plants do not generally cause wilting unless the attack is severe.	**Confusion possible** (especially when the plant is wilted) 1. Dig up the plant and look for galls or cysts on the roots; if these are found it is definitely a nematode cause. Nematodes that do not produce galls or cysts cause blackening and decay of the roots but this can be caused by both pests. Look for symptoms on the stem: nematodes rarely attack far above ground whereas water moulds may spread up the stem.
14 **WATER MOULDS/ INSECTS**	1. **Wilts.** Insects that bore into twigs and stems or feed on roots can cause plants to wilt in a similar way to phytophthoras.	**Confusion possible** 1. Split the stem and look for tunnels containing insects or frass. Look for insects eating the roots.
	2. **Leaf and fruit spots.** Capsids and other insects that inject toxins cause leaf and fruit spots similar to *Phytophthora* leaf spots.	2. Insect feeding usually results in fruit and leaf spots that are all of the same size; those of water moulds are rapidly spreading, especially in wet weather.
15 **WATER MOULDS/ NUTRIENTS**	1. **Rots.** Nutrient deficiency rarely causes rot-like symptoms, but blossom end rot caused by calcium deficiency and tip dieback due to boron deficiency can be confused with water mould infection.	**Confusion unlikely** 1. Look for foliar symptoms as well as symptoms on the end of the fruit or tip of the plant. Water moulds will be aggressive especially in wet weather.

PEST COMBINATION	SYMPTOMS IN COMMON	TECHNIQUES FOR DIFFERENTIAL DIAGNOSTICS
16 **WATER MOULDS/ PHYSICAL & HERBICIDES**	1. **Leaf spots.** Incomplete paraquat (herbicide) coverage can look like water mould leaf spots.	**Confusion possible** 1. Look for the pattern of spread. Herbicide damage is usually seen as a gradient away from the site of application, from severe to mild symptoms.
	2. **Wilts.** Drought stress can look like a water mould-induced wilt.	2. Look for unrelated plants wilting nearby. If they are found, there may be a general shortage of water.
17 **BACTERIA/VIRUSES**	1. **Mosaic/mottle.** Early stage bacterial infection can be limited by the leaf veins and look a little like viral infection.	**Confusion unlikely** 1. Look for water-soaking around the leaf spot by holding it up to the light. Look for more severe symptoms where the bacterial pathogen has spread over leaf veins and begun to kill the tissue.
	2. **General yellowing.** This is a sign of general stress in the case of bacterial infection whereas yellowing may occur as a true symptom in viral infections. Very few viruses produce symptoms similar to bacteria on some crops, in these cases you just need to know the examples and become familiar with the symptoms.	2. The viral yellowed leaves may also be distorted; bacteria never distort leaves.
18 **BACTERIA/NEMATODES**	1. **Wilt and yellowing.** A common symptom of both pests.	**Confusion possible** (especially when the plant is wilted) 1. Dig up the plant and look for galls or cysts on the roots; if these are found it is definitely a nematode cause. Nematodes that do not produce galls or cysts cause blackening and decay of the roots but this can be caused by both pests. The bacterial streaming test can be used.
	2. **Leaf spots.** Very rarely nematodes produce leaf spots and only do so on ornamental plants.	2. Nematodes do not produce leaf spots on food or fibre crops.

19 **BACTERIA/INSECTS**	1. **Wilt.** Insects that bore into twigs and stems or feed on roots can cause plants to wilt in a similar way to many bacteria such as *Ralstonia* or *Xanthomonas*.	**Confusion possible** 1. Split the stem and look for signs of insects such as adults, larvae, frass and tunnels. Look for insects eating the roots.
	2. **Leaf and fruit spots.** Fruit spots caused by insects are relatively rare. They are often concentrated close to the stem of the fruit or on the side of the fruit that is closest to the plant, i.e. more protected. Insect-induced leaf spots are not common and may cause the leaf to curl around the insect.	2. Toxin injection is quite rare and often does not kill the tissue immediately. Look for feeding sites associated with every lesion. Fruit and leaf spots caused by insect feeding are usually of similar size.
	3. **Rots.** Bacteria are often secondary invaders after insect attack.	3. Can be very difficult to tell the primary cause of a rot. Look for signs of insect attack with no associated rot.
	4. **Galls.** Insect-induced galls could be mistaken for bacterial ones.	4. Insect galls usually have immature insects within them. Unlike most insect galls, bacterial galls are usually rough in texture and found at the base of the plant.
20 **BACTERIA/MITES**	1. **Galls.** Bacteria occasionally produce galls, the most common example being crown gall disease.	**Confusion unlikely** 1. Bacterial galls are not determinate, are rough in texture, often large (< 10mm) and often found at the base of the plant. Mite galls are smaller, smoother, often pigmented and may contain very small hair-like structures.
21 **BACTERIA/MAMMALS & BIRDS**	1. **Rots.** Bite or peck marks are common entry points for bacterial pathogens, especially on fruits.	**Confusion possible** 1. Attempt to find recent animal damage where the rot has not set in, indicating that the bacterial rot is secondary.
22 **BACTERIA/NUTRIENTS**	1. **Leaf spots.** Severe lack of potassium (K) can look like bacterial leaf spots.	**Confusion possible** 1. If neighbouring plants have similar symptoms then this may indicate a mineral deficiency issue. If the symptoms are symmetrical or if all the plants show the symptoms at the same growth stage (e.g. only on old or young leaves) it is more likely to be a mineral deficiency issue.
	2. **Rots.** Nutrient deficiency rarely causes rot-like symptoms, but blossom end rot caused by calcium deficiency and tip dieback due to boron deficiency can be confused with bacterial infection.	2. Look for foliar symptoms as well as symptoms on the end of the fruit or tip of the plant.

PEST COMBINATION	SYMPTOMS IN COMMON	TECHNIQUES FOR DIFFERENTIAL DIAGNOSTICS
23 **BACTERIA/PHYSICAL & HERBICIDE**	1. **Leaf spots.** Incomplete paraquat coverage can look like bacteria-induced leaf spots.	**Confusion possible** 1. Look for the pattern of spread with regard to herbicide application. There will often be a gradient effect, from severe to less severe symptoms. Look for water-soaking around the spots caused by bacterial infection.
	2. **Wilts.** Drought stress can look like a bacterial-induced wilt.	2. Look for unrelated plants wilting nearby. If they are found, there may be a general shortage of water.
24 **VIRUSES/ PHYTOPLASMAS**	1. **Small leaves.** Both virus and phytoplasma infection can result in leaves of reduced size.	**Confusion possible** 1. Viral infected leaves are often distorted in shape and may have mosaic symptoms. Phytoplasma infection does not distort leaves (except for witches' broom-type symptoms). The small leaves produced as a result of phytoplasma infection are often bunched due to a shortening of the internodes (gaps between the leaves).
	2. **Yellowing.** Common symptom of both pathogens.	2. Yellowing by phytoplasma infection is usually a uniform yellow without a mosaic or mottle.
25 **VIRUSES/NEMATODES**	1. **Wilts.** Wilts are an extremely common symptom of nematode attack.	**Confusion unlikely** 1. Look at the roots for galls and nematode lesions. Wilts caused by virus infection are uncommon, e.g. only found in tomato, pineapple and broad bean.
	2. **Yellowing.** This is a sign of general stress in the case of nematode attack whereas yellowing occurs in otherwise healthy leaves in viral infection.	2. Yellowing that is stress-induced is likely to be caused by nematodes and is often accompanied by wilting. Virus-induced yellowing is often in the form of a mosaic pattern and not associated with wilting.
26 **VIRUSES/INSECTS**	1. **Leaf distortion.** Curling of leaves is a symptom common to both viruses and insects, especially sucking insects.	**Confusion possible** 1. Look out for curled leaves where there has been no insect feeding (indicating viral cause).
	2. **Yellowing.** The intimate relationship between viruses and sucking insect pests can make working out the initial cause difficult.	2. Insects do not often cause yellowing, but if they do it is generally an even yellow between the veins. They generally do not produce a mosaic pattern.
27 **VIRUSES/MITES**	1. **Mosaic and mottling.** Mites cause minute stippling of the leaves, which can be confused with mosaic symptoms.	**Confusion possible** 1+2. Use a hand lens to look for mites, which are often more numerous on the underside of the leaves close to the leaf veins. Hold plants up to the light and look for webbing associated with mites. Mites also cause bronzing type symptoms on leaves.
	2. **Leaf distortion.** In high numbers and on developing leaves, mites can cause distortion similar to that of viruses.	

28 **VIRUSES/NUTRIENTS**	1. **Mottling and mosaic.** A vector (usually an insect) may be required for virus transmission. Check for association of symptoms and any potential vectors.	**Confusion likely** You need experience as well as knowledge of the crop and the soil. 1. The border between the yellow and green may be sharper in the case of viral infections and the leaf patterns may not be symmetrical on either side of the leaf midrib. Provide soil supplements such as manure or compost to see if this alleviates or eliminates the symptoms.
	2. **Poor growth.**	2. Nutritional problems do not spread directly from one plant to another, so monitor the spread. Look at the pattern of distribution in the field. Viruses are more likely to have a patchy distribution and attack plants and plant parts of different ages (stages of development).
	3. **Distorted leaves and fruits.**	3. Viruses are much more likely to distort leaves and fruits.
29 **VIRUSES/PHYSICAL & HERBICIDE**	1. **Leaf distortion.** Mild (sublethal) glyphosate damage can look like virus infection with strappy leaves.	**Confusion possible** 1+2. Ask about local herbicide use.
	2. Soil acting herbicides can mimic the yellowing effect of viruses.	
30 **PHYTOPLASMAS/MITES**	1. **Witches' broom.** Witches' broom symptoms are often linked with mite and phytoplasma infection. Mites can be the vector for phytoplasma infection in some species.	**Confusion likely** 1. It is not possible to tell these two causes apart in the field. The mites that usually produce witches' brooms are far too small to see, even with a hand lens.
31 **PHYTOPLASMAS/ NUTRIENTS**	1. **Abnormal colour.** Reddening or yellowing of leaves and stunted growth are symptoms of both phytoplasmas and nutrient deficiencies.	**Confusion unlikely** 1. Although phytoplasmas produce abnormal colourations in plants, they are usually associated with other symptoms such as proliferation, small leaves, witches' brooms and stunting. Add fertiliser to overcome any potential shortage in the soil (reddening add phosphorus (P) and yellowing add nitrogen (N) and sulphur (S)).
32 **PHYTOPLASMAS/ PHYSICAL & HERBICIDES**	1. **Witches' broom.** Witches' brooms caused by a phytoplasma can look like regrowth after glyphosate application (small clumped leaves).	**Confusion possible** 1. Enquire about local use of glyphosate.
33 **NEMATODE/INSECTS**	1. **Wilts.** Insect larvae or nematodes attacking the roots or stems.	**Confusion unlikely** 1. Examine the stems and roots for insects or for signs of insect feeding, or galls, cysts or blackening and decay produced by nematodes.

PEST COMBINATION	SYMPTOMS IN COMMON	TECHNIQUES FOR DIFFERENTIAL DIAGNOSTICS
34 **NEMATODES/NUTRIENTS**	1. **Yellowing.** Nematodes may cause nutrient disorders as they destroy roots' ability to take up minerals (see below).	**Confusion possible** 1. Dig up the plant and look for galls or cysts on the roots; if these are found it is definitely a nematode cause. Nematodes that do not produce galls or cysts cause blackening and decay of the roots. The pattern of nematode attack in the field will often be patchy and not uniform.
	2. **Yellowing.** This is a classic symptom of nitrogen (N) or sulphur (S) deficiency.	2. Add fertiliser to overcome any potential shortage in the soil. Look for galls, cysts or blackened roots, all of which are signs of nematodes.
35 **NEMATODES/PHYSICAL & HERBICIDE**	1. **Wilt.** Symptom common to both nematodes and drought.	**Confusion possible** 1. Check the crop has adequate water supply; dig up the crop and observe the roots for galls or cysts. Generally nematode problems are in patches and not uniform across the whole crop.
	2. **Yellowing.** Can be induced by nematodes and herbicides.	2. Enquire about the use of soil acting residual herbicides.
36 **INSECTS/MITES**	1. **Leaf silvering** and **bronzing.** Mites and small leaf-feeding insects both produce silvering and bronzing symptoms on leaves and fruit.	**Confusion possible** 1. Look for the causative agents and for webbing associated with mites. Moth and butterfly larvae (caterpillars) also produce webbing, however they usually leave visible frass behind.
	2. **Yellowing.** A common symptoms of both small insects and mites.	2. Insect and mite feeding can produce yellowing of leaves. Look for the causal agent or evidence of its feeding using a hand lens.
	3. **Galls.** Outgrowths on leaves and stems are commonly associated with both groups of pests.	3. Insect-induced galls usually contain immature insect(s) within a hollow chamber in the gall. Galls of mites are usually small, containing very small hair-like structures amongst which the mites live, but the mites are usually too small to be seen.
37 **INSECTS/MAMMALS & BIRDS**	1. **Chewing.** Insect feeding on leaves and fruits (by large insects such as grasshoppers, large caterpillars) which makes holes from the edge of leaves may be confused with damage by small mammals or birds.	**Confusion unlikely** 1. Search for the pest. Insect pests will usually be nearby, whereas mammals and birds will have left the area.
38 **INSECTS/NUTRIENTS**	1. **Yellowing and mosaic.** Potassium (K) deficiency can appear similar to feeding by some insects.	**Confusion unlikely** 1. Use a hand lens to look for the insects or signs of insect feeding, e.g. eggs, cast skins or black dots of frass.
	2. **Yellowing.** Root feeding insects can produce symptoms similar to nitrogen (N) deficiency.	2. Dig up the plant and look for pests eating the roots.

39 **INSECTS/PHYSICAL & HERBICIDE**	1. **Holes in leaves.** Hail can produce holes in the leaves similar to insect feeding.	**Confusion unlikely** 1. Damage is usually tears rather than holes with material missing.
	2. **Yellowing.** Can be caused by both root feeding insects and residual herbicide.	2. Enquire on the local use of residual herbicides and look for root feeding insects.
40 **MITES/NUTRIENTS**	1. **Yellowing and mosaic.** Potassium (K) deficiency symptoms can look like mite damage. Some mites have phytotoxic saliva that turns the leaves yellow.	**Confusion possible** 1. Use a hand lens to look for the mites which are often more numerous on the underside of the leaves close to the leaf veins. Hold plants up to the light and look for webbing associated with mites.
41 **MITES/PHYSICAL & HERBICIDE**	1. **Witches' broom.** Witches' brooms caused by mites can look like regrowth after glyphosate application (small clumped leaves).	**Confusion possible** 1. Enquire about local use of glyphosate.
42 **MAMMALS & BIRDS/ PHYSICAL & HERBICIDE**	1. **Crop flattened.** Could be caused by wind or large animals.	**Confusion unlikely** 1. Enquire about local conditions.
43 **NUTRIENTS/PHYSICAL & HERBICIDE**	1. **Leaf** or **fruit spots.** Potassium (K) deficiency symptoms look like paraquat damage or scorch by the sun.	**Confusion unlikely** 1. Paraquat damage will not be symmetrical within a leaf nor spread over a wide area. Sun scorch will not be symmetrical and is limited to the exposed areas.
	2. **Yellowing.** Nitrogen (N) or sulphur (S) deficiency can look like soil acting herbicides.	2. Add fertiliser to overcome any potential shortages in the soil. Enquire about herbicide application.
	3. **Yellowing** and **abnormal colour.** Cold stress can give deficiency type symptoms (yellowing and leaf colour changes) but occur very quickly (overnight).	3. Local conditions will generally indicate if symptoms are due to cold injury.

MAKING RECOMMENDATIONS

'BIG 5' Key considerations when making a recommendation

Once a pest, disease or some other limitation to plant growth and productivity has been diagnosed, various options for control are open to extension workers. Each of these options (including doing nothing) will have consequences, implications and costs for the farmer. When making a recommendation to intervene (or not), the following 'Big 5' features of the advice should be considered.

When making a recommendation, advisors have to ask themselves if the advice they are providing has all of the following characteristics. If the guidance does not meet all of these criteria, the advice is either of no use to the farmer or is poor advice.

A recommendation must be:

1. Economic
2. Effective
3. Safe
4. Practical
5. Locally available

BIG 5 – Economic

Generally the control measures that you recommend to farmers must pay for themselves, i.e. the increase in yield and/or quality is worth more than the labour and input you suggest. It is important to remember, and to remind farmers, that the presence of a pest does not necessarily require pest management action. Farmers should monitor their problems closely and only invest money or labour when the pest poses a significant threat to crop quality or yield.

In some cases, the best advice for farmers is actually to 'do nothing'. This should be the case if the problem is only minor and will not have an important impact on the crop (that is, the farmer might actually lose money overall by investing in control measures). A second scenario that may arise is where the affected crop is soon to be harvested. For some kinds of problems, harvesting the crop may protect it from further damage. Furthermore, if a pesticide is recommended, farmers should be very cautious about applying the product to their crops shortly before the harvest, especially if it is food for immediate consumption. Finally, farmers might be advised not to invest in controlling a current pest problem if the crop is so heavily damaged that any attempt to save the crop will fail. In that case, the best advice may be to harvest what is available and to use preventive measures to avoid having the same problem during the next cropping season.

There can be occasions when it is not economic to control a pest on that particular crop but nevertheless it is good agricultural practice to do so, to protect human health from fungal contaminants of crops, prevent the spread of a pest vectoring disease, reduce future re-infestation, or minimise pest contaminants of planting material. Good agricultural practice is all about making sure that the environment is respected while maintaining good yields in the long term.

BIG 5 – Effective

Any recommendation made to farmers must be effective. Extension workers should only make recommendations that have either been scientifically validated, for example by national agricultural research stations; or that are based on commercially available products which have gone through all necessary registration and testing; or that are based on locally tried and tested farmer practices that have stood the test of time and that extension workers have witnessed and seen beneficial results for themselves.

BIG 5 – Safe

Many crop protection products can be poisonous to humans and safety is an important concern. Farmers often take risks with pesticides. Extension staff should discourage unsafe practices and encourage farmers to wear appropriate, clean and relevant protection (and not then change their behaviour and take greater risks because they are wearing it).

While it is under the control of the sovereign government of any country to decide which pesticides can and cannot be used in agricultural production, broadly the same pesticides are banned or restricted in many countries because of international agreements that most countries have signed. There are, however, minor, but significant, local differences in pesticide use. Through its Plantwise programme, CABI promotes compliance with specific international conventions/protocols and has a policy of discouraging the use of potentially dangerous pesticides that are named in those agreements. The complete list of pesticides banned or restricted by the international conventions is provided in the Plantwise Pesticide Red List (Annex 3). This list is constantly being revised, so please obtain regular updates from the Plantwise knowledge bank website.

There are two kinds of poisoning: acute and chronic. Acute poisoning occurs when an individual is exposed to a large single dose of pesticide, such as if a child were to drink some concentrate. You may see immediate and drastic symptoms, or it may take up to 24 hours for the symptoms to appear. The kind of symptoms associated with organophosphate pesticide poisoning are provided in Table 7 below. If pesticides have been swallowed, wash the victim's mouth with lots of water. The pesticide label should tell you whether or not the victim should drink water to dilute the chemicals, so read the label carefully. Always seek medical advice.

Table 7. Symptoms associated with acute organophosphate poisoning (including chlorpyriphos, malathion and dimethoate)

POINT OF EXPOSURE	SYMPTOMS
Inhalation	Chest tightness and wheezing Coughing Frothy sputum (foaming at the mouth)
Skin	Localized sweating Muscle twitching
Ingestion	Increased salivation Nausea and vomiting Diarrhoea (often watery) Cramping abdominal pains Involuntary defecation
Eyes	Constricted pupils Pain Excess tears Blurred vision

Chronic poisoning is the result of repeated exposure to the harmful chemicals at low levels over a long period of time, often due to absorption through the skin, inhalation of spray or dust as well as contamination of the mouth. This is most common among farmers who use pesticides regularly. Symptoms can include nervousness, slowed reflexes, irritability and an overall decrease in health, as well as arthritis.

BIG 5 – Practical

The practicality of the recommendation should be considered when providing advice. There are plenty of effective and safe methods of control which are entirely impractical for many farmers. This may be because they are too time consuming or require the use of specialist equipment. For example, hand picking caterpillars from a field of kale could be effective but would be totally impractical except for a very small area.

BIG 5 – Locally available

If a product is not available to the farmers then there is little point in making the recommendation. This may involve equipment as well as fertilizer, seed and biological control agents as well as pesticides.

Biology of the pest

Knowledge of the biology of the pest enables us to consider the options we have in our attempts to control it. The following tables provide very general advice as to the biology of various pests.

The way in which the pest survives in the absence of a susceptible crop plant has great implications in the control of pests.

Table 8. The means by which various pests survive in the absence of crop plants

PEST	RESTING STAGE	NOTES
Fungi	Yes (spores)	Fungi often produce two types of spore: one for survival during dormant periods and one for rapid spread under favourable conditions. Necrotrophic fungi and bacteria can survive and continue to grow on crop debris (the biotrophic fungi such as rusts, powdery mildews and smuts cannot do this).
Water moulds	Yes (spores)	As above; biotrophic water moulds include downy mildews. Necrotrophic ones include *Phytophthora* spp.
Bacteria	No	Plant pathogenic bacteria do not produce spores. They survive in crop debris or in the soil.
Nematodes	Yes (cysts, eggs)	Adult nematodes cannot survive for long outside the host but cysts and eggs can survive desiccation for many years.
Insects	Yes	There is no dormant stage equivalent to a seed, but most insect species have stages (usually egg or pupa) that will survive for months of adverse conditions without feeding.
Mites	Yes	Some mites can pass periods of adverse conditions without food as eggs or adults. This is particularly true in temperate regions, but also occurs during the dry season.
Viruses	No	Plant viruses generally cannot survive outside the host plant or vector (i.e. the insect which transmits the virus). They survive in volunteer crop plants, or alternative host plants including some weeds when there is no crop available. The main exception is Tobacco mosaic virus, which can remain infective outside a host for years.
Phytoplasmas	No	As for viruses with no known exceptions.
Weeds	Yes (seeds)	Seeds of weeds can lie dormant for many years and can be transferred to new areas as a contaminant of crop seeds.
Parasitic plants	Yes (seeds)	As for weeds.
Mammals		Can survive for days or weeks without food and will often change food source to what is available.
Birds		Highly mobile and can generally find food.

The features of pest transmission (how it moves around) will affect the control options available. Movement of irrigation water, soil and seed as well as vector behaviour all influence pest transmission. Some insects are weak fliers but can be carried great distances by the wind. Mites cannot fly but are carried by wind on the fine strands of silk that they spin. Some fungal spores blow in from hundreds of miles around, even from other continents.

Table 9. Means by which pests can be moved from one plant or area to another

PEST	WIND	WATER	SOIL	VECTOR	INDEPENDENT	MECHANICAL (TOOLS)	VEGETATIVE PLANTING MATERIAL	SEED
Fungi	Yes	Yes	Yes	No	No	Yes	Yes	Yes
Water moulds	Yes	Yes	Yes	No	No	Yes	(No)	(No)
Bacteria	(Yes)	Yes	Yes	Yes	No	Yes	Yes	Yes
Nematodes	(No)	Yes	Yes	(No)	(Yes)	No	(Yes)	(No)
Insects	Yes	No	Yes	–	Yes	–	Yes	No
Mites	Yes	No	No	–	(Yes)	No	Yes	No
Viruses	No	No	No	Yes	No	(Yes)	Yes	(Yes)
Phytoplasmas	No	No	No	Yes	No	No	Yes	No
Parasitic plants	Yes	No	Yes	Yes	No	–	No	(Yes)
Weeds	Yes	No	Yes	Yes	No	–	–	(Yes)
Mammals	No	No	No	No	Yes	–	–	–
Birds	No	No	No	No	Yes	–	–	–

NOTES

Bracketed responses indicate that the statement is generally true but with a small number of important exceptions. For cases where there is no response possible, a '–' is shown.

Downy mildews (water moulds) can be carried in seeds. *Phytophthora* can be carried on seed potatoes.

Bacteria are not generally transmitted by wind, but strong wind (especially with rain) can spread bacteria considerable distances.

Nematodes can wriggle short distances (a few centimetres). They can contaminate vegetative planting material if roots are included. Nematode cysts can be carried on the wind, as can adult nematodes if hidden in soil crumbs. Very few nematodes have specialised relationships with vectors, although red ring disease of coconut is an important example of a nematode that is vectored by an insect.

Mites can walk between plants and between crops but this is only important in extremely heavy infestations.

Viruses are generally not transmitted mechanically in the field (through contact with plant material or tools); however there are two important exceptions: Tobacco mosaic virus and Potato virus X.

Viruses can be transmitted through seed but this is not especially common.

Seeds of parasitic plants and weeds commonly contaminate soil and seed lots.

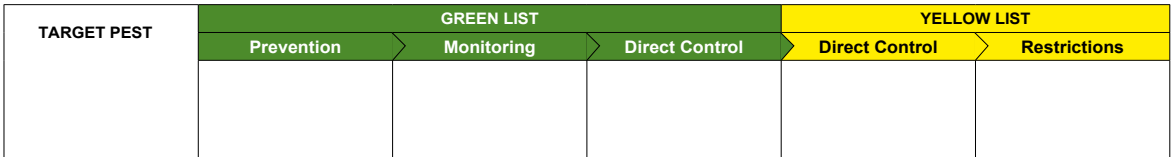
Note that the table indicates whether any species within a pest group can be transmitted by the means mentioned. It is very rare that all the species within a pest group can spread from plant to plant through the same process. For example, several species of fungi are transmitted through seed but most are not transmitted in this manner.

Integrated pest management

Plant doctors are trained within the Plantwise programme to offer sustainable plant health management advice to farmers following the principles of Integrated Pest Management (IPM). IPM involves the use of cultural, biological and mechanical methods, alongside targeted interventions with fertilisers and pesticides when justified, as outlined by the UN's Food and Agriculture Organisation (FAO). The FAO defines IPM as 'the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the

environment. IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms'.

Plantwise promotes IPM through the publication of pest management decision guides – see www.plantwise.org/kb/pmdg. These 'green and yellow lists', produced by local experts, and 'green lists', produced for global use, serve as a reminder to plant doctors and other extension staff about the multiple ways that crop pests can be managed. This includes preventive measures, tips on how to monitor pests, non-chemical control options and, in the case of green and yellow lists, chemical options for dealing with pests once they have established in the crop or the risk of infestation/infection is high.



Most of the farmers who come to a plant clinic are looking for a remedy for the problems they face in their current crops. In addition to giving advice on how to manage the current problems, plant doctors should take time to explain how the farmers can prevent the same problems from occurring again in the following season. Pest prevention includes a wide range of activities, such as crop rotation, selecting resistant varieties, planting when pest pressure is low, intercropping, or removing crop residues after harvest. Preventive measures not only reduce the likelihood of pest establishment but also reduce the spread of pests within a crop if an infestation or infection does occur.

A general principle of integrated pest management is to monitor the crop regularly to detect problems as early as possible. Therefore, plant doctors should encourage farmers to watch for early symptoms and to bring unknown problems to the plant clinic for diagnosis and advice before the problems become too serious. Prevention is the most effective way to manage pests and, if pests do establish in the crop, they are easier to control in the early stages of attack.

While pest management without pesticides is possible and can provide good control in some circumstances, it is often necessary to use a pesticide. Unlike an outbreak of some insect pests, diseases generally do not become self-limiting and if a disease strikes, pesticides are often the only option for management. Tables 10 and 11 provide general guidance as to the active ingredients that could be considered in the management of various insect, mite, fungus and water mould pests. The information provided relates to the active ingredient; commercial products containing these chemicals will have to be sourced locally. The pesticides listed in Tables 10 and 11 are not necessarily recommendations for your particular location. Many of them may not even be registered for use in your country. For the active ingredients included in the charts, there are no restrictions on the use of the chemicals, other than those imposed by the national government or the manufacturer. Pesticides that appear on the Plantwise Pesticide Red List, which have been banned or restricted by various international treaties and agreements, are not listed. A list of banned/restricted active ingredients – which should never be recommended by extension workers – is provided in Annex 3.

Pesticide resistance management

When pesticides with the same mode of action are used repeatedly against a pest, the pest population may begin to develop resistance. This happens because some of the individual pest organisms may be able to tolerate the pesticide more than others. Those more tolerant individuals will be more likely to survive and reproduce. The next generation will therefore consist of a higher proportion of tolerant (or fully resistant) pest individuals, making the pesticides less effective. Resistance develops in all agricultural pest groups: insects, mites, fungi, bacteria, nematodes and weeds. Pesticide resistance management is an effort to slow or prevent the development of resistance, thereby prolonging the effective life of pesticides.

In the fungi and water moulds table (Table 10), the fungicides with the same mode of action are represented in the same colour; for example kresoxim-methyl, azoxystrobin and pyraclostrobin are all represented in the same colour (pale green) and are therefore all in the same mode of action group. Swapping between these fungicides will not help prevent the build-up of resistance as they all work in the same way. Fungicides which are represented in other colours need to be chosen to help prevent resistance from occurring. Rotating fungicides used (between colours) will help to prevent the build-up of resistant strains. During discussions with farmers, find out which fungicides they have been using and recommend that they try a different one, or give them prescriptions with two or more fungicides with different modes of action and explain the need to alternate between them.

Table 11 relates to insecticide use. Unlike the previous table, in this case, the mode of action is indicated by the column. To prevent the development of insecticide resistance, you should make sure that the insecticides you recommend are not all in the same column. Change between columns regularly so that farmers are not always using insecticides with the same modes of action.

Alternative pesticides and home remedies

In addition to the synthetically produced pesticides, there are naturally produced chemicals, usually extracted from plant tissue. Some common examples of these so-called 'botanical insecticides' or 'botanicals' include extracts of neem (which is now widely used and sold in commercial forms), chili and garlic. Commercially available botanicals must be nationally registered for use as a pesticide in order to be included in pest management recommendations. However, these products are often locally produced by the farmers themselves. The quality and effectiveness can be highly variable due to the different methods of production and the unpredictable concentrations of the active ingredients in the plant material used. Hence, the correct dosage is difficult to establish. These preparations can be effective but may not always be so. Some of them can even be very toxic, even though they are from natural sources (for example, nicotine is highly toxic and is listed on the Plantwise Pesticide Red List). These factors should be considered before recommending their use.

Other ingredients, such as soap (applied as soapy water) or wood ash are used for pest management as they are cheap and readily available. Some can be effective, but some are not. However, some of these materials can also be toxic to the plants, so these factors should be considered before recommending their use.

Field Diagnosis and Recommendation Overview

Diagnosis

- Carefully examine the specimen and gather as much information as you can from the farmer.
- Cut the specimen open (where appropriate) and look for internal symptoms, use a hand lens when appropriate.
- Are the symptoms symmetrical on the plant? Is it localised? Does the whole plant appear to be suffering?
- Consider whether you have enough information or if a field visit is required.
- Compare the symptoms with photos in this diagnostic field guide and others you may have available; use your own experience.
- Consider that the plant may be suffering from two or more problems (although some may be of little consequence).
- Seek support, if required, from others, such as plant doctor colleagues, supervisors, local experts (university and research) or formal diagnostic support services. Keep in mind that the feedback from formal diagnostic services may take too long to help solve a current problem.
- Do not guess but provide the farmer with as much information as you can as to the cause of the problem.

Recommendation

- Remember the Big 5 features of a recommendation for managing a plant health problem.
- Assess the severity of the problem and use your experience to judge whether management is required. This is probably the most difficult aspect of making a recommendation.
- Ensure that pest management advice is based on IPM principles, using multiple effective methods and minimising risks from pesticide use.
- Make sure you provide advice on how the problem can be prevented or delayed next season.
- Encourage farmers to alternate between different active ingredients as resistance in insects and fungi is a big problem.
- Remember to avoid recommending pesticides that appear in the Plantwise Pesticide Red List.
- Make sure that you get feedback from the farmers so that you will learn from their crop management experience and share that experience with your colleagues.

Table 10. **Pesticides used in the control of fungi and water moulds**

	Water moulds *Phytophthora*, Downy mildews, Damping off	**Ascomycetes** Many foliar diseases	**Basidiomycetes** Rusts, Smuts, Bunts
Seed Dressing	**Metalaxyl*** **Metalaxyl-M*** Mancozeb Thiram Fosetyl-Al	Carboxin[1] Fludioxonil[1] Thiram Silthiofam Prochloraz Hymexazole*	Fludioxinil[1] Carboxin[1] Flutriafol[1] **Prothioconazole** Prochloraz **Triadimenol**
Fruit Foliar Symptoms	**Metalaxyl*** **Dimethomorph** Mancozeb Propineb Copper Metiram Chlorothalonil Zineb	Sulphur Copper Captan **Tebuconazole[1]** Dithianon **Fenbuconazole[1]** **Fenarimol[1]** Thiram Kresoxim-methyl[1] **Boscalid[1]** Chlorothalonil Penconazole[1] Thiophanate-Methyl Cyprodinil[1] Fludioxonil[1] Myclobutanil[1]	
Vegetable Foliar Symptoms	Thiram **Metalaxyl*** Cymoxanil[1] **Dimethomorph** Fosetyl-Al Chlorothalonil Copper Metiram Propineb Zineb Fluazinam **Propamocarb** **Fenamidone[1]**	Copper Chlorothalonil Thiophanate-Methyl **Fenarimol[1]** **Azoxystrobin[1]** Cyproconazole[1] Fludioxonil[1] Iprodione* Metconazole[1] Difenoconazole[1] **Boscalid[1]** **Fenpropimorph*** Pyraclostrobin[1] **Tridemorph** **Tebuconazole[1]** Carbendazim*	Difenoconazole[1] **Azoxystrobin[1]** **Boscalid[1]** Cyproconazole[1] Pyraclostrobin[1] Chlorothalonil Metconazole[1] **Tebuconazole[1]** **Fenpropimorph***
Cereal Foliar Symptoms		**Azoxystrobin[1]** Thiophanate-Methyl **Epoxiconazole[1]** Chlorothalonil Difenoconazole[1] **Isoprothiolane** **Quinoxyfen*** **Boscalid[1]** Pyraclostrobin[1] **Fenpropimorph*** **Bromuconazole[1]** **Tridemorph** Cyproconazole[1]	**Azoxystrobin[1]** **Epoxiconazole[1]** Chlorothalonil **Prothioconazole[1]** **Flusilazole[1]** **Fenpropimorph*** Pyraclostrobin[1] Difenoconazole[1]
Fruit/Ear Diseases		Propiconazole[1] Fluoxastrobin[1] Cyproconazole[1] **Azoxystrobin[1]** Carbendazim* **Tebuconazole[1]** Chlorothalonil Thiophanate-Methyl	Chlorothalonil **Epoxiconazole[1]** Cyproconazole[1] **Azoxystrobin[1]** **Tebuconazole[1]** **Prothioconazole[1]** Flutriafol[1]

Colours of text in the table relate to the following modes of action (detailed knowledge of modes of action is not required to make a good recommendation).

- Sterol biosynthesis membranes
- Sterol biosynthesis demethylation inhibitors
- Mitosis and cell division (MBCs)
- Respiration quinone outside inhibitors
- Respiration succinate dehydrogenase inhibitors
- Unknown
- Lipids and membrane synthesis
- Disruption of DNA synthesis
- Signal transduction

Fungicides are not active against bacterial diseases. Copper containing compounds are effective against bacteria, but should only be used when appropriate, antibiotic use is not endorsed by Plantwise.

Underlining indicates multisite activity, resistance very unlikely **Bold** indicates systemic activity * Indicates possibility of resistance [1] Indicates resistance has previously been recorded

Table 11. **The groups of insecticides and their potential targets**

	Pyrethroids	Neonicotinoids	Organophosphates	Other modes of action
Aphids	Cypermethrin Deltamethrin lambda-Cyhalothrin tau-Fluvalinate alpha-Cypermethrin Bifenthrin Fenvalerate Permethrin	**Acetamiprid Imidacloprid Thiamethoxam**	**Dimethoate** Chlorpyrifos Malathion **Acephate**	**Pirimicarb** Pymetrozine Fatty acids (Savona) *Verticillium lecanii* **Carbosulfan**
Mealybugs/Scales	Deltamethrin	**Thiamethoxam**		Fatty acids Petroleum oil (with caution)
Caterpillars	Cypermethrin Deltamethrin Permethrin lambda-Cyhalothrin Bifenthrin Fenvalerate		Fenitrothion **Acephate** Chlorpyrifos	*Bacillus thuringiensis* Diflubenzuron Lufenuron Novaluron
Leaf miners	lambda-Cyhalothrin Permethrin	**Imidacloprid Thiamethoxam**	**Dimethoate Acephate**	Abamectin Novaluron
Soil-borne larvae	lambda-Cyhalothrin	**Imidacloprid Thiamethoxam**	Chlorpyrifos Fenitrothion	
Leaf hoppers	Deltamethrin	**Thiamethoxam**	Malathion	
Weevils/Beetles	Cypermethrin alpha-Cypermethrin Deltamethrin Permethrin lambda-Cyhalothrin tau-Fluvalinate	**Imidacloprid Thiamethoxam**	Chlorpyrifos Malathion Fenitrothion	**Pirimicarb Carbosulfan**
Midges	Deltamethrin		Chlorpyrifos Fenitrothion	
Whitefly	Deltamethrin Permethrin	**Thiacloprid Imidacloprid Acetamiprid Thiamethoxam**	Chlorpyrifos **Dimethoate**	*Verticillium lecanii* Novaluron
Thrips	Deltamethrin	**Thiamethoxam**	**Acephate** Fenitrothion	Lufenuron
Wireworms		**Clothianidin Thiamethoxam**		**Carbosulfan**
Red spider mites	alpha-Cypermethrin Deltamethrin lambda-Cyhalothrin Bifenthrin Cypermethrin tau-Fluvalinate		Chlorpyrifos **Dimethoate** Malathion Pirimiphos-methyl	Tebufenpyrad Spirodiclofen (top fruit) Clofentezine Abamectin Lufenuron Etoxazole Fenpyroximate

The pesticides listed here vary in their levels of toxicity to humans and non-target organisms. Some have acute toxicity and short term exposure will cause illness and death; others have both acute and cumulative effects so that sublethal doses will give rise to symptoms (and death) after repeat exposure. **Bold** indicates systemic activity.

Do not use or recommmend pesticides unless they are permitted in your country.

ANNEXES

Annex 1: Scientific names of crops mentioned

AMARANTHUS	*Amaranthus tricolor*	LETTUCE	*Lactuca sativa*
APPLE	*Malus domestica*	LIME	*Citrus aurantifolia*
AVOCADO	*Persea americana*	LONGAN	*Dimocarpus longan*
ASH	*Fraxinus nigra*	LUCERNE	*Medicago sativa*
BANANA	*Musa* spp.	MAIZE	*Zea mays*
BEECH	*Fagus sylvatica*	MANGO	*Mangifera indica*
BIRCH	*Betula lenta*	MELON	*Cucumis melo*
BEAN	*Phaseolus vulgaris*	MILLET	*Panicum miliaceum*
BLUEBERRY	*Vaccinium* spp.	NETTLE	*Urtica dioica*
BUFFALO GOURD	*Cucurbita foetidissima*	OIL SEED RAPE	*Brassica napus*
BRAMBLE	*Rubus fruticosa*	ONION	*Allium cepa*
CABBAGE	*Brassica oleracea*	PAPAYA	*Carica papaya*
CACAO	*Theobroma cacao*	PEA	*Pisum sativum*
CAPSICUM PEPPER	*Capsicum annum*	PEAR	*Pyrus* spp.
CARROT	*Daucus carota*	PEACH	*Prunus persica*
CASHEW	*Anacardium occidentale*	PEARL MILLET	*Pennisetum glaucum*
CASSAVA	*Manihot esculenta*	PHASEOLUS BEAN	*Phaseolus vulgaris*
CLOVER	*Trifolium* spp.	PIGEON PEA	*Cajanus cajan*
CHINCHONA	*Chinchona* spp.	PINEAPPLE	*Ananas comosus*
CLUSTER BEAN	*Cyamopsis tetragonoloba*	POTATO	*Solanum tuberosum*
CASTOR BEAN	*Ricinus communis*	FRANGIPANI	*Plumeria* spp.
CHERRY	*Prunus serotina*	RICE	*Oryza sativa*
COCONUT	*Cocus nucifera*	RADISH	*Raphanus sativus*
COFFEE	*Coffea arabica*	ROSE	*Rosa* spp.
COTTON	*Gossypium hirsutum*	SAPODILLA	*Manilkara zapota*
CRACK WILLOW	*Salix fragilis*	SILVER BIRCH	*Betula pendula*
CUCUMBER	*Cucumis sativa*	SPINACH	*Spinacia oleracea*
CURRANTS	*Ribes* spp.	SQUASH	*Cucurbita* spp.
DRY BEAN	*Phaseolus vulgaris*	SUGARBEET	*Beta vulgaris*
EGGPLANT	*Solanum melongena*	SUGARCANE	*Saccharum officinarum*
GOURD	*Lagenaria* spp.	SUNFLOWER	*Helianthus annuus*
GRAPE VINE	*Vitis* spp.	SWEET PEPPER	*Capsicum annuum*
GREEN GRAM	*Vigna radiata*	SWEET POTATO	*Ipomoea batatas*
GROUNDNUT	*Arachis hypogaea*	TOBACCO	*Nicotiana tabacum*
POTATO	*Solanum tuberosum*	TOMATO	*Solanum lycopersicum*
JAMAICAN SORREL	*Hibiscus sabdariffa*	TARO	*Colocasia esculenta*
JATROPHA	*Jatropha curcas*	WALNUT	*Juglans regia*
LENTIL	*Lens culinaris*	WHEAT	*Triticum aestivum*

Annex 2: Plantwise policy on the use of pesticides

Plant doctors are trained within the Plantwise programme to offer sustainable plant health management advice to farmers, following the principles of Integrated Pest Management (IPM). IPM involves the use of cultural, biological and mechanical methods, alongside targeted interventions with fertilisers and pesticides when justified, as outlined by the FAO[1]. Plantwise facilitates the development of pest management decision guides (country-specific 'green and yellow lists' and global 'green lists') to support the practical implementation of IPM. Based on a traffic light system, these lists guide plant doctors and other extension staff through the most appropriate pest preventive measures and curative management options[2].

Where the use of pesticides is unavoidable, plant doctors are advised to recommend only locally registered and available pesticides to the extent that this information is available. Furthermore, plant doctors are made aware that they must not recommend pesticides that are subject to international restrictions, such as those listed by the Stockholm Convention on Persistent Organic Pollutants, the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, and the Montreal Protocol on Substances that Deplete the Ozone Layer, as well as pesticides listed as Classes Ia and Ib by the WHO Recommended Classification of Pesticides by Hazard (WHO, 2009). Above all, plant doctors are encouraged to give advice that keeps pesticide usage to the lowest effective level and ensures minimal risk to human health and the environment. Conflicts of interest can exist when extension services that provide pest management advice are also involved in the sale of pesticides[3]. Given that this is one of the root causes of pesticide overuse, Plantwise discourages plant doctors from selling pesticides for profit.

The Plantwise knowledge bank provides the plant doctors, other agricultural extension workers and researchers with an array of resources to assist them with diagnosis and management options. Where pesticides are considered as a potential management option by information resources available in the knowledge bank, all references to internationally-restricted pesticides, as listed above, are avoided.

[1] International Code of Conduct on the Distribution and Use of Pesticides (FAO, 2002).

[2] The concept for green and yellow lists was first developed by the *IOBC Commission on IP Guidelines and Endorsement* of the International Organization for Biological and Integrated Control of Noxious Animals and Plants, West Palearctic Regional Section (IOBC/WPRS).

[3] Guidance on Pest and Pesticide Management Policy Development (FAO, 2010).

Annex 3: Plantwise Pesticide Red List

It is Plantwise policy that plant doctors should not recommend the use of pesticides that are banned or restricted by international agreements. The table below lists the pesticides identified as Classes Ia and Ib by the WHO Recommended Classification of Pesticides by Hazard, as well as pesticides banned or restricted by the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, the Stockholm Convention on Persistent Organic Pollutants, and the Montreal Protocol on Substances that Deplete the Ozone Layer. The only pesticide banned by the Montreal Protocol is methyl bromide; it is almost unavailable now but should not be used in any case.

Please note: This table was last updated on 10th September 2014. Under these agreements, procedures exist for restricting additional pesticides and, as a consequence, the list of restricted pesticides may change from time to time. Refer to the websites of the agreements (given below) for the most up-to-date lists of banned and restricted pesticides.

DON'T USE OR RECOMMEND THESE – THE PESTICIDES LISTED HERE ARE HIGHLY HAZARDOUS

2,4,5-T and its salts and esters
3-Chloro 1-2 propanediol (3MCPD)
Acrolein
Alachlor
Aldicarb
Aldrin
Allyl alcohol
alpha hexachlorocyclohexane
Alphachlorohydrin
Azinphos-ethyl
Azinphos-methyl
beta hexachlorocyclohexane
Beta-cyfluthrin
Binapacryl
Blasticidin-S
Brodifacoum
Bromadiolone
Bromethalin
Butocarboxim
Butoxycarboxim
Cadusafos
Calcium arsenate
Calcium cyanide
Captafol
Carbofuran
Chlordane
Chlordecone
Chlordimeform
Chlorethoxyfos
Chlorfenvinphos
Chlormephos
Chlorobenzilate
Chlorophacinone
Coumaphos
Coumatetralyl
CVP, also called Chlorfenvinphos
Cyfluthrin
DDT
DDVF, also called Dichlorvos
DDVP, also called Dichlorvos
Demeton-S-methyl
Dichlorvos
Dicrotophos
Dieldrin
Difenacoum
Difethialone
Difolatan, also called Captafol
Dinitro-ortho-cresol (DNOC) and its salts (such as ammonium salt, potassium salt and sodium salt)
Dinoseb and its salts and esters
Dinoterb
Diphacinone
Disulfoton
DMTP, also called Methidathion
DNOC
EDB (1,2-dibromoethane)
EDDP, also called Edifenphos
Edifenphos
Endosulfan
Endrin
EPN Ethyl p-nitrophenyl phenylphosphorothioate
Ethiofencarb
Ethoprop, also called Ethoprophos
Ethoprophos
Ethylene dichloride
Ethylene oxide
Ethylthiometon, also called Disulfoton
Famphur
Fenamiphos
Flocoumafen
Flucythrinate
Fluoroacetamide
Formetanate
Furathiocarb
Gamma HCH (Lindane)
HCH (mixed isomers)
Heptachlor
Heptenophos
Hexachlorobenzene
Isoxathion
Lead arsenate
Lindane (gamma-HCH)
M74, also called Disulfoton
Mecarbam
Mercaptodimethur, also called Methiocarb
Mercuric chloride

Mercuric oxide
Mercury compounds, including inorganic mercury compounds, alkyl mercury compounds and alkyloxyalkyl and aryl mercury compounds
Metaphos, also called Parathion-methyl
Methamidophos
Methidathion
Methiocarb
Methomyl
Methyl bromide
Methylmercapthphos teolovy, also called Demeton-S-methyl
Methyl-parathion
Metilmerkaptophosoksid, also called Oxydemeton-methyl
Metriltriazotion, also called Azinphos-methyl
Mevinphos
Mirex
Monocrotophos
Nicotine
Omethoate
Oxamyl
Oxydemeton-methyl
Parathion
Parathion-methyl
Paris green
Pentachlorobenzene
Pentachlorophenol
Perfluorooctane sulfonic acid
Phenylmercury acetate
Phorate
Phosphamidon
Propetamphos
Sodium arsenite
Sodium cyanide
Sodium fluoracetate
Strychnine
Sulfotep
Tebupirimfos
Tefluthrin
Terbufos
Thallium sulfate
Thiofanox
Thiofos, also called Parathion
Thiometon
Thioxamyl, also called Oxamyl
Timet, also called Phorate
Toxaphene (Camphechlor)
Triazophos
Triazotion, also called Azinphos-ethyl
Tributyl tin compounds
Trizazotion, also called Azinphos-ethyl
Vamidothion
Warfarin
Zeta-cypermethrin
Zinc phosphide

If possible, monitor the websites from which the lists are created as they are regularly updated.

The Plantwise Pesticide Red List is available on the Plantwise knowledge bank:
www.plantwise.org/pesticide-restrictions

Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade:
www.pic.int

Stockholm Convention on Persistent Organic Pollutants:
chm.pops.int

Montreal Protocol on Substances that Deplete the Ozone Layer:
www.ozone.unep.org

The WHO Recommended Classification of Pesticides by Hazard and Guidelines to Classification 2009:
www.who.int/ipcs/publications/pesticides_hazard/en/

Annex 4: Glossary of terms

Term	Definition
Active ingredient	The part of a pesticide mix that has the effect of killing an organism.
Acute	The opposite of chronic, a one-off severe event (which may of course reoccur after a period of absence).
Annual	A plant that will grow from seed and produce more seed in less than one year.
Arthropods	Jointed legged animals covered with a hard external skeleton, including insects, mites, spiders, crabs, millipedes, etc.
Bactericide	A product that kills bacteria. Antibiotics are occasionally used in agriculture but are costly, are often not readily available and increase the risk of drug resistance in bacteria. Copper is the most widely used bactericide.
Bacterial gums	Glue-like material produced by bacteria.
Blight	A widely used term that is quite confusing as it can mean different things. Generally involves death and necrosis of large areas of tissue.
Biological control (or biocontrol)	The use of living organisms (e.g. insects, nematodes, fungi) to suppress populations of pests.
Bore hole	A small tunnel eaten into a plant (stem, fruit, tuber, etc.) by an insect or insect larva.
Canker	Open wound on the woody part of a tree caused by a pathogen, often has raised edges.
Cell	A tiny enclosed part of the plant which is far too small to be seen.
Chronic	Long term and ongoing (cf. acute).
Concentric	Rings of circles one inside the other so that it appears like a target.
Cyst (nematode)	The swollen body of a nematode full of eggs and attached to the root system.
Deficiency	To have a shortage of something.
Deformed	Not in its usual or expected shape.
Determinate	Will grow to a certain (pre-determined) size and no more, the opposite of indeterminate which describes things that will continue to grow.
Diagnosis	The process of determining what the cause of one (or more) symptom is.
Disease	Abnormal growth of a plant caused by microorganisms.
Dormancy/dormant	Remaining alive but not active.
Dose	Quantity of pesticide applied per individual or per unit area or weight.
Drift	Spray or dust carried by natural air currents beyond the target area.
Economic injury level	The lowest pest population density that will cause economic damage.
Economic threshold	The pest population level at which control measures should be started to prevent the pest population from reaching the economic injury level.
Frass	Particulate faeces/excrement of insects.
Formulation	The blend of chemicals in a pesticide.
Fungicide	Pesticides intended to kill fungi, usually prior to infection.
Gall	Abnormal growth (swelling) of plant tissue in response to a pest.
Grub	Beetle larva which is thick bodied with a well-developed head and true legs, no pseudo legs and usually sluggish in behaviour.
Herbaceous	The non-woody parts of a plant.
Herbicide (also called weedicide)	A pesticide intended to kill weeds.
Honey dew	Sugary material excreted by sap sucking insects often collected by ants. When it falls on leaves, it promotes the growth of sooty mould.
Host	The organism in or on which a parasite lives; the plant on which an insect feeds.

Identification (of a pest)	Identification (of a pest) to species (or as near as possible) – compare with diagnosis.
Infect (plants)	To enter and establish a pathogenic relationship with a plant.
Infection	The process of being infected (with a pathogen or parasite).
Infestation	Being infested (covered in); usually by insects, mites or weeds.
Insect	Six legged arthropods.
Insecticide	A poison effective against insects.
Integrated pest management (IPM)	The management of pests using techniques that complement each other rather than work against each other.
Invertebrate	An animal without a backbone or spine, e.g. arthropods, molluscs.
Knowledge bank (KB)	A large store of information held electronically. The Plantwise KB is on plant pests.
Larva (plural, larvae)	The part of a life cycle for many insects between the egg and the pupa.
Leaf lamina	Areas of the leaf between the leaf veins.
Leaf vein	Ribs of material fanning out into the leaf providing support and a plumbing system.
Lesion	Discrete area of necrotic host tissue caused by a pathogen or the toxic saliva of some insects.
Localised	Restricted to limited areas.
Maggot	Fly larva (without a head capsule and with no legs).
Mammals	Warm blooded animals with fur.
Metamorphosis	The life cycle: egg-larva-pupa-adult or egg-nymph-adult in insects.
Microorganism	An organism too small to be seen with a hand lens.
Mildew	Visible fungal growth on plant surfaces.
Mildew (downy mildew)	Diseases that are usually characterised by the production of downy growth on the lower surface of leaves (usually pink or cream). They are caused by water moulds.
Mildew (powdery mildew)	Diseases characterised by the production of white powdery growth on the upper surface of leaves. Caused by true fungi.
Mite	A tiny eight-legged, spider-like animal; those on plants include pest and predator species.
Monocotyledons	A group of plants that includes bananas, palms, gingers, as well as maize, sorghum and all other grasses.
Mosaic	Mottled pattern on leaves often used to describe viral symptoms. It does not describe any malformation of the leaf although leaf distortion may be associated with mosaic. It is similar to mottled but in a mosaic, the regions of different colours are more clearly defined.
Mode of action	The way in which a pesticide works, that is, how it kills the target pest.
Mottled	Used to describe the pattern of yellow and green on a leaf surface. Very similar to mosaic but the areas of different colours are less distinct in a mottle.
Natural enemies	Living species (including insects, mites, spiders and pathogens) that kill pests.
Necrotic	Browning and cell death.
Nematode	A kind of tiny worm that cannot be seen in the field and causes plant disease.
Nitrogen fixing	Those plants that (together with a bacterium) can convert nitrogen gas into usable nitrogen fertilizer.
Nodule	A small lump or bump (in this case a swelling that houses nitrogen fixing bacteria).
Nutrients	Sustenance and minerals.
Nymph	A young instar of an insect that does not go through complete metamorphosis.
Oomycetes	See water moulds.
Ornamental	A plant grown to look attractive and not for eating.
Pathogen	A microbial parasite.
Pest	Any organism that will reduce crop productivity, including fungi, bacteria, viruses and weeds as well as insects, mites, birds and mammals.
Pesticide	Any product used to kill pests.

Parasite	An animal or plant that forms an intimate relationship with a host, from which it obtains material (essential for its existence) to the detriment of that host.
Predator	An animal that eats others, e.g. an insect or mite that eats other insects or mites.
Pustule	Discrete area on a plant with fungal material swelling from it.
Phytoplasma	An infective agent that can cause disease in plants. Transmitted via insects (like a virus), it has no survival outside the host.
Phytotoxic	Poisonous to plants or part of plants.
Recommendation	Detailed advice on what action to take to overcome a particular problem.
Resistance	The natural or induced capacity of a plant to avoid or repel attack by pests. The ability of a pest to withstand the toxic effects of a pesticide intended to kill it.
Rot	A disease symptom in which plant material is softened and putrefied.
Rust	A group of biotrophic fungi that are characterised by the production of reddish orangey or yellow dusty pustules on plant surfaces.
Rugose	The leaf surface does not lie flat and is uneven and bumpy.
Sawfly	A class of insect pests whose larvae resemble caterpillars but are related to wasps.
Sclerotia	Tough resting bodies produce by *Sclerotinia* fungi.
Sign	The physical presence of a pest or its by-products.
Smut	A type of fungus that infects the developing seed and turns it into a black powdery mass.
Spore (plural, spores)	The reproductive body of a fungus or water mould that can give rise to a new organism. Spores are small and can often remain dormant for prolonged periods. They serve similar roles (but are not the same) as seeds of higher plants.
Sporulation	The production of spores.
Superficial	On the surface only but can also mean not serious.
Susceptible	Capable of being infected; not resistant.
Symmetry/symmetrical	Left and right side appearing the same.
Symptom	The way in which a plant responds to a pest.
Systemic	Spreading throughout the plant.
Target	The region (or organism or species) intended to receive treatment.
Threshold	The level at which intervention is appropriate.
Tissue	The mass of plant material that makes up the plant organs: leaf tissue, root tissue, etc.
Transmission	The spread of an organism from one host to another.
Toxic	Poisonous.
Toxin	Naturally produced poison.
Tuber	Swollen underground storage organ often used as means of propagation, e.g. potato, yam.
Vegetative planting material	Material used to increase the number of plants without the use of seed.
Viral	Pertaining to a virus.
Virus	Sub microscopic organism that can replicate in plants and cause disease.
Volunteer plant	A crop plant growing where the farmer did not intend it to grow, usually self-seeding, late germinating or growing from crop remnants.
Water moulds	Oomycetes; previously considered to be fungi but are now seen as a separate group of organisms (they are fungus-like).
Webbing	Layers or linings made of silk threads produced by insects or mites.
Weed	A plant that is limiting crop production by competing with the crop for light, water or nutrients.
Xylem	The tubes that carry water up stems to the leaves.

Annex 5: Photographic glossary of symptoms

Invertebrate pests (usually insects but also slugs, snails and mites) are generally large enough to be seen and their presence is a diagnosis in itself. In contrast, pathogens which cause disease, such as fungi and bacteria, are generally too small to be seen and it is usually the symptoms that are used to identify the cause. There are exceptions to this and sometimes you can see the pathogen (e.g. fruiting bodies of witches' broom on cacao) or fail to see the invertebrate pests (e.g. if the pest is no longer on the damaged plant or it is too small or too well concealed). Use your skill and training to interpret the photographs here and compare them with samples brought to you by farmers or which you find in the field. Note that no images are provided for some symptoms such as fruit drop or leaf fall as these are considered sufficiently self-explanatory.

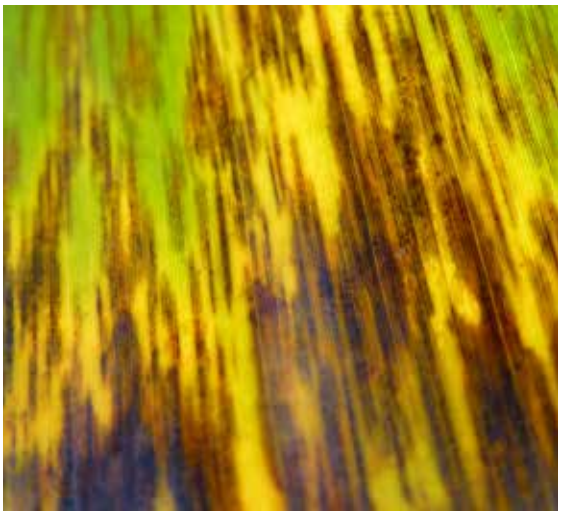
WILTED	Leaves and young stems droop down due to lack of water reaching them. Woody parts of plants cannot wilt, only the attached leaves.
 Bean plants wilting and yellowing, these two symptoms are commonly seen together. Robert Reeder, CABI	 Squash plants wilting due to shortage of water. The leaves are drooping but the plants have not yet collapsed. Gerald Holmes, Valent USA Corporation, Bugwood.org
 Sweet potato wilting. The leaf will not survive in this wilted state and will become dried and necrotic. Gerald Holmes, Valent USA Corporation, Bugwood.org	 Single capsicum pepper plant wilting. Note fully healthy neighbouring plants. Gerald Holmes, California Polytechnic State University at San Luis Obispo, Bugwood.org

YELLOWED	Leaves are normally green but when they lose their green colour they often become yellow. The cause of the yellowing may be on a different part of the plant to the yellowed leaves. Although yellowing is an extremely common symptom, the pattern of yellowing, e.g. older leaves or leaf veins can be diagnostic.
 Leaves can turn yellow or can be yellow when they are produced. Eric Boa, CABI	 The yellow peach leaves contrast strongly with the healthy one below. Notice how the leaf veins have remained green, this can be a diagnostic feature in some cases. L.S. Murphy, International Plant Nutrition Institute
 Dramatic contrast between the healthy wheat on the left and the diseased on the right. Keith Weller, USDA Agricultural Research Service, Bugwood.org	 Yellowed leaves at the top of the plant are often smaller than green ones; this is because the plant is under stress. Eric Boa, CABI

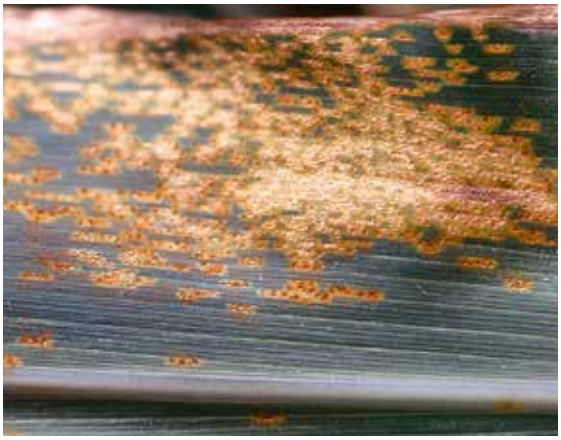
ABNORMAL COLOUR	Leaves have changed colour from green (but are not yellow). They often turn purple or red. This can be a sign of stress and the cause of the stress may be some way from the symptom.
 Some plants have colour in the leaves even when healthy, make sure you know what a healthy plant looks like before looking at symptoms. In this pineapple the red colouration is more pronounced than usual. Paul van Mele, Agro Insight	 Reddening of the leaves may be associated with loss of the green colouration. It may also be a sign of aging. Julien Lamontagne-Godwin, CABI
 Reddening of banana can be a sign of stress. International Plant Nutrition Institute	 Some plants may turn red much more readily than others and for some ornamental plants the abnormal colours can be part of their appeal. Julien Lamontagne-Godwin, CABI
 The lower leaves have gained the red colour, the upper leaves are only slightly coloured. D. Janaki, International Plant Nutrition Institute	 Note that it is the borders of the leaf that are turning red and the middle remains green. This may be diagnostic. Dr Prakash Kumar, CABI

STUNTED	Stunted plants are usually at the same developmental stage but smaller due to conditions (caused by pests, nutrients etc.). If a plant has been eaten by a mammal then although it is smaller, it is not considered to be stunted.
	
These two wheat plants are about to produce an ear but the one on the right will produce only a small yield. The whole plant (including the roots) is small compared to the healthy one on the left. Phil Taylor, CABI	Young Brassica seedlings; those on the left are smaller but with just as many leaves as the healthy plants on the right. Phil Taylor, CABI
	
The taro plant on the right is the same age as that on the left but much smaller. The leaf stalks, the leaf lamina and the roots are not showing any obvious symptoms but the whole plant is stunted. Scot Nelson, University of Hawaii	As these plants were all grown from the same seed, it is clear that there is something different about the soil that is reducing the growth of the wheat plants on the left, relative to those on the right. They are smaller, have fewer leaves and the tips of the leaves have turned yellow. CIMMYT

DIEBACK	The tip of the plant is dead and the effect may spread down the stem affecting the immature leaves. Dieback does not include symptoms that spread up the plant.
	
There are no other symptoms on this avocado except for the drying/necrosis at the tip. Eric Boa, CABI	The very end of this coffee branch is wilting and the leaves are dying; the leaves further down the stem are beginning to show symptoms. Scot Nelson, University of Hawaii
	
Severe blackening and death of the very tip of this citrus shoot. There are no other symptoms on the plant. Phil Taylor, CABI	The tip of this sugarbeet plant is unable to grow, and the leaves are not developing. L.S. Murphy, International Plant Nutrition Institute

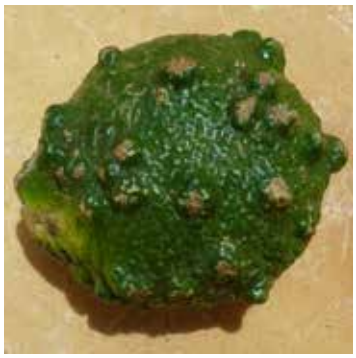
STREAK	Patterns of yellow or brown and green stripes on the leaves or stems. These are common on grasses but can occur on bananas too, the pattern of leaf veins create the effect.
 These leaf spots have spread up and down the leaf creating a streak-like pattern. Phil Taylor, CABI	 Commonly seen on banana, these brown and yellow streaks are running at right angles to the midrib of the leaf. Phil Taylor, CABI
 The maize leaf is showing alternate white and green stripes which are considered to be streaks. Phil Taylor, CABI	 The discolouration on the maize leaf runs up and down the leaf creating a streak. Dr Prakash Kumar and Dr Manoj Kumar Sharma

LEAF SPOT	A discrete zone on a leaf that is a different colour from the remainder of the leaf. Most leaf spots are caused by a fungal, water mould or bacterial infection.
 Leaf spots on cassava clearly seen contrasting against the green leaf. Robert Reeder, CABI	 These discrete leaf spots on coffee consist of a pale interior surrounded by a dark border with a yellow zone around that. Scot Nelson, University of Hawaii
 Note that these leaf spots are all of a similar size and they have a yellow border, partially limited by the leaf veins. These observations can be important in diagnosis. Scot Nelson, University of Hawaii	 Circular leafspots with a clearly defined border. Notice how they reach a maximum size. Scot Nelson, University of Hawaii
 In some cases the leaf spots are creating such a drain on the leaf that the areas between the leaf spots turn yellow, as is happening here on the leaf of this rose. Phil Taylor, CABI	 These leaf spots have no yellowing around them; pale material is in the centre of the leaf spot and brown dead material is around the outside, directly against the green healthy material. Phil Taylor, CABI

PUSTULES	A discrete zone on a leaf that is a different colour from the remainder of the leaf. Most leaf spots are caused by a fungal, water mould or bacterial infection.
 Dusty pustules on bean leaf, yellow regions are infection sites that have not yet broken through the leaf surface. Phil Taylor, CABI	 Pustules appear more waxy on leek. Phil Taylor, CABI
 Pustules are often brightly coloured (orange and brown), but can be black or white as shown in this photo. Scot Nelson, University of Hawaii	 Pustules are elongated and in chains along the length of the leaf due to the leaf veins. Scot Nelson, University of Hawaii
 Minor host reaction around these pustules on coffee. Robert Reeder, CABI	 Dusty brown pustules on ground nut. Scot Nelson, University of Hawaii

CHEWED	Many pests eat leaves leaving characteristic marks where the leaf material has been eaten away. Note that many small insects (including aphids, scales, whitefly, mealybug, thrips) and mites do not chew leaves. Look for frass near the damage as that can often assist in diagnosing the pest.
 The damage caused has not made holes through the leaf but has just eroded the surface. The brown regions are due to the healing reactions of the leaf and are not a rot. Phil Taylor, CABI	 This eggplant leaf has been eaten. The holes are mostly between the veins, and although the leaf has been extensively eaten, it is not considered to be distorted. The leaf is normal in shape and size but with portions eaten. Phil Taylor, CABI
 This banana leaf was attacked by two boring insects when immature, i.e. the insects ate through the leaf when it was still rolled up in the pseudostem. Once the leaf unfolds, the lines of holes appear. Phil Taylor, CABI	 The very edges of these bean leaves have been chewed. Phil Taylor, CABI

BLISTERED	This phrase includes buckled, wrinkled or puckered leaves where the leaf is not truly blistered but it will not lie flat. The correct term for this symptom is 'rugose' but here we include it under blistered.
 This distorted cotton leaf has a blistered appearance. Gerald Holmes, Valent USA Corporation, Bugwood.org	 The blistered regions may be a different colour to the remainder of the leaf as in this photo. Phil Taylor, CABI
 The blistering can be associated with other forms of distortion whereby the leaf has folded or twisted as well as blistered. IITA Image Library	 Blistered and misshapen tomato leaf. Gerald Holmes, California Polytechnic State University at San Luis Obispo, Bugwood.org

DISTORTED	Leaves or fruits grow into an unusual shape due to a pest OR the leaves are manipulated into an unusual position once formed.	
 In this severe leaf distortion, notice how some leaflets are severely affected whereas others close by are healthy. Phil Taylor, CABI	 The leaves appear normal except that they are curled at the edges, forming these boat-like cupped structures. Phil Taylor, CABI	 This cassava leaf has grown distorted and has developed yellow areas. Julien Lamontagne-Godwin, CABI
 This potato plant has very small, distorted leaves. Julien Lamontagne-Godwin, CABI	 The leaf lamina is extremely reduced on this papaya giving the appearance that it may have been eaten but the plant has grown into this shape. Robert Reeder, CABI	 Tiny, curled and distorted leaves clustering around the tip of the plant. Robert Reeder, CABI
 This lime appears healthy except for the lumps covering the surface. Phil Taylor, CABI	 It is not just the above-ground regions of the plant that can become distorted. Here the lower cassava tuber appears to be constricted at various points along its length. This is a very distinctive symptom. Robert Reeder, CABI	 These limes are misshapen and lopsided. Phil Taylor, CABI

LITTLE LEAVES	Small and clustered leaves. Remember that a leaf has to be much smaller than normal (but otherwise appearing healthy) to be considered a 'little leaf'. Leaves which are smaller due to a plant being under stress are not considered to be 'little leaves'.
 The symptoms of little leaf and witches' broom are similar and often go together. In each of the these cases, notice how the leaves appear healthy but extremely small. Eric Boa, CABI	 The symptom can affect the whole plant or just a section of it. Eric Boa, CABI
 Phil Taylor, CABI	 Eric Boa, CABI

LEAF MOSAIC	An unevenness in the greenness of the leaf, with yellow areas mixed with green areas, giving a mottled or patchwork pattern effect (unlike 'yellowed' where the colour tends to be a uniform block across large areas of the leaf). The whole leaf may turn yellow or the yellowing may start from the margins inwards or the centre outwards. Sometimes the regions are not so distinct and the patches of yellow and green fade into each other. Flecking and silvering of leaves (often from insect or mite feeding) can produce symptoms that look superficially like a mosaic but are generally not considerd such if the colouration is only in the surface layers, and a hand lens may be required to see this.		
		
This taro leaf has patterns of yellow and green within it. Not a typical mosaic but can be considered in this category. Often called feathering due to the 'feather-like' pattern. Phil Taylor, CABI	On close inspection this leaf is seen to be made up of small areas of yellow surrounded by green and is not an even yellow colour. Robert Reeder, CABI	This citrus shoot has a marbled effect, which can be considered mosaic. Phil Taylor, CABI
		
The symptoms here are of stange yellow patterns especially around the leaf veins. Not a typical mosaic but can be classed as one. Robert Reeder, CABI	The patches of yellow and green on this leaf are not a typical mosaic but may be considered as such. Julien Lamontagne-Godwin, CABI	An extreme mosaic with clearly defined lines between the green and yellow zones. Mosaics are rarely this contrasting; more often the transition between green and yellow areas is more diffuse. Scot Nelson, University of Hawaii

LEAF EDGE SCORCH	The edges of the leaf become brown and die (necrotic). This condition always has an abiotic cause. Bacterial infections spreading from the edges of the leaf are not considered leaf edge scorch.
 The tips of these leaves have died and become necrotic. Eric Boa, CABI	 Note the very sharp divide between the healthy leaf and the dead region near the tip. Eric Boa, CABI
 The very edge of this lettuce leaf has turned brown and died. Phil Taylor, CABI	 The edge of this leaf is under stress; the edge is brown but there is a yellow zone between it and the healthy green area. M.K. Sharma and P. Kumar, International Plant Nutrition Institute
 The edges of this mango leaf have dried up and died. Phil Taylor, CABI	 The blistering of this leaf is natural and is unrelated to the leaf edge scorch. Daren Mueller, Iowa State University, Bugwood.org

WITCHES' BROOM	The growing tip splits into many smaller competing shoots or branches that cluster together. Often associated with little leaf.
	
The shoots are competing with each other, creating a small witches' broom on this bramble. Robert Reeder, CABI	This tree is full of witches' brooms; each clump on the branches is a bundle of small leaves forming a broom. Phil Taylor, CABI
	
This small bundle of branches is a witches' broom; they are all growing from the same point. Phil Taylor, CABI	This longan tree is full of witches' brooms, all of which are showing little leaf. Phil Taylor, CABI

SURFACE GROWTH	This is a sign rather than a symptom as you are not only able to see the symptoms but the microorganism is present in such numbers that it is visible to the unaided eye. Not all surface growth is a problem and can be a secondary problem caused by something else. It is all on the leaf rather than in the leaf and if it is true surface growth, it is possible to wipe it off with a wet finger.	
 The light green material growing on the leaf is not causing the damage to the edge of the leaf. Phil Taylor, CABI	 This white growth over the surface of these grapes is a common problem in grape production. Julie Beale, University of Kentucky, Bugwood.org	 A very common problem usually associated with insect attack. This is sooty mould growing on the sugar excreted by insects on the surface of the sapodilla. Phil Taylor, CABI
 The white powdery material can be wiped off easily. Gerald Holmes, Valent USA Corporation, Bugwood.org	 This growth is pink and fluffy and found on the underside of leaves. Phil Taylor, CABI	 This reddish surface growth can be wiped from the upper surface of the leaf. Phil Taylor, CABI
 This orange is almost completely consumed by the the pathogen, seen as white and green areas on the surface. Robert Reeder, CABI	 This papaya fruit has a whiteish growth spreading over the surface. Scot Nelson, University of Hawaii	 This onion leaf has a purple coloured downy material covering certain areas. Phil Taylor, CABI

CANKERS (STEM LESIONS)	An open wound in woody or semi-woody stems.
	
This cherry tree has a classic canker in the side. Notice how the edges of the canker are bulging. Phil Taylor, CABI	This is a very early canker that is just beginning to form on blueberry. The stem has split and the characteristic shape is beginning to form. Gerald Holmes, Valent USA Corporation, Bugwood.org
	
An old and mostly dead canker on beech; the swollen edges of the canker remain although the canker does not appear active. Phil Taylor, CABI	Young canker developing on walnut. The infection may girdle the stem in which case the shoot will die. Alternatively the plant will seal it off so that it will become a canker. Curtis Utley, Colorado State University Extension, Bugwood.org

BORE HOLES (STEM/FRUIT)	The entry or exit hole of an insect pest, sometimes surrounded by frass. It is often the laval stages that produce the bore hole, but it can be the adults too.
 Insect bore hole in banana stem. Julien Lamontagne-Godwin, CABI	 Insect bore hole in avocado. Eric Boa, CABI
 Insect bore hole in tomato. Julien Lamontagne-Godwin, CABI	 Maize shoot borer and its bore hole damage, with associated secondary rot and scattered frass. Mattthew Cock, CABI

GALLS/SWELLINGS	The plant material grows in an abnormal way, often as a swelling, for the benefit of the pest.
	
Galls on roots, the roots are swollen and misshapen. Eric Boa, CABI	Galls on woody twigs. These galls are growing in a disordered fashion and are not determinate. Phil Taylor, CABI
	
Galls on the underside of tree leaves. Phil Taylor, CABI	Gall on buffalo gourd stem which has been cut open to reveal the insect larva inside. Whitney Cranshaw, Colorado State University, Bugwood.org
	
Insect galls on oak. Note that they are all precisely the same size. Robert Reeder, CABI	Spectacular galls on crack willow. Robert Reeder, CABI

ROTS	The tissue has to become soft and slimy (in addition to brown) to be considered a true rot.
	
This sweet potato tuber has two areas of infection which are spreading through and across the tuber. Charles Averre, North Carolina State University, Bugwood.org	Fruit is especially prone to rotting as it is often sweet and soft. These bananas are rotting from one end and it is spreading down the length of the banana. Scot Nelson, University of Hawaii
	
The wheat roots on the left are blackened and rotten compared with the healthy ones on the right. William M. Brown Jr., Bugwood.org	Classic rot on cacao; the rot is spreading up from the base of the pod (surface growth is also visible on the outside of the fruit in the blackened area). Phil Taylor, CABI

STAINING	This usually refers to streaks that are only visible once the stem has been split; make sure you compare it with a healthy stem. The insides of a tuber can be discoloured even though the material is not rotting. The discolouration on the outside of a fruit due to rotting or surface growth is not considered staining.
 Internal staining within a banana stem split lengthways. Julien Lamontagne-Godwin, CABI	 Internal staining within a banana stem cut crossways. Eric Boa, CABI
 The bark has been removed on this cinchona tree to reveal the internal staining beneath. Julien Lamontagne-Godwin, CABI	 Internal staining within a radish. Depending on whether the material had softened this could also be considered as rot. Eric Boa, CABI
 Brown flecks on the cut surface of a capsicum stem. Phil Taylor, CABI	 Internal staining is a common symptom in field-grown tomatoes. Clemson University – USDA Cooperative Extension Slide Series, Bugwood.org

DRYING	Severe localised stress, often associated with dieback.
	
On one small branch of this pear, the leaves have dried and shrivelled. The remaining leaves appear unaffected. Phil Taylor, CABI	Some branches on this coffee have dried. The whole plant is wilting but there are some areas where the material has dried. Robert Reeder, CABI
	
This eggplant has dried, the leaves have all shrivelled and turned brown, and the plant is dead or dying. Phil Taylor, CABI	This walnut fruit is drying. The condition is similar to rot but the material has not become soft and slimy but has remained hard and dry. Andrej Kunca, National Forest Centre – Slovakia
	
Complete drying of a coffee plant. Robert Reeder, CABI	Drying of isolated branches is a common symptom on mango. Phil Taylor, CABI

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Plantwise Diagnostic Field Guide

A tool to diagnose crop problems and make recommendations for their management

Compiled by Phil Taylor

Every day, extension workers are bombarded by questions from farmers on how to overcome problems with their crops. The huge variety of crops grown and the numerous biotic and abiotic factors that can reduce crop quality and yield make it very difficult to diagnose all plant health problems and give good recommendations to farmers.

The Plantwise Diagnostic Field Guide provides the essentials of diagnosing plant health problems, covering all the main problems that crops encounter (nine groups of pests and two abiotic conditions) to group level. It includes summary sheets that cross-reference symptoms with causes, line drawings of the major insect pest groups, and photos of the symptoms of the major microbial pest groups and symptoms associated with mineral deficiencies.

This diagnostic field guide has a full colour glossary to allow for accurate symptom description. It also has a section that explains how to tell the difference between similar symptoms with different causes.

Following a successful diagnosis, the farmer still requires advice on how to manage the problem. Basic principles of giving good recommendations are summarised in this book. Regarding pests (pathogens, animals and weeds), there is an emphasis on integrated pest management (IPM) with additional information on avoidance of the most toxic pesticides.

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