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A Visual Guide to Nutritional  
Disorders of Tropical Timber Species:  
*Swietenia macrophylla* and *Cedrela odorata*

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# Introduction

As sources of high-value tropical timbers from natural forests dwindle, there is strong commercial and community interest in producing these timbers from plantations. However, because forestry must compete with other land uses, the sites available for plantation establishment are frequently infertile and/or have been degraded by previous unsustainable land uses. Such sites are often deficient in one or more of the plant nutrients that are necessary to maintain acceptable rates of tree growth. Recent research in the humid tropics has revealed the widespread extent and severity of these nutrient limitations and demonstrated the cost effectiveness of targeted fertiliser applications in increasing growth and wood yield. Nonetheless, the extent of the potential production lost because of nutrient deficiencies is still not widely recognised by many forest managers due to a lack of available information and/or appropriate 'tools' to aid in identifying nutritional problems in tropical trees. The visual symptoms outlined in this book are a first step in alerting plantation managers to nutrient deficiencies they may encounter in the nursery and the field.

The recognition of symptoms on leaves and stems which result from nutritional disorders is a powerful tool in determining nutritional constraints to the growth of trees—especially when little other nutritional information is available. When used in conjunction with other information, such as soil parent material, climate, soil analysis, concentration of nutrients in tissues, site history, and nutrient (fertiliser) trials, it can often lead to rapid diagnosis of major nutritional constraints.

On their own, symptoms can often be the first indication that nutritional constraints to production exist.

Recognition of these symptoms can lead to trials or experiments which may confirm the existence of nutritional constraints.

Whilst some symptoms may be the result of any one (or combination) of a number of disorders, others such as iron deficiency often have features that are highly distinctive and are recognisable across a wide range of species.

Although the diagnosis of symptoms can be useful, it should **not** be relied on as the sole system of managing the nutrition of trees. In most cases, by the time symptoms appear, the deficiency is quite severe and substantial losses in potential production may have already occurred.

The manifestation of symptoms depends on two main features of each nutrient: its biological function, and its mobility (the ease with which it is transported) within the plant. Biological function affects certain processes (for example, chlorophyll production, leaf expansion, or stem elongation) and thus will determine the type of symptom produced. Mobility within the plant will determine the most likely location of the symptom—for example, highly mobile nutrients will usually show symptoms in the older leaves and tissues, whereas immobile nutrients will usually show symptoms in the younger leaves and tissues. Unfortunately, however, there are some exceptions to these guidelines.

While the symptoms described and illustrated in this book can be used in an empirical fashion (i.e. specific for these species), an understanding of function and mobility of key elements will assist in diagnosing symptoms in other species for which deficiencies have not been documented.

## Methodology

This book is the first attempt to document the visible symptoms of nutrient deficiencies for *Swietenia macrophylla* and *Cedrela odorata*. The symptoms have been developed under carefully controlled conditions, mainly in solution cultures in glasshouses, but also in soil cultures in pots and in field studies. The symptoms are primarily derived from young plants less than 8 months old, and while the descriptions in this book will be useful for identification of nutritional disorders in young plants (eg nursery stock and newly planted field plants), the symptoms visible in mature trees may differ somewhat from those in this book.

It was not always (technically) possible to obtain the necessary degree of deficiency (or excess) to induce symptoms for all nutrients for all species, especially for the micronutrients. Therefore, if visible symptoms for a particular element are not included in this book, this omission does not mean that visible symptoms do not exist for that nutritional disorder; but rather that they were not developed under the conditions used in the present study.

## Acknowledgments

The authors are pleased to thank Grace Baker and Sue Joyce for technical assistance. We also wish to thank Alan Brown and Richard Bell for valuable comments on the manuscript.

## How to Use this Book

Success in getting a useful diagnosis depends on more than just symptom information, so do read the next section, Steps in the Diagnosis of Nutritional Disorders. The more additional information you have at hand, the more likely it is that you will be able to make a reliable diagnosis.

The book has been designed to assist in reducing the number of possible diagnoses to the two or three most likely. It will not necessarily result in an absolute and definitive diagnosis.

There is a key provided for each species as a first step in reducing the number of possible diagnoses. This is not a typical dichotomous key commonly used in symptom identification, but rather, this key may lead to a number of possible diagnoses.

A good approach is to identify the location (leaf, stem or growing point) of the symptom and then identify the type of symptom (colour, shape etc). Do this with each of the symptoms present. With this information, follow the keys for each symptom. Take note of ALL of the descriptions that are appropriate. The key will usually lead to a number of possible diagnoses. Read the detailed description of the symptoms for each of the possible diagnoses in the sections following the key, taking into account the 'likely' and 'unlikely' scenarios, to come up with the most likely one or two nutrients that could be responsible for the symptoms observed. At this point it may be necessary to collect additional information or even undertake some experimentation to narrow the possibilities further.

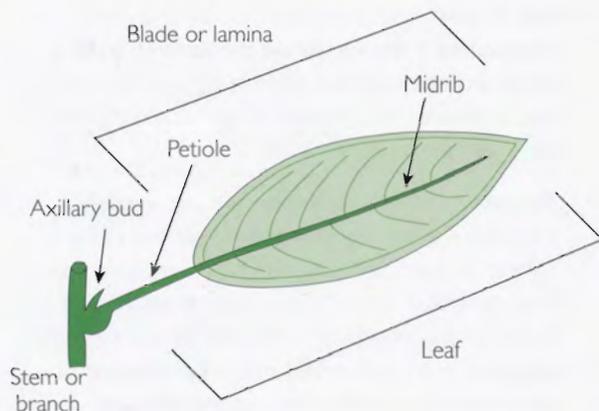
In using this book, it is important to keep the following points in mind:

- Different disorders can have very similar symptoms, and the key may suggest that more than one nutrient be considered.
- Not all symptoms listed in the key for a given nutrient may be present in the affected plant at any one time.
- Not all symptoms under each nutrient may be represented in the key. So use the pictures in the key as examples. Do not exclude a possible nutrient simply because the symptom does not exactly match the example shown.
- The categories listed in the key are not mutually exclusive. A plant may have more than one of the symptoms listed and may even have symptoms that have descriptions which seem in apparent conflict. For example, depending on its severity, iron deficiency can result in a very marked interveinal chlorosis or a chlorosis that is uniform across the veins and interveins. So take note of all symptom descriptions that are appropriate.
- Excessive (toxic) concentrations of some nutrients (or non-nutrients) can cause a deficiency of other nutrients, and the visible symptoms may be a combination of the symptoms of the toxicity of one nutrient and the deficiency of another nutrient.
- Similarly, deficiencies of some nutrients may induce a toxicity of other nutrients.
- Any conclusion based solely on visible symptoms should be considered as a preliminary diagnosis to be confirmed wherever possible by other methods such as soil and plant analyses, pot culture assays, and field experiments.

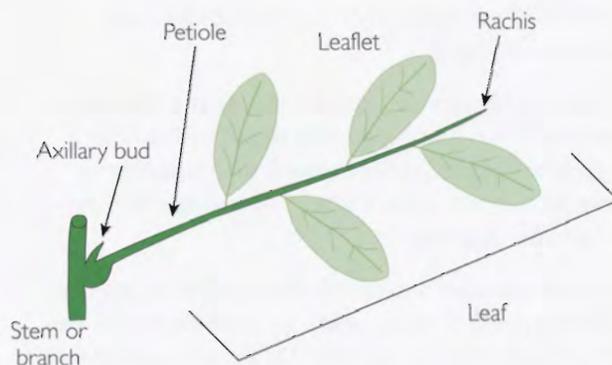
## Notes on Terminology

As far as possible, we have tried to be botanically correct in the use of terms without making the book 'unreadable' to a non-botanist. In both *Swietenia macrophylla* and *Cedrela odorata*, all but the first few leaves developed on a young seedling are **compound** leaves. This means that the true leaf is actually divided into leaflets. Usually, the descriptions in this book refer to these leaflets.

The term 'nutrient' has been used in preference to 'element' even though in many other texts on symptoms of nutritional disorders, the terms are used interchangeably.



Simple leaf



Compound leaf

## Brief Glossary of Terms

### **axillary bud**

The bud from which a branch grows. It is called an axillary bud because it is in the axil of the leaf. It is this bud which defines a leaf.

### **abscise/abscission**

Detach; fall off.

### **basal**

Near the base of the leaf; i.e. closest to the stem.

### **chlorophyll**

The photosynthetic pigment in plants that gives leaves their green colour.

### **chlorotic/chlorosis**

Leaves (and sometimes other plant tissue) lose their normal green colour and turn yellow or white. Chlorosis is caused by the loss of chlorophyll from the tissue.

### **compound leaf**

The leaf blade is divided into leaflets.

### **distal**

Near the tip of the leaf, i.e. away from the stem.

### **internodes**

The portion of the stem between two nodes.

### **interveinal**

Refers to the tissue between the veins of the leaf.

### **lamina (leaf blade)**

The flattened part or blade of the leaf.

### **marginal**

Occurring on the edges of the leaf.

### **meristem**

The growing point, usually of the stem.

### **nodes**

Points where the leaves (or branches) emerge from the stem.

### **petiole**

The stalk that connects the leaf lamina to the stem.

### **necrotic/necrosis**

Tissues, or patches of tissue, which are dead. Usually such patches are brown in colour and have a dried out, papery appearance.

### **rachis**

An extension of the petiole in a compound leaf. It is equivalent to the midrib of a simple leaf.

### **simple leaf**

The leaf blade is entire and is not divided into separate leaflets.

# Steps in the Diagnosis of Nutritional Disorders

Grundon (1987) is one of the few references which describe the steps in diagnosis of nutritional disorders, and what follows is a précis of his suggestions.

**Know the healthy plant.** Before visible symptoms can be used to assist in the diagnosis of a disorder, it is essential that you know what a healthy plant looks like during all stages of its growth, and how a healthy plant reacts to different environmental conditions of rainfall, temperature and light. For this reason, a description of a healthy seedling is included in this booklet before the visual symptoms of each nutritional disorder are described. This description should be read as the first step in diagnosis of possible nutritional disorders.

**Develop a case history.** Develop a case history of the problem and the area where the plants are growing. Questions that can be asked to develop a case history include:

- What has been the recent rainfall and temperature? This is especially important if they have been unusual for the locality. For example, unusually heavy rainfall can leach very soluble nutrients such as nitrate from the root zone of recently transplanted seedlings, causing a temporary nitrogen deficiency.
- What is the soil type where the problem occurs? Some soil types are prone to causing particular nutritional disorders. For example, deficiencies of copper and iron are more likely to occur in peat and other soils high in organic matter where the organic matter 'locks up' soluble copper and iron, whereas a deficiency of manganese is most unlikely in peat soils because the low pH makes manganese more soluble

and therefore more available to plants. Hence occurrence of a disorder is affected by the soil type rather than the species growing on it, and knowledge of the soil type can eliminate some disorders from consideration. For this reason, soil types where a disorder is unlikely or highly unlikely to occur have been listed in this book under each nutrient.

- Has a soil test been completed on the soil? This information can be most important as it can eliminate certain nutrients from consideration. For example, when the soil is very acidic, with a pH less than 4.5, manganese and aluminium become more soluble and can occur in toxic concentrations in the soil solution. Likewise, when the soil pH becomes very alkaline, with a pH above 8.0, some elements such as zinc become less soluble. Under these conditions, plants may be unable to absorb sufficient quantity for healthy growth, even though there is a large quantity of total zinc in the soil.
- Has fertiliser been applied in the past? If so, what fertiliser was it and when was it applied?
- Has the plant material been chemically analysed; what were the results?

**Describe the symptoms.** While visible symptoms of deficiency or excess are usually more apparent on the leaves, they can occur on any part of the plant, including the stem, fruit and roots. Because insects, disease or nematodes can cause visible symptoms also, it is essential to note if these are present, and if present to include them in the possible cause of the visible symptoms. When describing the symptoms, pay particular attention to the following:

- The location of the symptom. Does it appear only on the leaves or stem or roots? If it is on the leaves, are they the youngest or oldest leaves or over the whole plant? Does it occur mainly near the tip of the leaf, mainly near the base or over the whole leaf? Does it occur only on the leaf margins or does it occur only in the body of the leaf? Does it occur only between the veins with the veins remaining unaffected, or are the veins the only parts affected?
- The colour of the symptoms. Are they pale green, or a pale or deep yellow (i.e. chlorotic), or brown, or red?
- Is the tissue live or dead (i.e. necrotic)? Here it is important to realise that dead tissue is not always coloured brown, but may be white or even yellow.
- Has the size of the plant or organ changed? Stunted growth is sometimes the only symptom of phosphorus deficiency in some trees.
- Has the shape of the organ changed? Some disorders cause the margins of the leaves to turn upwards and the whole leaf may become cupped.
- Has the orientation of the plant or organ changed? In some disorders the plant or leaves may have a wilted, limp appearance, or the tips of the leaves may become twisted.
- Can you see a pattern to the development of the visible symptoms from mild to severe? The sequence or order in which the visible symptoms appear usually follows a definite pattern as the disorder progresses from mild to very severe. For example, in the early or mild stage of a disorder, pale yellow chlorotic spots may appear near the margins of the leaf, mainly towards the tip or distal portion of the leaf. These chlorotic spots may advance towards the margins and, as the tissue dies, become brown necrotic spots

surrounded by a halo of yellow chlorosis. Eventually, as the disorder becomes more severe, the necrotic spots join up to produce a brown marginal necrosis that grows towards the basal portion of the leaf, and advances into the body of the leaf between the veins. By carefully examining a number of leaves on the same plant, or a number of different plants, it is possible to see and describe all stages of the disorder.

**The final diagnosis.** When as much information as possible has been gathered, use one of the keys in this book to identify possible nutritional causes for the symptoms.

#### **Notes of caution**

An absence of a symptom does not necessarily mean that nutrient constraints are absent. For example, P deficiency can cause severe growth reduction without the development of other visible symptoms. Similarly, plants grown in soils of generally low fertility may appear healthy in all respects (visual appearance, nutrient concentrations, photosynthetic capability) but still have reduced growth rates.

Some symptoms in trees can be caused by agents other than nutrient deficiencies, such as insects and other herbivores, environmental stresses (temperature, wind, water), salinity, toxicities of nutrient and non-nutrient elements, pathogens, pollutants, pesticides and herbicides, and genetic factors (Dell *et al.* 2001). The possibility that these factors may also be present must be considered when assessing the cause of a particular visible symptom.

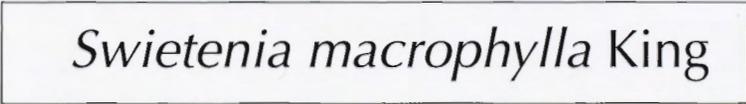
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Nutrient disorders in plantation eucalypts. 2nd edition.  
Canberra, ACIAR Monograph No. 74. 188 pp.
- Grundon, N.J. 1987. Hungry crops: a guide to nutrient deficiencies in field crops. Brisbane, Queensland Department of Primary Industries. 246pp.

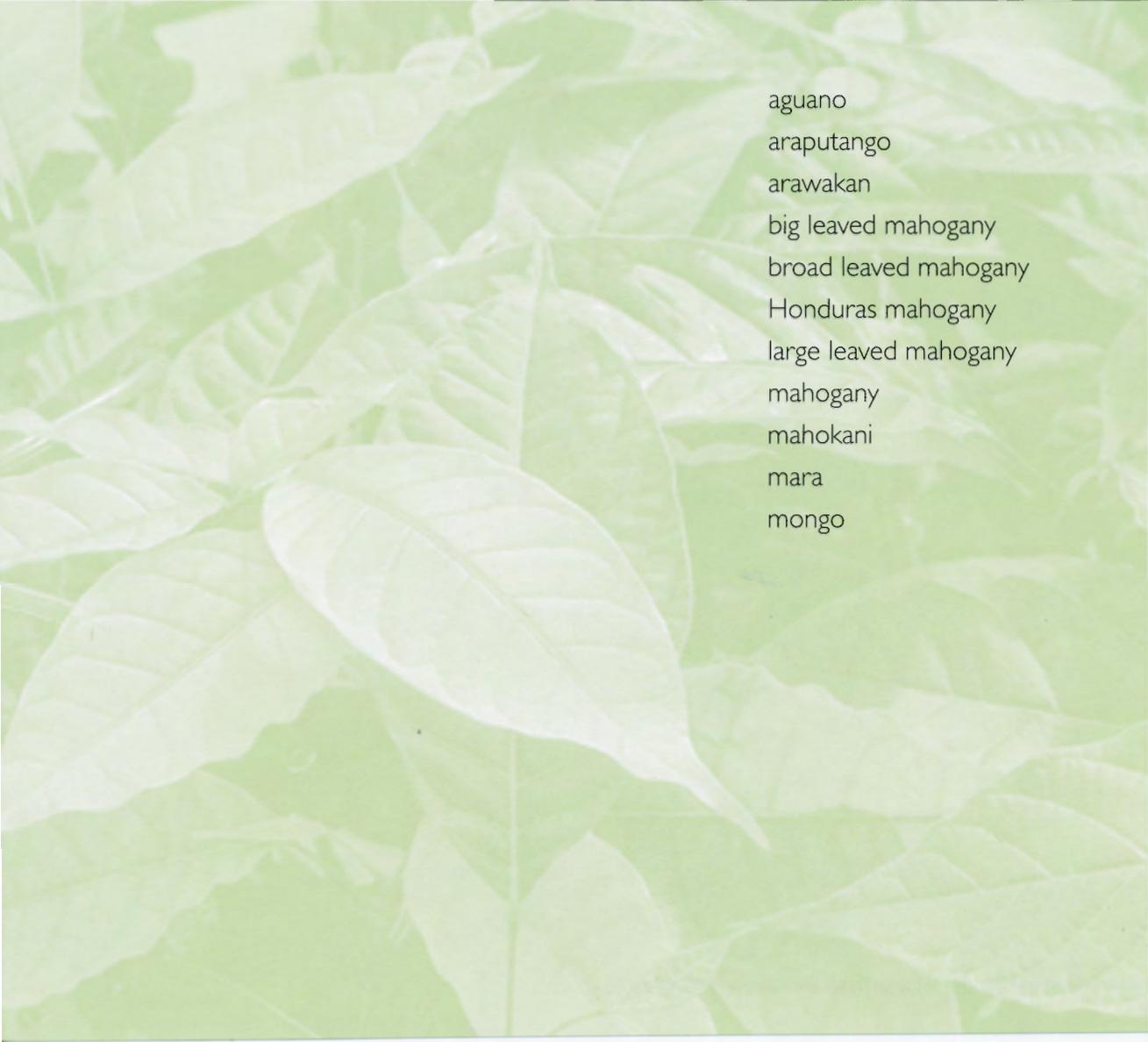
## Other Useful Resources

The following bibliography refers to either photographic or written descriptions of symptoms of nutritional disorders in trees, but not necessarily *Swietenia macrophylla* or *Cedrela odorata*. Many other references to symptoms of nutritional disorders in trees are listed in Grundon *et al.* (1997).

- Bergmann, W. (ed) 1992. Colour atlas of nutritional disorders of plants: visual and analytical diagnosis. Jena, Gustav Fischer. 386pp.
- Grundon, N.J., Robson, A.D., Lambert, M.J. and Snowball, K. 1997. Nutrient deficiency and toxicity symptoms. In: Plant analysis: an interpretation manual. Second edition. Collingwood, Victoria, CSIRO Publishing, 37–51.
- Kamala, B.S., Angadi, V.G., Parthasarathi, K. and Rai, S.N. 1986. Symptoms of deficiency of trace elements and the associated changes in peroxidase isoenzyme pattern in the seedlings of teak, mahogany and eucalyptus. Van Vigyan, 24, 49–55.



*Swietenia macrophylla* King



aguano  
araputango  
arawakan  
big leaved mahogany  
broad leaved mahogany  
Honduras mahogany  
large leaved mahogany  
mahogany  
mahokani  
mara  
mongo

# Symptom Key

No apparent symptoms on leaves

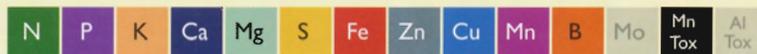
N	<b>P</b>	K	Ca	Mg	S	Fe	Zn	Cu	Mn	B	Mo	Mn Tox	Al Tox
---	----------	---	----	----	---	----	----	----	----	---	----	-----------	-----------

## Symptoms based on

- Leaf colour ..... Key pages 14-15
- Leaf shape and condition ..... Key pages 22-23
- Stems and growing point ..... Key pages 24-25

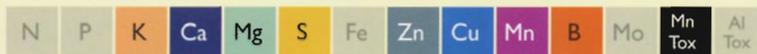
## Symptoms based on leaf colour: overall

Pale green/  
yellow/white  
(chlorosis)



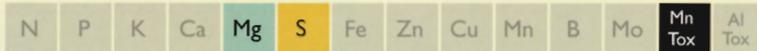
Key pages  
16-19

Brown patches  
or spots – dead  
(necrotic)



Key pages  
20-21

Brown spots –  
alive (not  
necrotic)



Pink



N P K Ca Mg S **Fe** Zn Cu Mn B Mo Mn Tox Al Tox

Dark green



N P K **Ca** Mg S Fe Zn **Cu** Mn B Mo Mn Tox Al Tox

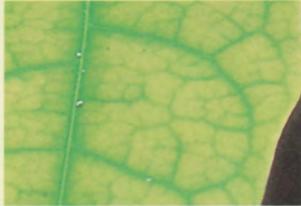
Red tinge



**N** P K Ca Mg S Fe Zn Cu Mn **B** Mo Mn Tox Al Tox

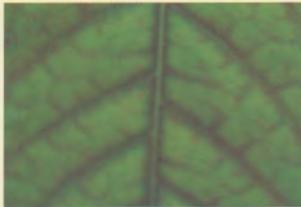
## Symptoms based on leaf colour: pattern of chlorosis

Veins green;  
interveinal  
areas strongly  
chlorotic



N P **K** Ca Mg S **Fe** **Zn** Cu Mn B Mo **Mn Tox** **Al Tox**

Veins green;  
interveinal areas  
mildly chlorotic



N P K **Ca** Mg S Fe **Zn** Cu **Mn** B Mo **Mn Tox** **Al Tox**

Veins green;  
interveinal areas  
weakly chlorotic



N P K Ca Mg **S** **Fe** **Zn** **Cu** Mn B Mo **Mn Tox** **Al Tox**

## Symptoms based on leaf colour: position of chlorosis

Basal



N P K Ca Mg S Fe Zn Cu Mn B Mo Mn Tox Al Tox

Distal



N P K Ca Mg S Fe Zn Cu Mn B Mo Mn Tox Al Tox

Marginal



N P K Ca Mg S Fe Zn Cu Mn B Mo Mn Tox Al Tox

Lobed



N P K **Ca** Mg S Fe **Zn** Cu Mn B Mo **Mn Tox** **Al Tox**

Body of leaf



N P K Ca **Mg** S Fe Zn Cu Mn B Mo **Mn Tox** **Al Tox**

Uniform over leaf



**N** P K Ca **Mg** **S** **Fe** **Zn** **Cu** Mn B Mo **Mn Tox** **Al Tox**

## Symptoms based on leaf colour: necrosis

Basal



N P K Ca Mg S Fe Zn Cu Mn B Mo Mn Tox Al Tox

Distal



N P K Ca Mg S Fe Zn Cu Mn B Mo Mn Tox Al Tox

Marginal



N P K Ca Mg S Fe Zn Cu Mn B Mo Mn Tox Al Tox

Lobed



N P K **Ca** Mg S Fe Zn Cu Mn B Mo Mn Tox Al Tox

Body of leaf



N P K **Ca** Mg **S** Fe Zn Cu **Mn** B Mo **Mn Tox** Al Tox

Necrotic areas between veins



N P **K** **Ca** Mg **S** Fe Zn Cu Mn **B** Mo **Mn Tox** Al Tox

## Symptoms based on leaf shape and condition

Wavy edges



N	P	<b>K</b>	Ca	Mg	S	Fe	Zn	Cu	Mn	<b>B</b>	Mo	Mn Tox	Al Tox
---	---	----------	----	----	---	----	----	----	----	----------	----	-----------	-----------

Twisted tips



N	P	K	Ca	Mg	S	Fe	Zn	<b>Cu</b>	Mn	<b>B</b>	Mo	Mn Tox	Al Tox
---	---	---	----	----	---	----	----	-----------	----	----------	----	-----------	-----------

Flaccid



N	P	K	<b>Ca</b>	Mg	S	Fe	Zn	<b>Cu</b>	Mn	<b>B</b>	Mo	Mn Tox	Al Tox
---	---	---	-----------	----	---	----	----	-----------	----	----------	----	-----------	-----------

Rapid death  
of new leaves



N P K **Ca** Mg S Fe **Zn** Cu Mn B Mo Mn Tox Al Tox

'Water-soaked'  
areas



N P K Ca Mg S Fe **Zn** Cu Mn B Mo Mn Tox Al Tox

## Symptoms based on stems and growing point

Short and stout



N P K Ca Mg S Fe Zn Cu Mn B Mo Mn Tox Al Tox

Thin/spindly/  
leggy



N P K Ca Mg S Fe Zn Cu Mn B Mo Mn Tox Al Tox

Death of  
growing point  
or meristem



N P K Ca Mg S Fe Zn Cu Mn B Mo Mn Tox Al Tox

Abscission  
of leaves



N	P	K	Ca	Mg	S	Fe	Zn	Cu	Mn	B	Mo	Mn Tox	Al Tox
---	---	---	----	----	---	----	----	----	----	---	----	-----------	-----------

Shortened  
internodes



N	P	K	Ca	Mg	S	Fe	Zn	Cu	Mn	B	Mo	Mn Tox	Al Tox
---	---	---	----	----	---	----	----	----	----	---	----	-----------	-----------

## Healthy Seedlings

Healthy mahogany seedlings usually have an unbranched stem that grows rapidly to reach 30 cm to 40 cm in 12 weeks. The first 5 to 10 leaves to develop are simple leaves, followed by compound leaves carrying firstly 3 leaflets and later 5 to 7 leaflets.

The young leaves are often pale brown to golden brown with a soft texture. As they mature, the young leaves turn pale green and may have a mottled appearance. When they are fully expanded the leaves are an even dark green with a glossy, shiny appearance. Thus a healthy seedling generally has pale brown to pale green younger leaves and glossy, dark green older leaves.

The roots of a healthy seedling are extensively branched, the younger roots being pale brown to white while the older roots are dark brown. The roots tips have no signs of malformation such as being club-shaped or with brown or black necrotic lesions.



Plate 1: Young healthy seedling. Note the paler green younger leaves and the dark green, glossy older leaves.



Plate 2: (a) Older healthy seedling with well-developed, pale green young compound leaves and dark green older leaves.



Plate 2: (b) New growth (in foreground) is much paler in colour than older leaves even in large trees.



Plate 3: Leaves separated to show the simple older leaves that are followed by the compound younger leaves. Again, note the paler green colour of the younger leaves.



Plate 4: Extensively branched root system of a healthy seedling.



Plate 5: Pale brown to golden brown colour seen on young leaves and leaflets of the youngest leaves.



Plate 6: Glossy, dark green colour seen on the youngest mature leaves.



Plate 7: Young maturing leaves and leaflets sometimes develop a slightly mottled appearance before turning an even glossy dark green on reaching maturity.

# Nitrogen (N) Deficiency

## Symptoms

In seedlings, the symptoms develop rapidly when nitrogen supply becomes limiting. Growth slows down quickly and the stems become thin and spindly.

In contrast to most other species where the symptoms appear firstly on older leaves, in mahogany the symptoms always appear first and are more severe on the youngest leaves. A pale green to yellow chlorosis develops evenly over the whole leaf, producing pale green to yellow younger leaves while the older leaves remain a glossy dark green. At this early stage of development of the deficiency, it is difficult to distinguish between nitrogen deficiency and sulphur deficiency (compare also with iron deficiency).

With a mild deficiency, the older leaves remain a dark, glossy green and only the youngest leaves develop the pale green to yellow chlorosis. As the deficiency becomes more severe, even the older leaves develop the chlorosis and turn a pale green colour. When the onset of the deficiency is unusually rapid, a red colour may develop in the midvein of the older leaves and the lamina may become almost bronze in colour.

## Occurrence likely

- Mineral soils low in organic matter, with a neutral to alkaline pH, and where organic matter has been depleted and is not being replaced.
- Where large amounts of organic matter with a high C:N ratio have been incorporated. This may be only a transient deficiency.
- Light-textured soils (eg sands, sandy loams) where rainfall is high and soils can be easily leached.

## Occurrence highly unlikely

- Peat soils recently limed for the first time.
- Soils where large amounts of organic matter with low C:N ratio have been recently incorporated.
- Clay soils (with smectite minerals) with a recent history of ammonium fertilisation or ammonification of organic matter.



Plate 8: Nitrogen-deficient young seedlings. Note the even, pale yellow chlorosis on the youngest leaves while the older leaves remain a glossy dark green colour. (Compare with sulphur and iron deficiency).



Plate 9: Leaves separated to show the pale green to yellow younger leaves and the dark green older leaves. (Compare with newly developed leaves in healthy plants shown earlier).



Plate 10: Severe nitrogen deficiency in older seedlings has caused growth to almost cease, and the older leaves have now developed a pale green chlorosis. The younger leaves are now a pale yellow.



Plate 11: Youngest mature leaves from a nitrogen-deficient plant (top) and a healthy plant (bottom).



Plate 12: Note the decrease in severity of nitrogen deficiency symptoms from (a) to (d). While all seedlings have pale green younger leaves, those at the top have a greater proportion of yellow to pale green younger leaves and fewer dark green older leaves than those at the bottom. From (a) to (d) plants have received nil, 23, 375 and 1125 mg N/kg soil.

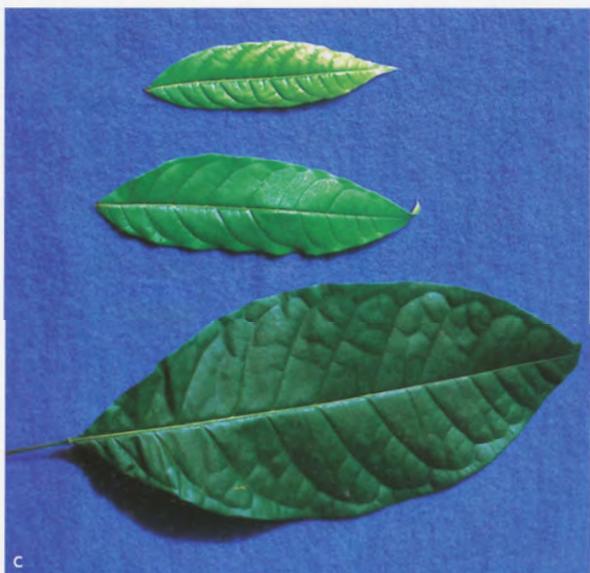


Plate 13: Appearance of leaves from plants receiving nil, 23, 375 and 1125 mg N/kg soil showing extremely deficient symptoms (a), severely deficient symptoms (b), mildly deficient symptoms (c) and no symptoms from a healthy plant (d). Within each frame, leaves are the youngest (top), youngest mature (middle), and oldest (bottom). Note the red colouring of the midrib and the bronze colouring of the lamina in the very deficient leaves in (a) and (b).

# Phosphorus (P) Deficiency

## Symptoms

In contrast to many other tree species, phosphorus deficiency does not produce characteristic foliar symptoms in mahogany. Seedlings lacking phosphorus grow slower than healthy seedlings, but there is generally no other difference in appearance between phosphorus-deficient and healthy seedlings. Hence, if there is *a priori* knowledge of growth rates and history of the plants, then phosphorus deficiency might be considered a possibility when there are no characteristic foliar symptoms but the plants are growing slower than expected.

When a very severe phosphorus deficiency is prolonged (eg 4 to 5 months duration), the seedlings are very stunted and all leaves may develop a slight chlorosis.

## Occurrence likely

Phosphorus is one of the most widespread deficiencies in tropical soils. Deficiency of phosphorus is more likely to occur in:

- Mineral soils low in organic matter.
- Highly weathered, aluminium- and iron-rich acid soils (eg old soils from basalt) where phosphate is fixed in less available forms.
- Acidic soils that contain allophane (eg volcanic ash soils) or kaolinite clays.
- Alkaline soils high in calcium and magnesium where the phosphate may be tied up in insoluble phosphates.
- Leached quartz sand, and peat soils.
- Soils where the topsoil has been lost through erosion.

## Occurrence highly unlikely

- Soils recently converted from agricultural use (where P fertilisers were used).



Plate 14: Seedlings which have had phosphorus withheld for one month have a healthy appearance with no characteristic foliar symptoms. Compare this with the rapid onset of symptoms in this species when other nutrients are withheld.



Plate 16: Seedlings which have had phosphorus withheld for five months are very stunted and all leaves develop a pale green chlorosis, the only foliar symptoms to appear. The marginal necrosis near the tips is atypical.



Plate 15: Seedlings which have had phosphorus withheld for three months still have a healthy appearance with no characteristic foliar symptoms. However, there has been a slight reduction in growth rate.



Plate 17: The foliage of seedlings grown without phosphorus (left) and with phosphorus (right) is very similar in appearance even though there is a substantial effect of phosphorus deficiency on growth.



Plate 18: Close-up of phosphorus-deficient plants in Plate 17 showing little in the way of diagnostic symptoms.



Plate 19: Adding phosphorus substantially increases growth of seedlings. However, it has little effect on the appearance of leaves. From left to right, rates of application are 0, 25, 50, 100, 150, 200, 250, 500 and 1000 mg P/kg soil.



Plate 20: Young leaves from plants shown in Plate 19. Note that increasing the addition of phosphorus from 0 mg P/kg soil (top left) to 1000 mg P/kg soil (bottom right) has no effect on the appearance of these young leaves even though it has a substantial effect on seedling growth.



Plate 21: Youngest mature leaves from plants shown in Plate 19. Note that increasing the addition of phosphorus from 0 mg P/kg soil (top left) to 1000 mg P/kg soil (bottom right) has no effect on the appearance of these young mature leaves even though it has a substantial effect on seedling growth.



Plate 22: Mature leaves from plants shown in Plate 19. Note the mottled yellow interveinal chlorosis that has developed on the most severely deficient plant receiving 0 mg P/kg soil, the first and only appearance of foliar symptoms (top left). Also note that increasing the addition of phosphorus from 25 mg P/kg soil (top, second from left) to 1000 mg P/kg soil (bottom right) has no effect on the appearance of these mature leaves even though it has a substantial effect on seedling growth.

# Potassium (K) Deficiency

## Symptoms

As potassium becomes deficient, the young seedlings grow more slowly and stems become thin and spindly.

The development of wavy edges on the younger maturing leaves is the first foliar symptom to appear. As the deficiency increases in severity, brown necrotic spots develop in the lamina between the main veins and near the margins of the young maturing leaves. As these leaves become mature, the necrosis spreads towards the leaf margin to form a continuous necrotic margin. Initially, the marginal necrosis is more pronounced towards the leaf tip than the leaf base, but spreads from the tip towards the base of the leaf as the severity of the deficiency increases in the maturing leaves. When the deficiency is very severe, the young leaves also develop a strong yellow interveinal chlorosis between the main vein and the leaf margin which remain dark green.

## Occurrence likely

- Highly weathered mineral soils low in organic matter.
- Light-textured soils (eg sands and sandy loams) formed from parent material low in potassium (eg sandstone, limestone and some granites).
- Mineral soils where the original potassium has been leached by heavy rainfall.

## Occurrence highly unlikely

- Potassium deficiency is unlikely in **young** soils formed from parent material that is rich in potassium, eg soils from igneous rocks.



Plate 23: Seedlings grown without potassium (left) are much smaller than those grown with adequate potassium.



Plate 24: A young seedling showing the beginning of 'wavy' edges (arrowed) on the younger leaves. The paler green colour of the younger leaves is not a response to low potassium as this variation in colour between older and younger leaves is typical of healthy plants.

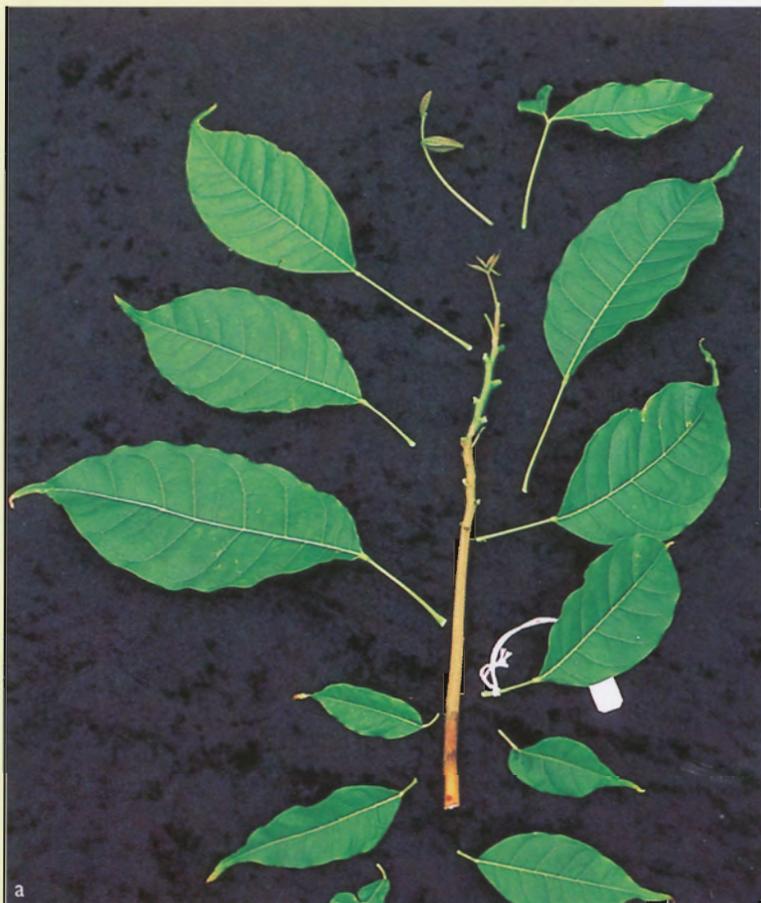


Plate 25: Leaves separated (a) to show the development of 'wavy' edges (b) on the younger leaves of a potassium-deficient plant.



Plate 26: Brown necrotic spots and patches develop on the leaf margins (a, b) and between the veins near the leaf margin (c) of young maturing leaves on potassium-deficient plants.

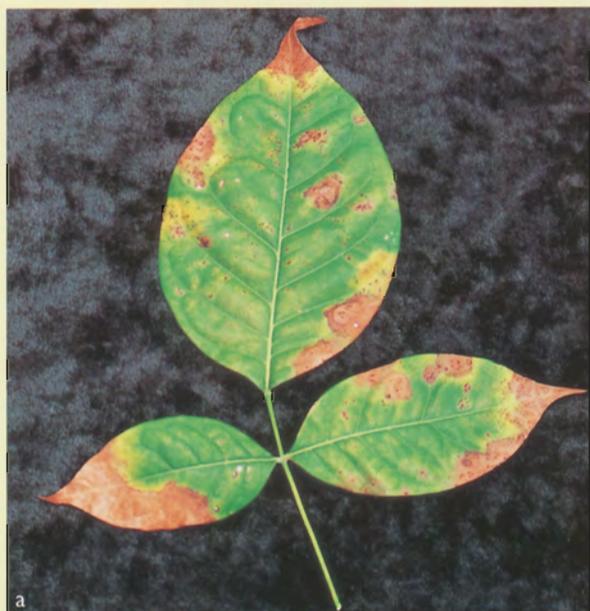


Plate 27: Severe marginal and leaf tip necrosis in mature leaves of a potassium-deficient plant. Note how the marginal necrosis is more severe towards the leaf tip (a) and advances from the leaf tip towards the base of the leaf (b). Also note the abrupt colour change from apparently healthy green tissue to brown necrotic tissue with little, if any, chlorotic zone.



Plate 28: An interveinal yellow chlorosis develops in younger leaves when potassium deficiency is very severe. Note the dark green main veins and leaf margins.

# Calcium (Ca) Deficiency

## Symptoms

Calcium-deficient seedlings stop growing and develop short, stout stems. The roots become short and thickened, and growth of the lateral roots ceases, giving the root system an overall stumpy appearance.

The first symptoms to appear on the leaves are an interveinal pale yellow chlorosis that is similar to, but not as striking as, that produced by iron deficiency. As the deficiency becomes more severe, brown necrotic patches develop within the yellow chlorosis on the new leaves. As the deficiency progresses, a brown marginal necrosis develops on the new leaves and extends into the interveinal areas producing a colour pattern on the new leaves consisting of a dark brown necrotic margin with a pale yellow chlorotic area separating the marginal necrosis from the dark green tissue surrounding the midvein. Only the new leaves are affected; the older leaves remain a healthy dark green colour and without visible symptoms.

When the deficiency is very severe, the emerging leaves become flaccid, wilt rapidly and die, often within two days and before other symptoms can develop. Eventually, the meristem stops producing new leaves, and the youngest mature leaves, which had remained dark green, develop a marginal yellow chlorosis and brown necrosis. The oldest leaves (i.e. those that had developed before calcium became deficient) turn a deep dark green colour but otherwise show no visible symptoms.

## Occurrence likely

- Acid coarse-textured soils (eg sandy soils from granites) in the humid tropics where the original calcium has been removed by heavy rainfall.
- Strongly acid peat soils where total calcium is low.
- Alkaline sodic soils where high pH and high exchangeable sodium depresses the uptake of calcium.
- Many humid tropical soils where the pH is less than 4.5 and soluble aluminium is high and exchangeable calcium is low.

## Occurrence highly unlikely

- Calcareous soils (eg those derived from coral or limestone).
- Soils in arid regions.

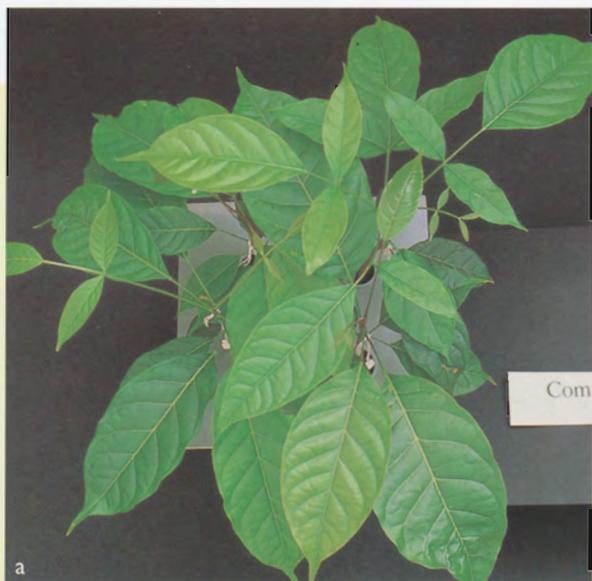


Plate 29: A young calcium-deficient seedling showing the early symptoms of an interveinal pale yellow chlorosis on the younger leaves (b) compared with a healthy seedling above left (a). Note that on some leaflets, the basal area remains relatively green and the chlorosis occurs towards the tip of the leaflet (c). (Compare this with iron deficiency where the interveinal chlorosis is more distinct and distributed evenly over the whole leaflet). Also note the darker green colour of the older leaves that is typical of healthy plants (b); but compare this colour with the deeper dark green colour that develops on the older leaves as the deficiency becomes very severe (Plate 34).

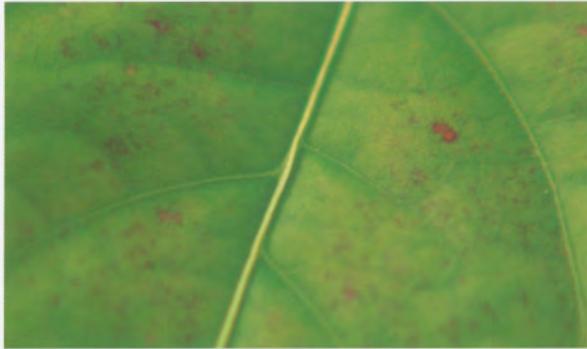


Plate 30: Brown necrotic patches develop within the yellow chlorotic areas in the young leaves of calcium-deficient seedlings.



Plate 31: Necrotic patches develop within interveinal areas on a mature leaf from a calcium-deficient seedling.



Plate 32: The leaf on the right shows further development of symptoms of calcium deficiency. The yellow chlorosis has become more extensive and some marginal brown necrosis is appearing. (Compare with boron deficiency). The leaf on the left is healthy and shows no symptoms.



Plate 33: Symptoms of severe calcium deficiency on newer, young leaves showing extensive marginal necrosis (a) that is often more severe towards the tip of the leaflet (b). Also note that the older leaves have now become a deep, dark green.



Plate 34: A young leaf from a severely calcium-deficient plant shows the 3-tone colour pattern characteristic of calcium deficiency. Note that the deeply lobed brown necrosis on the margin is separated from the green midveins by a wide zone of yellow chlorosis. A similar 3-tone pattern also develops in potassium deficiency, but there the chlorotic zone is very narrow or absent.



Plate 35: The youngest developing leaf of a calcium-deficient seedling showing interveinal yellow chlorosis and flaccid, wilting leaflets. (Compare with boron deficiency).



Plate 36: The same leaf as in Plate 35, but two days later; note that the leaflets that were flaccid and wilting in Plate 35 have died and dried out.



Plate 37: Young shoot from a seedling with severe calcium deficiency. Note the increasing severity of calcium deficiency symptoms showing up as necrosis of the leaf tips, whole leaflets, petioles, and the apical meristem. (Compare with boron deficiency).



Plate 38: A plant suffering from very severe calcium deficiency showing complete loss of young leaves, and rapid death of any newly emerging leaves.



Plate 39: The root system of plants suffering severe calcium deficiency become stunted with short, stumpy laterals caused by death of the apical growing point of the roots. (Compare with boron deficiency).

# Magnesium (Mg) Deficiency

## Symptoms

As mahogany seedlings become magnesium-deficient, their growth slows and their stems become spindly.

Even when plants appear healthy, symptoms appear first on the younger mature leaves where small patches of brown tissue develop generally in the interveinal areas towards the midvein. As these leaves become more mature, a yellow chlorosis develops to surround the brown spots. The yellow chlorosis spreads to become a general interveinal chlorosis evenly spread over the whole leaf while the brown spots become larger and turn necrotic. At this stage of development, the youngest leaves still appear healthy. As the deficiency becomes more severe, the youngest leaves also develop the pale yellow interveinal chlorosis, but this is much less severe than that in the young mature leaves.

When the deficiency is very severe, the oldest leaves develop symptoms similar to those shown by the young mature leaves. Brown spots appear and become surrounded by a yellow chlorosis that spreads generally over the interveinal areas of the whole leaf.

## Occurrence likely

- Coarse-textured acid soils (eg sandy soils derived from granites) in the humid tropics where the original magnesium has been removed by leaching.
- Strongly acid peat soils where total magnesium is low.
- Soils that have been over-fertilised with calcium (eg over-limed), potassium or ammonium, thus inhibiting the uptake of magnesium.

## Occurrence highly unlikely

- Soils derived from parent material high in magnesium, eg serpentine.

Mg



Plate 40: Young seedling that appears to be healthy, but has developed the very first stages of the symptoms of magnesium deficiency (see Plate 41).



Plate 41: First sign of symptoms appeared as small brown patches in interveinal areas near the main vein. This leaf is the youngest mature leaf from the plant in Plate 40.



Plate 42: A young seedling showing the pattern of development of symptoms of magnesium deficiency: Note that the youngest leaves have no symptoms and appear normal, while the middle or youngest mature leaves have symptoms of brown necrotic patches surrounded by yellow chlorosis, and the oldest mature leaves show areas of dark brown necrosis with little or no chlorosis (see Plate 43 for close-up).



Plate 43: Leaves of different age from the same seedling showing the variation in symptom development: top right is an immature leaf; top left is a young mature leaf; bottom is an old leaf.



Plate 44: The top four leaves are young mature leaves showing different degrees of symptom development. Although the intensity differs, the symptoms are the same – a pale yellow chlorosis in the interveinal areas. The leaf at the bottom is from a healthy plant.



Plate 45: On young leaves, the symptom begins as a loss of green in the interveinal areas. The loss of colour is quite well defined with even the third order vein remaining green. Beginning at the leaf base the chlorosis becomes quite severe with patches becoming almost white.



Plate 46: A young leaf slightly older than that shown in Plate 45 where the interveinal chlorosis has become more severe. Note the development of a very pale yellow to white chlorosis in the interveinal areas at the base of the leaf.



Plate 47: As the severity of the deficiency increases, the symptoms develop rapidly in the recently matured leaves with the areas of interveinal chlorosis and necrosis becoming more defined and more widespread over the whole leaf. Compare the intensity of the symptoms in this plate with those shown in Plate 42, Plate 43 and Plate 44. Note that the very new leaves (top left of this plate) are still quite green when they first emerge.



Plate 48: In contrast to the recently matured leaves (Plate 47), the symptoms in the older mature leaves do not change as rapidly. For some time the symptoms in the older mature leaves remain as brown spots with little or no encircling chlorosis.



Plate 49: When the deficiency is very severe for an extended period, the symptoms on the older mature leaves progress to resemble those on the younger mature leaves, i.e. green veins with strongly patterned brown necrosis surrounded by a yellow chlorosis in the interveinal areas.

# Sulphur (S) Deficiency

## Symptoms

Symptoms develop rapidly when sulphur is omitted from the nutrient supply; within two weeks seedlings stop growing, become very spindly, and develop an overall pale green to pale yellow appearance.

Early stages of symptom development are characterised by the youngest leaves turning pale yellow while the older leaves remain green. At this stage it is difficult to discriminate between sulphur and nitrogen deficiency, although the veins stay slightly greener than the surrounding tissue in sulphur deficiency (compare also with iron deficiency).

As the deficiency becomes more severe, small necrotic spots appear on the older leaves, especially near the veins. Eventually, the older leaves develop chlorotic patches between the main veins. After some time, the chlorotic patches spread across most of the old leaves, leaving them slightly mottled compared to the younger leaves.

## Occurrence likely

- Acid sandy soils in the humid tropics where the original sulphur has been leached by heavy rainfall.
- Coarse-textured soils (eg sandy soils) low in organic matter.
- Soils formed from parent material low in sulphur (eg from volcanic rocks and ash).

## Occurrence highly unlikely

- Soils high in decomposing organic matter.
- Soils where atmospheric inputs could be high (such as soils adjacent to coal-burning industries, major cities, oceans, or marshes), especially calcareous soils or soils high in aluminium and iron hydrous oxides (eg highly weathered basalts).



Plate 50: Young seedling showing early stages of sulphur deficiency. Note the pale green to yellow young leaves with darker green older leaves.



Plate 51: Leaves separated from sulphur-deficient seedlings (a and b) to show the rapid change in colour from pale green to yellow younger leaves and the dark green older leaves.



Plate 52: Close-up of a young leaf from a sulphur-deficient seedling showing the even, pale yellow chlorosis and pale green veins characteristic of sulphur deficiency. (Compare with iron and nitrogen deficiency).

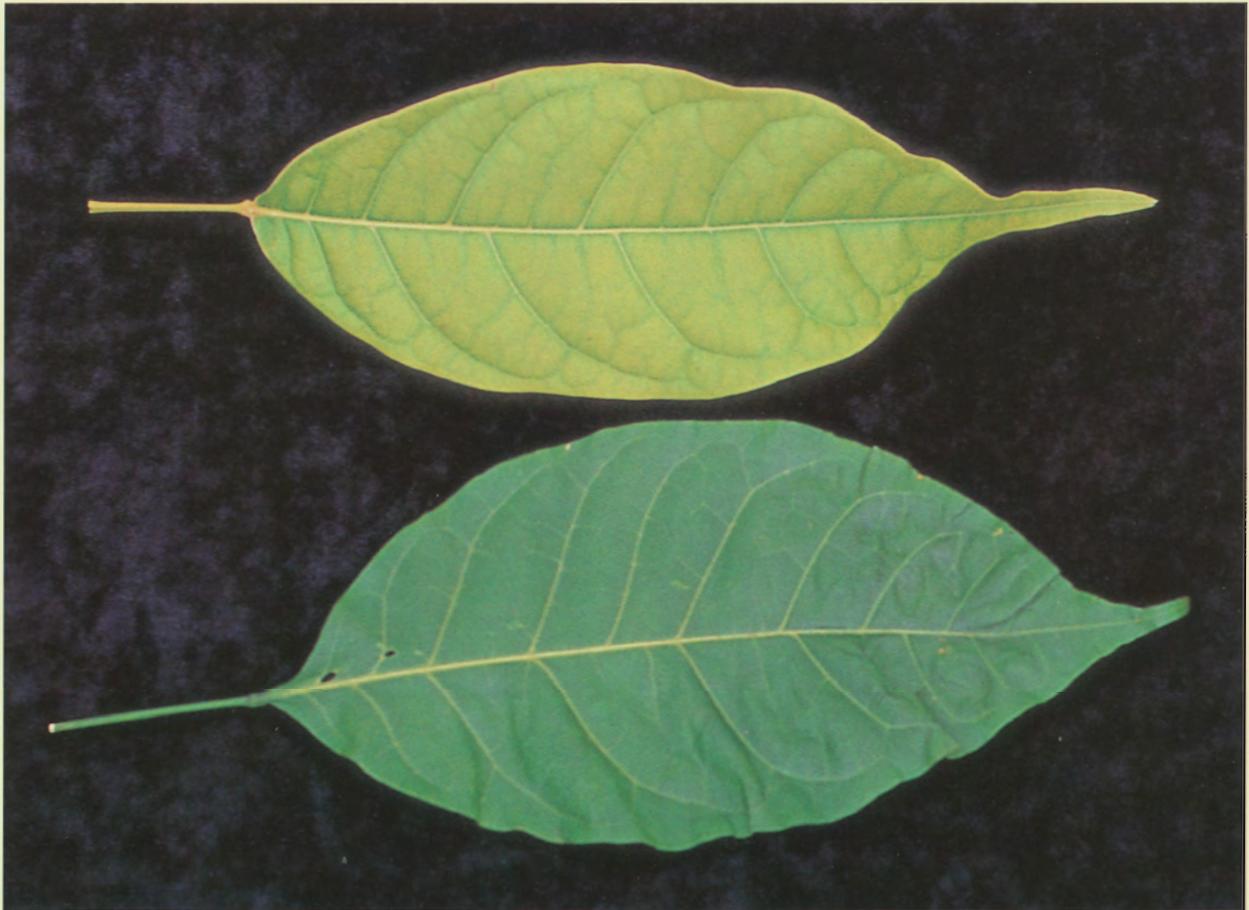


Plate 53: Pale yellow, sulphur-deficient young leaf (top) compared with a dark green, healthy young leaf (bottom).



Plate 54: As the severity of the deficiency progresses, the pale yellow chlorosis seen on the younger leaves develops also on the young mature leaves immediately below them.



Plate 55: An older mature leaf from a sulphur-deficient seedling. Note the development of brown necrotic spots near and along the veins in the interveinal areas of the leaf.

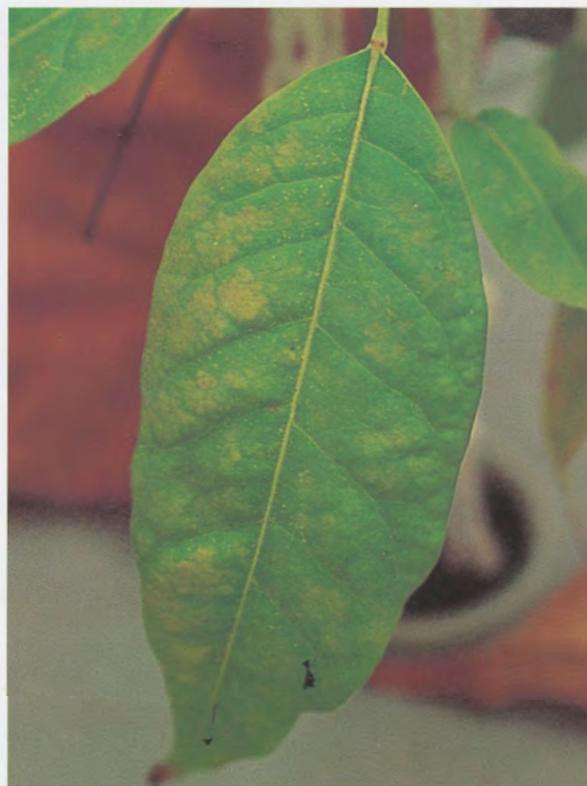


Plate 56: Severe symptoms of sulphur deficiency on an older mature leaf. Note the development of chlorotic patches in the interveinal areas between the major veins.



Plate 57: Seedling suffering very severe sulphur deficiency. Note that all leaves have now become chlorotic, and that the older leaves appear to be paler in colour than the young leaves. (Compare with iron and nitrogen deficiency).

# Iron (Fe) Deficiency

## Symptoms

The symptoms of iron deficiency appear rapidly, although the seedlings may initially show no reduction in rate of growth. As the severity of the deficiency increases, growth of the young plant slows down and the stem becomes spindly.

The first symptom to appear is a faint yellow interveinal chlorosis in the most recently matured leaves. At this stage the youngest leaves appear a normal and healthy pale green colour and the older leaves a normal and healthy dark green colour (compare with nitrogen and sulphur deficiency). As the severity of the deficiency increases, the interveinal chlorosis becomes characteristic for iron deficiency; the veins remain green as in a normal healthy leaf and the interveinal areas of the whole leaf become an even, pale yellow colour.

When the deficiency is very severe, the interveinal areas often turn almost white and only the major veins remain pale green. By this stage, the characteristic symptoms of interveinal chlorosis have appeared on both the young maturing leaves and the new expanding young leaves, and even some of the older mature leaves may begin to show some interveinal chlorosis. The newly developing young leaves often turn a distinctive pale pink colour when the deficiency is very severe.

## Occurrence likely

- Alkaline or calcareous soils with high pH (7.4 – 8.5) where levels of soluble iron are low.
- Waterlogged or compacted (wet) calcareous soils (including roads made from coral rubble).
- Coarse-textured soils low in total iron (eg bleached white sands).
- Peat soils where organic matter ties up soluble iron.
- Acid soils with very high levels of soluble manganese, zinc, copper (either natural or from excessive applications of copper-based fungicides), or nickel (eg serpentine soils) which depress the uptake of iron by plants.

## Occurrence highly unlikely

- Acid to neutral mineral soils that are not high in soluble manganese, zinc, copper or nickel.
- Flooded non-calcareous soils.
- Mineral soils high in organic matter (but not peat soils).



Plate 58: Young seedling showing the very early stage of iron deficiency. Note the first stages of a pale yellow interveinal chlorosis on the youngest mature leaf.



Plate 59: Iron-deficient leaf showing the characteristic interveinal chlorosis that develops as the severity increases. The pale yellow interveinal chlorosis is spread evenly over the whole leaf blade with the green veins standing out against the yellow background in this youngest mature leaf.



Plate 60: Older leaves from plants shown in Plate 59. Note the lack of distinctive symptoms; only a slight chlorosis is apparent at this early stage of development of the symptoms.



Plate 61: Seedling showing more severe symptoms of iron deficiency. The characteristic interveinal chlorosis now appears on both the expanding and recently matured leaves. The older mature leaves show only a slight chlorosis and have become pale green.



Plate 62: Severe interveinal chlorosis on the youngest mature leaf. At this stage only the main veins remain green.

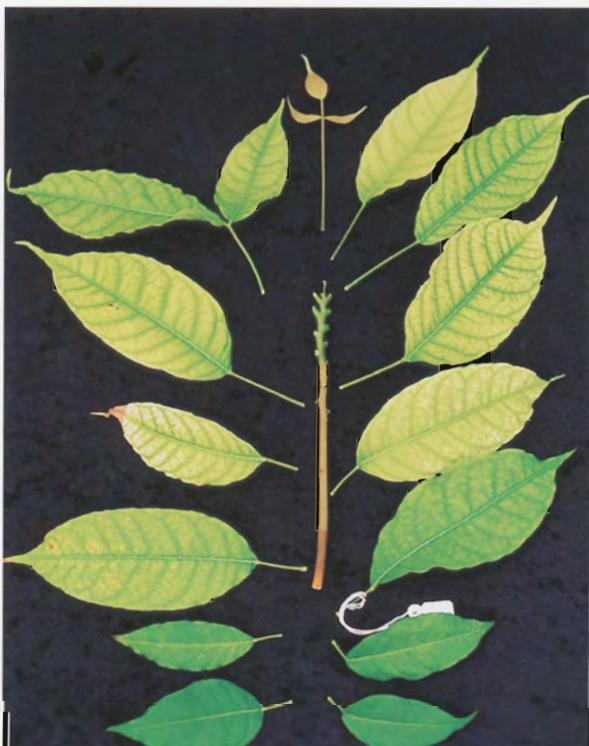


Plate 63: Leaves separated to show the change in intensity of the symptoms with age of leaf. Note the pale green youngest leaves, pale yellow younger mature leaves, and the green older mature leaves.



Plate 64: Close-up of leaves showing the pattern of development of the characteristic interveinal chlorosis associated with iron deficiency. The youngest mature leaf (far left) shows the patchy development of the yellow interveinal chlorosis in the early stage of symptom expression. The older leaves (to the right) show increasing intensity of the yellow chlorosis until the interveinal areas have turned almost white and the main veins have turned pale green. The leaf at the top of the plate is from a healthy seedling.



Plate 65: Young developing leaf on a seedling showing symptoms of severe iron deficiency. Note that the interveinal chlorosis has become very pale, almost white in colour:



Plate 66: Iron-deficient leaf showing the almost total loss of colour, even in the main veins, that occurs when the deficiency is very severe.



Plate 67: Seedling showing symptoms of extreme iron deficiency. The young expanding leaves have lost almost all colour; the recently matured leaves are strongly chlorotic, and even the older mature leaves are developing the interveinal chlorosis characteristic of iron deficiency.



Plate 68: Newly emerging leaves on a seedling with extremely severe iron deficiency often develop a distinctive pale pink colour.



Plate 69: Old mature leaves from the plant in Plate 67 showing the development of the mottled yellow interveinal chlorosis and green veins that is the characteristic symptom of early stages of iron deficiency.

# Zinc (Zn) Deficiency

## Symptoms

Zinc deficiency reduces the rate of growth of seedlings so that they eventually become very stunted, with short internodes and spindly stems.

The first foliar symptoms to appear develop on the younger leaves as a 'scalloped' marginal chlorosis that advances rapidly across the blade until the whole leaf becomes almost white with only the main vein remaining green. In the younger newly emerging leaves, the yellow chlorosis begins at the leaf margin but advances inwards between the secondary veins. As these leaves become more mature, the chlorosis is followed by a marginal brown necrosis that also advances inwards, mainly between the secondary veins.

As the severity of the deficiency increases, the newly emerging leaves exhibit a new pattern of symptom expression. Tissue that has a 'water-soaked' appearance develops in the regions between the veins, particularly in the area near the stalk of the leaf. These 'water-soaked' areas die rapidly and become necrotic, turning pale brown.

When the deficiency is severe, the newly emerging leaves wither and die soon after expanding, leaving the petioles attached near the tip of the stem. By this stage, the internodes near the tip of the shoot have become very short, giving the stem a stunted appearance.

## Occurrence likely

- Strongly alkaline soils, especially those with free lime, where the availability of zinc is depressed.
- Sandy-textured soils where total zinc is low.
- Soils derived from parent materials low in zinc (eg granites, gneisses).
- Some soils which are very low in organic matter.
- Some organic soils where zinc can be tied up in forms less available to plants.
- Soils where erosion or management practices have exposed subsoils with low levels of total zinc.
- Acidic, coarse-textured soils where soluble zinc has been leached by heavy rainfall.
- Soils where frequent heavy applications of phosphorus, copper, manganese and iron have occurred and uptake of zinc is inhibited by high levels of these elements in the soil.
- Flooded or compacted soils (possibly because of high levels of available iron and manganese).
- Soils high in fine clay or silt.

A temporary deficiency of zinc can occur under drought conditions when uptake of zinc is inhibited by the isolation of available zinc in a dry soil horizon.

## Occurrence highly unlikely

It is difficult to define a natural soil type that would generally be regarded as never being zinc-deficient. For example, in Vanuatu, some basaltic soils may be high in total zinc but similar soils in other parts of the South Pacific may be very low.

Thus, zinc deficiency is unlikely to occur in:

- Acidic soils formed from parent materials rich in zinc (eg basic igneous rocks such as basalt).
- Soils with a reasonable organic matter content.
- Soils where foliar zinc sprays or fungicides that contain zinc have been applied regularly to crops.
- Soils close to zinc mines where management operations cause zinc minerals to contaminate the surrounding regions.



Plate 70: A generally healthy young seedling showing the early signs of zinc deficiency as a marginal chlorosis on the young leaf (arrowed).

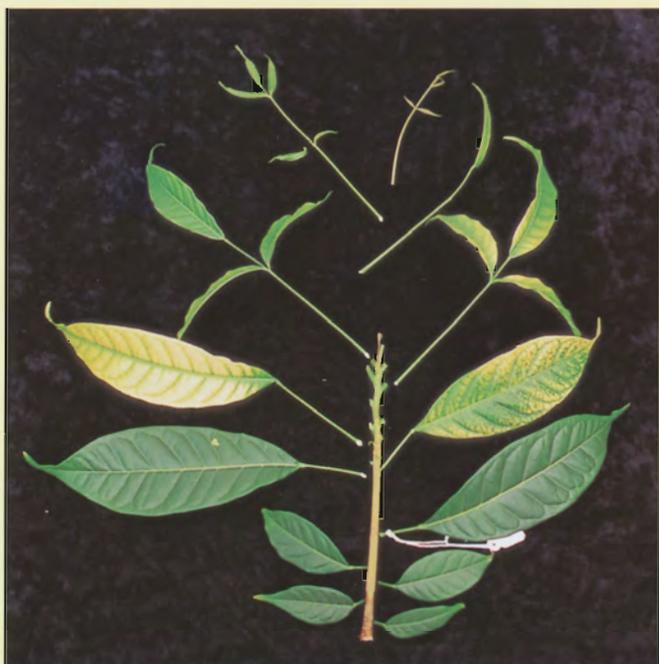


Plate 71: Leaves separated from zinc-deficient seedling to show the development of symptoms on leaves of different age. Note the appearance of marginal chlorosis on the young expanding leaves but the more pronounced chlorosis on the younger mature leaves. Note also the apparently healthy green of the oldest mature leaves.



Plate 72: Close-up of young expanding leaf with developing symptoms. The chlorosis starts at the margins and then moves inwards between the secondary veins.



Plate 73: Close-up of older leaves from a zinc-deficient seedling showing more widespread chlorosis and mottling than in Plate 72.

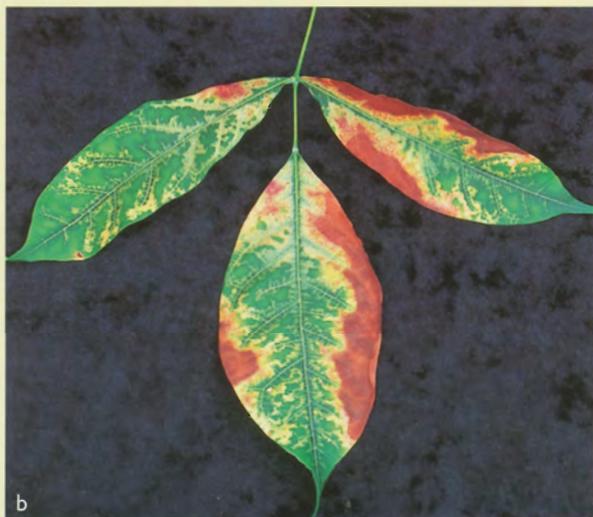


Plate 74: Older leaves from a zinc-deficient seedling showing pronounced chlorosis and marginal necrosis. The chlorosis and necrosis is more severe towards the margins of the leaf and may be restricted to areas between the secondary veins (a), but may sometimes occur generally around the margins of the leaf (b).



Plate 75: Close-up of the tip of the stem showing the petioles remaining after death and abscission of the leaflets on a zinc-deficient seedling. Note that the newly emerging leaf appears to be a healthy soft brown colour.



Plate 76: Tip of the stem of a zinc-deficient seedling showing (1) the yellow chlorosis developing on the youngest mature leaf and (2) the petioles remaining after the leaflets have died and fallen from the newest expanding leaves.



Plate 77: Tip of the stem of a zinc-deficient plant that is producing apparently healthy new leaves above the remnant petioles (curved) from leaves where the leaflets have died and fallen off. Note the shortened internode length in this region of the stem.

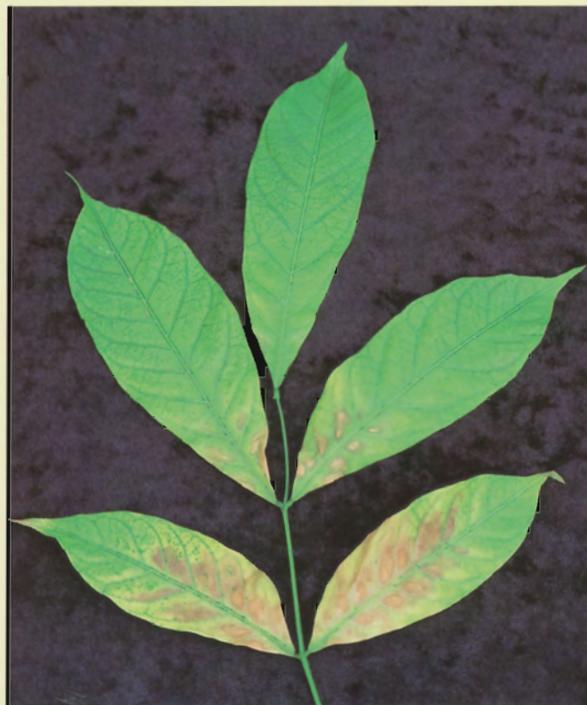


Plate 78: Young leaves from a severely zinc-deficient seedling showing the 'water-soaked' symptom that develops near the junction of the main veins and the secondary veins in the basal portion of the leaflets. The necrosis is not preceded by a chlorosis; that is, the necrotic patches did not go through an initial chlorosis, but instead had the 'wet' appearance of frozen and thawed tissue which had lost cellular integrity. This quickly dried out and turned necrotic.

# Copper (Cu) Deficiency

## Symptoms

The early visual symptoms on the foliage begin as a general yellowing of the young leaves. With increasing severity, the tips of the leaflets become twisted and malformed (compare with boron deficiency). As the deficiency becomes very severe, the old mature leaves become dark green whilst the younger leaves develop malformed leaflets; initially the tips of the leaflets become twisted or curled and develop a brown necrosis and die. Eventually the leaflet dies and falls off at the base of the blade, leaving the petiole attached to the stem (if a simple leaf) or rachis (if a compound leaf).

## Occurrence likely

- Peat and muck soils where soluble organic ligands tie up the soluble copper in forms less available to plants.
- Soils formed from parent materials low in copper such as some metamorphic rocks (eg schists), and acid volcanic materials (eg granites, rhyolites, pumice and ash).
- Siliceous sands where total copper is low.
- Alkaline calcareous soils, such as those derived from limestone or where free lime is present and total copper is low.
- Excessively leached podsollic soils.

A temporary deficiency of copper can occur under drought conditions when uptake of copper is inhibited by the isolation of available copper in a dry soil horizon.

## Occurrence highly unlikely

- Fine-textured soils (eg clays) derived from basic igneous rocks (eg basalts) unless free lime is present.
- Acid soils.
- Soils where copper fungicides have been regularly used (eg Bordeaux mixture; copper oxychloride).



Plate 79: Young seedling showing the early signs of copper deficiency. Note the slight interveinal yellow chlorosis on the younger leaves.



Plate 80: Young leaves from a copper-deficient plant showing the twisted, malformed tips of the leaflets.



Plate 81: Older seedlings showing symptoms of severe copper deficiency. Note the very dark green of the older leaves and the very malformed leaflets on the younger leaves.



Plate 82: Close-up of the shoot tip of the plant in Plate 81. Note the malformations of the leaflets: (1) the abscission of the leaflets at the base of the blade, leaving the petiole attached to the rachis; (2) death and twisting of the leaflet tips; (3) curling and malformation of the tips of many leaflets.

# Manganese (Mn) Deficiency

## Symptoms

Manganese deficiency manifests itself in a number of ways. In some leaves an interveinal chlorosis begins around the smallest veins. In other leaves, a marginal necrosis moves inwards between the secondary veins.

## Occurrence likely

- Strongly alkaline soils, especially those with free lime, eg calcareous soils, where manganese is converted into forms less available to plants.
- Strongly acidic peat soils where total manganese is low.
- Peaty soils overlying calcareous subsoils.
- Poorly drained soils with a high content of organic matter where manganese is tied up in forms less available to plants.
- Acidic sandy mineral soils where manganese has been removed by leaching.
- Soils derived from parent material low in manganese (eg acid igneous rocks).
- Soils that fluctuate regularly between well-drained and waterlogged, where the manganese can be reduced to water-soluble forms that are then readily leached.
- Soils over-limed with lime or dolomite.
- Soils over-fertilised with copper, iron or zinc that inhibits plant uptake of manganese.

## Occurrence highly unlikely

- Flooded soils where the level of total manganese is adequate.
- Acid mineral soils, especially those formed from parent materials rich in manganese (eg basic igneous rocks such as basalt).



Plate 83: Beginning in the basal part of the youngest mature leaf and extending to the tip over time, a pale yellow chlorosis develops around the smallest veins. Eventually, all tissue between the largest veins turns yellow leaving the tissue adjacent to these veins green.



Plate 84: In other leaves, just slightly older; in addition to the chlorosis described above, a reddish-brown necrosis advances from the tip to the base and inwards from the margins between the main veins.



Plate 85: In young expanding leaves, there is a pattern of chlorosis similar to that described above. However, the necrotic pattern is paler, almost pink, and the edge of the necrosis is less well defined.



a

Plate 86: A less advanced stage of that shown in Plate 83 showing the beginnings of chlorosis in areas between the tertiary veins.



b



Plate 87: In the young leaf, brown patches have developed within the leaf between the main veins.

# Boron (B) Deficiency

## Symptoms

The first visual symptom on the foliage is the appearance of a pale brown necrosis in the interveinal areas in the basal section of the young leaves. As the deficiency becomes more severe, the edges of newly developing leaves become wavy and the leaf tips may be malformed and develop a brown necrosis. These young leaves become flaccid (or wilted), and develop a reddish tinge on the underside of the lamina.

When the deficiency is very severe, the tertiary veins of the older leaves develop a yellow chlorosis, giving these leaves a mottled appearance. The tips and margins of these leaves often become necrotic and die.

The root systems of boron-deficient plants also cease growing and the lateral roots become stunted, giving the whole root system a stumpy appearance. As the severity increases, the roots become discoloured and brown lesions develop on the older roots.

## Occurrence likely

Boron deficiency is more likely to occur in highly weathered soil in high rainfall areas, with increasing distance from oceans, and in acid peat soils.

Typical sites for boron deficiency include:

- Coarse-textured soils formed from parent materials low in boron such as acid igneous rocks (eg granites), metamorphic rocks, and freshwater sandstones and shales.
- Acid sandy soils (eg podsollic soils) from which boron has been leached by rainfall.
- Alkaline, or calcareous soils, especially those with free lime.
- Soils low in organic matter.
- Acidic soils rich in aluminium oxides.
- Soils derived from pumice and volcanic ash rich in allophane.
- Peat soils, especially after liming.

A temporary deficiency of boron can occur under drought conditions when uptake of boron is inhibited by the isolation of available boron in a dry soil horizon.

## Occurrence highly unlikely

- Soils formed from marine sediments.
- Soils close to oceanic coastal influences.
- Fine-textured soils with high clay content (eg from basalts or shales) unless highly weathered.
- Soils of naturally high pH that have no free lime.

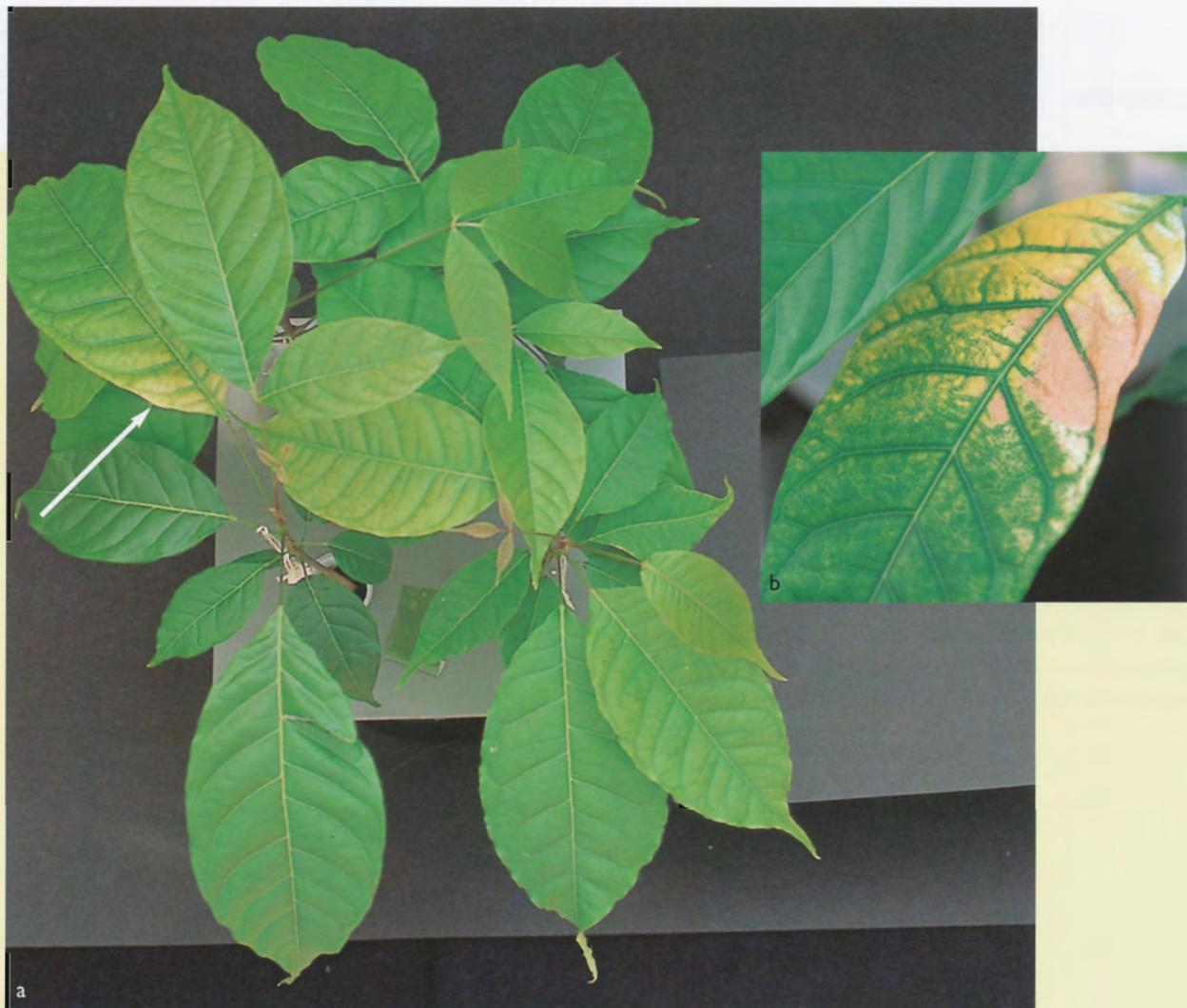


Plate 88: Young seedling showing the early stages of boron deficiency symptoms (a) on the young leaves (arrowed). Note the development of a pale brown necrosis in the interveinal areas in the basal section of the leaf (b; compare with zinc deficiency).

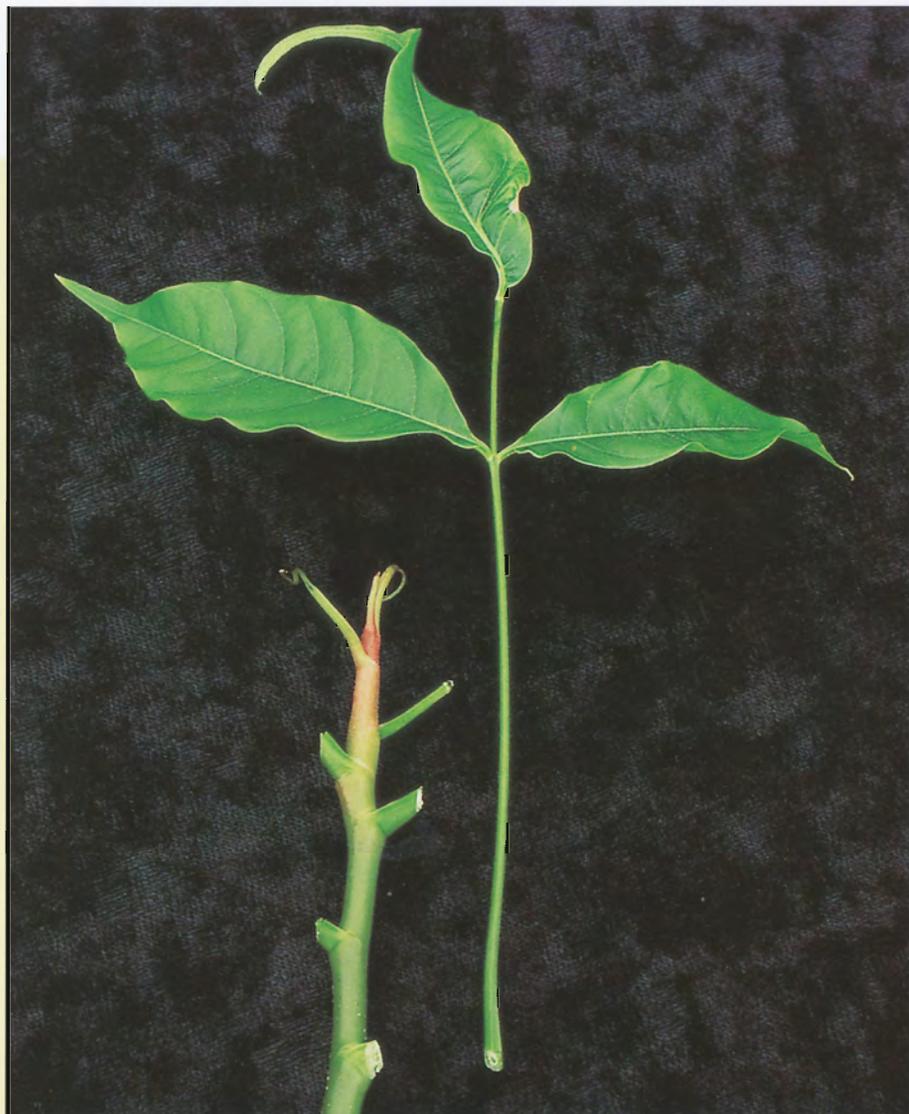


Plate 89: Malformed new expanding young leaves from a boron-deficient seedling. Note the wavy edges, and malformed and necrotic tips of the leaflets. (Compare with calcium deficiency).



Plate 90: Young leaves from a severely boron-deficient seedling. The young developing leaves have become flaccid and wilted (a; compare with calcium deficiency) with a wrinkled appearance and reddish tinge on the underside of the leaf blade (b).



Plate 91: Seedling showing symptoms of severe boron deficiency (a). Note the development of necrosis of the tips and margins (b; compare with calcium deficiency) and the appearance of mottling in the older leaves caused by chlorosis of the tertiary veins (c).

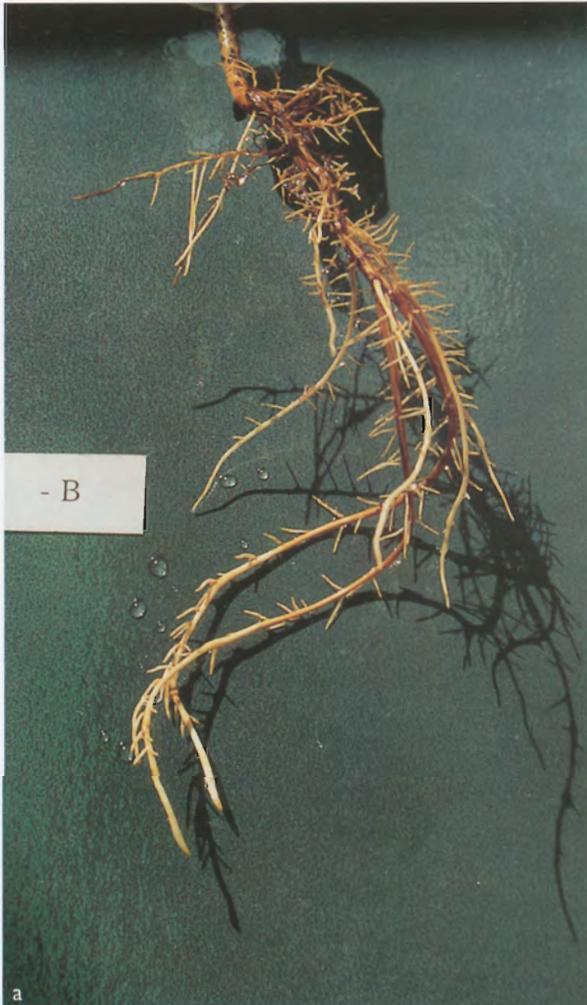


Plate 92: Root system from a seedling suffering from boron deficiency (compare with calcium deficiency). The poor development and growth of the lateral roots give a stumpy appearance (a) and the brown lesions developed on the main roots (b) when the severity of the deficiency increases.

# Manganese (Mn) Toxicity

## Symptoms

The first foliar symptom to appear is the development near the main and secondary veins of small light brown spots with a slight yellow chlorosis surrounding the spot on the surface of the older mature leaves. This symptom is followed rapidly by the development of a general yellow chlorosis throughout the blade of the younger mature and newly expanding leaves. This chlorosis is similar to that developed on the younger leaves of nitrogen-deficient plants.

As the toxicity becomes more severe, the older leaves develop a marked yellow chlorosis with the main veins remaining green. The brown spots now are easily distinguished on the older leaves where they occur more frequently near the veins, and also on the petioles.

## Occurrence likely

- Waterlogged acid soils where poor aeration causes the unavailable manganic ions to be reduced to manganous ions that can be taken up by plants.
- Strongly acid soils formed from parent material high in manganese (eg basic igneous rocks); in acidic conditions there is an increase in the solubility of manganese and its concentration in the soil solution may reach levels that are toxic to plants.

## Occurrence highly unlikely

- Strongly alkaline soils, especially those with free lime, eg calcareous soils, where manganese is converted into forms less available to plants.
- Strongly acidic peat and muck soils where total manganese is low.
- Peaty soils overlying calcareous subsoils.
- Poorly drained soils with a high content of organic matter where manganese is tied up in forms less available to plants.
- Acidic sandy mineral soils where manganese has been removed by leaching.
- Soils derived from parent material low in manganese (eg acid igneous rocks).
- Soils that fluctuate regularly between well-drained and waterlogged, where the manganese can be reduced to water-soluble forms that are then readily leached.
- Soils over-limed with lime or dolomite.



Plate 93: Older mature leaf from a seedling showing the first signs of manganese toxicity. Note the appearance of small brown spots with a slight yellow chlorotic halo.



Plate 94: Seedling showing a general chlorosis of the youngest leaves caused by manganese toxicity. This symptom is very similar to the yellow chlorosis seen in nitrogen-deficient plants.



Plate 95: Manganese toxicity in a young mature leaf showing the brown spots and slight, general yellow chlorosis (a). The brown spots develop mainly along the main and secondary veins (b). A slight yellow chlorosis has also developed generally over the entire leaf.



Plate 96: Older mature leaf from plant in Plate 95 showing similar brown spots (a and b), but not as prolific as seen in the younger mature leaf.



Plate 97: Leaves separated from a seedling displaying manganese toxicity to show the change in colour from pale green to yellow younger leaves and the dark deep green older leaves (a). Close-up of younger mature leaf (b; top) and older mature leaf (b; bottom); note the more prolific brown spotting on the older leaf and the more general chlorosis on the younger leaf.



Plate 98: An older mature leaf showing the development of small brown spots near the main and secondary veins from manganese toxicity.

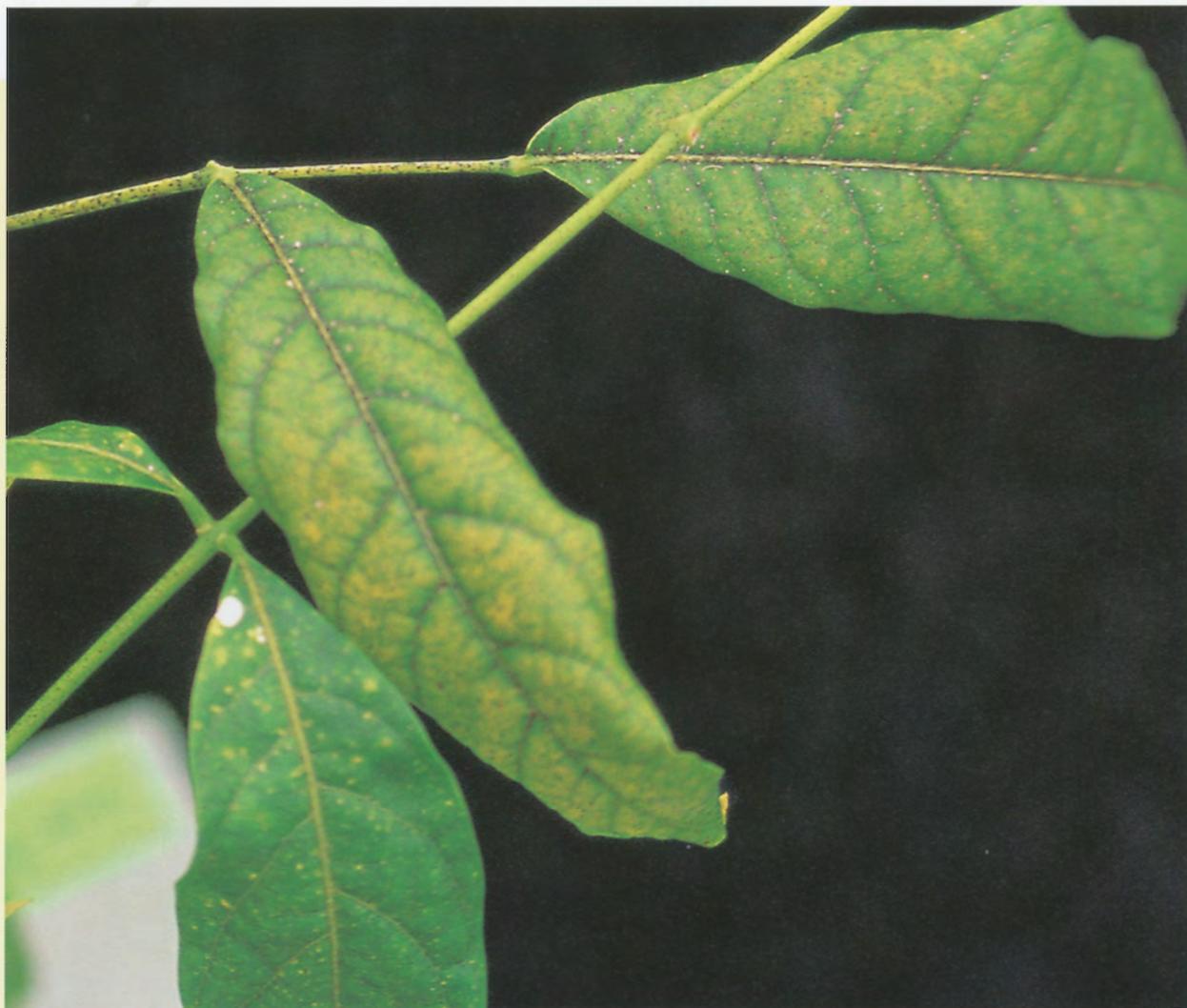


Plate 99: Older mature leaves from a seedling showing severe manganese toxicity. Note the development of a general yellow chlorosis with the main and secondary veins remaining green. The brown spots are more frequent near the major veins, and can also be seen on the petiole. Soon after this stage, the older leaves drop off.

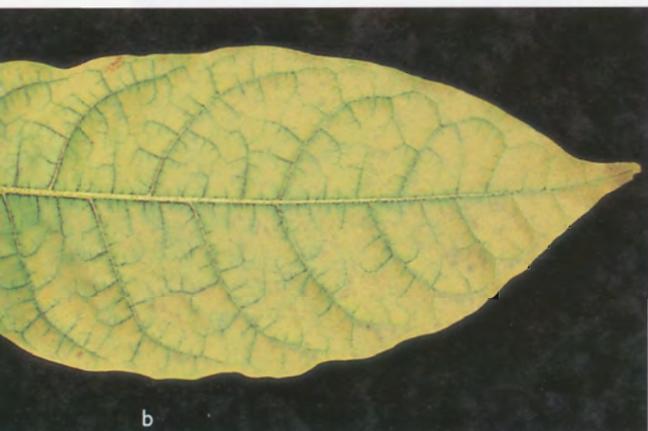
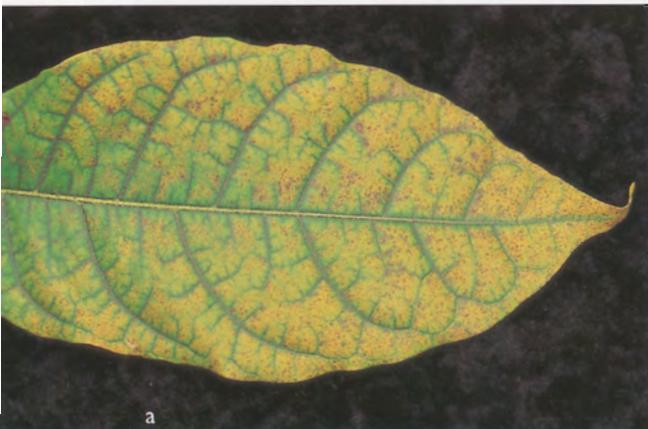


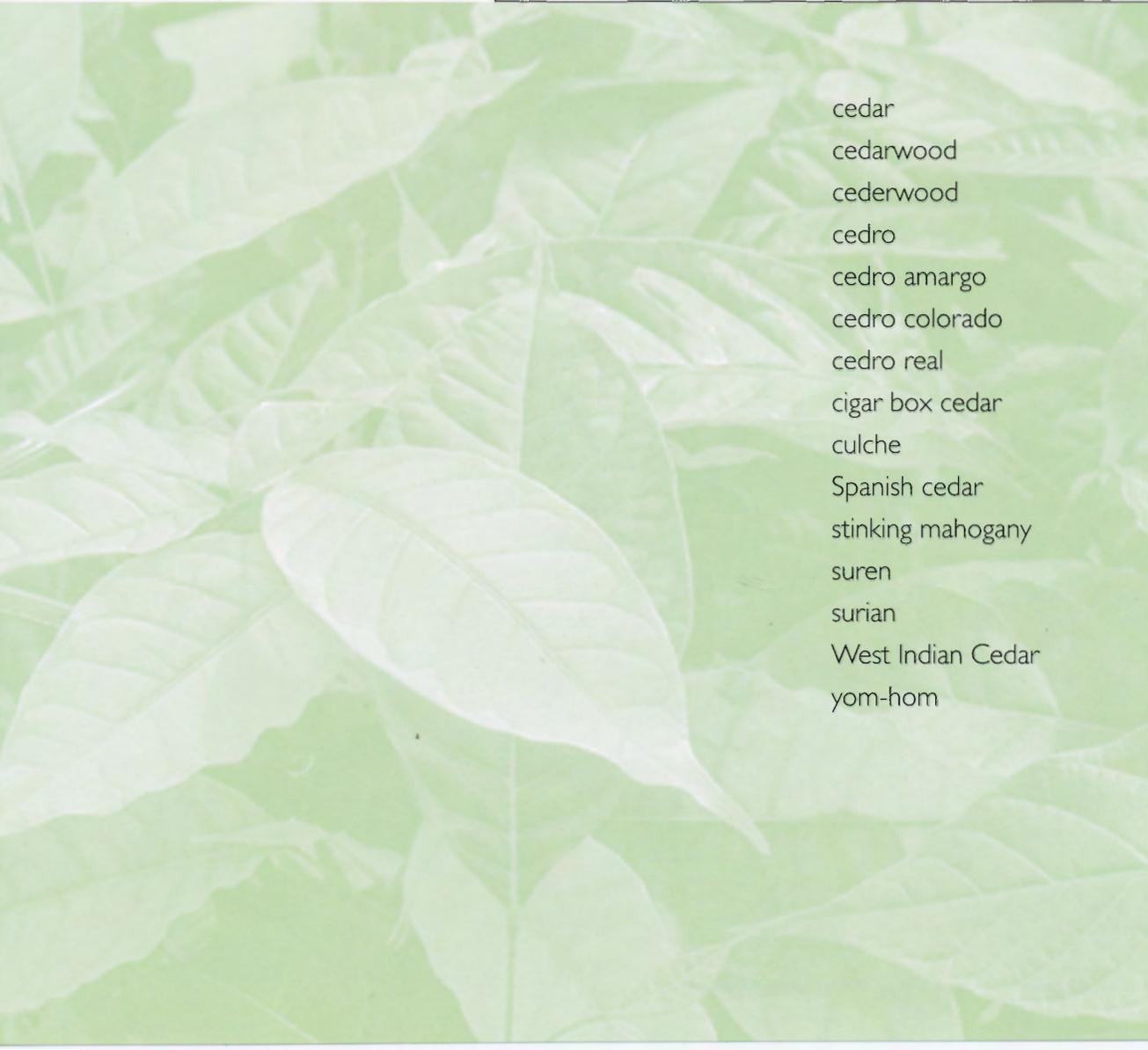
Plate 100: Older leaves that have fallen from a manganese-toxic seedling showing marked chlorosis and brown spotting that is more visible on the upper surface (a) than the lower surface (b).



Plate 101: Seedlings severely affected by manganese toxicity can lose much of their foliage except for a few newly developing leaves, leaving the stems almost leafless.



*Cedrela odorata* L.



cedar  
cedarwood  
cederwood  
cedro  
cedro amargo  
cedro colorado  
cedro real  
cigar box cedar  
culche  
Spanish cedar  
stinking mahogany  
suren  
surian  
West Indian Cedar  
yom-hom

## Symptom Key

### Symptoms based on

Leaf colour .....	Key pages 109-113
Leaf shape and condition .....	Key pages 114
Stems and growing point .....	Key pages 115-116

## Symptoms based on leaf colour: chlorosis pattern

Veins green;  
interveinal area  
strongly  
chlorotic



N	P	K	Ca	Mg	S	Fe	Zn	Cu	Mn	B	Mo	Mn Tox	Al Tox
---	---	---	----	----	---	----	----	----	----	---	----	-----------	-----------

Veins green;  
interveinal area  
mildly chlorotic



N	P	K	Ca	Mg	S	Fe	Zn	Cu	Mn	B	Mo	Mn Tox	Al Tox
---	---	---	----	----	---	----	----	----	----	---	----	-----------	-----------

Veins green;  
interveinal area  
weakly chlorotic



N	P	K	Ca	Mg	S	Fe	Zn	Cu	Mn	B	Mo	Mn Tox	Al Tox
---	---	---	----	----	---	----	----	----	----	---	----	-----------	-----------

Veins and  
interveinal areas  
are uniformly  
chlorotic



N	P	K	Ca	Mg	S	Fe	Zn	Cu	Mn	B	Mo	Mn Tox	Al Tox
---	---	---	----	----	---	----	----	----	----	---	----	-----------	-----------

## Symptoms based on leaf colour: chlorosis position

Basal



N P K Ca Mg S Fe Zn Cu Mn B Mo Mn Tox Al Tox

Distal



N P K Ca Mg S Fe Zn Cu Mn B Mo Mn Tox Al Tox

Marginal



N P K Ca Mg S Fe Zn Cu Mn B Mo Mn Tox Al Tox

Symptoms based on leaf colour patterns

Lobed



N	P	K	Ca	Mg	S	Fe	Zn	Cu	Mn	<b>B</b>	Mo	Mn Tox	Al Tox
---	---	---	----	----	---	----	----	----	----	----------	----	-----------	-----------

Uniform over  
leaf



<b>N</b>	P	K	Ca	Mg	S	<b>Fe</b>	Zn	Cu	Mn	B	Mo	Mn Tox	Al Tox
----------	---	---	----	----	---	-----------	----	----	----	---	----	-----------	-----------

## Symptoms based on leaf colour: necrosis

Pattern:  
Interveinal



N P K Ca Mg S Fe Zn Cu Mn B Mo Mn Tox Al Tox

Veins and  
interveins  
uniformly  
necrotic



N P K Ca Mg S Fe Zn Cu Mn B Mo Mn Tox Al Tox

Position:  
Basal



N P K Ca Mg S Fe Zn Cu Mn B Mo Mn Tox Al Tox

Distal



N	P	K	Ca	Mg	S	Fe	Zn	Cu	Mn	B	Mo	Mn Tox	Al Tox
---	---	---	----	----	---	----	----	----	----	---	----	-----------	-----------

Body of leaf



N	P	K	Ca	Mg	S	Fe	Zn	Cu	Mn	B	Mo	Mn Tox	Al Tox
---	---	---	----	----	---	----	----	----	----	---	----	-----------	-----------

Uniform over  
leaf



N	P	K	Ca	Mg	S	Fe	Zn	Cu	Mn	B	Mo	Mn Tox	Al Tox
---	---	---	----	----	---	----	----	----	----	---	----	-----------	-----------

## Symptoms based on leaf shape and condition

Flaccid



N P K **Ca** Mg S Fe Zn Cu Mn B Mo  $\frac{\text{Mn}}{\text{Tox}}$   $\frac{\text{Al}}{\text{Tox}}$

Distorted shape



N **P** K **Ca** Mg S Fe Zn Cu **Mn** B Mo  $\frac{\text{Mn}}{\text{Tox}}$   $\frac{\text{Al}}{\text{Tox}}$

Corkiness of main rib



N P K Ca Mg S Fe Zn Cu Mn **B** Mo  $\frac{\text{Mn}}{\text{Tox}}$   $\frac{\text{Al}}{\text{Tox}}$

# Symptoms based on stems and growing point

Short and stout



N	<b>P</b>	K	Ca	Mg	S	Fe	Zn	Cu	Mn	B	Mo	Mn Tox	Al Tox
---	----------	---	----	----	---	----	----	----	----	---	----	--------	--------

Thin/spindly/  
leggy



N	P	K	Ca	<b>Mg</b>	S	Fe	Zn	Cu	Mn	B	Mo	Mn Tox	Al Tox
---	---	---	----	-----------	---	----	----	----	----	---	----	--------	--------

Death of  
growing point or  
meristem



N	P	K	Ca	Mg	S	Fe	Zn	Cu	Mn	<b>B</b>	Mo	<b>Mn Tox</b>	Al Tox
---	---	---	----	----	---	----	----	----	----	----------	----	---------------	--------

Abscission of leaves



N P K Ca Mg S Fe Zn Cu Mn B Mo Mn Tox Al Tox

Death of terminal leaflet



N P K Ca Mg S Fe Zn Cu Mn B Mo Mn Tox Al Tox

Rapid death of whole plant



N P K Ca Mg S Fe Zn Cu Mn B Mo Mn Tox Al Tox

## Healthy Seedlings

A healthy seedling usually has an unbranched stem that grows rapidly to reach about 30 cm in 12 weeks. Plants are light green and leaves have a dull or matt appearance. The young emerging leaves may be brown with a soft texture to begin with, but they quickly turn a light green. As the young leaf matures, it remains a bright green.

The roots of a healthy seedling are extensively branched, the younger roots being pale brown to white while the older roots are dark brown. The root tips have no signs of malformation, such as being club-shaped or with brown or black necrotic lesions.



Plate 102: Young and healthy plant showing light green leaves that have a soft texture.



Plate 103: Slightly older plant with similar light green leaves that have a soft texture.



Plate 104: Close-up of leaflets showing the soft 'matt' appearance



Plate 105: Close-up of a healthy growing point with a newly emerging leaf.

# Nitrogen (N) Deficiency

## Symptoms

Symptom development is quite rapid when nitrogen supply becomes limiting. Growth slows down quickly and the stems become thin and spindly.

In striking contrast to most other species where the symptoms appear firstly on older leaves, in *Cedreia odorata* the symptoms always appear first on the youngest leaves. Generally, the leaves turn pale green then yellow with younger leaves more severely affected than older leaves. At this early stage of deficiency it is difficult to discriminate between nitrogen and sulphur deficiency (compare also with iron deficiency). With mild deficiency, the older leaves remain quite dark green and only the newly developing leaves show signs of chlorosis. As the deficiency becomes more severe, the chlorosis is more pronounced and the older leaves also lose colour. Newly developing leaves may have less chlorosis than older leaves at this stage; however, chlorosis within a leaflet may not be uniform—typically the terminal leaflets are more chlorotic than those closer to the leaf stalk.

## Occurrence likely

- Mineral soils low in organic matter, with a neutral to alkaline pH, and where organic matter has been depleted and is not being replaced.
- Where large amounts of organic matter with a high C:N ratio have been incorporated; this may cause only a transient deficiency.
- Light-textured soils (eg sands, sandy loams) where rainfall is high and soils can be easily leached.

## Occurrence highly unlikely

- Peat soils recently limed for the first time.
- Soils where large amounts of organic matter with low C:N ratio have been recently incorporated.
- Clay soils (with smectite minerals) with a recent history of ammonium fertilisation or ammonification of organic matter.



Plate 106: Nitrogen-deficient plants on left; nitrogen supply increases to the right. The nitrogen-deficient plants are slightly smaller and noticeably more chlorotic. Interestingly this chlorosis first appears in the younger leaves with the older leaves remaining green. This is in contrast to the pattern described for many agricultural crops.



Plate 107: Close-up of deficient and healthy plants. Notice that the colour of the old leaves is similar, irrespective of nitrogen status but the young leaves are chlorotic in the nitrogen-deficient plant on the left.



Plate 108: Nitrogen-deficient plant showing how the deficiency develops. As the chlorosis becomes more intense, it spreads to more leaves.



Plate 109: Severe nitrogen deficiency in the seedling on the left compared with a healthy plant on the right. Note the development of a strong chlorosis affecting most of the leaves on the severely deficient plant.



Plate 110: Nitrogen-deficient seedling where the chlorosis appears to be more severe in the older leaves with some of the newly emerging leaves being quite green.



Plate 111: As deficiency progresses and leaf senescence occurs, some of the younger leaves may appear green.



Plate 112: A close inspection of the leaves of plants in Plate 111 shows that, although some parts of these new leaves are green, other parts are chlorotic.



Plate 113: Severely nitrogen-deficient seedling where most of the leaves have died and fallen off. The few new leaves that are able to develop can be quite green.

# Phosphorus (P) Deficiency

## Symptoms

Apart from affecting the size of plants, phosphorus deficiency has few other visual effects that can be used reliably to diagnose the deficiency, except under extremely severe conditions. This is in marked contrast to most other species in which symptoms such as darkening of leaves or reddening/purpling of petioles are commonly reported.

Seedlings lacking phosphorus grow slower than healthy seedlings, but there is no difference in appearance between phosphorus-deficient and healthy seedlings.

When phosphorus is withheld for some time, the whole shoot loses some of its green colour but not in a way that might be a useful indicator without a healthy plant as a reference.

Only in the case of extreme P deficiency is there some development of symptoms in mature leaves that could be a useful guide (see Plate 119 onwards). These symptoms include some necrosis, leaf loss and leaf curling. However, if there is *a priori* knowledge of growth rates and history of the plants, phosphorus deficiency might be considered as one possibility when there are no symptoms but plants are not growing at the expected rate.

## Occurrence likely

Phosphorus is one of the most widespread deficiencies in tropical soils. It is more likely to occur in:

- Mineral soils low in organic matter.
- Highly weathered, aluminium- and iron-rich acid soils (eg old soils from basalt) where phosphate is fixed in less available forms.
- Acidic soils that contain allophane (eg volcanic ash soils) or kaolinite clays.
- Alkaline soils high in calcium and magnesium where the phosphate may be tied up in insoluble phosphates.
- Leached quartz sand, and peat soils.
- Soils where the topsoil has been lost through erosion.

## Occurrence highly unlikely

- Soils recently converted from agriculture (where P fertilisers were used).



Plate 114: Note the substantial reduction in growth in the phosphorus-deficient plant on the left in both photographs. Plants are approximately two months old.

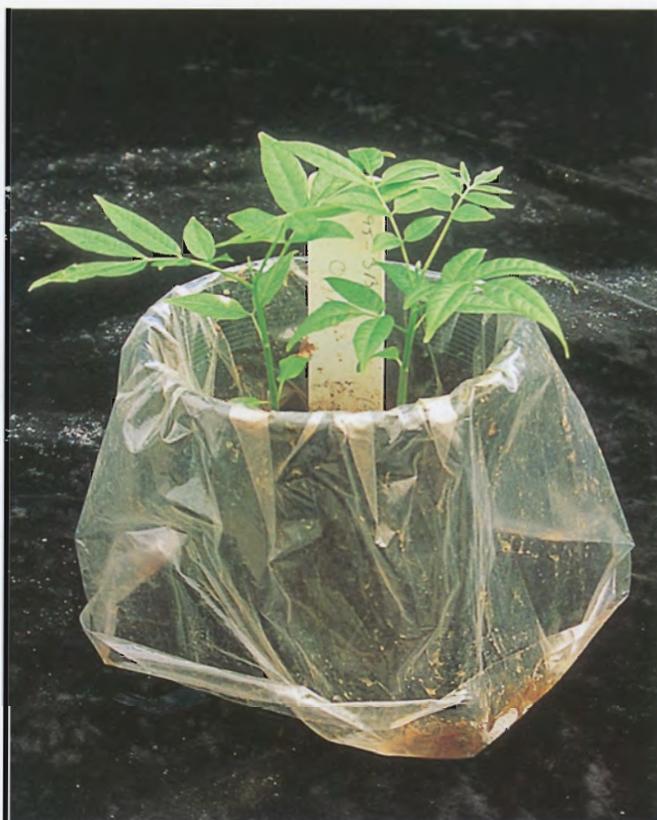


Plate 115: Close-up of phosphorus-deficient plant from Plate 114. In spite of the growth reduction, there are no diagnostic symptoms.

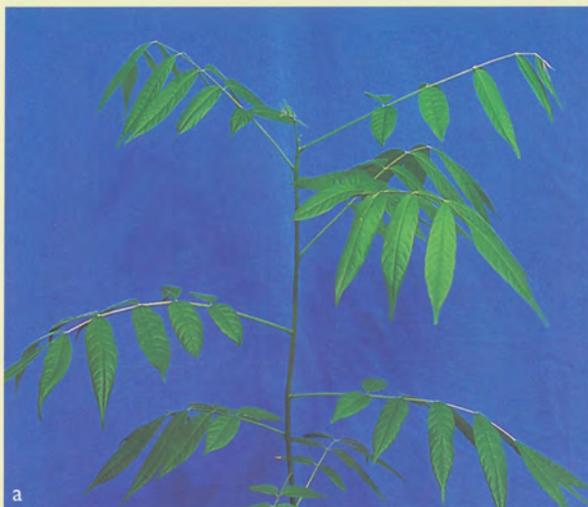


Plate 116: Even in older plants there is little to distinguish a phosphorus-deficient plant (above) from a healthy plant (below).



Plate 117: Young leaves from plants similar to those shown in Plate 116. Apart from an obvious difference in size there is no other symptom of phosphorus deficiency. Top left to bottom right: 0, 25, 50, 100, 150, 200, 250, 500, 1000 mg P added / kg soil.



Plate 118: Youngest mature leaves from plants similar to those shown in Plate 117. Apart from an obvious difference in size there is no other symptom of phosphorus deficiency. Top left to bottom right: 0, 25, 50, 100, 150, 200, 250, 500, 1000 mg P added / kg soil.



Plate 119: Old leaves from plants similar to those shown in Plate 116. Only in these old leaves is there any visual symptom, apart from a reduction in size, that might be an indication of a nutritional disorder. Top left to bottom right: 0, 25, 50, 100, 150, 200, 250, 500, 1000 mg P added / kg soil.



Plate 120: When the deficiency is severe or prolonged some symptoms develop on the old leaves with the remainder of the plant appearing quite healthy.



Plate 121: Close-up of leaves from plant in Plate 120. Note the development of necrotic patches with little or no associated chlorosis.



Plate 122: As the deficiency becomes severe, the older leaves die and fall off while the leaflets on the remaining young leaves become stiff and curl downwards.

# Potassium (K) Deficiency

## Symptoms

As potassium becomes deficient, young seedlings grow more slowly and stems become thin and spindly.

Potassium deficiency affects older leaves more severely than younger leaves. The first sign of potassium deficiency is a slight chlorosis in the middle of the blade of older leaves. This is followed by a marginal chlorosis in the youngest mature leaves which eventually develops into a strong interveinal chlorosis. Although the leaflets develop a severe chlorosis, the bases of the leaflets remain green. When the deficiency becomes more severe, the tips of the leaflets become necrotic, but their bases remain green. By this stage the young leaves are starting to show some chlorosis. Some older leaves develop small and distinct necrotic patches in the mid-region of the leaflets.

## Occurrence likely

- Highly weathered mineral soils low in organic matter.
- Light-textured soils (eg sands and sandy loams) formed from parent material low in potassium (eg sandstone, limestone and some granites).
- Mineral soils where the original potassium has been leached by heavy rainfall.

## Occurrence highly unlikely

- Potassium deficiency is unlikely in **young** soils formed from parent material that is rich in potassium, eg soils from igneous rocks.



Plate 123: A young seedling in the early stages of potassium deficiency. There is little effect on the youngest mature leaf (a). However, a slight pale yellow chlorosis develops in the middle of the leaf between the secondary (b) and tertiary (c) veins of older leaves.



Plate 124: Close-up of the youngest mature leaf showing the chlorosis that appears on the leaf margins as the deficiency becomes more severe.



Plate 125: Close-up of the leaves showing another feature of potassium deficiency. The base of the leaflet remains green while the rest loses colour.



Plate 126: Close-up of older leaves of a potassium-deficient plant showing the characteristic green area at the base of the leaflet.



Plate 127: Close-up of leaves from the same plant showing the progression of symptoms from youngest to older leaves. Even when the deficiency becomes quite severe, young leaves are little affected (a). However, youngest mature leaflets are now showing much more severe chlorosis but the base of the leaflet remains green (b). By this stage mature leaves have become severely chlorotic as well as developing necrosis of leaf tips. Again note the green base of leaflets (c). Old leaves are now severely chlorotic (d).



Plate 128: Close-up of leaves from the same plant suffering from severe potassium deficiency. The young leaves are starting to develop a slight chlorosis (a). The youngest mature leaf becomes more chlorotic but the base of the leaflets remains green (b). The middle-aged leaves become severely chlorotic (c). Other middle-aged leaves show a different pattern of tip necrosis (d). Old leaves show severe chlorosis (e).



Plate 129: Old leaves from a severely potassium-deficient plant. Note the development of distinct localised necrosis.

# Calcium (Ca) Deficiency

## Symptoms

Calcium-deficient seedlings stop growing and develop short, stout stems. The roots become short and thickened, and growth of the lateral roots ceases, giving the root system an overall stumpy appearance.

On the stem, calcium deficiency appears firstly in the emerging leaves which become either twisted or cupped. In older leaves, a pale yellow chlorosis develops at the leaf tip, but the chlorotic area quickly dies and turns a pale brown, so that the region of chlorosis is usually quite narrow (compare with potassium deficiency). In some leaves, the terminal leaflet withers and dies, often quite rapidly so that at times the leaves appear flaccid.

## Occurrence likely

- Acid coarse-textured soils (eg sandy soils from granites) in the humid tropics where the original calcium has been removed by heavy rainfall.
- Strongly acid peat soils where total calcium is low.
- Alkaline sodic soils where high pH and high exchangeable sodium depresses the uptake of calcium.
- Many humid tropical soils where the pH is less than 4.5 and soluble aluminium is high and exchangeable calcium is low.

## Occurrence highly unlikely

- Calcareous soils (eg those derived from coral or limestone).
- Soils in arid regions.



Plate 130: Close-up of young developing leaves showing the first signs of calcium deficiency. Note the twisting (a) or cupping (b) of the leaves.

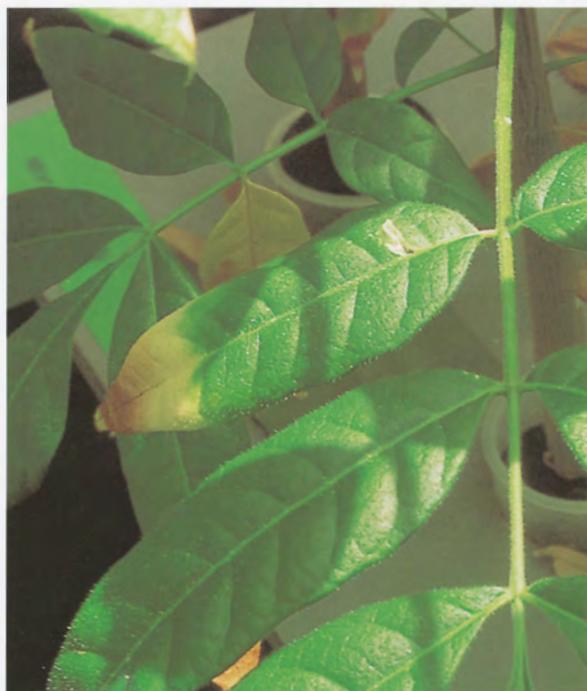


Plate 131: Older leaves of calcium-deficient plants develop chlorosis of the leaf tips that is followed by necrosis of tips as the chlorosis extends along the leaf.



Plate 132: As calcium deficiency becomes more severe, the young leaflets become strongly curved and the terminal leaflets and that portion of the rachis die.



Plate 133: Middle-aged leaves from a calcium-deficient plant. The tips of the leaflets become necrotic with a distinct, sharp boundary between necrotic and healthy tissue and a small (if any) region of chlorosis (a, b). In some leaves (c), the terminal leaflets die and fall off.



Plate 134: Older leaves from a calcium-deficient plant where the necrosis is much more developed.



Plate 135: On some middle-aged leaves, calcium deficiency causes the leaves to appear flaccid as well as necrotic.

# Magnesium (Mg) Deficiency

## Symptoms

The growth of magnesium-deficient seedlings slows down and the stems become spindly.

The first symptom to appear on the shoots is a pale yellow chlorosis which begins as a mild interveinal chlorosis on young leaves, becoming more severe as the leaves age. On older leaves, small brown spots appear which become larger and more diffuse and eventually turn necrotic. These brown necrotic patches then turn white and coalesce to form large areas of white necrosis within the interveinal areas of the leaf.

## Occurrence likely

- Coarse-textured acid soils (eg sandy soils derived from granites) in the humid tropics where the original magnesium has been removed by leaching.
- Strongly acid peat soils where total magnesium is low.
- Soils that have been over-fertilised with calcium (eg over-limed), potassium or ammonium, thus inhibiting the uptake of magnesium.

## Occurrence highly unlikely

- Soils derived from parent material high in magnesium, (eg serpentine).



Plate 136: Leaves from magnesium-deficient plants. Magnesium deficiency starts as a mild interveinal chlorosis (a), becoming more severe as these young leaves age (b, c).

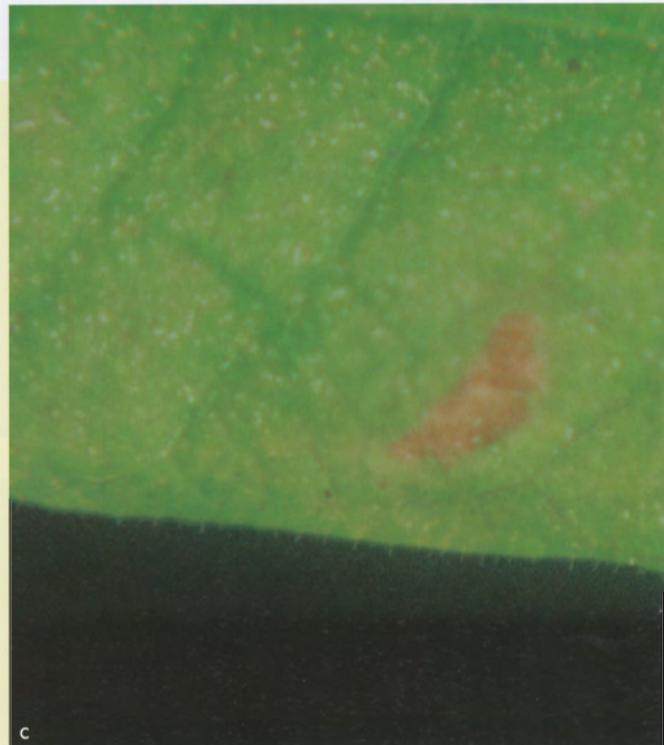


Plate 137: Older leaves from magnesium-deficient plants. Note the development of brown spots on the leaves (a). These spots become larger and more diffuse (b) and eventually turn into a necrotic patch (c).



Plate 138: Close-up of leaves showing how the necrosis turns to white patches of various sizes as the deficiency becomes more severe. These patches are still mainly within the interveinal areas of the leaflets.



Plate 139: Older leaves from a magnesium-deficient plant showing how the patches are similar to those in younger leaves but may begin to join up (b). In both younger leaves and old leaves these white patches have a sharp boundary with very little brown and no yellow surrounding the patch except where the entire leaf is chlorotic (see upper left leaflet in b).



Plate 140: Close-up of the oldest leaves which developed before the deficiency was severe. Note the development of a general chlorosis with only a small number of necrotic patches.





Plate 141: A young seedling suffering from magnesium deficiency. Note that the entire plant appears spindly and weak with many of the leaves lost.

# Sulphur (S) Deficiency

## Symptoms

Symptoms develop rapidly when sulphur is omitted from the nutrient supply. Within two weeks seedlings stop growing, become very spindly, and develop an overall pale green to pale yellow appearance. The younger leaves become pale green to yellow and the older leaves initially remain dark green. The yellow chlorosis is uniform across the leaf blade and veins but may vary along the length of the leaf or even the leaflet. This pattern of symptom development is similar to that found in other species. At this early stage it is difficult to discriminate between nitrogen and sulphur deficiency, as the patterns of development are similar. This is unusual in that, in other species, nitrogen deficiency generally affects older leaves first (see nitrogen deficiency). As the deficiency becomes more severe, the older leaves also become chlorotic and develop necrotic areas on the tips of each leaflet.

## Occurrence likely

- Acid sandy soils in the humid tropics where the original sulphur has been leached by heavy rainfall.
- Coarse-textured soils (eg sandy soils) low in organic matter.
- Soils formed from parent material low in sulphur (eg from volcanic rocks and ash).

## Occurrence highly unlikely

- Soils high in decomposing organic matter.
- Soils where atmospheric inputs could be high (such as soils adjacent to coal-burning industries, major cities, oceans, or marshes), especially calcareous soils or soils high in aluminium and iron hydrous oxides (eg highly weathered basalts).



Plate 142: The young plant on the right displays the early stages of sulphur deficiency as a pale yellow chlorosis of younger leaves. The healthy plant on the left is an overall green colour.



Plate 143: Chlorotic young sulphur-deficient leaves. The yellow chlorosis is uniform across the leaf blade and veins (compare with iron deficiency).



Plate 144: Newly developing leaves on a sulphur-deficient plant. As the deficiency progresses, new leaves are pale green to yellow as they emerge, giving the whole plant a general chlorotic appearance. In (a) the sulphur-deficient plant is in the middle.



Plate 145: In young, recently developed leaves, the distal leaflets are more chlorotic than the proximal leaflets



Plate 146: Even within a leaflet, the distal region is more chlorotic than the proximal region.



Plate 147: By contrast, some older leaves are uniformly chlorotic.



Plate 148: As the deficiency progresses, some of the older leaves develop necrotic tips whilst the oldest leaves may die and drop off.

# Iron (Fe) Deficiency

## Symptoms

The symptoms of iron deficiency appear rapidly, although the seedlings may initially show no slowdown in growth. As the severity of the deficiency increases, growth of the young plant slows and the stem becomes spindly.

Iron deficiency affects younger leaves more than older leaves. The pale yellow chlorosis is quite uniform across the leaf blade and includes the veins. This pattern is not typical of iron deficiency found in other species.

## Occurrence likely

- Alkaline or calcareous soils with high pH (7.4–8.5) where levels of soluble iron are low.
- Waterlogged or compacted (wet) calcareous soils (including roads made from coral rubble).
- Coarse-textured soils low in total iron (eg bleached white sands).
- Peat soils where organic matter ties up soluble iron.
- Acid soils with very high levels of soluble manganese, zinc, copper (either natural or from excessive applications of copper-based fungicides), or nickel (eg serpentine soils) which depress the uptake of iron by plants.

## Occurrence highly unlikely

- Acid to neutral mineral soils that are not high in soluble manganese, zinc, copper or nickel.
- Flooded non-calcareous soils.
- Mineral soils high in organic matter (but not peat soils).



Plate 149: Young seedling showing how the whole plant is generally a pale yellow with younger leaves slightly more chlorotic than older leaves.



Plate 150: Young leaves from an iron-deficient plant. Note the general yellow chlorosis of leaves including the veins. This is in contrast to the more typical symptom of iron deficiency in which the interveinal regions of the leaf (leaflet) are quite chlorotic with the veins remaining green.

# Manganese (Mn) Deficiency

## Symptoms

The symptoms of manganese deficiency are more severe in young leaves than in old leaves. The whole plant develops a general pale yellow chlorosis which is more noticeable on the younger leaves. Within the leaflet, the chlorosis is localised rather than general over the whole leaflet. In young leaves, the youngest leaflets sometimes develop an abnormal shape when they become chlorotic. Eventually, the chlorosis develops into a diffuse brown necrotic patch.

## Occurrence likely

- Strongly alkaline soils, especially those with free lime, eg calcareous soils, where manganese is converted into forms less available to plants.
- Strongly acidic peat soils where total manganese is low.
- Peaty soils overlying calcareous subsoils.
- Poorly drained soils with a high content of organic matter where manganese is tied up in forms less available to plants.
- Acidic sandy mineral soils where manganese has been removed by leaching.
- Soils derived from parent material low in manganese (eg acid igneous rocks).
- Soils that fluctuate regularly between well-drained and waterlogged, where the manganese can be reduced to water-soluble forms that are then readily leached.
- Soils over-limed with lime or dolomite.
- Soils over-fertilised with copper, iron or zinc that inhibits plant uptake of manganese.

## Occurrence highly unlikely

- Flooded soils where the level of total manganese is adequate.
- Acid mineral soils, especially those formed from parent materials rich in manganese (eg basic igneous rocks such as basalt).



Plate 151: Young seedling suffering from manganese deficiency. The whole plant is slightly chlorotic with younger leaves more chlorotic than older leaves.



Plate 152: Close-up of a young leaf showing that the chlorosis is localised rather than across the entire leaf.



Plate 153: Close-up of a developing young leaf showing that the localised chlorosis is also noticeable in the newly emerging leaves. Also note the abnormal shape of the youngest leaves.



Plate 154: Close-up of the leaflets on an older leaf. The chlorosis develops into a diffuse necrotic patch.

# Boron (B) Deficiency

## Symptoms

A number of different symptoms are associated with boron deficiency. As boron becomes deficient, seedlings stop growing and become stunted with stout stems. Death of the terminal leaflet is common, as is abscission of newly emerged leaves. To a lesser extent lobed chlorosis and small white necrotic patches are also seen on some older leaves. On some leaves a brown 'corkiness' near the midrib of the leaflet is apparent.

## Occurrence likely

Boron deficiency is more likely to occur in highly weathered soils in high rainfall areas, with increasing distance from oceans, and in acid peat soils.

Typical sites for boron deficiency include:

- Coarse-textured soils formed from parent materials low in boron such as acid igneous rocks (eg granites), metamorphic rocks, and freshwater sandstones and shales.
- Acid sandy soils (eg podsollic soils) from which boron has been leached by rainfall.
- Alkaline, or calcareous soils, especially those with free lime.
- Soils low in organic matter.
- Acidic soils rich in aluminium oxides.
- Soils derived from pumice and volcanic ash rich in allophane.
- Peat soils, especially after liming.

A temporary deficiency of boron can occur under drought conditions when uptake of boron is inhibited by the isolation of available boron in a dry soil horizon.

## Occurrence highly unlikely

- Soils formed from marine sediments.
- Soils close to oceanic coastal influences.
- Fine-textured soils with high clay content (eg from basalts or shales) unless highly weathered.
- Soils of naturally high pH that have no free lime.