PestSmart Diagnostic Field Guide

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

Compiled by **Phil Taylor**

CABI

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Version **1.2**

CABI

CABI is a trading name of CAB International

CABI
Nosworthy Way
Wallingford
Oxfordshire OX10 8DE
UK

T: +44 (0)1491 832111
F: +44 (0)1491 833508
E: info@cabi.org
www.cabi.org

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Production editor: Tracy Head, CABI

Line drawings in Table 2: Robert Reeder, CABI

Design and typesetting by Sarah Hilliar, CABI

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We also offer CAB Direct, CABI's online development platform, providing a single point of access to all your CABI database subscriptions.

Preface

CABI's *PestSmart Diagnostic Field Guide* is intended for a wide range of users around the world. It should be a companion to anyone whose work or hobby requires them to associate poor plant health with likely causes. This applies to those who work in the field as well as those who are laboratory based.

Plants can suffer from such a variety of problems it is not possible for a person to be an expert on all problems of all plants. The *PestSmart Diagnostic Field Guide* provides information relating to common symptoms expressed by crop plants when under attack from a wide variety of pathogens and pests as well as symptoms due to sub-optimal growing conditions.

The Field Guide assists the reader in linking the symptoms seen on plants with the potential causes. Where there is more than one potential cause it provides information on how to tease the two candidates apart so as to find the problem. While this guide commonly uses the term 'crop' and does focus on agricultural crops, the principles outlined can be applied to all types of plants, regardless of how they are grown and whether they are grown for commercial, aesthetic or other purposes.

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 CABI's Plantwise knowledge bank and Factsheet app.

Comments on CABI's *PestSmart Diagnostic Field Guide* are welcome.

To provide feedback, please send it in an email: **info@cabi.org**.

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The *PestSmart 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 compilation of this field guide was led by Dr Phil Taylor, with contributions by many others, both inside and outside of CABI, who provided content and feedback.

The content on 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.

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

Ulrich Kuhlmann
Executive Director, Global Operations, CABI

INTRODUCTION

The first step to identifying possible solutions to a plant health problem is understanding the problem correctly. CABI's *PestSmart Diagnostic Field Guide* supports diagnostic decisions by showing relationships between common symptoms on plants and the various possible causes.

This document provides images and descriptions of many typical symptoms associated with biotic and abiotic factors that harm plant health. Among the biotic factors, the major pest groups are represented. Throughout the 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 book does not attempt to show all possible plant/disorder combinations; 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.

The 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. Many biotic and abiotic factors create very similar symptoms in plants, therefore a table is provided (Potential sources of confusion) that identifies these areas of overlap and provides methods to differentiate between the possible causes.

The Field Guide concludes with a short section on important points to remember when selecting management options for crop problems following an integrated pest management approach.

FIELD DIAGNOSIS: A PROCESS OF ELIMINATION

The process of diagnosing a plant health problem without any specialised laboratory equipment is called 'field diagnosis'. 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 plant being examined 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 to identify corrective measures. A diagnosis of a pest group, such as fungus or stem-boring insect, will provide a lot of useful information for developing an adequate solution. The precision and accuracy of the diagnosis ultimately depends on one's knowledge of the plants and the known problems in the area, with additional support from tools like the *PestSmart 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, 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 the virus, 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.

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. Remember to ALWAYS eliminate all the alternative causes before pronouncing your final diagnosis.

In many cases, a single plant sample and information may not be enough to make a diagnosis, in which case a visit to the production site or garden 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

For those who advise others on managing plant health, there is often a limited amount of information available to them, especially if they are only shown a plant sample. Furthermore, the sample may not contain all the important symptoms required for a diagnosis and 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 problem. If you intend to send a sample to another 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 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 and mites (Tables 1 and 2) to a group level, so no additional text is supplied in this *PestSmart Diagnostic Field Guide*.

Plant pathogen pests

As microorganisms are generally not visible, diagnosis is primarily based on symptoms (Table 3) however additional information is provided in the remainder of this *PestSmart Diagnostic Field Guide*.

Mineral deficiencies

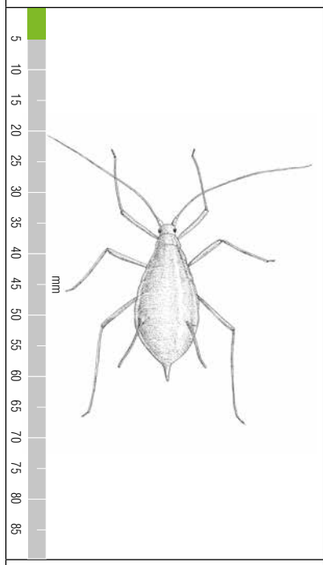
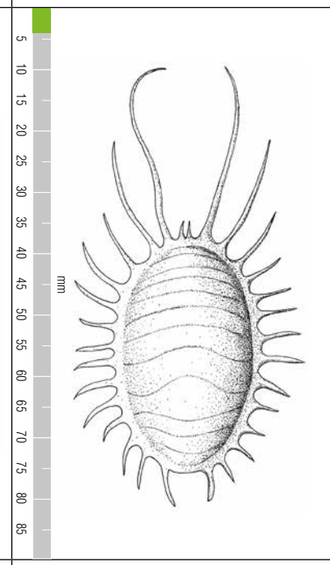
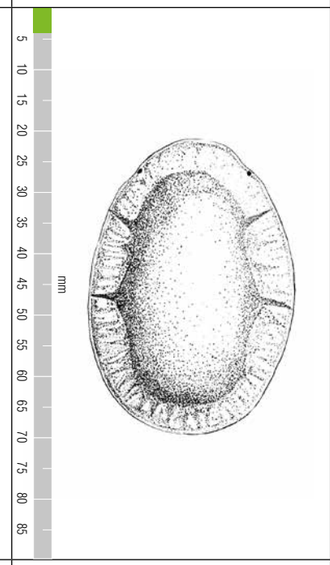
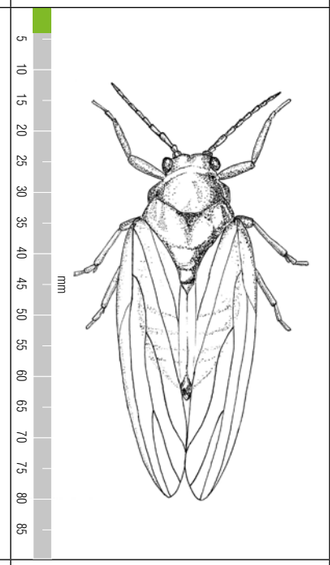
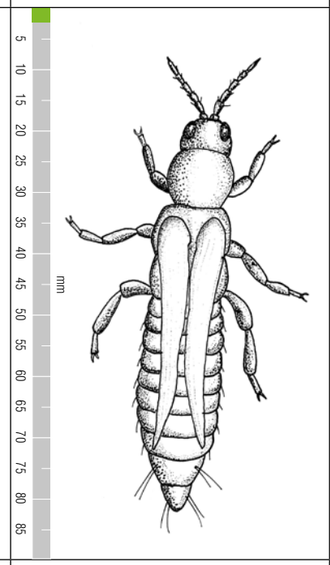
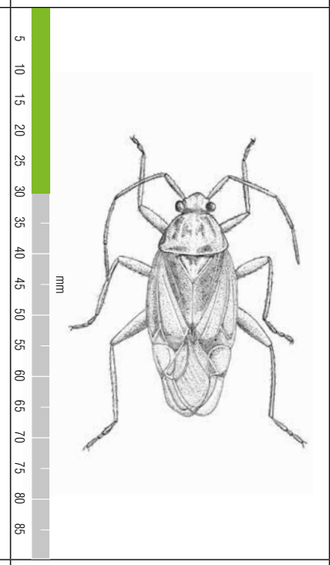
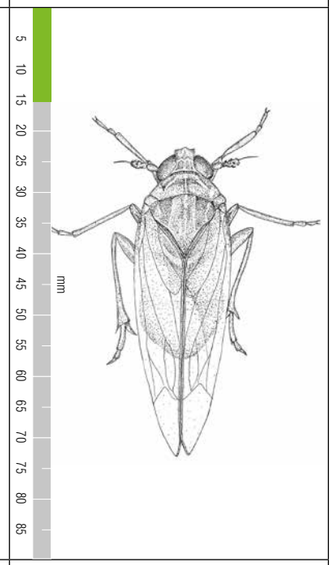
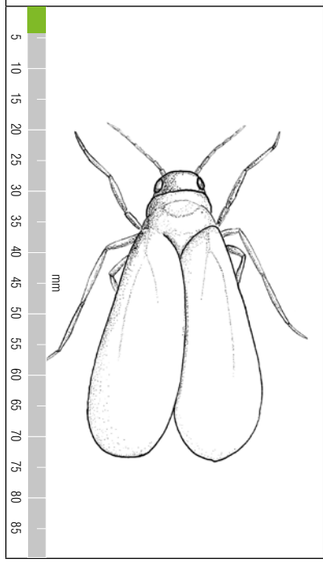
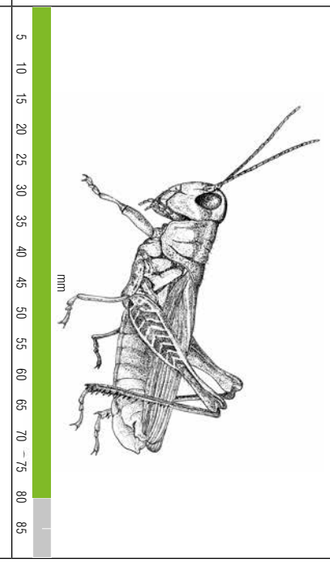
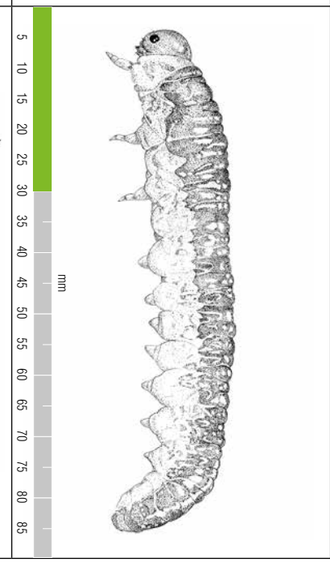
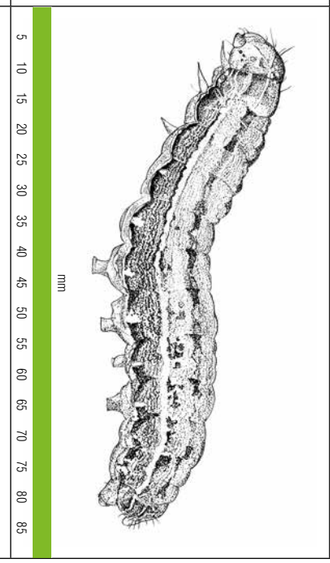
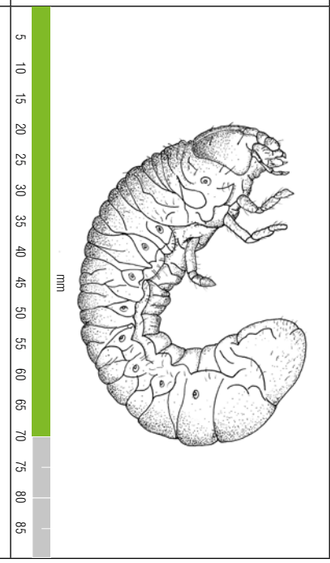
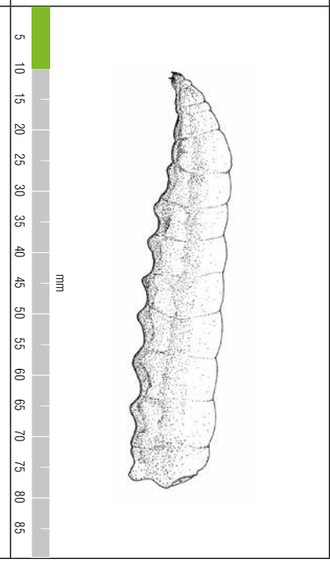
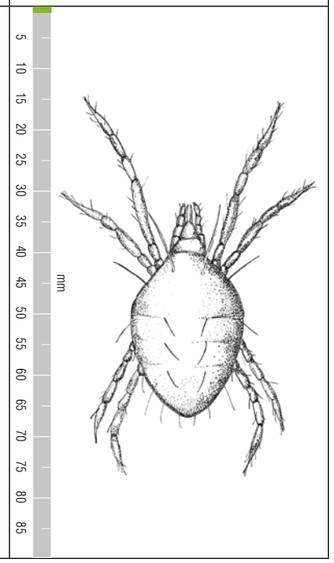
This ready reckoner (Table 4) summarises the major symptoms that many plants show when short (deficient) of a mineral. It provides only general information and shortage of a mineral is just one of many causes that can produce some of these symptoms. Not all crop plants display the same symptoms even 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 person 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 someone 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 and mites**

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	N**O**	**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	**YES** They can infect woody stems	**YES** Common	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**
Mosaic / Mottle	**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	Severe stunting can occur	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	Poor flowering and fruiting	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	Not common	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	Less available at pH over 7	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	Common especially after the pH has been raised	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	Manganese deficiency	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	Legume crops	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. 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 listed previously 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.
	
Internal staining is commonly associated with fungal pathogens that cause wilts. In this cinchona stem the staining is apparent once the outer bark has been removed. Julien Lamontagne-Godwin	*Fusarium oxysporum* f.sp. *cucumerinum* on cucumber. Leaves are severely short of water. The leaves will soon turn yellow and then brown as the plant cannot survive in such conditions. CABI
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 oil seed rape seedlings having damped off after attack by *Pythium*. Phil Taylor, CABI	 *Phytopthora capsici* attacking the roots of capsicum pepper, the plant is severely wilted due to the damage to the roots. CABI
 *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* attacking the roots and base of this squash plant has caused the plant to wilt Howard F. Schwartz, Colorado state university Bugwood.org
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. CABI
 The lower leaves of the egg plant have wilted and yellowed due to the bacterial infection in the lower stem. Phil Taylor, CABI	 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.

Phil Taylor, CABI

Tomato spotted wilt virus symptoms on fruit.

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.

Cassava shoot fly, the tip of the plant has wilted due to the feeding of the larva within the stem.

Shamela Rambadan, CABI

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).

Phil Taylor, CABI

The whole of this bean seedling is wilting due to the beanfly maggots attacking the base of the stem.

Asaba Joseph Mercy, Local Government, Hoima District, Uganda

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.

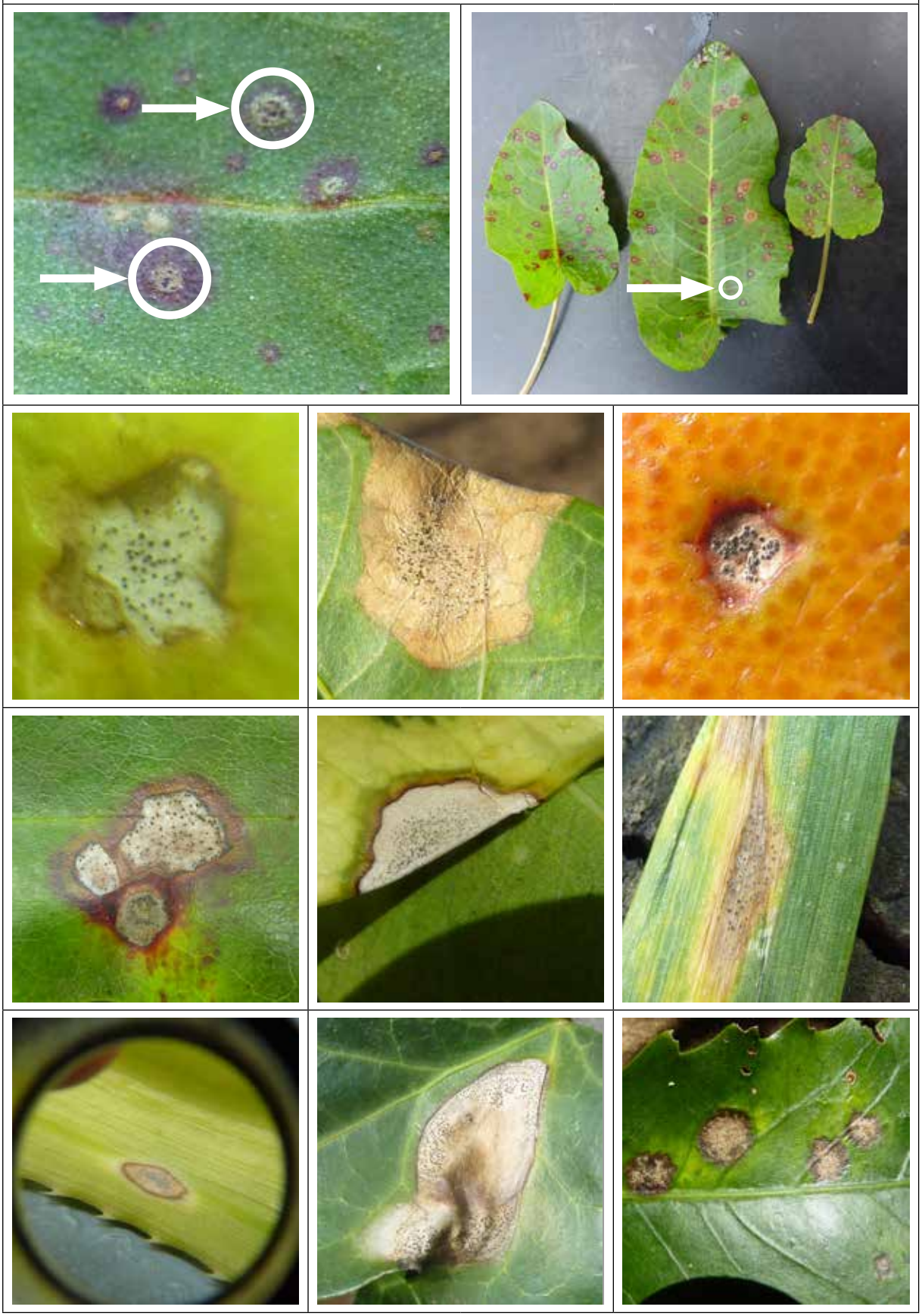
Yubak Dhoj, Department of Agriculture, Nepal

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

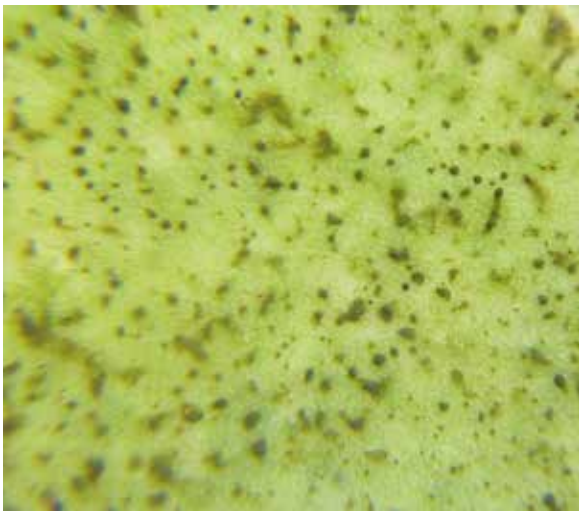
Pictures of fungal fruiting bodies in leaf spots. The presence of the fruiting bodies is a sure indication that the pathogen is a fungus, but if they cannot be found then this does not mean that it is not a fungus causing the problem. In the top pair of photographs only the two spots arrowed (right) 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.

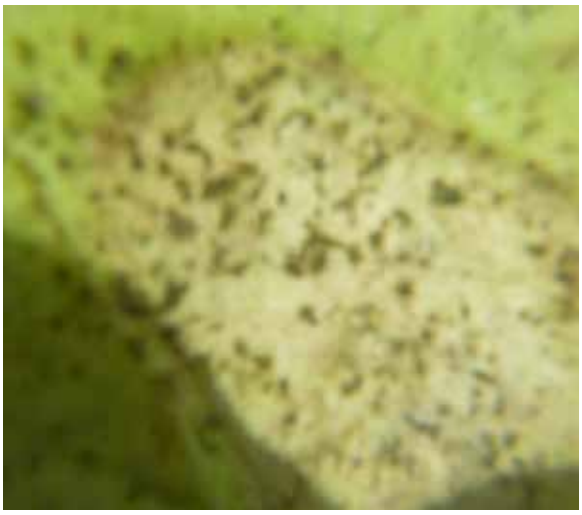
Phil Taylor, CABI



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 colocasiae* on Taro. The leafspot is spreading rapidly, there is some water soaking around the edges of the lesion. The tan dots are not fungal fruiting bodies (this is a water mould) but dried droplets of exudate that had oozed from the leaf. Adhikari, Shalik ram, Plant Protection Directorate (PPD), Nepal
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.

Phil Taylor, CABI

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.

These rings and crescent shapes have a viral cause but spots with rings within them are more typically produced by fungal pathogens.

Scot Nelson, University of Hawaii

These water soaked patches are a very unusual symptom of a virus, these symptoms are more associated with a bacterial infection.

Phil Taylor, CABI

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 (marrow).

Phil Taylor, CABI

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

Phil Taylor, CABI

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

Shamela Rambadan, CABI

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 pigeon pea.

Phil Taylor, CABI

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.
	
Doses of glyphosate that do not kill the plant can induce unusual growth habit. Note the reduced leaf size and clustered internodes. Nettle (left) and annual mercury (right) showing regrowth following glyphosate treatment. Eric Boa CABI (nettle), Phil Taylor CABI (annual mercury).	
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	 Phil Taylor, CABI
 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.

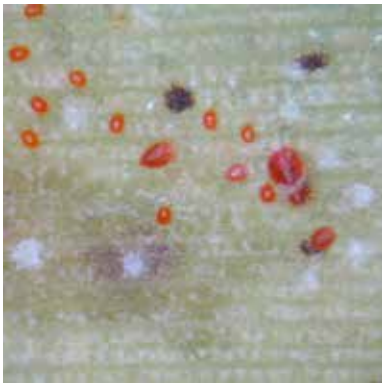
SYMPTOM	BACTERIA
Yellowing of leaves	**YES** Common. A general or non-specific symptom indicating general decline of the plant.

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 CONTINUED
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 CONTINUED
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.
	
Rob Reeder, CABI	Phil Taylor, CABI
Distortion of leaves by fungi is not common but can occur. A very obvious example is peach leaf curl which causes great distortion (and reddening) in the leaves of stone fruits (left). A more typical example would be that seen on the right, the citrus scab fungus is making the leaves of this grapefruit thickened and curled.	

SYMPTOM	**WATER MOULD**
Distortion of leaves	**YES** Not common. Downy mildews can cause unusually shaped leaves.
	
Leaf distortion the systemic infection of pea by *Peronospora pisi* causes the leaves to become leathery and thickened. Phil Taylor, CABI	White rust attacking a common weed, note how the stem is distorted (right). Phil Taylor, CABI
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. The whole tip of the plant is affected. The leaves are tiny and rolled. Phil Taylor, CABI	 The lettuce has severe leaf distortion; in this case the leaf veins are unusually large, distorting the whole appearance of the leaf. CABI
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 cassava leaves.

Rob Reeder, CABI

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.

Phil Taylor, CABI

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.
	Distorted soybean leaves due to herbicide drift from nearly spraying. Bob Scott, University of Arkansas

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.
 The potato is showing signs of little leaf. The leaves are small and tightly clustered around the tip. Rob Reeder, CABI	 Groundnut rosette virus. The groundnut plant is small partially due to the stem length but also because of the severe reduction in leaf size. Kalule Okello David, Ministry of Agriculture, 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.
	Tiny leaves clustered at the top of this Saba vegetable is typical of phytoplasma infection. The leaves are not just small they are tiny as a direct symptom of the pathogen. 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.	

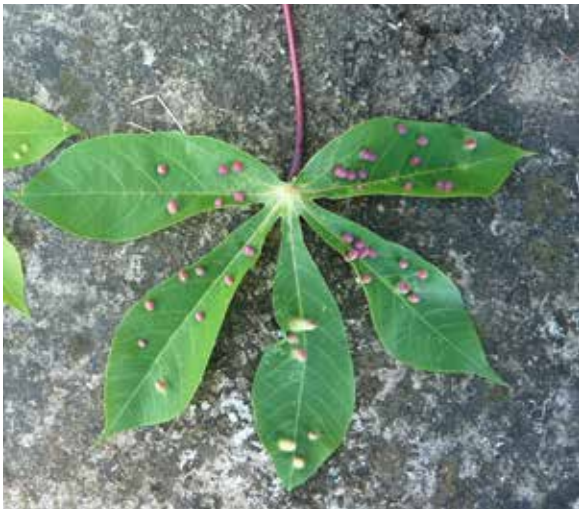
Galls

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 mango (right). The bacterial pathogen has caused the plant material to grow in this unstructured and disorganised manner. Phil Taylor, CABI (left), Scot Nelson, University of Hawaii (right)	
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 (as seen in the photo on the right).	

SYMPTOM	INSECTS & MITES
Galls	**YES** Very common. Seen on many types of plant.
 Phil Taylor, CABI	 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 lettuce. Note the extensive rotting spreading over the leaves. Phil Taylor, CABI

SYMPTOM	WATER MOULDS
Drying/necrosis/blight	**YES** Very common. Associated with many types.
	Late blight on tomato, the lower leaves have died and the plant has collapsed. Phil Taylor, CABI
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.

The stem and tendrils of the pea have turned brown and died and the bacterial infection is rapidly spreading through the stipules.

Phil Taylor, CABI

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.	

TABLE 6: 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.

	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.

PEST COMBINATION	SYMPTOMS IN COMMON	TECHNIQUES FOR DIFFERENTIAL DIAGNOSTICS
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.

PEST COMBINATION	SYMPTOMS IN COMMON	TECHNIQUES FOR DIFFERENTIAL DIAGNOSTICS
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.
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.

PEST COMBINATION	SYMPTOMS IN COMMON	TECHNIQUES FOR DIFFERENTIAL DIAGNOSTICS
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).

PEST COMBINATION	SYMPTOMS IN COMMON	TECHNIQUES FOR DIFFERENTIAL DIAGNOSTICS
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.

PEST COMBINATION	SYMPTOMS IN COMMON	TECHNIQUES FOR DIFFERENTIAL DIAGNOSTICS
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.

PEST COMBINATION	SYMPTOMS IN COMMON	TECHNIQUES FOR DIFFERENTIAL DIAGNOSTICS
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.

PEST COMBINATION	SYMPTOMS IN COMMON	TECHNIQUES FOR DIFFERENTIAL DIAGNOSTICS
27 **VIRUSES/MITES**	1. **Mosaic and mottling.** Mites cause minute stippling of the leaves, which can be confused with mosaic symptoms. 2. **Leaf distortion.** In high numbers and on developing leaves, mites can cause distortion similar to that of viruses.	**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.
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. 2. **Poor growth.** 3. **Distorted leaves and fruits.**	**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. 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. 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. 2. Soil acting herbicides can mimic the yellowing effect of viruses.	**Confusion possible** 1+2. Ask about local herbicide use.
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)).

PEST COMBINATION	SYMPTOMS IN COMMON	TECHNIQUES FOR DIFFERENTIAL DIAGNOSTICS
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.
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.

PEST COMBINATION	SYMPTOMS IN COMMON	TECHNIQUES FOR DIFFERENTIAL DIAGNOSTICS
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.

ANNEXES

Annex 1: Scientific names of crops mentioned

AMARANTHUS	*Amaranthus tricolor*	LIME	*Citrus aurantifolia*
ANNUAL MERCURY	*Mercurialis annua*	LONGAN	*Dimocarpus longan*
APPLE	*Malus domestica*	LUCERNE	*Medicago sativa*
AVOCADO	*Persea americana*	MAIZE	*Zea mays*
ASH	*Fraxinus nigra*	MANGO	*Mangifera indica*
BANANA	*Musa* spp.	MELON	*Cucumis melo*
BEECH	*Fagus sylvatica*	NETTLE	*Urtica dioica*
BIRCH	*Betula lenta*	OAK	*Quercus robur*
BEAN	*Phaseolus vulgaris*	OIL SEED RAPE	*Brassica napus*
BRAMBLE	*Rubus fruticosa*	ONION	*Allium cepa*
CABBAGE	*Brassica oleracea*	PAPAYA	*Carica papaya*
CACAO	*Theobroma cacao*	PARSNIP	*Pastinaca sativa*
CAPSICUM PEPPER	*Capsicum annum*	PEA	*Pisum sativum*
CARROT	*Daucus carota*	PEAR	*Pyrus* spp.
CASHEW	*Anacardium occidentale*	PEACH	*Prunus persica*
CASSAVA	*Manihot esculenta*	PEARL MILLET	*Pennisetum glaucum*
CHIVES	*Allium schoenoprasum*	PHASEOLUS BEAN	*Phaseolus vulgaris*
CLOVER	*Trifolium* spp.	PIGEON PEA	*Cajanus cajan*
CLUSTER BEAN	*Cyamopsis tetragonoloba*	PINEAPPLE	*Ananas comosus*
CASTOR BEAN	*Ricinus communis*	POTATO	*Solanum tuberosum*
CHERRY	*Prunus serotina*	RICE	*Oryza sativa*
COCONUT	*Cocus nucifera*	RADISH	*Raphanus sativus*
COFFEE	*Coffea arabica*	RASPBERRY	*Rubus idaeus*
COTTON	*Gossypium hirsutum*	ROSE	*Rosa* spp.
CRACK WILLOW	*Salix fragilis*	SABA VEGETABLE	*Sauropus androgynus*
CUCUMBER	*Cucumis sativa*	SAPODILLA	*Manilkara zapota*
CURRANTS	*Ribes* spp.	SHEPHERD'S PURSE	*Capsella bursa-pastoris*
DRY BEAN	*Phaseolus vulgaris*	SILVER BIRCH	*Betula pendula*
EGGPLANT	*Solanum melongena*	SOURSOP	*Annona muricata*
GRAPE VINE	*Vitis* spp.	SPINACH	*Spinacia oleracea*
GREEN GRAM	*Vigna radiata*	SQUASH	*Cucurbita spp.*
GROUNDNUT	*Arachis hypogaea*	SUGARBEET	*Beta vulgaris*
POTATO	*Solanum tuberosum*	SUGARCANE	*Saccharum officinarum*
JAMAICAN SORREL	*Hibiscus sabdariffa*	SWEET PEPPER	*Capsicum annuum*
JATROPHA	*Jatropha curcas*	SWEET POTATO	*Ipomoea batatas*
JERUSALEM ARTICHOKE	*Helianthus tuberosus*	TOMATO	*Solanum lycopersicum*
LEEK	*Allium ampeloprasum*	TARO	*Colocasia esculenta*
LENTIL	*Lens culinaris*	WATERMELON	*Citrullus lanatus var. lanatus*
LETTUCE	*Lactuca sativa*	WHEAT	*Triticum aestivum*

Annex 2: 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 3: 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 real samples you see. Note that no images are provided for some symptoms such as fruit drop or leaf fall as these are considered sufficiently self-explanatory.

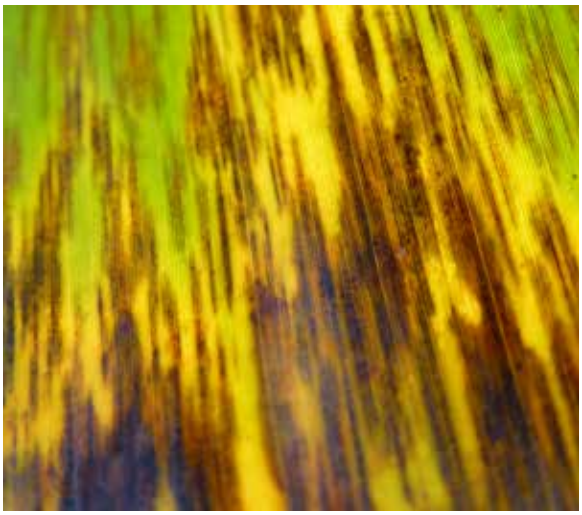
WILT	Leaves and young stems droop down due to lack of water reaching them. Woody parts of plants cannot wilt, only the attached leaves.
 Bean plants wilting and yellowing, these two symptoms are commonly seen together. Robert Reeder, CABI	 Watermelon plants wilting due to shortage of water. The leaves are drooping but the plants have not yet collapsed. Phil Taylor, CABI
 Sweet potato wilting. The leaf will not survive in this wilted state and will become dried and necrotic. Phil Taylor, CABI	 Single capsicum pepper plant wilting. Note fully healthy neighbouring plants. Phil Taylor, CABI

YELLOW	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. Phil Taylor, CABI	 The yellow leaf laminar contrast strongly with the green leaf veins this can be a diagnostic feature in some cases. Phil Taylor, CABI
 Yellow and green areas of this crop are due to the unequal distribution of fertilizer. Phil Taylor, CABI	 This yellow maize crop is stunted and will produce no yield. Phil Taylor, CABI

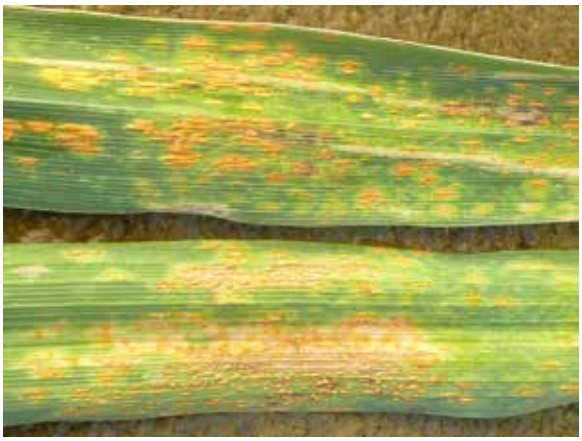
REDDENING	Leaves have changed colour from green (but are not yellow). They often turn purple or red. This can be a sign of stress and the cause of the stress may be some way from the symptom.
 Some plants will change to yellow before turning red as is the case in these wheat leaves. Phil Taylor, CABI	 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
 Normally green, the reddening of the leaves of this weed (Silver cockscomb; *Celosia argentea*) can be used as a means of assessing soil fertility Prakash Kumar, CABI	 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 leaf on the left is stressed and has lost almost all green colour, it has turned red and yellow the leaf on the right is healthy. Phil Taylor, CABI	 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 banana plant appears healthy but is very short due to banana bract mosaic virus infection. David Jones	 This crop is severely stunted. It is clearly water stressed and short of minerals. Phil Taylor, CABI

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 tip of this pear tree has died, note that the leaves have not fallen and this can be a characteristic feature. Phil Taylor, CABI
 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 raspberry has died, if the plant is to survive it will have to shoot from elsewhere. Rob Reeder, CABI

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 are all of a similar size, have a dark interior and are spreading slightly along the minor leaf veins. All these symptoms can be important in diagnosis. Robert Reeder, CABI
 Large leaf spots but with the characteristic dead interior and a clear border region. Phil Taylor, CABI	 Circular leafspots with a clearly defined border. Notice how they reach a maximum size. Phil Taylor, CABI
 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

PUSTULE	A discrete zone on a leaf that is usually raised and dusty; almost always due to a fungal 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, white pustules are usually caused by a water mould, not a fungus. Phil Taylor, CABI	 Pustules are elongated and in chains along the length of the leaf due to the leaf veins. Phil Taylor, CABI
 Almost no host reaction is typical around pustules as seen on this beetroot leaf. Robert Reeder, CABI	 Dusty brown and black pustules on chives. Phil Taylor, CABI

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.
 The blistering on this leaf is mild but colour patterns clearly indicate a viral infection. Phil Taylor, CABI	 The blistered regions may be a different colour to the remainder of the leaf as in this photo. Phil Taylor, CABI
 This grapevine leaf has what appear to be raised blisters in the surface but the remainder of the leaf is not distorted. Phil Taylor, CABI	 The distortion of these birch leaves is in the form of multiple blisters on the leaf surface Phil Taylor, CABI

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

MOTTLING/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.

Phil Taylor, CABI

The symptoms here are of stange yellow patterns especially around the leaf veins.

Robert Reeder, CABI

The blotchy pattern on the leaf are best described as a mottle.

Julien Lamontagne-Godwin, CABI

This inter veinal yellowing is producing a mottled pattern that could be considered a mottled pattern.

Shamela Rambadan, CABI

LEAF EDGE SCORCH	The edges of the leaf become brown and die (necrotic). This condition usually has an abiotic cause but bacterial infections spreading from all around the edge of a leaf can produce a similar effect.
 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	 Notice how the edges of the older leaves are affected but not the middle region or the younger leaves. Phil Taylor, CABI

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	 What appears to be white growth over the surface of this soursop is a coating of insects and not a fungal infection. Shamela Rambadan, CABI	 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. Phil Taylor, CABI	 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 cashew fruit has a whiteish growth spreading over the surface. Robert Reeder, CABI	 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	The ooze of material from the wound is typical of some cankers. Scot Nelson, University of Hawaii
	
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	Cankers can develop resinous lumps as the plant sap becomes solid when leaves the plant. Phil Taylor, CABI

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	 Insect gall on thistle, note that the gall is smooth. Phil Taylor, CABI
 Insect galls on oak. Note that they are all precisely the same size. Robert Reeder, CABI	 Spectacular galls on crack willow. Robert Reeder, CABI

ROT	The tissue has to become soft and slimy (in addition to brown) to be considered a true rot.
 This lettuce is rotting rapidly, the leaves have lost all structure and are falling apart. Phil Taylor, CABI	 Fruit is especially prone to rotting as it is often sweet and soft. This mango is rotting from one end and will soon consume the whole fruit. Phil Taylor, CABI
 Rot on the tuber of Jerusalem artichoke. Phil Taylor, CABI	 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 of the stem is commonly associated with pathogens that cause plants to wilt. CABI

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	These cashews have not developed and have dried out but have remained hard and have not rotted. Rob Reeder, CABI
	
Complete drying of a coffee plant. Robert Reeder, CABI	Drying of isolated branches is a common symptom on mango. Phil Taylor, CABI

FRASS	Many insect pests (larvae and adults) leave excreta (faeces) on the surface of the plant; it may indicate the type of insect attacking the plant even if the insect is absent.
 Ball shaped soft pellets of frass are typical of many types of caterpillar. Phil Taylor, CABI	 Tiny black dots (some of which are ringed) of sticky material are typical of the frass of thrips, often seen alongside the white areas of thrips feeding. Robert Reeder, CABI
 Small white pellets deposited on the surface of these seeds are the frass of the boring beetle that hollowed them out. Phil Taylor, CABI	 Slimy brown oval shaped frass is typical of many grasshoppers. Robert Reeder, CABI

WEBBING	Insect larvae and mites have the ability to spin thin silken webs; they often use these threads to create a habitat for themselves.
 These larvae live together and combine their webbing to make a communal habitat. Phil Taylor, CABI	 Live mites, castoff skins and frass are visible on the webbing when held against a white background. Phil Taylor, CABI
 Mites have produced a sleeve of webbing over this badly infested aubergine (eggplant, brinjal) leaf. Phil Taylor, CABI	 Sometimes the webbing is seen as fine silk threads, larvae pull leaves together with these threads for protection. Tim Haye, CABI

Contact us

Africa

Ghana

CABI, CSIR Campus
No. 6 Agostino Neto Road
Airport Residential Area
P. O. Box CT 8630, Cantonments
Accra, Ghana

T: +233 (0)302 797 202
E: westafrica@cabi.org

Kenya

CABI, Canary Bird,
673 Limuru Road,
Muthaiga,
PO Box 633-00621
Nairobi, Kenya

T: +254 (0)20 2271000/20
E: africa@cabi.org

Zambia

CABI, 5834 Mwange Close
Kalundu
PO Box 37589
Lusaka, Zambia

E: southernafrica@cabi.org

Americas

Brazil

CABI, UNESP-Fazenda Experimental
Lageado, FEPAF (Escritorio da CABI)
Rua Dr. Jose Barbosa de Barros 1780
Fazenda Experimental Lageado
CEP:18.610-307
Botucatu, San Paulo, Brazil

T: +5514-38826300
E: y.colmenarez@cabi.org

Trinidad & Tobago

CABI, Gordon Street, Curepe
Trinidad and Tobago

T: +1 868 6457628
E: caribbeanLA@cabi.org

USA

CABI, 745 Atlantic Avenue,
8th Floor, Boston,
MA 02111, USA

T: +1 617 6829015
E: cabi-nao@cabi.org

Asia

China

CABI, Beijing Representative Office
Internal Post Box 85
Chinese Academy of Agricultural Sciences
12 Zhongguancun Nandajie
Beijing 100081, China

T: +86 (0)10 82105692
E: china@cabi.org

India

CABI, 2nd Floor, CG Block,
NASC Complex, DP Shastri Marg
Opp. Todapur Village, PUSA
New Delhi – 110012, India

T: +91 (0)11 25841906
E: cabi-india@cabi.org

Malaysia

CABI, PO Box 210,
43400 UPM Serdang
Selangor, Malaysia

T: +60 (0)3 89432921
E: cabisea@cabi.org

Pakistan

CABI, Opposite 1-A,
Data Gunj Baksh Road
Satellite Town, PO Box 8
Rawalpindi-Pakistan

T: +92 (0)51 929 2064 / 3
E: sasia@cabi.org

Europe

Switzerland

CABI, Rue des Grillons 1
CH-2800 Delémont,
Switzerland

T: +41 (0)32 4214870
E: europe-CH@cabi.org

UK

CABI, Nosworthy Way
Wallingford, Oxfordshire
OX10 8DE, UK

T: +44 (0)1491 832111
E: corporate@cabi.org

UK

CABI, Bakeham Lane
Egham, Surrey
TW20 9TY, UK

T: +44 (0)1491 829080
E: microbiologicalservices@cabi.org
E: cabieurope-uk@cabi.org

PestSmart Diagnostic Field Guide

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

Compiled by Phil Taylor

The huge variety of plants that are grown for various reasons and the numerous biotic and abiotic factors that can reduce plant vigour make it very difficult to diagnose all plant health problems. That is a problem since a good diagnosis is the first step in identifying solutions.

The *PestSmart 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 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.

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