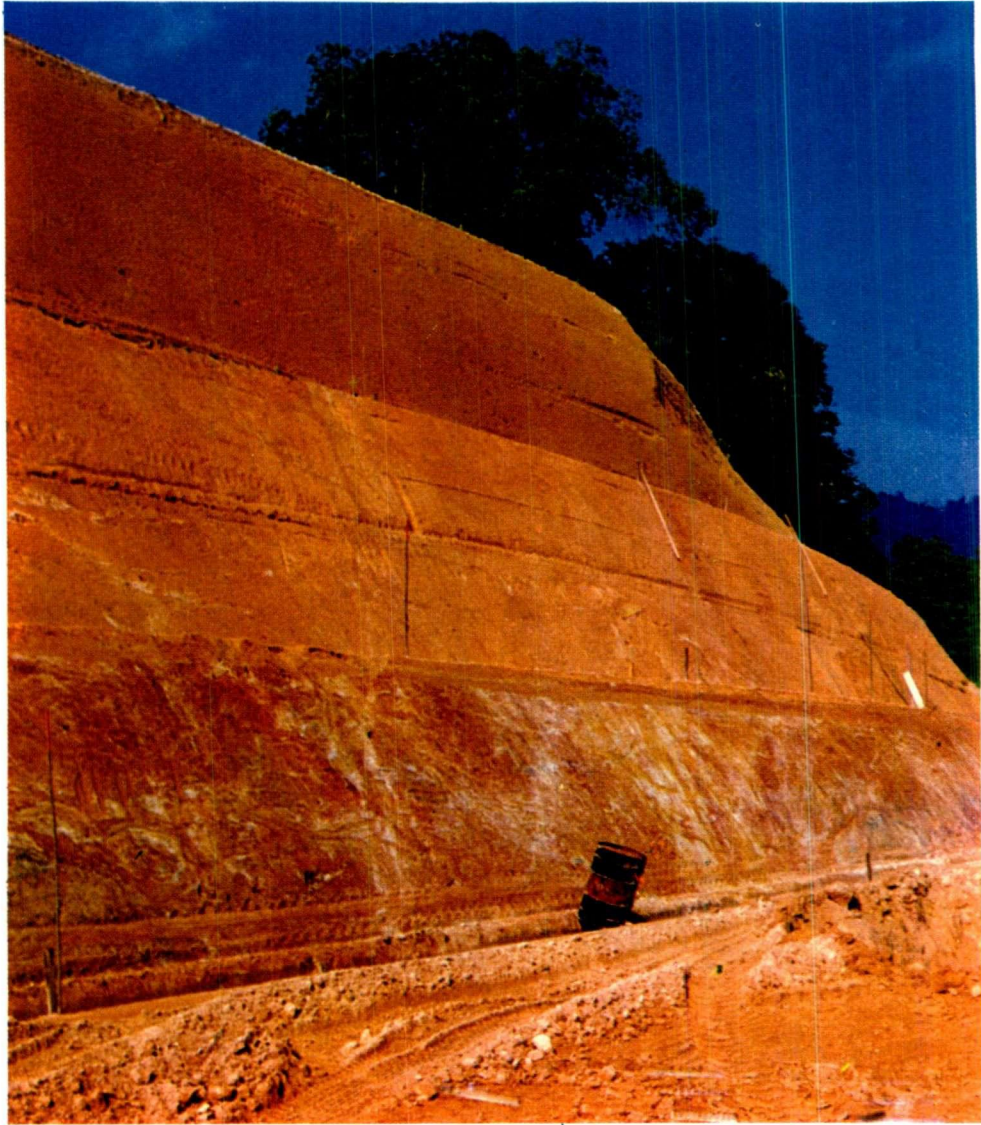


**Mineral Deficiencies in Hevea
and Associated Cover Plants**



Deeply weathered soil derived *in situ* from granite under conditions of high rainfall and temperature in Malaya. *Hevea* develops free and extensive rooting on this soil, but even so symptoms of magnesium and manganese deficiency are common.

Mineral Deficiencies in Hevea and Associated Cover Plants

Hevea brasiliensis

Pueraria phaseoloides

Centrosema pubescens

Calopogonium mucunoides

by Victor M. Shorrocks

Rubber Research Institute
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FOREWORD

The principal aim of this book is to provide the rubber planter with the means to identify nutrient deficiency symptoms in *Hevea brasiliensis* and to correct the deficiencies when diagnosed. Symptoms occurring in three commonly used leguminous creeping cover plants, *Pueraria phaseoloides*, *Centrosema pubescens* and *Calopogonium mucunoides*, are also described, for their appearance in the field will indicate low soil nutrient levels and may serve as an indicator of the likely fertiliser requirements of the *Hevea*. Reference is made to Malayan conditions almost exclusively; there is no reason to believe that deficiency symptom expression is likely to be different in other countries, and in so far as direct deficiencies occur it is considered that the fertiliser application rates can be safely applied to other rubber-growing areas in the world.

Preliminary work on the expression of nutrient deficiency symptoms in *Hevea* was first carried out in 1938,⁵⁸ and visual symptoms of deficiencies of *Hevea* seedlings grown in sand culture were described in detail by Bolle-Jones in 1956¹⁴ and illustrated by watercolours. In this book, which is an extension of the earlier work, the illustrated leaves and plants have been obtained both from the field and from sand culture studies. The symptoms observed on young seedling material in sand-culture and on older seedling and bud-grafted rubber in the field have been found to be similar, but it has been found that on mature rubber consideration needs to be given to the position on the tree where the symptoms are observed. As there are basic similarities between the deficiency symptoms of *Hevea* and those of the three cover plants, the illustrations of given deficiency symptoms in all four species are arranged together, while the symptoms shown by the three legumes are described under one heading.

Reference to different fertilisers has been intentionally restricted to those in common use in Malaya and to those that are likely to be used. It is possible of course for new fertilisers to be placed on the market which may offer economic advantages and which may be just as suitable as those currently used: in this event the necessary calculation of application rates can be made by reference to the tables given in this book.

Chapters on the essential plant nutrients and on the soil as a source of supply of nutrients have been included so that the planter may appreciate some of the complexities of the soil-plant nutrient relationships. No attempt has been made, however, to provide a comprehensive textbook on plant nutrition.

As with many perennial crop plants, increasing emphasis is being given to the study of the fertiliser requirements of particular soils and planting material: the tools used are principally those of plant and soil chemical analysis. With such developments in mind, and also to provide background knowledge, some analytical data on the nutrient elements in *Hevea brasiliensis*, *Pueraria phaseoloides*, *Centrosema pubescens* and *Calopogonium mucunoides* are given in the *Appendix*.

ACKNOWLEDGMENTS

In the preparation of a book of this nature a debt is inevitably due to previous workers in the same field. The published and unpublished findings and observations of many who have investigated nutritional problems of *Hevea* cultivation in Malaya have been sources of information: the identity of many such sources is given in the bibliography.

Particular tribute must however be paid to Dr. E. W. Bolle-Jones, who developed modern techniques of sand culture at the Rubber Research Institute of Malaya in 1953 and was the first to demonstrate clearly the deficiency symptoms of *Hevea*: this book owes him a large debt. Much benefit was derived from Mr. G. Owen's twenty years' experience in the field of *Hevea* cultivation particularly in the early stages of preparation of this book.

Special acknowledgment is due to Dr. G. A. Watson, Head of the Soils Division, and to Mr. W. J. Baulkwill, the Publications Officer of the Institute, who have assisted and given valuable advice at all stages of writing.

The careful work of Mr. Chin Tet Tsoy in the daily maintenance of plants raised for deficiency symptom demonstration, the analytical work of Mr. K. Ratnasingam, and also the work of associated staff of the Soils Division is acknowledged. The assistance of Mr. Chan Tham Yew during the photographing of the majority of the subjects is much appreciated.

The preparation of this volume has been carried out at the Rubber Research Institute of Malaya, and acknowledgment is due to the Board and Director of the Institute for their support of the project and for sanctioning its publication.

THE ESSENTIAL INORGANIC NUTRIENTS AND THEIR ROLES

Information regarding the inorganic elements which are indispensable for the growth of plants is of fundamental importance in plant nutrition. It might be considered that an accurate analysis of the inorganic constituents of plants that have grown satisfactorily through the vegetative and reproductive stages of their life cycle would provide an inventory of the elements which are essential for growth. This is not so, for the plant has a capacity, within rather wide limits, for indiscriminate absorption. According to one source,³⁷ approximately sixty elements have been identified in plants; non-essential, and even at times injurious elements are absorbed as well as the essential nutrients.

The criteria of essentiality of an element for plant growth are: a deficiency of it makes it impossible for the plant to complete the vegetative or reproductive stage of its life cycle; the element must be directly involved in plant metabolism quite apart from any effect it may have in correcting some unfavourable microbiological or chemical condition of the soil; a deficiency of the element can be prevented or cured only by supplying that element.

Identification of Essential Nutrient Elements

The identity of those nutrient elements that are essential for satisfactory plant growth has been established by growing plants under controlled conditions in water and sand cultures. The main advantage of using such techniques is that nutrient solutions can be prepared lacking one element at a time but containing all others accepted as being essential for plant growth; the failure to grow in the absence of the element and resumption of growth upon the addition of the deficient element are taken as evidence of essentiality. In the complete or partial absence of any essential nutrient the test plant will exhibit symptoms, either of discoloration or of some type of distortion or stunting, characteristic of the particular deficiency. The identification of such symptoms in sand and water culture has been of immense value in studying nutrient requirements in the field, and the characteristic deficiency symptoms shown by *Hevea brasiliensis*, *Pueraria phaseoloides*, *Centrosema pubescens* and *Calopogonium mucunoides* described in later chapters were identified in this way.^{12, 43}

The Major Nutrients—Nitrogen, Phosphorus, Potassium, Calcium, Magnesium and Sulphur

It was basically with the above approach that the classical list of essential elements was compiled in the nineteenth century. The list included (apart from carbon, hydrogen and oxygen obtained from carbon dioxide and water) seven elements, namely nitrogen, phosphorus, potassium, calcium, magnesium, sulphur and iron. All but the last mentioned of these elements are required by the plant in relatively large quantities, and they are known as the major nutrients to distinguish them from the minor nutrients, which are required in only very small amounts.

The Minor Nutrients—Boron, Copper, Zinc, Iron, Manganese, Molybdenum and Chlorine

There was little to indicate to the early worker that plants could require very small concentrations of certain nutrients now known as the minor nutrients. Nevertheless, as early as 1869 it was suggested that zinc should be considered an essential element for plants following the discovery that zinc was essential for the growth of the fungus *Aspergillus niger*. In 1914⁵¹ it was reported that small

quantities of boron, zinc, chlorine, aluminium and silicon were essential elements for plants, and in the 1930's it was confirmed that in addition to the seven elements on the classical list, five others, namely boron, zinc, copper, manganese and molybdenum,⁶ should be included among the nutrients essential for the growth of plants. More recently, in 1954²⁷ and 1957,⁴⁶ the essentiality of chlorine has been demonstrated.

No final conclusion can yet be made as to whether the above elements complete the list of nutrients that are essential to plant growth, and there is still no conclusive evidence that aluminium and silicon are essential for plant growth, although experimental evidence indicates that some species may grow better in the presence of these elements. Despite the refined purification methods now employed, it is certain that solutions of specified nutrients still contain minute impurities of other elements, and consequently as techniques improve the essential nature of additional elements may be demonstrated. It seems obvious, however, that any such elements will be required in only exceedingly small amounts.

Nutrient Elements and their Roles in Plant Metabolism

The different essential elements play important and at times highly specific roles in the physiological processes taking place in the plant, and a knowledge of the mechanisms involved will assist understanding of the ways in which deficiency symptoms may develop. Shortage of a plant nutrient will cause disturbances in those processes in which it is directly involved, and as a result a whole range of physiological processes may be unbalanced. The net effect will be either shortages of metabolites essential for satisfactory growth, or an accumulation of intermediate products which may be toxic when present in large amounts, both of which conditions can lead ultimately to symptom development.

In the following sections a brief outline is given of the roles played by the essential nutrient elements.

✓ *Magnesium*

Magnesium plays a vital role in photosynthesis as a constituent of the chlorophyll molecule, and a deficiency of the element results in a leaf chlorosis caused by a reduction in the amount of chlorophyll in the leaf. Magnesium is also concerned with many enzyme systems, particularly in phosphate metabolism and thus in respiration. It is regarded as being a specific activator for a number of enzymes, often closely associated with the energy-supplying phosphorus compounds, acting in the role of a carrier for this element. Particular significance is attached to the magnesium content of the latex of *Hevea*; certain clones possessing high levels of magnesium in the latex tend to have unstable latex, and treatment of such clones with magnesium fertiliser is likely to accentuate the condition. The balance between magnesium and phosphorus in latex is thought to be important,^{9, 33, 47, 56} and an optimal Mg : P ratio in latex of 0.7-1.3 has been suggested.¹¹

✓ *Potassium*

Unlike all the other major nutrients, potassium has not been shown to enter into any specific reaction or to become part of stable organic compounds in the plant, for example proteins, carbohydrates, chlorophyll and fats. The nature of its role in any specific process has yet to be elucidated, although at one time or another it has been associated with almost every important physiological process, such as the synthesis of amino acids and proteins, photosynthesis, respiration, the process of translocation and the storage of carbohydrates in the plant. The importance of potassium may depend on its monovalent character almost as much as on its specific action on metabolic processes. It is however evident that potassium occupies a central position in plant metabolism, and it is present in large quantities in meristematic tissue where active growth is taking place.

A reduction in the potassium supply can result in an accumulation of incompletely metabolised

nitrogenous compounds; for instance, a marked increase in the amino acid content of potassium-deficient rubber leaves has been recorded.⁶¹ Potassium can often be replaced to a limited extent by sodium and rubidium, but in *Hevea* nothing is known about any such replacement. It seems unlikely, from the low sodium content of *Hevea* leaves, that replacement of potassium by sodium is of importance in the field.

✓ *Calcium*

Calcium is one of the constituents of the cell wall, the middle lamella, which contains calcium pectate; it is necessary for the proper functioning of meristems and is of special importance in root development. When the element is deficient, normal cell division becomes abnormal or even suppressed, and misshapen root systems are in consequence a notable feature of calcium-deficient plants. It has also been suggested that calcium has a role in the nitrogen metabolism in the plant, and in the absence of calcium some plants are unable to absorb or assimilate nitrates. Calcium oxalate crystals are frequently found in the bark of *Hevea*, but calcium-deficient seedlings have been found to contain no such crystals.⁶¹

Although it is often found that a large proportion of the calcium contained in the plant is water-soluble, calcium is relatively immobile and is not readily redistributed in the plant even under deficiency conditions; old leaves may have relatively high calcium contents when younger leaves on the same plant are deficient in calcium. Very old leaves, just prior to their abscission, contain large quantities of calcium, further indicating considerable immobility of calcium.

✓ *Nitrogen*

Nitrogen is essential for plant growth, being a constituent of all proteins and thus of all protoplasm, and is required in relatively large quantities. It is a constituent of chlorophyll, and nitrogen-deficient leaves contain relatively little chlorophyll and will tend to be typically pale green or even yellow in colour.

An increase in the nitrogen supply to a plant results notably in a large increase in leaf growth. Another result of such an increase is the more rapid conversion of assimilated carbohydrates to proteins and to protoplasm, leaving a smaller proportion of the carbohydrates for the building up of cell wall material which consists largely of nitrogen-free carbohydrates. As a result of the increase in the proportion of protoplasm to cell wall material the cell size is increased and the cell wall thickness reduced, making the leaves more succulent. A further consequence is that the proportion of water in the leaf is increased, while that of calcium is decreased, since protoplasm contains more water and less calcium than cell walls. On the other hand a very low nitrogen supply results in small leaves, with small cells and thick cell walls.

✓ *Phosphorus*

Phosphorus is a constituent of nucleic acids, which occur in the nuclei of all living cells, and is thus essential for cell division and for the development of meristematic tissue.

Phosphorus plays a very important part in enzyme systems within the cell, being concerned with many biochemical reactions in the metabolism of carbohydrates, and particularly in respiration.

Phosphorus compounds often act as suppliers of energy for specific reactions, providing a link between the energy released in respiration and reactions requiring energy. A deficiency of phosphorus will therefore limit respiration and the utilisation of the energy so released.

✓ *Sulphur*

Sulphur occurs in plants mainly as a constituent of proteins, being a component of certain amino acids, and also of the growth-regulating substances, biotin and thiamine. Sulphur is concerned in chlorophyll formation although it is not a constituent of chlorophyll. Similarities are found between sulphur and nitrogen deficiency symptoms: common features to both deficiencies are reduced

chlorophyll content, reduced protein content, and an increase in the soluble nitrogen compounds present in the leaf resulting from a reduction in protein synthesis. Sulphur is considered to be relatively immobile in the plant and the symptoms of deficiency are usually found in the young leaves and not in the older leaves as is the case in nitrogen deficiency. It has however been demonstrated that sulphur, present as the sulphate radical, can circulate in the phloem, but that circulation is rapidly curtailed by accumulation in young leaves where the sulphate appears to be quickly incorporated into proteins.

✓ *Manganese*

Manganese has several functions in the plant. It is closely connected with iron in chlorophyll formation and it is thus not surprising that the same general pattern of leaf symptoms, namely a chlorotic mottling leaving the veins and midrib green, occurs in both iron-deficient and manganese-deficient plants, as has been found with *Pueraria phaseoloides*, *Centrosema pubescens* and *Calopogonium mucunoides*. Manganese is also a constituent of some respiratory enzymes and of certain enzymes responsible for protein synthesis: an accumulation of amino acids in manganese-deficient *Hevea* seedlings has been recorded.⁶¹ Manganese and magnesium are interrelated in *Hevea*: manganese deficiency has been induced on seedlings grown in sand culture by heavy application of magnesium, and magnesium uptake has been reduced by heavy application of manganese.¹⁶ In field experiments a marked depressive effect of magnesium limestone on manganese uptake, which was not related to any increase in soil pH, has been found,²¹ whereas little or no effect of manganese applications on magnesium has been observed.⁷²

✓ *Iron*

Iron is necessary for chlorophyll synthesis and deficiency of this element induces a characteristic chlorosis: it is not however a component of the chlorophyll molecule. Iron is also a constituent of many enzymes concerned with respiration and other oxidation systems.

The state in which iron occurs in plant tissues is important in determining its influence in chlorophyll synthesis. Chlorosis similar to that associated with a deficiency of the element is sometimes found in leaves where the iron is sufficient in quantity, but present in an unavailable form. This condition may be due to antagonism between iron and manganese, to the effect of other heavy metal elements which may interfere with the metabolism of iron, or to such factors as potassium deficiency, high phosphorus levels and high light intensity which may limit the mobility of the element. The lack of mobility of iron may also account for the fact that iron deficiency is normally first apparent on the younger tissues.

✓ *Boron*

Many roles have been assigned to boron; probably the most important are in connection with the normal activity of meristems and the translocation of sugars, where the element is essential. Under conditions of boron deficiency, normal cell division does not proceed satisfactorily to the complete separation of the dividing cells, so that eventually the shoot and root apical meristems die or become extremely moribund; stunted side shoots then develop from axillary meristems. The typical symptoms of boron deficiency, such as lack of elongation of internodes and the distortion of leaves, are related to this effect of boron on the apical meristem.

Boron has been shown to be essential in plant auxin metabolism. The application of auxin to the shoot and root tips of boron-deficient plants can mitigate the deficiency effects, an increase in the translocation of sugars to the meristem and a concomitant increase in metabolic activity taking place. This suggests that in the early stages of boron deficiency the translocation system of the plant will function, but at a much reduced capacity because substrates are not being used up at sites of synthesis, particularly the meristems. In the later stages of deficiency internal tissue injury is of common occurrence: browning and death of the pith, phloem necrosis, degeneration of meristematic tissue and of cell walls can take place. In boron-deficient *Hevea* a marked necrosis of

the pith cells, and a heavy deposition of calcium oxalate crystals is to be found in the pith and the bark.⁶¹

Boron is essential for the normal development of root nodules on leguminous plants. Whilst the marked reduction in nodulation shown by boron-deficient plants can be explained as being primarily due to their reduced root growth, it has been found that with inadequate supplies of boron the vascular tissue of the root nodules themselves is abnormal.

The safety margin between sufficiency of boron and toxicity seems to be relatively small in many plants, and caution should be used when treating boron deficiency with borax to avoid excessive levels of application which can cause acute toxicity and death of the plant.

✓ *Molybdenum*

Molybdenum has been shown to be an essential constituent of the nitrate reductase system in plants, that is in the conversion of absorbed nitrate to nitrite, the first step in the formation of amino acids and eventually of proteins. Molybdenum deficiency in *Hevea* results in an accumulation of nitrate in the leaves,¹⁸ and in sand culture studies the typical deficiency symptoms, usually a chlorosis, are normally observed when nitrogen is supplied in the form of nitrate. Molybdenum is however still required when the nitrogen is supplied in the form of ammonium and it therefore seems necessary for further processes in addition to the reduction of nitrate.

Molybdenum has also been shown to be essential for the process of nitrogen fixation by soil bacteria (*Azotobacter chroococcum*), and for the symbiotic association of rhizobia with leguminous plants. When molybdenum is lacking, leguminous plants may possess rhizobia nodules but these nodules do not appear to fix nitrogen.

✓ *Zinc*

Zinc deficiency usually results in dwarfed growth, the development of small leaves and in structural malformations to root tips: the terms 'little leaf' and 'rosette formation' are often used in describing symptoms of zinc deficiency on many plants. The association of the deficiency symptoms with the two main meristems on the plant, namely the shoot and root apical meristems, strongly suggests that a relationship between zinc and synthesis of the auxin indoleacetic acid is of major importance; this is confirmed by the fact that zinc deficiency usually results in a reduction in the level of indoleacetic acid in plants. Zinc is also to be found in a number of enzymes and, like manganese, it can affect the activity of certain enzymes of which it is not an essential constituent.

In rubber seedlings growing in sand culture in a glasshouse, zinc deficiency has been found to predispose leaves to infection by *Oidium heveae*.¹⁵ In Ceylon however, where *Oidium* is endemic, the incidence of attack does not appear to be related to zinc deficiency.³¹

Copper

The main function of copper in plants is as an activator of a group of oxidase enzymes which help to metabolise ascorbic acid and polyphenols, among other substances, by oxidation. Copper plays a fundamental role in the final stage in the chain of respiratory oxidation, at which oxygen is actually consumed. It has been suggested that as polyphenol oxidase is found in the chloroplasts of some plants copper enzymes may participate in photosynthesis. Protein levels are often high in a copper-deficient plant, suggesting that the breakdown of proteins may be impaired by copper deficiency.

Copper, applied as copper sulphate injected into the trunk, has been used on rubber as a yield stimulant for a number of years; its mode of action is however not understood.

Copper is required for the formation of the haemoglobin pigment found in nodules of leguminous plants: whilst nodules may be formed on copper-deficient legumes, they are found to lack haemoglobin and also to be ineffective in fixing nitrogen.⁴⁰ Very few nodules have been found in copper-deficient *Pueraria phaseoloides*.

Chlorine

Chlorine has been shown to be an essential micro-nutrient for the growth of higher plants by a number of workers, ^{27, 46} and it is estimated that up to 3 lb per acre of chlorine are required annually for satisfactory growth of a number of crop plants. Chlorine deficiency has not been observed under field conditions despite the fact that chloride ions are freely leached through soils. It may be assumed that some process has been regularly replacing the chlorine leached away. A source of continued supply may be found in the chlorine content of rain water: the lower recorded values are in the order of 10 lb of chlorine per acre per annum. Little agricultural importance is attributed to chlorine and in consequence no attempt has been made to demonstrate chlorine deficiency symptoms on rubber or the cover plants.

Sodium, Vanadium, Cobalt, and Iodine

Some evidence for the essential nature of these four elements has been demonstrated but it cannot yet be said that they are all universally required by plants.

Sodium has been found to be an essential nutrient element for one plant whose normal habitat is a very salty soil²⁶ and for the growth of an alga.⁵ Apart from these two findings it is well known that sodium can to a certain extent replace the functions of potassium. In this context it should be noted that it has not been possible to demonstrate satisfactory plant growth in the absence of potassium, in spite of attempts to substitute sodium (or rubidium which behaves in a similar way with regard to potassium). When potassium is acutely deficient it has been found that sodium is ineffective as a partial substitute.

A requirement for cobalt by legumes when fixing nitrogen but not when supplied with combined nitrogen has been demonstrated, indicating that the cobalt is required by the nodule bacteria but not by the legume plant itself.^{1, 40} A beneficial effect of cobalt on the growth of rubber seedlings has been demonstrated.¹⁷

Vanadium has been found to be essential for the growth of one alga,⁷ but there is no evidence of a similar requirement for higher plants, although it might be argued that the demonstration of the essential nature of vanadium for higher plants awaits further improvements in the procedures of purification of plant growth media, and biochemical studies of enzyme systems.

Iodine is now considered as a micro-nutrient for plants in so far as the vegetative growth of some vegetable crops has been favourably influenced by supply of small amounts of iodine²⁴: it has yet to be proven that iodine is absolutely essential for growth.

Silicon and Aluminium

Although silicon and aluminium are almost universally present in plants no essential role has yet been ascribed to either element. Improved growth following the application of soluble silicates to crops deficient in phosphate has been observed.²⁵ Silicon is often deposited in cell walls, particularly in the epidermis: it is claimed that a high silica content can render a leaf less susceptible to fungal attack.

Aluminium, on the other hand, may be toxic to plants: in very acid soils the large quantities of soluble aluminium present can be detrimental to growth. Aluminium accumulates in roots and may reduce very considerably their power of translocating phosphate, resulting in a phosphate deficiency that cannot be corrected by normal levels of phosphate application.^{42, 85}

MINERAL NUTRIENTS IN THE SOIL AND THE EFFECT OF FERTILISERS ON SOIL NUTRIENT STATUS

The natural vegetation of the rubber-growing areas of the humid tropics is jungle, whose rich and evergreen vegetation gives an impression of high fertility. This appearance is deceptive, for under the conditions of high rainfall and temperature most soils of the area are highly leached and contain only low levels of plant nutrients. The vigour of the jungle is perpetuated only by an efficient recycling of nutrients that are absorbed from the soil by plant roots and returned to the soil in dead plant material for eventual reabsorption. Once the jungle is cleared, this cycle is broken, and the climatic conditions then favour a rapid breakdown of soil organic matter, the nutrients released from this organic matter and from the soil minerals being steadily leached down the soil profile. The soil quickly becomes depleted of its nutrient reserves, particularly if any exhaustive food cropping is practised, and even in plantation agriculture where an introduced tree crop replaces the jungle, the soil can be kept in productive cultivation only by the proper and continued use of fertilisers.

The mineral constituents and organic matter of soils both contain nutrients which may be available for plant uptake. The quantities of available nutrients are, however, usually small in relation to the total nutrient content of the soil, and the soil can be described as being a frugal custodian of plant nutrients. The soil is able to 'fix' nutrients, by chemical combination, by adsorption on to the surface of clay and organic colloids, and by incorporation into soil fauna and flora.

While a soil that contains high levels of total nutrients may not be correspondingly high in available nutrients because of the particular nature of its soil minerals or organic matter, it is necessarily the case that soils low in total nutrients, such as Malayan soils, will be low in available nutrients except where fertilisers have been applied.

In the following sections the sources and availability of the individual nutrients in the soil, and their supplementation by fertilisers, are discussed.

Occurrence and Availability of Nutrients

Magnesium, Potassium and Calcium

Magnesium, potassium and calcium occur in all soils, their level and proportion depending upon the nature of the parent material. Sodium, another cation, will also be present, but since it is not of major importance in rubber nutrition this element will not be discussed further.

In Malaya the cations may occur to a limited extent as carbonates, but the greater proportion will exist as calcium, magnesium or potassium aluminosilicates, the feldspar minerals, or in association with aluminium, silicon and other elements in secondary minerals of lesser importance. In soils derived from basic igneous rocks such as basalt, gabbro and andesite, calcium and magnesium will be the dominant cations, but in soils derived from more acidic or siliceous granites potassium will predominate. In soils derived from fine-grained sedimentary material, shales, phyllites and schists, the level of cations and particularly of potassium can be quite high, but in soils derived from the coarser grained sediments, such as sandstones, the general level of cations will be low.

In sandy alluvial soils the level of all cations is generally low, but in alluvial clays, such as the coastal clays of Malaya, levels of potassium are generally high while calcium levels may be low.

A proportion of the total cation content in soil will be associated with the soil exchange complex and will be in a exchangeable form available for plant uptake. At the same time this loosely held fraction, and particularly that of magnesium, can be easily displaced from the exchange complex and leached down the soil profile.^{20, 23} This leaching will be accelerated by any factor which tends to increase soil acidity, such as the application of nitrogen fertiliser in excess of the plants' requirement, or the application of fertilisers containing sulphate and chloride radicals.

A further factor to be taken into consideration is that application of any one of these cations will tend to displace the other cations from the exchange complex and at the same time hinder their uptake by the plant; the net effect is to increase the leaching of the cations in the soil solution down the profile, and under some conditions to induce a deficiency of the cation concerned. Magnesium deficiency in particular can be easily induced by heavy applications of potassium fertilisers, and such cases of induced magnesium deficiency have been observed on rubber in Malaya; in Ceylon it has been suggested that detrimental effects of potassium on growth of rubber are due to the reduction in magnesium absorption by the tree.³² The frequent observation of magnesium deficiency on rubber, the low magnesium status of Malayan soils, and the ease with which this cation is leached out, all indicate that close attention should be given to magnesium.

Nitrogen

The level of nitrogen in the soil can have a dominant effect upon its productivity, and it is important to establish and maintain a high soil nitrogen content. Nitrogen does not occur in the primary rocks from which soil is formed, but in nature is built up in the soil by the activity of rhizobia bacteria living in symbiosis with leguminous plants, and by certain micro-organisms which are able to fix and utilise nitrogen in the soil air. Minor quantities of nitrogen are also received from the atmosphere in rainfall. In rubber cultivation, leguminous cover plants are grown as a soil conservation measure in the early years after planting, and their high nitrogen content is an important factor contributing to their beneficial effects on tree growth.^{48, 50, 79, 82}

Rhizobia and other micro-organisms convert elemental nitrogen into protein, which on excretion or death may be converted by micro-organisms first to amino acids and then to the ammonium form in a mineralisation process. The ammonium ions can be taken up by plant roots but may also be held on the exchange complex of the soil in the same way as the cations calcium, magnesium and potassium. In due course the ammonium will be converted by micro-organisms into the nitrate form by a process called nitrification; the nitrate ion is available for plant uptake but is also free to be leached down the soil and away from the rooting zone – a deleterious effect, since it must be associated with a base during leaching and in this way may assist in the depletion of the calcium, magnesium and potassium reserves of the soil.

Phosphorus

Soil phosphorus is another key nutrient determining soil fertility, and phosphate applications are normally necessary on opening up new land for cultivation. In the acid, iron-rich soils of Malaya, phosphorus may be fixed in forms not easily available for plant uptake, mainly as insoluble iron and aluminium phosphates, from which phosphate is only slowly released.^{52, 54} However, a large proportion of soil phosphorus is held in the organic matter, and it may be that maintenance of high organic matter levels in the soil by the use of appropriate cover plants will enhance the availability of soil phosphorus.

Residual effects of phosphate applications made many years previously can be quite marked on rubber⁴⁹ and it is possible that heavy phosphate applications to leguminous covers made in the first few years after planting may build up the total soil phosphorus to a level at which the supply of available phosphorus will be sufficient to meet the requirement of the rubber tree for a number of years.²²

Sulphur

Sulphur normally occurs in rocks as sulphides which on weathering, and in well aerated soils, oxidise fairly readily to the sulphate form. However, in poorly drained soils sulphides may accumulate, and, particularly in the lower horizons of coastal alluvial clay soils in Malaya, high levels of sulphide, including hydrogen sulphide, often occur.

Sulphur is an important constituent of the protein content of plants and micro-organisms and is absorbed by them as the sulphate ion. Its continuous utilisation in this manner has resulted in a

concentration of the sulphur reserves in the soil organic matter content, from which it is freed for reabsorption as the sulphate ion by a mineralisation process conducted by the soil micro-organisms.

Sulphate ions in the soil solution in excess of the plants' requirements may be leached from the soil,²³ and since additions of sulphur to the soil due to rainfall are likely to be low in the rubber-growing areas (in the absence of industrial fumes containing sulphur dioxide) it might be thought that the development of sulphur deficiency would be an ever-present danger. The widespread occurrence of sulphur in soil parent material and the general use of ammonium sulphate fertiliser have so far prevented the development of such a deficiency in Malaya, but the possibility should not be overlooked that a deficiency of sulphur might occur on some soils if fertiliser practice were changed.

Manganese

Manganese is present to a varying extent in all soil parent materials. In basalt, for instance, very high levels may be present, while in siliceous granite only comparatively low levels will be found. During the process of weathering the manganese-containing minerals are decomposed and the availability for plant uptake of the manganese present becomes dependent on soil pH. At pH values of 6.5 and above, the manganese is only poorly available and a deficiency of the element, induced by the high pH, may occur in plants such as rubber that are adapted to acid soil conditions. In the climatic conditions of the wet tropics, the rapid weathering processes cause a leaching of the bases down the soil profile and a progressive reduction of the soil pH. At a pH value of about 5.0 the manganese content of the soil is highly available, and if large amounts are present, such as may occur in a young basalt-derived soil, the element may be taken up in toxic amounts. However, in the great majority of Malayan soils the weathering process has gone on for so long that a large proportion of the manganese has been entirely leached out of the soil, leaving barely sufficient for plant growth.² On certain deeply weathered soils derived from granite with an originally low manganese content, and on many of the more freely draining alluvial soils derived from such materials in Malaya, a direct and at times severe deficiency of the element occurs in *Hevea*.⁶⁵

On soils derived from the finer textured sedimentary rocks the leaching of manganese does not proceed to the same extent, and in the more poorly drained soils, as a result of alternating wet and dry conditions, manganese brought into soil solution is eventually deposited in concretionary form together with iron oxide. Manganese uptake is adequate under these conditions, and the deficiency is thus largely restricted to the soils derived from the acid granites and related alluvial soils that are freely draining. On such soils the application of fertilisers that acidify the soil may increase manganese uptake by the plant for a short while, but over a long period such fertilisers would increase the dissolution and leaching of soil manganese and so be deleterious.

Iron

In practically all soils iron is present in large quantities, in the form of oxides. Under conditions of good drainage and aeration the iron will be present in the ferric or oxidised state, and give the soil a red or brown colour. Under waterlogged conditions, however, the ferrous, or reduced, state will predominate, giving the grey-bluish colour typical of the badly drained coastal clays of Malaya. A poorly defined band of orange mottling is often found in badly drained soils just above the waterlogged region where a certain amount of oxidation of the ferrous compounds to the brown-red ferric compounds has taken place because of fluctuations in the water table, or because of penetration of air along root channels or naturally occurring cracks in the soil.

A direct deficiency of iron will only be found on the very poorest of leached sandy soils, or on leached sandy soils containing appreciable quantities of organic matter, such as well-drained soils of swamp alluvium origin, where the small proportion of iron present in the soil is held by the organic matter in an unavailable form for plant uptake. There are in addition several conditions under which a deficiency of the element may be induced. On soils freshly derived from limestone,

or in the presence of a bed of shells in coastal alluvia or of lime on old building sites, the soil pH is too high for normal uptake of iron to take place, and rubber and associated cover plants may show acute symptoms of iron deficiency. Iron deficiency may also be induced by the presence of high concentrations of manganese, zinc, copper and phosphorus and by deficiencies of calcium, magnesium and potassium, and a case of manganese-induced deficiency has been reported on rubber growing on soil derived from basic volcanic material.⁸⁰

In view of the intractable soil conditions involved in cases of direct iron deficiency, and because of the difficulty of amending conditions which favour the immobilisation of iron within the plant, the problem of correcting iron deficiency is difficult. The application of iron salts to the soil is usually ineffective, but the condition can be ameliorated, at least temporarily, by application of foliar sprays or by injection of iron salts into the plant.

Boron

The amounts and availability of boron in soils depends largely upon the soil parent material, although its availability may be reduced by liming. Soils derived from igneous rocks contain tourmaline (an important boron-containing mineral) which is of little value to plants, as it weathers only very slowly. Soils derived from sedimentary rocks normally contain boron in a more readily available form. Boron is present in sea water in fairly large quantities, and as a result considerable amounts of boron occur in certain marine sediments, particularly the shales and in coastal alluvial clay deposits: by contrast, little boron occurs in sandstone. It is normally found that far larger amounts of boron are present in soils with a high organic matter content than in sandy, freely draining soils, from which the boron is easily leached.

Molybdenum

Only small quantities of molybdenum are present in the soil and the element is present in a form that is largely unavailable for plant uptake. However, unlike other minor nutrients, molybdenum becomes increasingly available as the pH increases; large amounts of water-soluble molybdenum are present in alkaline soils, while a deficiency of molybdenum normally occurs only on very acid soils. Molybdenum deficiency may also be found on lateritic soils as a result of fixation of molybdate in association with iron. Liming can often correct molybdenum deficiency and an increased uptake of molybdenum by *Pueraria phaseoloides* and *Centrosema pubescens* following liming has been observed in Malaya.⁷⁸ The application of phosphatic fertilisers can also cause increases in molybdenum uptake. On the other hand, manganese and sulphate applications are usually found to depress the uptake of molybdenum; a depressive effect of sulphate on molybdenum absorption of *Hevea* seedlings in sand culture has been reported,¹⁸ and field trials have indicated a depressive effect of manganese sulphate on leaf molybdenum content.⁷²

Zinc

The proportion of zinc available for plant uptake normally decreases with an increase in pH. Zinc deficiency can be induced by excessive application of phosphatic fertiliser, and one case of zinc deficiency in rubber in Malaya was associated with a localised fertiliser effect which increased soil pH and the phosphate level. While it has been suggested that this induced zinc deficiency is due to the formation of insoluble zinc compounds in the soil, it should be noted that, when plants are supplied with large amounts of phosphate, zinc can be immobilised in the vascular tissue.

Copper

The total copper content of normal soils is usually low, and its exchangeable proportion is small and very firmly adsorbed on to colloidal material, especially to the organic matter. The organic matter may also complex, or fix, the copper in a non-exchangeable form, and this factor may be important in rendering copper unavailable to plants. Liming reduces the availability of copper,

but the relationship between soil pH and copper availability is little understood. Heavy application of phosphatic fertilisers has also been found to depress copper uptake and to induce temporary copper deficiency, a situation which has been reported in rubber in Malaya.

Fertiliser Effects on the Soil Nutrient Status

The main object in applying fertilisers is to provide nutrients for plant growth, and to improve yield and profit; the long-term necessity to maintain and if possible improve the fertility of the soil should not, however, be forgotten. Despite their generally beneficial effect on soil fertility, fertilisers can occasionally have an adverse effect, and it is important to understand the manner in which this may occur. In order that the long-term effects of fertilisers may be appreciated, a brief outline is given below of the composition of typical fertilisers, and also of some of the observed effects of the commonly used fertilisers on Malayan soils.

It is often forgotten that fertilisers generally contain at least two nutrient elements; most fertilisers are essentially salts that dissolve rapidly in water, furnishing cations such as ammonium (NH_4^+), potassium (K^+) and magnesium (Mg^{++}), and anions such as nitrate (NO_3^-), chloride (Cl^-), sulphate (SO_4^{--}) and phosphate (H_2PO_4^-). Thus ammonium sulphate, which is often considered as a purely nitrogenous fertiliser, provides both NH_4^+ and SO_4^{--} ions, both of which are important in affecting plant growth and soil nutrient status. In a similar manner potassium chloride provides K^+ and Cl^- ions, ammonium phosphate provides NH_4^+ and H_2PO_4^- ions, kieserite provides Mg^{++} and SO_4^{--} ions, and manganese sulphate provides Mn^{++} and SO_4^{--} ions.

Other fertilisers which are not soluble in water, such as rock phosphate, basic slag and magnesium limestone, are eventually broken down in the soil into simple ions: rock phosphate and basic slag can be considered as furnishing phosphate and calcium ions principally. Basic slag also contains small amounts of other nutrients, such as magnesium, potassium, manganese, molybdenum and zinc, which may at times be beneficial. Traces of nutrient elements are often found in fertilisers,⁷⁶ but are generally of little importance.

The fertiliser nutrients may be supplied in many forms: in simple association with one other radical or in a complex form with several, but the main principles concerning the effects of fertilisers on soil nutrient status can be illustrated by reference to the three fertilisers, ammonium sulphate, rock phosphate and potassium chloride, each employed to supply a single nutrient.

Ammonium Sulphate

In addition to increasing the soil nitrogen and sulphur status, ammonium sulphate applications will increase soil acidity and reduce the levels of exchangeable magnesium, potassium and calcium in the soil.^{20, 23} Magnesium, potassium and calcium ions are leached out of the soil, in association with sulphate ions and also with excess nitrate ions derived from nitrification of the ammonium.²³ Minimal leaching of magnesium, potassium and calcium would thus seem to depend partially upon the utilisation of nitrate by the plant: excess application should be avoided and optimum utilisation sought by applying ammonium sulphate and other nitrogenous fertilisers according to the principal 'little and often' so that only a little excess nitrate is free to leach through the soil.

Rock Phosphate

Very large increases in both the total and 'available' soil phosphate, and appreciable increases in the total and exchangeable calcium, are brought about by the routine application of rock phosphate during the early years of growth of *Hevea*²²: this suggests that after the initial build-up of soil phosphate little further phosphate may be required for several years and that large residual effects on phosphorus and calcium uptake by the tree will occur. A general recommendation to discontinue or reduce phosphate applications would not be justified because of the importance of phosphate for tree growth, and also because of the low cost of the fertiliser in relation to the value

MINERAL NUTRIENTS IN THE SOIL

of the crop. It is possible, however, that individual soil studies on particular areas will indicate when phosphate applications can be reduced.

Rock phosphate applications tend to make the soil less acid, and for this reason rock phosphate compensates, to a large extent, the depressive effect of ammonium sulphate on soil pH.^{22, 23} The calcium provided in rock phosphate will also tend to replace that lost in leaching. It is possible that the supply of calcium in rock phosphate in the past has been sufficient to maintain adequate soil calcium and prevent the appearance of calcium deficiency, and in any case it would appear that *Hevea* has a small requirement for calcium when compared with other crops.

Potassium Chloride

Application of potassium chloride, by providing K^+ ions which displace Mg^{++} and Ca^{++} ions from the exchange complex of the soil, and Cl^- ions, which are freely leached in association with the displaced ions, results in a reduction in the magnesium and calcium status of the soil.²² The levels of application of potassium chloride are usually low, seldom exceeding 4 oz per tree per annum, and the effects on soil magnesium and calcium are small. If large applications of potassium were found to be necessary, however, it might be advisable to use potassium sulphate, since experimental work has shown that sulphate is leached from the soil at a much slower rate than the chloride ion.²³

VISUAL SYMPTOMS OF DEFICIENCY

The primary object of this book is to enable particular fertiliser requirements to be assessed by the recognition of nutrient deficiency symptoms. It is pertinent, however, to consider firstly some of the limitations of this visual method, and secondly to consider other methods that can be used to determine fertiliser requirements in order to appreciate the value of the visual method and the context in which it should be considered.

The visual method of diagnosing a deficiency is entirely qualitative, and is based on the fact that plants suffering from an acute shortage of a nutrient usually develop characteristic symptoms in various tissues, particularly the leaves. It has the advantage of being rapid and requiring no special equipment, so that the planter can diagnose the problem without laboratory assistance. In common with other methods, when used on their own, the visual method of diagnosing deficiencies has its limitations. For instance growth may be severely retarded before actual symptoms are observed, and a method which would diagnose incipient cases of deficiency would be preferable: it is not normally possible to diagnose multiple deficiencies, for the symptoms of one deficiency may mask the symptoms of another: the symptoms may not be sufficiently characteristic and varietal differences may exist that render positive identification extremely difficult: there is often a danger that the effects of diseases, insects, water shortage, waterlogging, and sun scorch may be confused with nutrient deficiency symptoms. In the description of the individual symptoms some reference to possible confusing factors is made, but for an understanding of disease and pest effects the reader is referred to two books,* *Maladies of Hevea in Malaya* by R. N. Hilton (1959) and *Pests of Hevea Cultivation in Malaya* by B. S. Rao (to be published 1964).

Despite the above limitations, visual diagnosis of nutrient deficiencies can be a valuable tool. Confirmation of a deficiency may be obtained by chemical analysis of leaves in the laboratory, by quick semi-qualitative, chemical tissue tests carried out in the field, or by injection (into leaf, branch or trunk) or spray application of very small amounts of the nutrients thought to be deficient followed by observations of changes in colour of leaves or improved growth. The injection and spray application methods are seldom used for diagnostic purposes, largely owing to practical limitations: they can of course be used as remedial procedures, but it appears unlikely that they will be of more than minor importance in rubber cultivation.

Chemical analysis of plant material and particularly of leaves, has a great potential for determining nutrient requirements: it has been used extensively in Vietnam for a number of years as a basis for formulating manuring programmes for rubber,^{8, 9, 10} and in Malaya use has been made of the method in studying the effects of fertilisers,^{28, 70} and as a diagnostic tool for determining the fertiliser requirements of individual fields and estates.^{35, 36, 71, 73, 74}

Other methods of diagnosing fertiliser requirements are those involving assessment of soil nutrient status. Chemical analysis is used to determine the 'available' nutrients, the exchangeable cations and the total nutrient content of the soil. The difficulties of soil analysis are largely those of interpretation of the analytical results; comparisons of the 'extracting' power of the plant in the field (judged by chemical analysis of plant material) needs to be related to the soil extract obtained in the laboratory. The merit of soil analysis is largely that the basic pattern of soil nutrient status may be determined: this is particularly appropriate to a perennial crop such as rubber, and enables a rational fertiliser programme to be formulated according to soil type. Plants and micro-organisms can be used as the soil extractant in place of the chemical used in the laboratory and one such method is that of Neubauer for determining the phosphorus and potassium status of the soils by measuring their absorption by rye seedlings under standard conditions. A further method which is very useful in testing for multiple deficiencies is a subtractive technique, which involves growing a

* Published by the Rubber Research Institute of Malaya.

VISUAL SYMPTOMS OF DEFICIENCY

suitable indicator plant (or better still the crop plant) in the soil and treating the plant with all nutrient elements except one: a series of such treatments are arranged, each with a different 'deficiency' element. The technique is normally carried out under controlled conditions in pots and the comparative level in the soil of the 'deficient' element under test is determined by relating the growth of plants in each treatment to that obtained when all nutrients are supplied.

The final testing ground for all the methods of diagnosis is the field fertiliser experiment, in which fertiliser responses are determined from actual yield and growth data. Detailed fertiliser experiments can seldom be used to solve immediate nutritional problems however; because of the expense and labour involved, their value lies rather in providing the basic information on fertiliser responses at various stages of growth with different planting materials and on different soil types.

It can be seen from the above discussion that the visual method is the simplest but not the most perfect method of diagnosing fertiliser requirements. Despite this it can be used to great effect, and close regular inspection of rubber and cover plants should be carried out, particularly during the period of immaturity when a nutrient deficiency can retard growth markedly and delay the onset of tapping.

In the following sections the deficiency symptoms shown by *Hevea* and the three cover plants are illustrated mainly by leaf photographs showing the various stages of deficiency; in order to emphasise the similarities between the symptoms of a given deficiency in the four species, the text and photographs are arranged under the headings of individual nutrient elements. For each element there is an account of the occurrence and symptoms of the deficiency in *Hevea*, followed by a description of the symptoms shown by the three leguminous covers.

A distinction is made between the young unbranched rubber trees and the older branched rubber trees, that is those trees of approximately four years old and more in which the canopies of adjacent trees have met, resulting in shaded conditions low down in the trees. As can be seen from the key (p. 57) to the nutrient deficiency symptoms of *Hevea*, a distinction can be made on the unbranched rubber tree between those symptoms occurring on the old leaves lower down the stem and those occurring on the young or new growths at the top of the stem; a distinction can also be made on the mature tree between symptoms normally found on leaves at the top of the canopy exposed to full sunlight and those low down the canopy in the shade.

Magnesium deficiency

Hevea brasiliensis

Mg
(Magnesium)

OCCURRENCE

Magnesium deficiency in the field, definitely confirmed in Malaya only as recently as 1950-52, is now known to be widespread in Malaya⁶² and Ceylon,³⁰ both on young and old rubber, and is commonly found on young rubber in Nigeria.⁷⁷ In Malaya it is not possible to associate the deficiency with any one soil type, but its frequency is greater on the inland soils than on the heavy coastal alluvial clay soils.

SYMPTOMS

Leaf. The characteristic symptom of magnesium deficiency is the development of a chlorosis in the interveinal areas on the leaf.

Generally the chlorosis appears to spread inwards from the leaf margins, giving a herring-bone pattern (Plates 1 and 3), but in young seedlings or buddings a few months old it is sometimes found that the chlorotic areas are not contiguous with the leaf margin (Plate 2).

In cases of severe deficiency the chlorosis, which is generally a deep yellow colour, is often followed by interveinal necrosis (Plate 2) and sometimes by marginal necrosis. In cases of mild deficiency the herring-bone pattern may be seen but the chlorosis is of a dull yellowish green. There is usually only little reduction in leaf size, although when the deficiency is extremely severe there can be considerable defoliation and marked reduction in tree growth and leaf size.

Young unbranched tree. The symptoms are first to be found on the leaves in the lower or older storeys on the plant (Plate 3).

Old branched tree. The deficiency symptoms are found on leaves exposed to full sunlight. Such leaves are normally in terminal whorls at the top of the canopy. Leaves borne on low branches exposed to full sunlight, such as can occur on trees adjacent to a clearing or road, will also show the symptoms.

On mature trees the symptoms are seldom seen before August.



Plate 1 Magnesium deficiency: *Hevea brasiliensis*. Stages in the development of the herring-bone pattern of interveinal chlorosis which commences at the leaf margin. Notice the regularity of the pattern. (PB 86, nineteen years. Average nutrient composition of the four deficient leaves 0.08% Mg, 1.23% K, 1.05% Ca, 0.18% P, 2.53% N and 134 p.p.m. Mn).

Mg



Plate 2 Magnesium deficiency: *Hevea brasiliensis*. Stages in the development of an interveinal chlorosis which is not contiguous with the leaf margin, and is followed by an interveinal necrosis as in the two leaves on the right. (Tjir 1 seedling, unbranched, under one year).



Plate 3 Magnesium deficiency: *Hevea brasiliensis*. Lower whorl of leaves on young unbranched budding, showing herring-bone pattern of interveinal chlorosis and some marginal necrosis. (PB 86, one-and-a-half years).

Magnesium deficiency

Mg

Pueraria phaseoloides, *Centrosema pubescens* and *Calopogonium mucunoides*

SYMPTOMS

General. The first symptoms of magnesium deficiency appear as an overall yellowing of the older leaves on all three cover plants; there is a tendency for the yellowing to be more pronounced in the interveinal areas, leaving the tissue adjacent to the midrib and main veins dark green. Unlike the characteristic magnesium deficiency symptom in *Hevea brasiliensis*, the interveinal yellowing does not appear to start from the leaf margin, neither is it regular over the entire leaf; it is often found that only one or two interveinal areas are affected.

When the deficiency is severe, necrotic patches develop in the interveinal areas (Plates 4, 5 and 16). These patches are not contiguous with the leaf margin. It is only when the deficiency is very severe, and marginal necrosis occurs, that the necrotic patches coalesce and sometimes give the impression that the necrosis has developed inwards from the leaf margin.

Pueraria phaseoloides. The somewhat irregular necrotic patches (Plate 4) are not preceded by any marked interveinal yellowing, whereas in *Centrosema pubescens* and *Calopogonium mucunoides* (Plates 5 and 6) a definite yellowing first occurs.

Calopogonium mucunoides. It is difficult to distinguish between the leaf symptoms of the early stages of magnesium and calcium deficiency, as interveinal yellowing is a feature common to both deficiencies. The appearance of interveinal necrosis in the case of magnesium deficiency allows a distinction to be made (c.f. Plate 16).



Plate 4 Magnesium deficiency: *Pueraria phaseoloides*. Severe stage of deficiency, showing marked interveinal necrosis and withering of leaf margins. (One month).

Mg

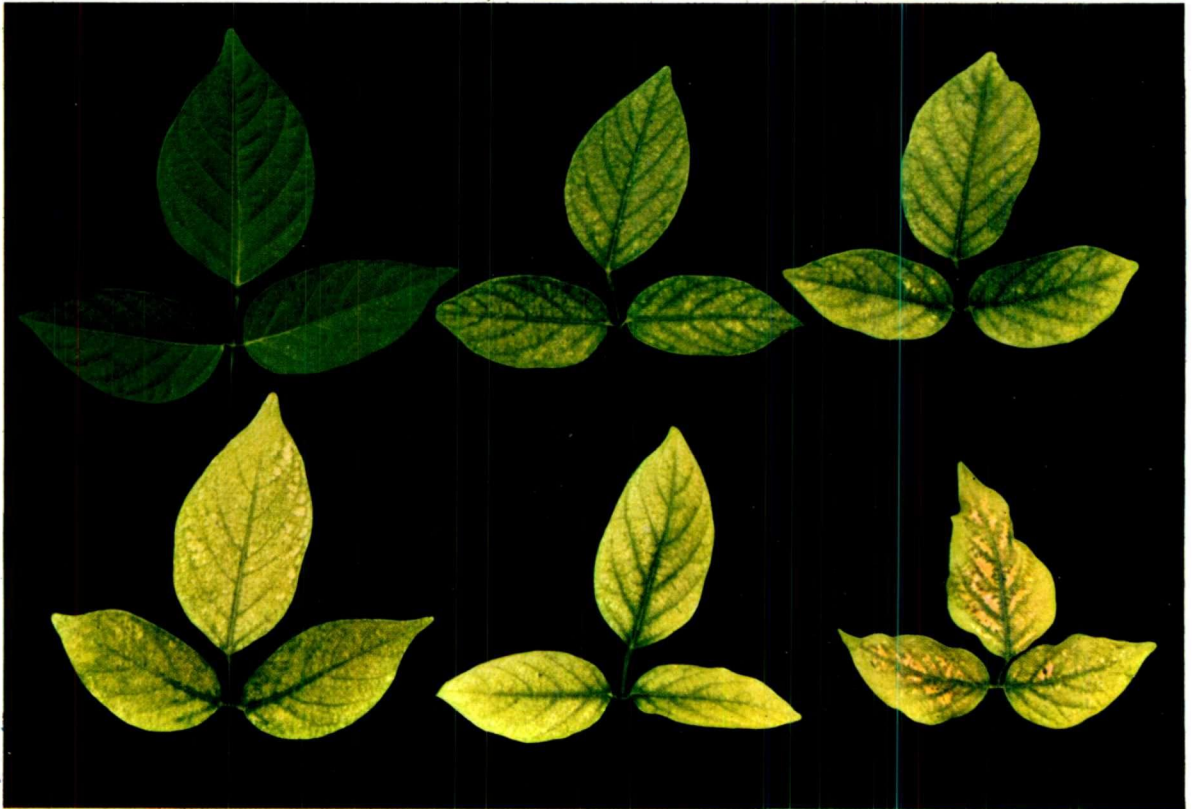


Plate 5 Magnesium deficiency: *Centrosema pubescens*. Stages in the development of chlorosis leaving midribs and main veins evident, and leading to an interveinal necrosis which is not contiguous with the leaf margin.



Plate 6 Magnesium deficiency: *Calopogonium mucunoides*. Marked chlorosis, particularly in interveinal areas, and subsequent interveinal and tip necrosis (see also Plate 16).

Potassium deficiency

Hevea brasiliensis

K
(Potassium)

OCCURRENCE

Potassium deficiency in rubber is commonly found, particularly on the more sandy inland soil types in Malaya; it is however by no means as widespread as magnesium deficiency.⁶⁷ In contrast it would appear that potassium deficiency is more common than magnesium deficiency in Vietnam, Ivory Coast and Nigeria, where potassium deficiency symptoms are commonly found on mature rubber.^{29, 44, 77}

SYMPTOMS

Leaf. The characteristic symptom of potassium deficiency is the development of a marginal and tip chlorosis, which is followed by a marginal necrosis.

In young unbranched seedlings or buddings the marginal chlorosis usually appears first as a yellow mottling as in the less affected leaf in Plate 7; later the mottled areas coalesce forming a fairly distinct marginal band of chlorotic tissue. This band quickly becomes necrotic, the necrosis first appearing at or near the leaf tip. The observation of such necrosis, and also the lack of any definite herring-bone pattern of yellowing, allows potassium deficiency symptoms to be distinguished from those of magnesium deficiency.

On leaves from older branched trees the chlorosis usually commences at the tip and along the leaf margins, but with the rapid development of the chlorosis over the leaf it is frequently found that only the tissue at the base of the leaf, and adjacent to the midrib, remains green (Plate 8). Sometimes one half of the leaf will be more affected than the other.

Young unbranched tree. The symptoms usually appear on the leaves in the lower or older storeys on the plant. When the deficiency becomes more severe the symptoms will appear on midstem storeys also; there can also be considerable reduction in size of new leaves and defoliation of the oldest leaves.



Plate 7 Potassium deficiency: *Hevea brasiliensis*. The development of a mottled marginal chlorosis is normally the first sign of the deficiency in unbranched trees; this is followed by the development of a bright yellow marginal band of chlorosis, which may be fairly uniform in width (as in the central deficient leaf), and also by tip and marginal necrosis.

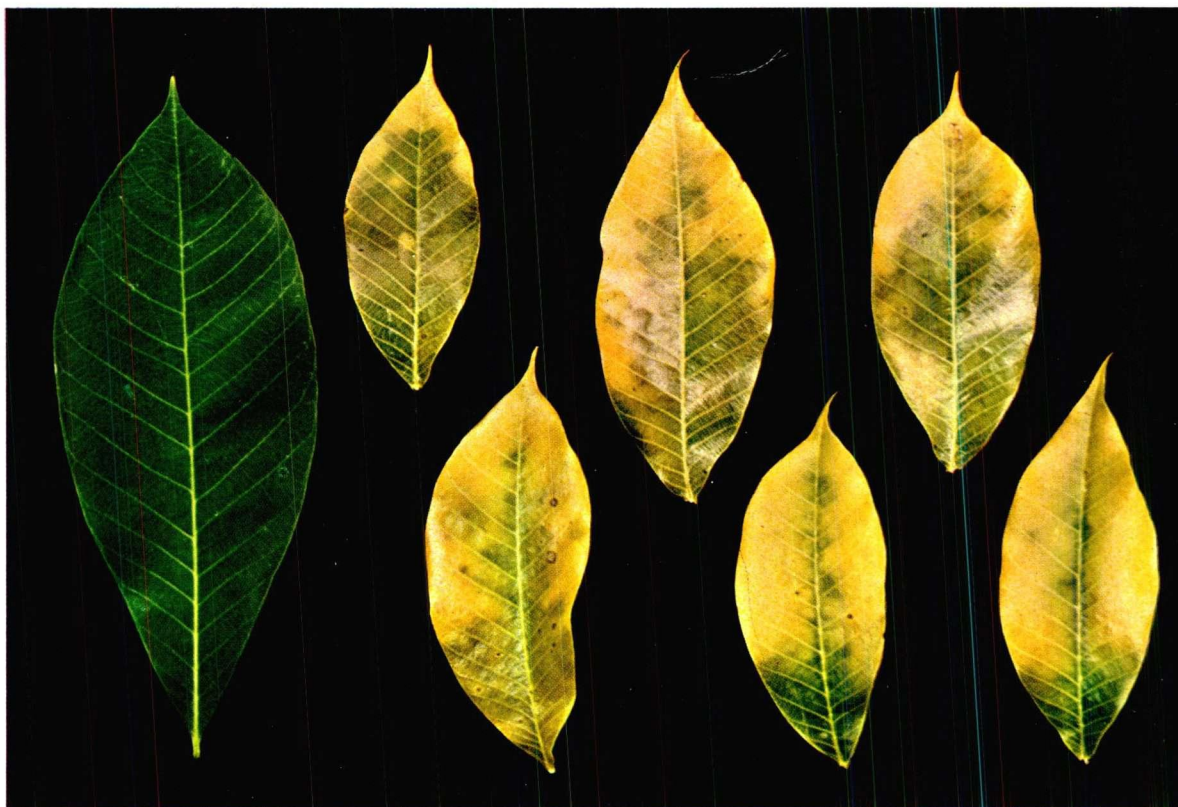
K

Plate 8 Potassium deficiency: *Hevea brasiliensis*. Patterns of chlorosis on leaves from mature trees: tip and marginal chlorosis (upper three leaves) is found in the less severely affected leaves, and a more general chlorosis of the entire leaf, leaving only the leaf base green, in the more severely affected leaves. (PB 86, mature branched tree, ten years. Average nutrient composition of the six deficient leaves: 0.26% K, 0.60% Mg, 2.36% Ca, 0.18% P, 2.14% N and 118 p.p.m. Mn).

Old branched tree. As in the case of magnesium deficiency, potassium deficiency symptoms are found on leaves exposed to full sunlight, and symptoms will only be observed on low branches when such branches are exposed and not shaded. Seen from afar, the crowns of affected trees appear predominantly yellow.

Considerable reduction in leaf size is caused by potassium deficiency, and this is very evident in deficient leaves from old trees.

On mature trees the symptoms are seldom seen before August. Wintering can be influenced by the potassium status of the tree: it has been observed that trees high in potassium winter earlier and more completely than trees low in potassium. In contrast, a low magnesium status results in early wintering.

Potassium deficiency

K

Pueraria phaseoloides, *Centrosema pubescens*, *Calopogonium mucunoides*

SYMPTOMS

General. Potassium deficiency results in a very characteristic marginal yellowing, which commences near the leaf tip and is followed by tip and marginal necrosis (Plates 9, 10 and 11). These symptoms are first found on the older leaves.

Pueraria phaseoloides. The marginal yellowing appears first as a well defined band of bright yellow tissue which eventually diffuses inwards as an ill defined yellow band, leaving only the basal and central portions of the leaf around the midrib green (Plate 9).

Centrosema pubescens. The marginal band of yellow tissue, which is wider near the tip of the leaf, remains well defined, and a considerable proportion of the leaf generally remains green (Plate 10); necrosis is usually confined to the leaf tip.

Calopogonium mucunoides. A gradual yellowing, often mottled (see central leaf in Plate 11), commences from the margin, generally near the leaf tip. In general no well-defined band of yellow tissue develops, and necrosis is usually confined to the leaf tip (Plate 11).



Plate 9 Potassium deficiency: *Pueraria phaseoloides*. Note the well-defined marginal band of chlorosis, characteristic of severe potassium deficiency, as found in the field.



Plate 10 Potassium deficiency: *Centrosema pubescens*. Développement of a definite tip and marginal chlorosis, which is often, but not always, followed by a tip necrosis.



Plate 11 Potassium deficiency: *Calopogonium mucunoides*. Two stages in the development of a mottled tip and marginal chlorosis, which is followed by marginal necrosis. (Average potassium concentration in the deficient leaves: 0.29% K).

Calcium deficiency

Hevea brasiliensis

OCCURRENCE

The existence of calcium deficiency on mature rubber is suspected in Malaya; a fairly frequently observed white marginal leaf scorch has been found to be associated with extremely low levels of leaf calcium.⁶⁷ There are indications that clone PR 107 shows the symptoms more than other clones. Calcium deficiency would not be expected where regular applications of rock phosphate (which contains 30% calcium, i.e. 42% CaO) have been employed.

SYMPTOMS

Leaf. Calcium deficiency, unlike magnesium and potassium deficiencies, does not result in any pronounced yellowing of the leaf. The first symptom is the development of a tip and marginal scorch usually white to light brown in colour, often over a large portion of the leaf as in the most affected leaves in Plates 12 and 13. The scorch may be accompanied by an infection of the fungus *Colletotrichum heveae* and sometimes by *Gloeosporium alborubrum*.

Young unbranched tree. The symptoms are observed on the leaves on the upper or younger storeys on the plant, and in severe cases the growing point itself may die back. There can be considerable reduction in leaf size.

Old branched tree. The symptoms of white papery scorch, associated with calcium deficiency, have been observed only on leaves low down in the tree in the shade of the canopy, and not on leaves exposed to full sunlight.

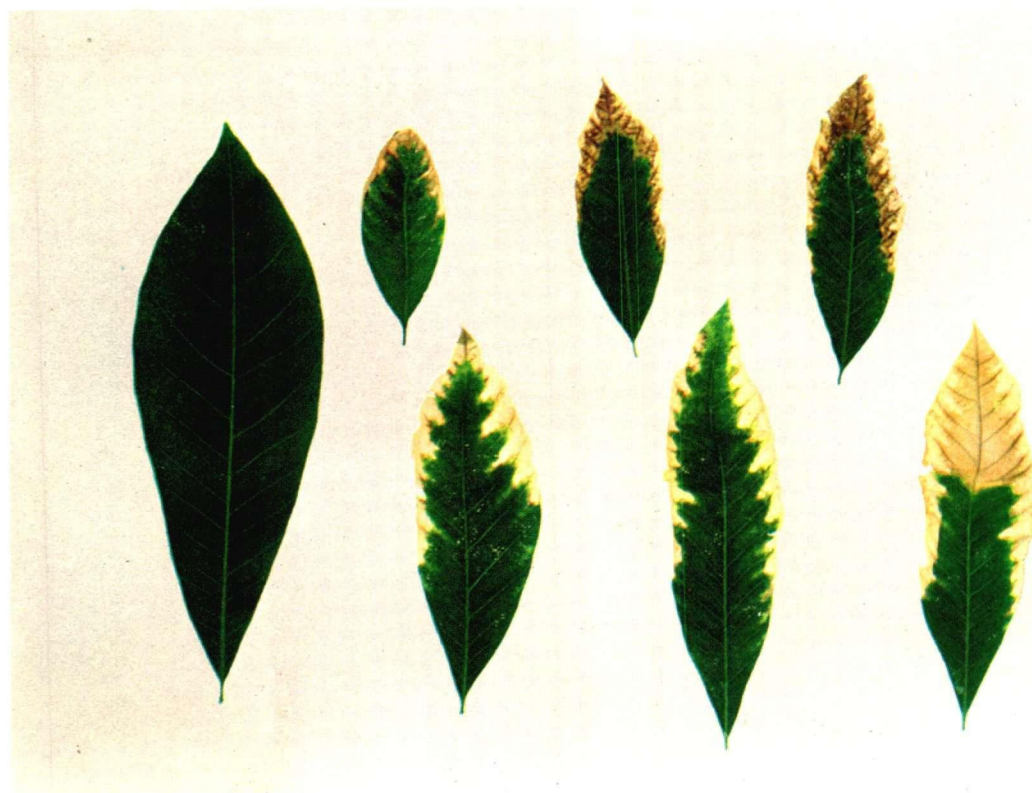


Plate 12 Calcium deficiency: *Hevea brasiliensis*. Development of white-brown papery scorch at the leaf margin and tip; notice that the scorch is not preceded by any pronounced yellowing. (Tjir 1, unbranched, one year).

Ca

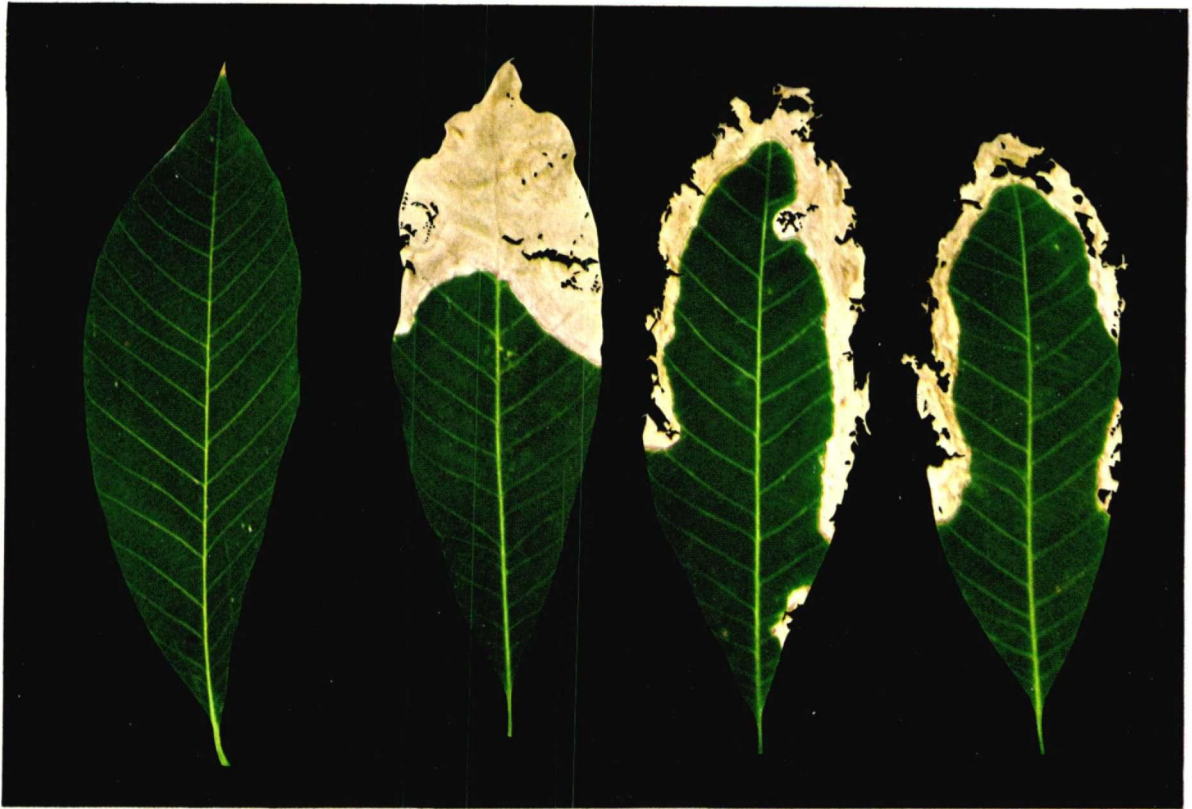


Plate 13 Calcium deficiency: *Hevea brasiliensis*. The development of a white papery marginal and tip scorch, which is not preceded by any chlorosis. (PR 107, mature branched tree, twelve years. Average nutrient composition of the three deficient leaves: 0.35% Ca, 0.27% Mg, 1.50% K, 0.22% P, 3.23% N and 38 p.p.m. Mn).

Calcium deficiency

Pueraria phaseoloides, *Centrosema pubescens* and *Calopogonium mucunoides*

SYMPTOMS

General. The symptoms of calcium deficiency first appear and are more pronounced on the younger leaves. The symptoms exhibited by *Pueraria phaseoloides* and by *Calopogonium mucunoides* can be very similar in the early stages, but are different from those exhibited by *Centrosema pubescens*. It is of interest to note that in sand culture the restoration of calcium supply to plants affected by severe calcium deficiency has not resulted in the rapid recovery that can normally be expected when correcting deficiencies.

Pueraria phaseoloides. The first symptom is the development from the leaf margin of an irregular patchy yellowing of the leaf. These areas often turn an orange-bronze colour (Plate 14), and when the deficiency is very severe necrotic patches develop in the discoloured areas of the leaf.

Calopogonium mucunoides. Similar symptoms are found, but frequently yellowing is more regular and is often confined to the interveinal areas, leading to possible confusion with magnesium deficiency; necrosis occurs at the leaf tip and margin, and so can be distinguished from the interveinal necrosis caused by magnesium deficiency: it is only when the deficiency is very severe and there is considerable reduction in leaf size that *Calopogonium mucunoides* shows any definite symptoms, and in this respect it is a poor indicator of the deficiency (Plate 16).

Centrosema pubescens. The typical symptom of calcium deficiency is found at the tips of the young leaves; the tips wilt and fail to expand, resulting in a slightly cupped, deformed leaf with tip necrosis. In the later stages an irregular chlorosis develops, and growth can be very much reduced (Plate 15).



Plate 14 Calcium deficiency: *Pueraria phaseoloides*. The development of a deep orange-bronze colour inwards from the leaf margin, particularly in the interveinal areas, is characteristic of severe calcium deficiency.

Ca



Plate 15 Calcium deficiency: *Centrosema pubescens*. Irregular chlorosis, usually commencing at the leaf margin, and occasional tip scorch, found on the leaves of severely stunted calcium-deficient plants. (Three-and-a-half months).

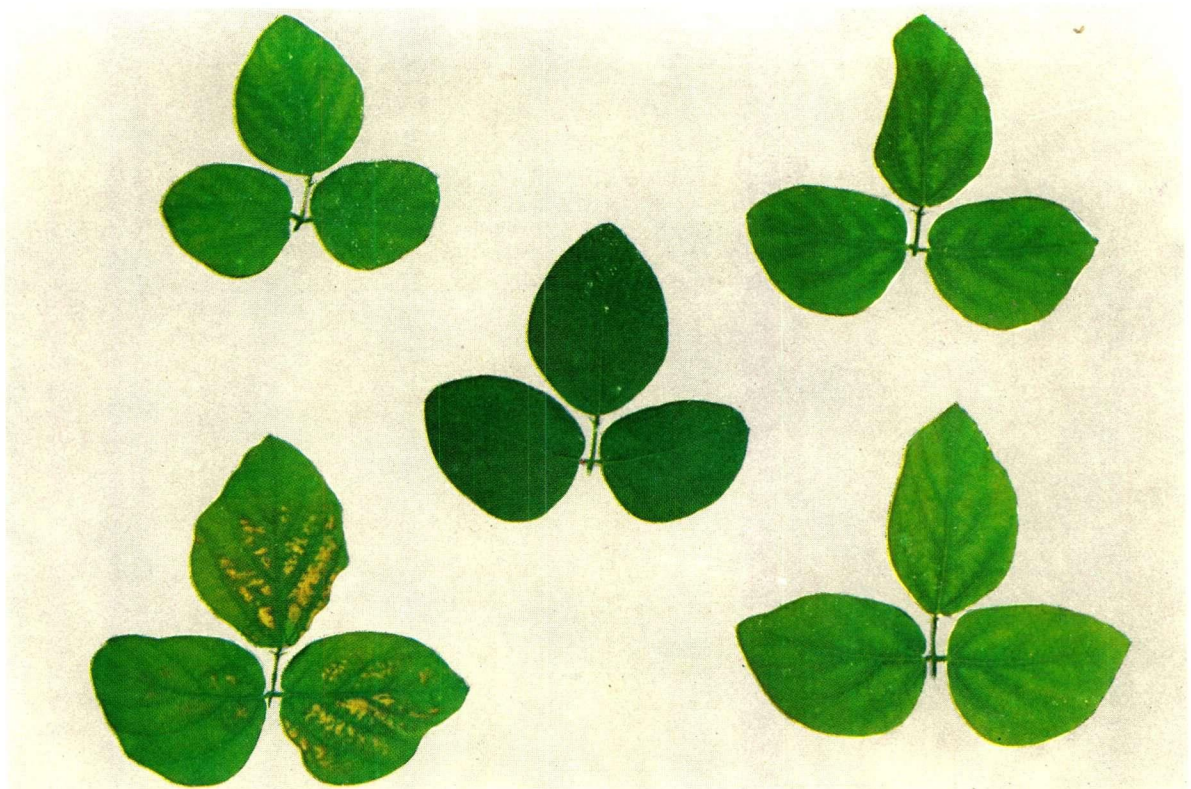


Plate 16 Deficiencies of magnesium (left) and calcium (right): *Calopogonium mucunoides*. Comparison of early symptoms; note the interveinal necrosis in the two magnesium-deficient leaves on the left (see also Plate 6), while with calcium deficiency only a faint interveinal chlorosis is evident. The earliest symptom of magnesium deficiency is, however, very similar to the normal symptom of calcium deficiency (cf. top left leaf with the two leaves on the right).

Nitrogen deficiency

Hevea brasiliensis

N
(Nitrogen)

OCCURRENCE

Nitrogen deficiency symptoms on rubber are seldom reported in Malaya: this is probably due to the widespread use of nitrogenous fertilisers, and also to the general use of leguminous cover plants when replanting rubber; a contributing reason is the fact that the symptom of nitrogen deficiency is not sufficiently characteristic. In poorly maintained plantings where fertiliser usage has been restricted, and in cases of severe competition, such as occurs when sheet lalang (*Imperata cylindrica*) is present,³⁸ nitrogen deficiency is likely to occur.

SYMPTOMS

A lack of nitrogen reduces the growth of the entire tree: this is reflected in reduced leaf size and number, and reduced girth. The tree becomes very stunted.

The main indication of nitrogen deficiency is a pale yellow-green colour of the leaves. No pattern of chlorosis develops; the whole leaf becomes first yellow-green and later yellow in colour (Plate 17).

Young unbranched tree. The symptoms will first appear on the older leaves in the lower storeys, and only when very severe will the deficiency affect the upper and younger storeys on the tree.

Old branched tree. Nitrogen deficiency results in a marked retardation of growth, particularly by reducing the size of the canopy: such stunted growth, which was frequently observed in the mid-1930's, and which was described as 'orchard type' growth,³⁷ is now rarely seen. The deficiency symptoms are likely to be more pronounced on leaves exposed to full sunlight than on leaves in the shade of the canopy.



Plate 17 Nitrogen deficiency: *Hevea brasiliensis*. Stages in the development of a general yellowing of the entire leaf: notice the marked reduction in size of the six nitrogen-deficient leaflets compared with the healthy leaf on the left. (Tjir 1 seedling, under one year).

N Nitrogen deficiency

Pueraria phaseoloides, *Centrosema pubescens* and *Calopogonium mucunoides*

SYMPTOMS

General. Nitrogen deficiency in legumes can only occur in the presence of low soil nitrogen levels and when no symbiotic fixation of nitrogen by associated rhizobial nodules is taking place. In regions where the same legume has been grown previously, or when artificial inoculation with rhizobia has been successfully carried out, nitrogen deficiency should not occur once the legumes are well established. If the deficiency is suspected the roots should be immediately examined for nodules. The nodules can be cut open and inspected; active nodules will be pink in colour.⁷⁵

The principal features of nitrogen deficiency on all three cover plants are a marked reduction in growth and the presence of pale yellow-green leaves. In plants growing in sand culture, nitrogen deficiency resulted in stunted growth for only the first four to six weeks after germination (Plate 19): the leaves were much reduced in size and were light green (Plate 18). The cotyledons of nitrogen-deficient *Calopogonium mucunoides* usually turned bright yellow before falling (Plate 20).



Plate 18 Nitrogen deficiency: *Centrosema pubescens*. Notice the stunted growth and the small, uniformly yellow leaves characteristic of nitrogen deficiency. (Plants three-and-a-half months, not inoculated with rhizobia).



Plate 19 Nitrogen deficiency (front row): *Calopogonium mucunoides* (left), *Centrosema pubescens* (centre) and *Pueraria phaseoloides* (right). Shows the stunted growth and the paleness of the leaves on the deficient plants which were not inoculated with rhizobia, compared with the plants behind which were inoculated and received nitrogen. (Cpt.= complete nutrient solution; -N= complete nutrient solution minus nitrogen). (All plants: five months).



Plate 20 Nitrogen deficiency: *Calopogonium mucunoides*. The earliest sign of nitrogen deficiency is the yellowing of the cotyledons and the very slow rate of growth, seen in the seedlings in the pot on the left. (Plants eighteen days).

P Phosphorus deficiency (Phosphorus) *Hevea brasiliensis*

OCCURRENCE

Although many cases are known where both immature and mature rubber have responded to the application of phosphate,^{4, 34, 55} symptoms of phosphorus deficiency have not been identified on mature rubber and are only infrequently found on immature rubber.

SYMPTOMS

Leaf. The distinguishing symptom of phosphorus deficiency is a bronzing of part of the under-surface of the leaf not clearly evident on inspection of the upper surface of the leaf. The bronzing is often largely restricted to one half of the leaf, and is usually first seen at the distal end of the lamina (Plate 21); the leaf tip frequently dies back. Pale bronze tints are sometimes found on the under-surface of very young, not fully expanded leaves, and such symptoms should not be confused with those of phosphorus deficiency.

Young unbranched tree. The symptoms are usually first found on leaves in the middle and upper storeys, and considerable defoliation can occur.

The yellowing and purpling of the oldest senescent leaves on the tree, just before abscission, should not be confused with phosphorus deficiency; the deficiency should only be suspected when the leaf symptoms are exhibited by trees backward in growth and bearing few storeys of leaves.

Old branched tree. Deficiency symptoms would be expected, on the basis of leaf analysis (see *Appendix, Table 3*), on leaves exposed to full sunlight, and not on shaded leaves. Shaded leaves on weak, lower branches of the canopy often show a general yellowing and bronzing prior to the defoliation, death and fall of the branch due to self-pruning. Such symptoms should not be confused with phosphorus deficiency; they are more often associated with vigorous growth and a dense upper canopy.

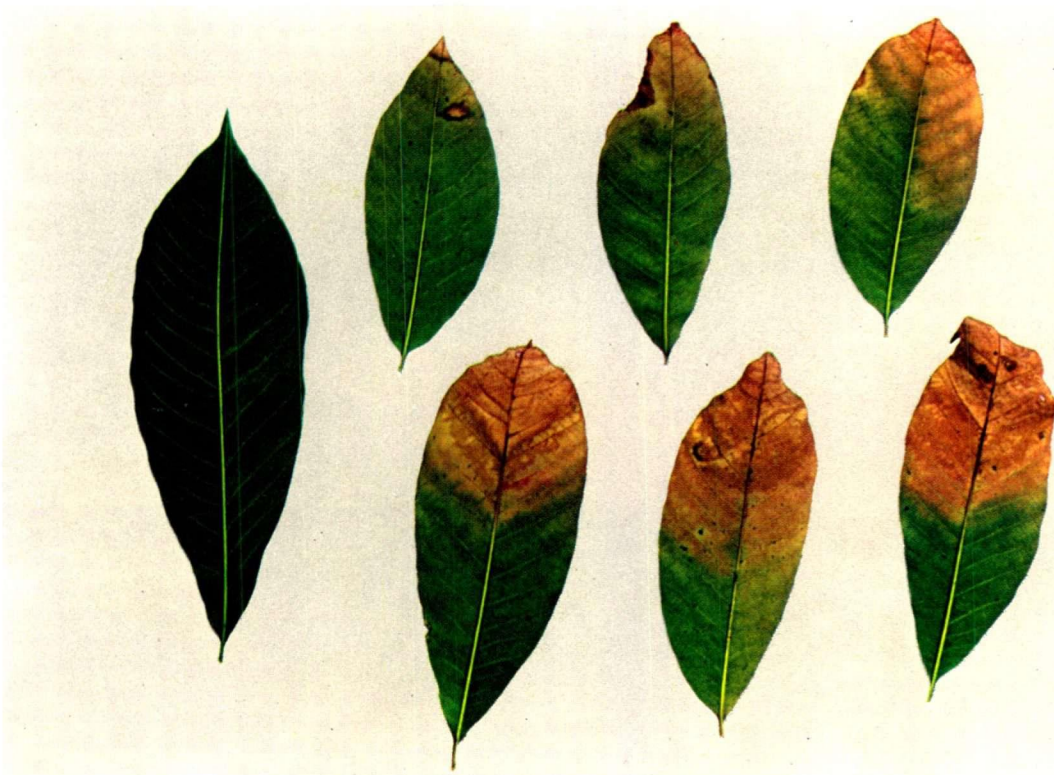


Plate 21 Phosphorus deficiency: *Hevea brasiliensis*. The under surface of six deficient leaflets, showing the development of a bronzing from the tip, which is followed by the death of the leaf tip: the bronzing is not normally evident on casual inspection of the upper surface of the leaf. (Tjir 1 seedling, under one year).

Phosphorus deficiency

P

Pueraria phaseoloides, *Centrosema pubescens* and *Calopogonium mucunoides*

SYMPTOMS

General. Phosphorus deficiency does not produce any well defined characteristic leaf symptoms in any of the three cover plants. Growth is markedly reduced (Plate 23), and defoliation occurs. The leaves are very small and lustreless, and are often dark green (Plate 22). The bines of all covers are very dark in colour, sometimes a dark red-purple, and in *Pueraria phaseoloides* there is a tendency for the under surface of the veins to be the same dark colour.

The older leaves are the first affected, but when the deficiency is extremely severe it is observed that the young leaves are very small, and a reduction in leaf size from the oldest to the youngest leaves can be seen along the bine.

Calopogonium mucunoides. Necrotic mottling of the lamina is found, and when the deficiency is very severe a tip necrosis develops.



Plate 22 Phosphorus deficiency (top row): *Calopogonium mucunoides* (left), *Centrosema pubescens* (centre) and *Pueraria phaseoloides* (right). The top three deficient leaves show a very marked reduction in size compared with the corresponding healthy leaves on the bottom row. There is no characteristic chlorosis, necrosis or alteration in leaf shape that would assist in diagnosis.

P



Plate 23 Phosphorus deficiency (front row): *Calopogonium mucunoides* (left), *Centrosema pubescens* (centre) and *Pueraria phaseoloides* (right). Notice the marked stunting of the phosphorus-deficient plants compared with the plants behind, which are well supplied with phosphorus.

Sulphur deficiency

Hevea brasiliensis

S
(Sulphur)

OCCURRENCE

No cases of sulphur deficiency have been observed on rubber in Malaya, perhaps because sulphur is applied regularly to most rubber in the form of ammonium sulphate, the principal nitrogen fertiliser used.

SYMPTOMS

Leaf. The first indication of the deficiency is very similar to that of nitrogen deficiency, namely a gradual uniform yellowing of the entire leaf, which is much reduced in size; later a tip scorch develops (Plate 24) which results initially in the cupping of the leaf, and later affects the whole of the distal end of the leaf.

Young unbranched tree. The symptom will be found first on leaves in the upper, younger storeys.



Plate 24 Sulphur deficiency: *Hevea brasiliensis*. Stages in the development of severe symptoms from a general yellowing of the entire leaf, which is much reduced in size, to the death of the leaf tip and the subsequent extensive tip necrosis. (Tjir 1 seedling, under one year. Average sulphur concentration in deficient leaves: 0.11%).

S Sulphur deficiency

Pueraria phaseoloides, *Centrosema pubescens*, *Calopogonium mucunoides*

SYMPTOMS

General. A lack of sulphur mainly affects the younger leaves and results initially in the development of pale green leaves of slightly reduced size. The later development of a marginal and tip necrosis, often as a band of necrotic tissue around the leaf, is the main characteristic feature of sulphur deficiency in all three cover plants. This necrosis is not preceded by marginal yellowing, such as occurs with potassium deficiency, and it is thus possible to differentiate between the two deficiencies.

Pueraria phaseoloides. The necrosis often develops from the leaf margin along the veins and then into the interveinal areas. Necrotic patches on the lamina, isolated from the leaf margins, are occasionally seen on *Pueraria phaseoloides* (Plate 25), but on *Calopogonium mucunoides* necrotic spots frequently develop over the whole lamina, following an irregular patchy yellowing in the interveinal areas; this is in addition to the marginal necrosis. These necrotic spots often coalesce to form large necrotic patches (Plate 27).

A similar effect is found at times in *Centrosema pubescens*, but is usually restricted to the development of the patchy yellowing, necrotic spots developing on the lamina only when the deficiency is extremely severe (Plate 26).

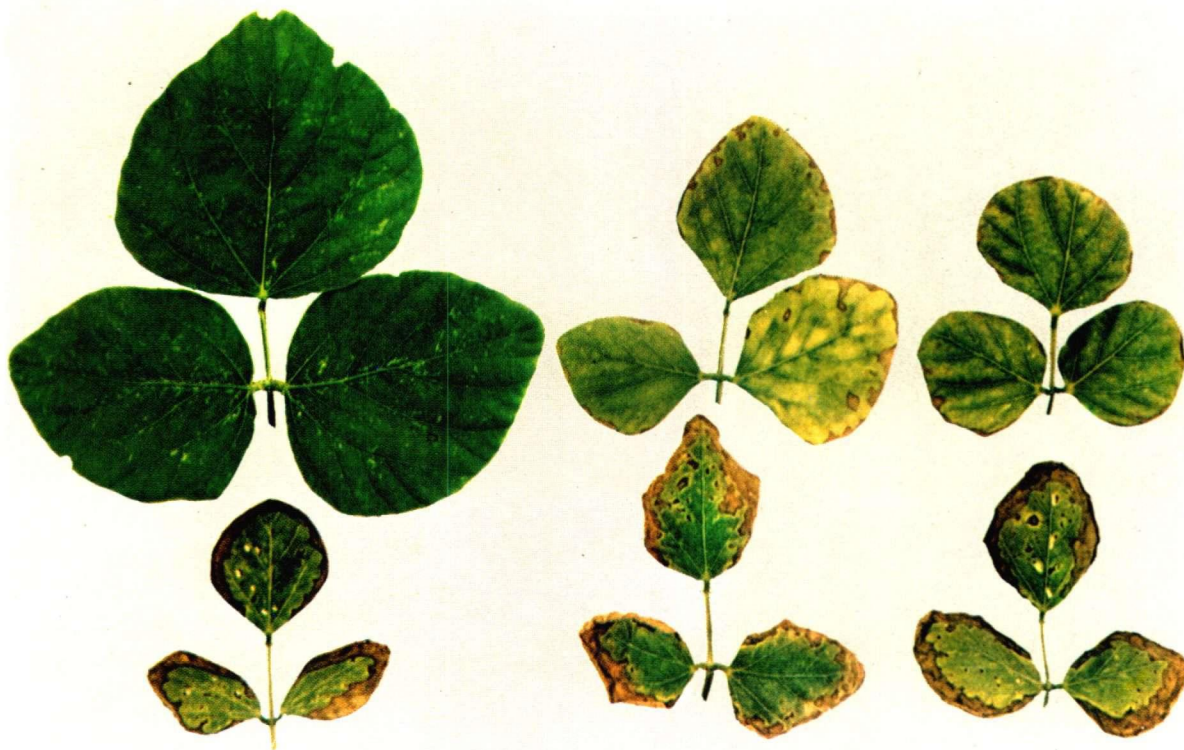


Plate 25 Sulphur deficiency: *Pueraria phaseoloides*. Shows the development of a dark-coloured marginal necrosis and to a lesser extent necrotic spots on the small deficient leaves (Healthy leaf top left). Notice that while the entire leaf is pale in colour, the necrosis is not preceded by any marginal yellowing. (Average sulphur concentration in the deficient leaves: 0.12%).

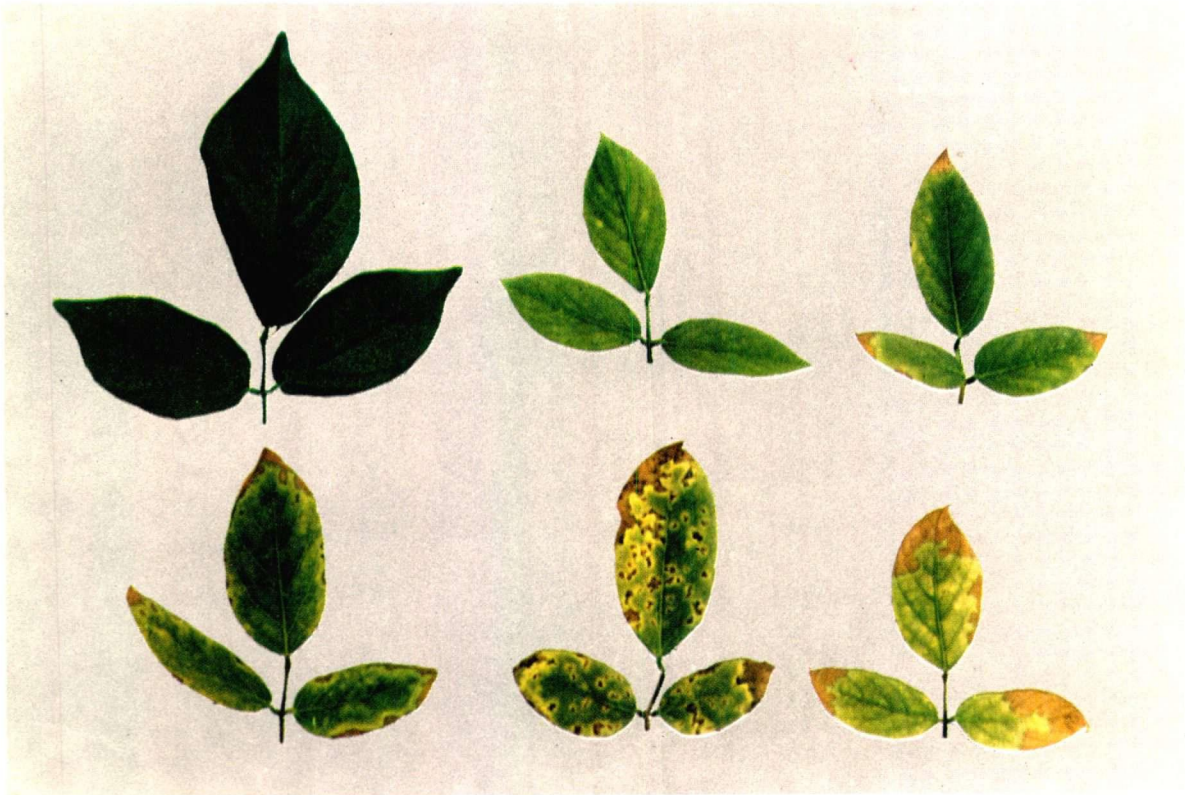


Plate 26 Sulphur deficiency: *Centrosema pubescens*. Development of a tip and marginal light brown necrosis, and also of necrotic spots on the small deficient leaves. Notice the pale colour, with no definite pattern of chlorosis. (Average sulphur concentration in deficient leaves: 0.11%).

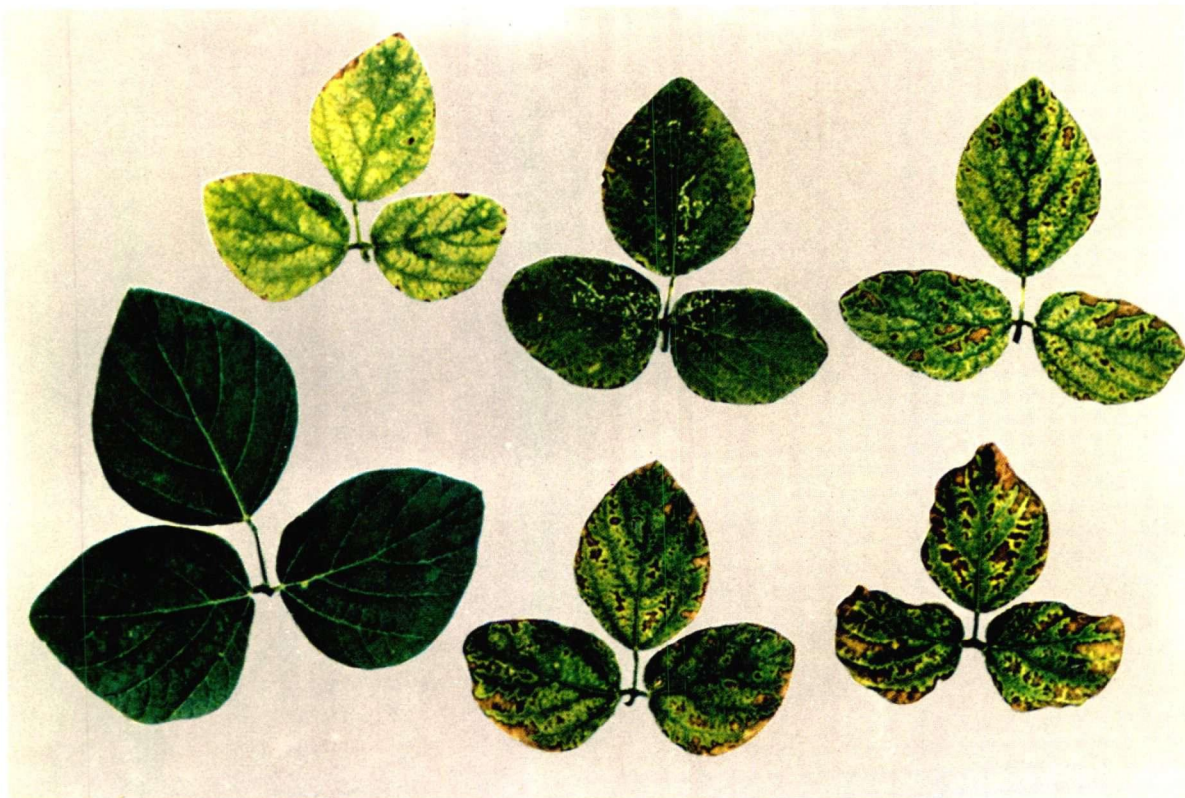


Plate 27 Sulphur deficiency: *Calopogonium mucunoides*. Necrotic spotting of the leaf with a tendency for the spots to coalesce, forming necrotic patches in the interveinal areas (bottom right) and also along the leaf margin (bottom centre).

Manganese deficiency

Hevea brasiliensis

OCCURRENCE

Manganese deficiency is widespread in Malaya, and it appears to be particularly severe on alluvial sandy soils and on certain soils derived from granite *in situ* or from granite-derived alluvium.⁶⁵

SYMPTOMS

Leaf. The typical deficiency symptom (Plate 28) is an overall paling and yellowing of the leaf with bands of green tissue outlining the midrib and main veins. As the deficiency becomes more severe the leaf becomes progressively more yellow, but the green midrib and main veins still remain evident. No necrosis of leaf tip or margin occurs. Little reduction in leaf size occurs even when the deficiency is severe, and it is frequently found that the symptoms are more often observed on the large leaves of a tree than on the small leaves.

Young unbranched tree. The symptoms appear first on the leaves in the lower and midstem region, but when severe the upper storeys will also be affected.

Old branched tree. Manganese deficiency symptoms will usually be found on shaded leaves on low branches in the tree. The manganese content of shaded leaves is normally less than that of leaves exposed to full sunlight: when the deficiency is severe the difference in manganese content of shaded and exposed leaves is small, and symptoms can be observed on exposed leaves also.



Plate 28 Manganese deficiency: *Hevea brasiliensis*. The general paling and yellowing of the leaf with bands of green tissue outlining the midrib and main veins is characteristic of manganese deficiency. Notice only a moderate reduction in leaf size. (Tjir 1 seedling, under one year. Average manganese concentration in deficient leaflets: 15 p.p.m.).

Manganese deficiency

Mn

Pueraria phaseoloides, *Centrosema pubescens*, *Calopogonium mucunoides*

SYMPTOMS

General. With all three cover plants manganese deficiency typically results in an overall yellowing of the leaf with the midribs and main veins outlined in healthy green tissue and thus clearly evident (Plates 29, 30 and 31). This symptom is very similar to the symptoms of slight iron deficiency, and without chemical analysis differentiation between the two deficiencies can be difficult (see Plate 36 – compare the lower older leaves in right-hand iron-deficient plants with the manganese-deficient leaves on the left). Iron deficiency occurs under particular soil conditions, but manganese deficiency occurs more generally and can be most easily distinguished from iron deficiency by the absence of very small, yellow, young leaves. Moreover manganese deficiency does not result in the marked reduction in plant vigour and leaf size seen in iron-deficient plants, where there is a typical gradation in size and colour of leaves along the bine (see Plates 33, 34, 35 and 36).

Pueraria phaseoloides, *Centrosema pubescens.* The younger leaves of manganese-deficient plants are not pale yellow in colour even when the deficiency is very severe, but in *Calopogonium mucunoides* small yellow leaves can sometimes be found on severely deficient plants.



Plate 29 Manganese deficiency: *Pueraria phaseoloides*. Stages in the development of a general paling and yellowing of the leaf with bands of green tissue clearly evident alongside the midrib and main veins.



Plate 30 Manganese deficiency: *Centrosema pubescens*. Stages in the general paling and yellowing of the leaf with green tissue outlining the midrib and main veins. Only slight reduction in leaf size.



Plate 31 Manganese deficiency: *Calopogonium mucunoides*. Shows the overall mottled yellowing, with the main veins and midrib clearly evident in the most severely affected leaf (bottom row, right). (Average manganese concentration in the deficient leaves: 10 p.p.m.).

Iron deficiency

Hevea brasiliensis

Fe
(Iron)

OCCURRENCE

Iron deficiency is observed at times on rubber in Malaya, but its occurrence is limited to the peat soils, humic sands and leached sands, and some heavy coastal clays where calcareous shell layers occur giving rise to alkaline soil conditions. In all these circumstances the iron deficiency generally occurs together with manganese deficiency.

SYMPTOMS

Leaf. The first leaf symptom of iron deficiency is a general leaf chlorosis resembling that of manganese deficiency. With increase in severity of the deficiency the entire leaf assumes a pale lemon yellow to white colour (Plate 32). The very pale leaves are often spotted with a fungus, *Corynespora cassiicola*, which is otherwise seldom found on *Hevea*. There is considerable reduction in leaf size.

Young unbranched tree. The characteristic feature of iron deficiency is the appearance of the symptoms on the leaves in the youngest, upper storeys on the plant, with the deficiency symptoms becoming progressively more severe on the younger leaves.

Old branched tree. The deficiency symptoms are found on leaves in terminal whorls exposed to full sunlight.



Plate 32 Iron deficiency: *Hevea brasiliensis*. Stages in the development of very severe deficiency symptoms from the small mottled yellow leaf (top row, left), to the markedly chlorotic leaf (top row, right), to the extremely small and almost white leaves (bottom row). Such a gradation in size and severity of the chlorosis is to be found in iron-deficient plants from the older (less affected) to the youngest (most severely affected) leaves.

Fe Iron deficiency

Pueraria phaseoloides, *Centrosema pubescens*, *Calopogonium mucunoides*

SYMPTOMS

General. The most characteristic feature of iron deficiency in all three cover plants can be clearly seen on a terminal section of a bine, where it will be found that there is a gradual reduction in size and change in colour from the older leaves, which are relatively large, green or green-yellow in colour, to the very small, pale yellow to white young leaves. This is a distinctive feature of iron deficiency common to many plants.

In the early stages, iron deficiency results in an overall paling of the leaves leaving the midribs and veins outlined in green healthy tissue, and at this stage it is not possible to distinguish iron and manganese deficiency symptoms. The recognition of iron deficiency is possible as it becomes more severe, when the young leaves are found to be very much reduced in size and pale yellow. The reduction in size of the younger leaves is most marked in *Centrosema pubescens*, which suggests that it is a good indicator of iron deficiency.

When the deficiency is very severe, marginal and interveinal necrosis occurs. In *Pueraria phaseoloides* and *Centrosema pubescens* the necrosis appears along the leaf margin, and in *Calopogonium mucunoides* as interveinal spots (compare Plates 34 and 35).

Iron deficiency is not infrequently found on the three cover plants in Malaya under soil conditions as described on pages 9 and 10. A case of iron deficiency on *Pueraria phaseoloides* induced by excessive uptake of manganese from a basalt-derived soil in Borneo has also been reported.⁸⁰

Calopogonium mucunoides. Manganese deficiency occasionally produces similar symptoms to those of iron deficiency, the younger leaves being very pale yellow in both cases.



Plate 33 Iron deficiency: *Pueraria phaseoloides*. Shows a marked chlorosis of the deficient leaves, and a slight graded reduction in leaf size from the leaves at top left to those along the bine in the centre. Notice the small leaf size but no marked chlorosis exhibited by the *Centrosema pubescens*.



Plate 34 Iron deficiency: *Centrosema pubescens*. Stages in the development from the slight symptoms of a general leaf yellowing to the very severe symptoms of marked chlorosis, tip and marginal necrosis of the very small young leaves.



Plate 35 Iron deficiency: *Calopogonium mucunoides*. Stages in the development of very severe symptoms of general chlorosis of the leaf: the reduction in leaf size and the loss of colour is less marked in *Calopogonium mucunoides* than in the other two legumes (see Plates 33 and 34).

Fe



Plate 36 Deficiencies of manganese (left) and iron (right): *Calopogonium mucunoides*. The early stages of iron deficiency (see lower, older leaves on the iron-deficient plants) in all three cover plants are very similar to manganese deficiency symptoms. In the later stages of iron deficiency the younger leaves become markedly chlorotic; this is not so with manganese deficiency. (All plants, six weeks).

Boron deficiency

Hevea brasiliensis

B
(Boron)

OCCURRENCE

There have so far been no substantiated cases of boron deficiency of *Hevea* in Malaya. Suspected cases have been due to a common error in associating a 'bottle-brush' type of extension growth on young unbranched trees with boron deficiency, without any consideration of the symptoms shown by individual leaves. It is reasonable to expect, however, that with the heavy leaching of Malayan soils boron deficiency on *Hevea* may eventually be found.

SYMPTOMS

Leaf. Boron-deficient leaves are distorted, reduced in size and somewhat brittle. The leaf deformation (see Plate 37) does not follow any consistent pattern. There is no loss of colour, and occasionally the veins may appear to be wider than normal.

Young unbranched tree. The first sign of boron deficiency is to be found in the younger, upper storeys on the plant, which will not be separated by any discrete internode. The individual storeys cannot be distinguished, and consequently there appears to be a continual production of new leaves, resulting in the 'bottle-brush' appearance of the stem. When the deficiency is severe the apical meristem may die and axillary meristems develop near the top of the stem. The 'bottle-brush' effect is not by itself a sure indication of boron deficiency; it is quite a common occurrence in Tjir 1 and GT 1 budgrafts and in some clonal seedlings.

It should be noted that leaf deformation as in Plate 37 can be a symptom of attack by yellow tea mites, in which case it is usual to find only one or two storeys on a young tree affected, with no tendency towards 'bottle-brush' formation; once again boron deficiency need not be suspected.

Old branched tree. Deficiency symptoms would be expected, on the basis of leaf analysis (see Appendix, Table 3), on leaves in the shade of the canopy and not on leaves exposed to full sunlight.

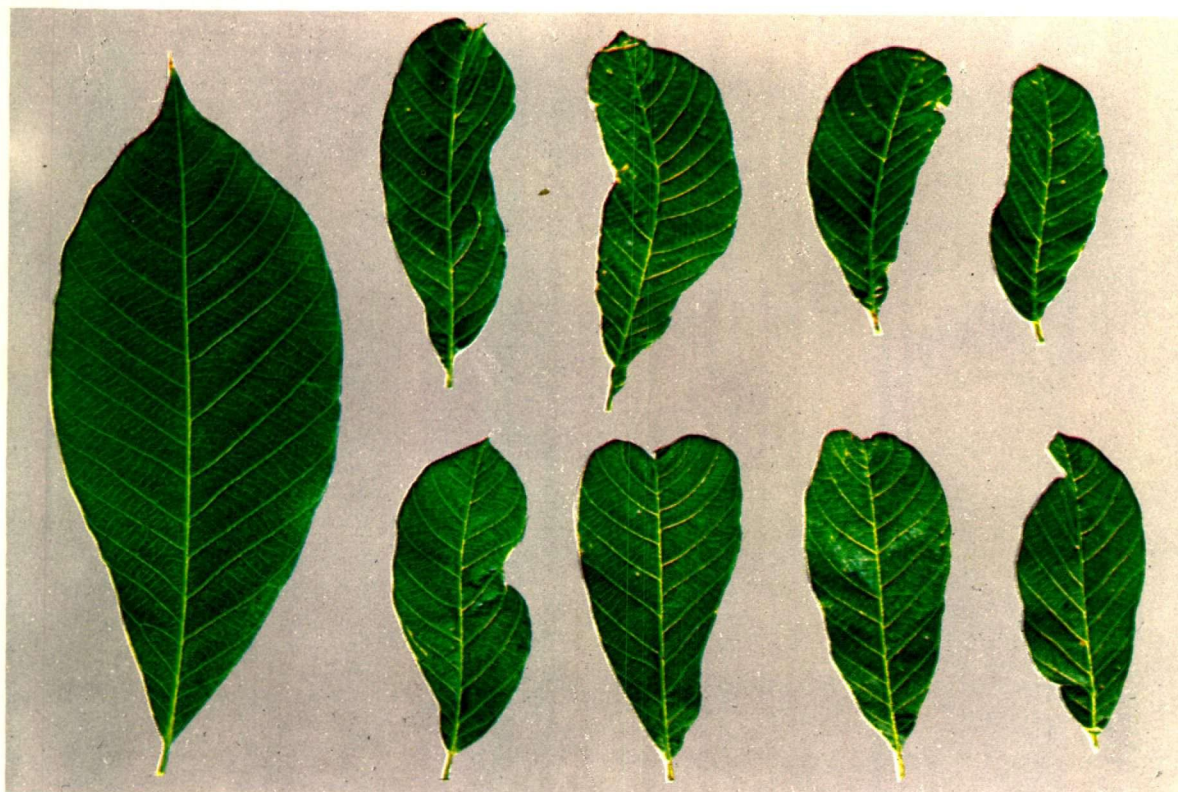


Plate 37 Boron deficiency: *Hevea brasiliensis*. A selection of distorted and stunted boron-deficient leaves. The leaf deformation does not follow any consistent pattern. No changes in leaf colour occur. (Tjir 1 seedling).

B Boron deficiency

Pueraria phaseoloides, *Centrosema pubescens*, *Calopogonium mucunoides*

SYMPTOMS

General. Boron deficiency has a striking effect on the morphology, leaf shape and size of all three cover plants. Deficient plants are very stunted in growth, and produce short thick bines which do not spread over the soil surface. The leaves are considerably reduced in size and misshapen, and the veins are frequently prominent.

The younger leaves are first affected and are noticeably thick and brittle to the touch.

These effects of boron deficiency are primarily due to the fact that a lack of boron results in a disorganisation of the dividing cells in the apical meristem; such meristems develop and expand longitudinally to a limited extent and then further development is arrested; the result is that the internodal extension growth is very short. As apical meristems cease to develop and become moribund or die, axillary meristems develop which in turn only develop to a limited extent. Such extension growth results in a 'prostrate clump' habit of growth.



Plate 38 Boron deficiency: *Pueraria phaseoloides*. Very small misshapen boron-deficient leaves which are thick and brittle to the touch; no characteristic chlorosis or necrosis is exhibited.

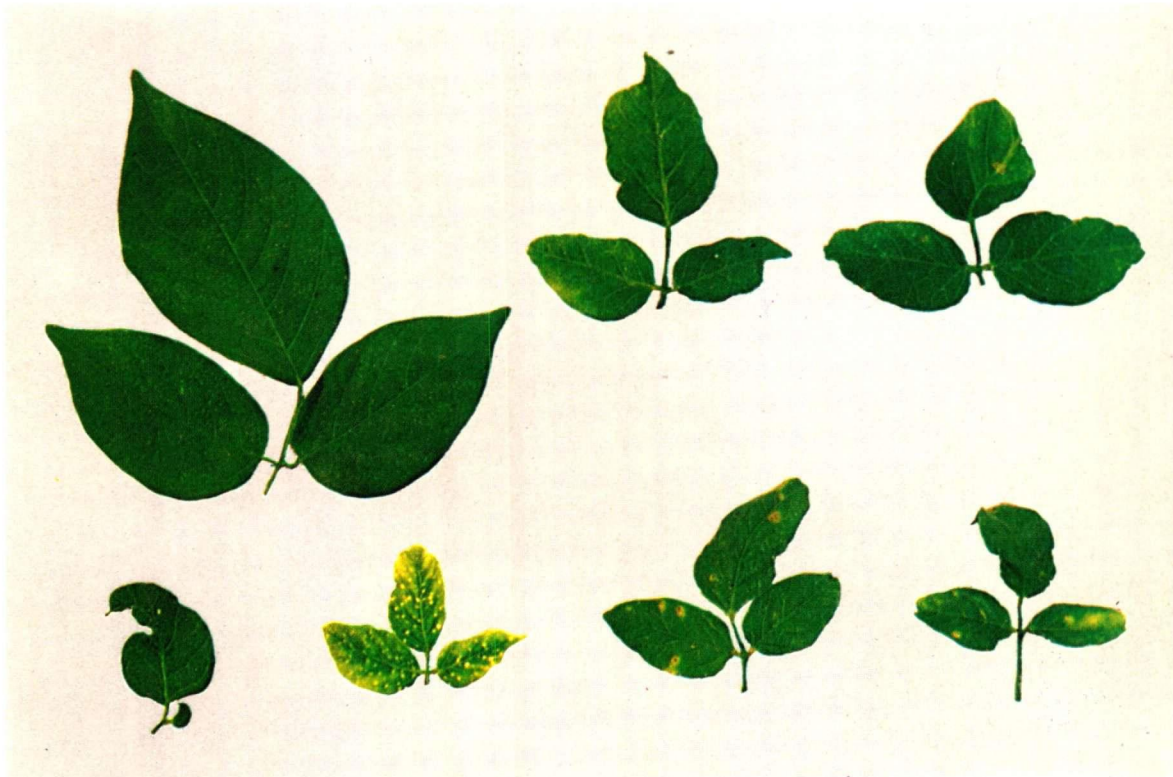


Plate 39 Boron deficiency: *Centrosema pubescens*. A selection of distorted, small, boron-deficient leaves which are thick and brittle to the touch.



Plate 40 Boron deficiency: *Calopogonium mucunoides*. Notice the grossly distorted leaves and the stunted, prostrate habit of growth typical of boron deficiency. (Plants, seven weeks).

Molybdenum deficiency

Hevea brasiliensis

OCCURRENCE

There have so far been no authenticated cases of molybdenum deficiency on rubber in Malaya; there have, however, been a few instances where leaves showing symptoms associated with molybdenum deficiency have been found to contain very low concentrations of molybdenum.

SYMPTOMS

Leaf. Molybdenum deficiency is characterised by the development of a very pale brown scorch around the leaf margins, particularly in the region of the leaf tip (Plate 41).

It has been observed that when rubber seedlings were grown in sand culture without molybdenum, but with a large proportion of the nitrogen supplied in the form of ammonium salts, the visible effects of the deficiency were very slight; when the nitrogen was supplied in the form of nitrate salts, however, there was a marked reduction in growth under conditions of deficient molybdenum supply.¹⁸

Young unbranched tree. The symptoms are found on the midstem and lower storeys.

Old branched tree. Deficiency symptoms would be expected, on the basis of leaf analysis (see Appendix, Table 3), on leaves exposed to full sunlight and not on the leaves in shade of the canopy.



Plate 41 Molybdenum deficiency: *Hevea brasiliensis*. Pale brown to white marginal scorch developing, without any prior yellowing, on older leaves on unbranched tree. (Tjir 1 seedling, one year).

Molybdenum deficiency

Mo

Pueraria phaseoloides, *Centrosema pubescens*, *Calopogonium mucunoides*

SYMPTOMS

General. Characteristic leaf symptoms of molybdenum deficiency are only observed after growing the plants for many months in the absence of any supply of molybdenum: only a very small quantity of molybdenum is required to correct the deficiency, and it appears unlikely that the deficiency will occur in the field.

Growth is only slightly reduced, and the leaves are at first pale green in colour; later the younger leaves on *Pueraria phaseoloides* and *Centrosema pubescens* develop a very pale brown papery tip and marginal scorch (Plates 42 and 44). *Pueraria phaseoloides*: interveinal necrosis occurs also, and defoliation of affected leaves ensues.

Calopogonium mucunoides. The symptoms appear as a necrotic mottling over the whole lamina, with a tendency for the development of a thin, marginal band of necrosis, similar to that observed in the case of sulphur deficiency. The necrotic spots coalesce and defoliation occurs (Plate 43).



Plate 42 Molybdenum deficiency: *Pueraria phaseoloides*. Development of marginal and interveinal scorch, very pale in colour, on leaves which initially exhibit a general chlorosis.



Plate 43 Molybdenum deficiency: *Calopogonium mucunoides*. Notice the necrotic spots which develop at the leaf margin and in the interveinal areas and later coalesce, resulting in a marginal band and interveinal necrosis.



Plate 44 Molybdenum deficiency: *Centrosema pubescens*. Development of a tip and marginal scorch which is very pale brown in colour. (Plants two-and-a-half months).

Zinc deficiency*Hevea brasiliensis*

OCCURRENCE

Zinc deficiency has been reported to occur in the field in Ceylon.⁴⁵ In Malaya, leaves showing symptoms associated with zinc deficiency and containing a low concentration of zinc have been observed on very young rubber: the symptoms are, however, only likely to be found under very particular situations on young rubber, for instance when the zinc content of the soil is made unavailable for plant uptake by application of unusually heavy dressings of either alkaline fertiliser or of soluble phosphatic fertiliser. Under such circumstances the symptoms will only be transient, and recovery will be fairly rapid if the roots extend into soil unaffected by the fertiliser dressing.

A common error is to associate with zinc deficiency the long strap-like leaves that are the result of thrip attack on the young expanding leaves; such leaves are usually not reduced in size but appear to be enlarged, whereas zinc deficiency results in a considerable reduction in leaf size.

SYMPTOMS

Leaf. The characteristic feature of zinc deficiency is that the lamina becomes very much reduced in breadth relative to its length (Plate 45). Frequently the lamina may become twisted and the margins appear wavy or undulating. There is also a general chlorosis of the leaf, similar to that observed in fairly severe cases of manganese deficiency, the midrib and main veins remaining dark green in colour.

Young unbranched tree. The symptoms are found on the top storeys. Death of the apical meristem occurs under conditions of very severe zinc deficiency, and sideshoots may develop from axillary meristems.

Old branched tree. Deficiency symptoms would be expected, on the basis of leaf analysis (see *Appendix, Table 3*), on leaves exposed to full sunlight and not on leaves in the shade of the canopy.



Plate 45 Zinc deficiency: *Hevea brasiliensis*. Notice the reduced size, the narrow shape and the overall chlorosis of the leaves: all three characters occur together on zinc-deficient leaves. The leaves are also often twisted and the margins appear wavy.

Zinc deficiency

Zn

Pueraria phaseoloides, *Centrosema pubescens*, *Calopogonium mucunoides*

SYMPTOMS

General. Zinc deficiency results in a marked reduction of growth and the formation of very small chlorotic leaves early in the life of all three cover plants (Plate 47). The youngest leaves are the first to be affected by the deficiency and develop the most severe symptoms. No other deficiency on any of the three cover plants results in the formation of such small young leaves as those developed on zinc-deficient plants. The leaves rapidly develop marginal necrosis and also spots of necrosis over the lamina.

Centrosema pubescens. The symptoms rarely become sufficiently severe to show extensive necrosis, and the main features of the deficiency are the very small leaves and a marked interveinal chlorosis (Plate 47).

Pueraria phaseoloides and *Calopogonium mucunoides* (Plates 46 and 48). Marked marginal and spot necrosis occurs, and in *Calopogonium mucunoides* there is a tendency for the incomplete expansion of the leaf near the tip to result in a slight upward cupping of the leaf.

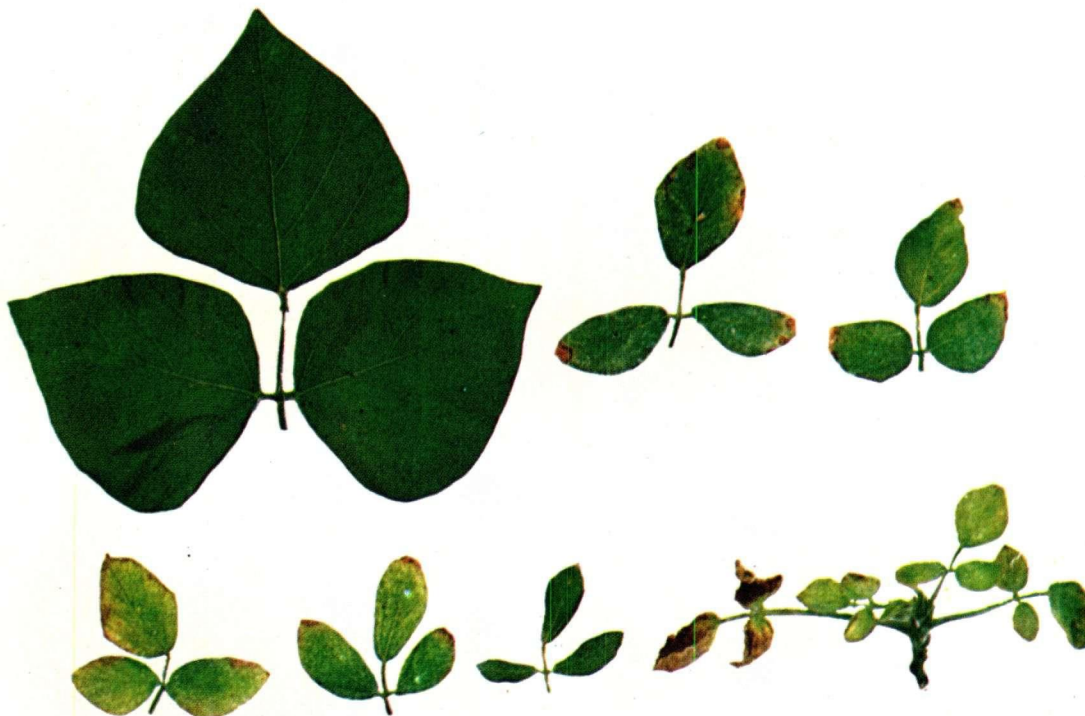


Plate 46 Zinc deficiency: *Pueraria phaseoloides*. A selection of zinc-deficient leaves which are very small and misshapen, and show a tip and marginal necrosis.

Zn



Plate 47 Zinc deficiency: *Centrosema pubescens*. Zinc deficiency can rapidly reduce growth: both sets of plants are fourteen days old, growing in purified sand. The right-hand plants received all nutrients; plants on the left received all nutrients except zinc.



Plate 48 Zinc deficiency. *Calopogonium mucunoides*. Notice the very small misshapen leaves and the development of necrotic spots which coalesce in the interveinal areas.

Copper deficiency

Hevea brasiliensis

Cu
(Copper)

OCCURRENCE

In Malaya, leaves showing symptoms associated with copper deficiency and containing a low concentration of copper have only been found under very particular circumstances: namely in a few locations and in soil pot-culture experiments where the copper content of the soil has been made unavailable for plant uptake by application of unusually heavy dressings of water-soluble phosphatic fertilisers. Under such circumstances the symptoms will only be transient and recovery will be fairly rapid.

It is not expected, on the basis of leaf analysis, that copper deficiency is likely to be a problem in rubber cultivation in Malaya.

SYMPTOMS

Leaf. The first sign of copper deficiency is wilting of the leaf margin at the tip, with subsequent upward cupping of the leaf tip. The wilting of the margin develops into a very pale brown scorch (Plate 49) which often spreads down the lamina from the tip; finally the lamina is shed. Frequently a large number of leaves are shed at the same time, leaving behind a bare stem. After such defoliation the apical growing point usually dies, and the new shoots which develop from axillary meristems give rise to multiple branching: if the copper supply is still inadequate, leaf cupping, scorching, leaf abscission, and death of the apical meristem will again occur. In severe cases the lamina on the new side shoots fail to expand properly, and the new side shoot may be covered with numerous dead and shrunken petioles as in Plate 49.

Young unbranched tree. The symptoms are first observed on the youngest leaves.

Old branched tree. Deficiency symptoms would be expected, on the basis of leaf analysis (see Appendix, Table 3), on leaves exposed to full sunlight and not on leaves in the shade of the canopy.



Plate 49 Copper deficiency: *Hevea brasiliensis*. The dieback of the original apical meristem results in the characteristic development of many abortive new side shoots from axillary meristems; a further symptom is the severe tip and marginal scorch which develops on the young leaves prior to and together with the extensive branching. (Tjir 1 seedling, fourteen months)

Cu Copper deficiency

Pueraria phaseoloides, *Centrosema pubescens*, *Calopogonium mucunoides*

SYMPTOMS

General. Leaf symptoms of copper deficiency, affecting the leaf tips of younger leaves, are clearly shown by all the three cover plants.

The leaves are thin, become pale green in colour and develop a pale brown to white scorch at the tips, and to a lesser extent at the margins, (Plates 50, 51 and 52). The tip scorch usually appears as a well defined area, but occasionally it can extend into the interveinal areas.

Like boron deficiency, copper deficiency affects the leaf shape, but without the leaf becoming grossly distorted; the leaves are narrower than healthy leaves, while leaf size is usually only slightly reduced (Plates 50, 51 and 52).

Centrosema pubescens. When the deficiency is very severe the young leaves often die back at the tip before leaf expansion is completed, resulting in the curling and cupping of the leaf at and around the leaf tip.



Plate 50 Copper deficiency: *Pueraria phaseoloides*. Development of a very pale tip and marginal scorch on leaves which show an overall chlorosis and are somewhat misshapen.



Plate 51 Copper deficiency. *Centrosema pubescens*. Selection of copper-deficient leaves, showing a light brown marginal and tip scorch, and also some distortion.



Plate 52 Copper deficiency: *Calopogonium mucunoides*. Notice the development of a light brown tip scorch on leaves which are small and misshapen.

OCCURRENCE

Symptoms associated with the presence of a high water table are frequently found on the alluvial clay soils in Malaya.

SYMPTOMS

The characteristic symptom is the development of a tip and marginal scorch without any leaf chlorosis (Plate 53). The scorch is normally light brown to grey in colour: the inner margin of the scorch has a dark brown boundary. There is a risk that these symptoms may be confused with the symptoms of calcium deficiency, in which the scorch is very pale in colour (see p. 23).

Old branched tree. The symptoms are found on leaves exposed to full sunlight, being particularly noticeable on the exposed leaves on trees at the edge of a field. The location of the scorched leaves on the tree and the position of the scorch on the leaf suggest that the scorch may be due to the accumulation of a toxic substance at the extremities of the leaf under the influence of transpiration. The toxic substance is very probably boron, which is present in large quantities in the affected leaves, particularly in the marginal scorch area, on trees growing on alluvial clay soils along the coast of Malaya.



Plate 53 Symptoms exhibited by *Hevea brasiliensis* growing under waterlogged conditions on a heavy alluvial clay soil. Notice the marginal scorch, which is light brown to grey in colour, and which has on its inner margin a dark brown boundary. (PB 86, branched, fourteen years. Average leaf nutrient composition: 2.41% N, 1.79% K, 0.29% P, 0.18% Mg, 0.59% Ca and 362 p.p.m. Mn).

Key to nutrient deficiency symptoms on *Hevea brasiliensis*

1. UNBRANCHED TREES

Deficient element

A. Symptoms found on older, lower leaves

- | | |
|--|------------|
| (i) Leaves chlorotic, generally uniform in colour | Nitrogen |
| (ii) Leaves chlorotic but not uniform in colour | |
| (a) Interveinal yellowing usually contiguous with leaf margin | Magnesium |
| (b) Marginal yellow mottling, often with tip scorch | Potassium |
| (iii) Leaves not chlorotic, but with extensive marginal scorch | Molybdenum |

B. Symptoms found on mid-stem and upper leaves

- | | |
|--|------------|
| (i) Leaves chlorotic | |
| (a) Leaves pale green in colour with midrib and veins dark green | Manganese |
| (b) Upper surface leaf shows yellowing; lower surface leaf with bronze tints | Phosphorus |

C. Symptoms found on new growth or top whorls

- | | |
|--|---------|
| (i) Leaves distorted | |
| (a) Leaves small, elongated and straplike with wavy margins | Zinc |
| (b) Leaves slightly reduced in size, dark uniform green in colour, with irregular shape; unusual to find two leaves similar in shape | Boron |
| (ii) Leaves not distorted | |
| (a) Tip and marginal scorch present, pale brown in colour, not preceded by chlorosis | Calcium |
| (b) Leaves small with tip scorch; with signs of branching from axillary meristems | Copper |
| (c) Leaves very small, no scorch present, pale green to lemon yellow in colour | Iron |
| (d) Leaves first with general chlorosis, then showing a tip scorch | Sulphur |

2. BRANCHED TREES*

A. Symptoms found on leaves exposed to full sunlight, normally at the top of the canopy

- | | |
|---|-----------|
| (i) Leaves chlorotic, uniform in colour, | |
| (a) Leaves pale green to lemon yellow in colour | Iron |
| (ii) Leaves chlorotic but not uniform in colour | |
| (a) Interveinal yellowing, contiguous with leaf margin | Magnesium |
| (b) Irregular yellowing with no well-defined boundary between chlorotic and green tissue, often more evident around leaf margin | Potassium |

B. Symptoms found on leaves in the shade of the canopy

- | | |
|--|-----------|
| (i) Scorch present, pale brown in colour | Calcium |
| (ii) No scorch present; leaves pale green in colour with midrib and veins dark green | Manganese |

* Leaf deficiency symptoms due to nitrogen and phosphorus are very infrequently found on old branched rubber: shortages of nitrogen and phosphorus normally result in stunted growth and poor canopies.

Deficiency symptoms on old branched trees due to boron, sulphur, copper, zinc and molybdenum have not yet been identified. It is likely that the symptoms will be similar to those on unbranched trees.

The following guide to the position on the old branched tree where the symptoms are likely to be found has been deduced from leaf analysis (see *Appendix, Table 3*) relating to shade and exposed leaves:

Symptoms to be expected on leaves exposed to full sunlight: phosphorus, nitrogen, copper, zinc and molybdenum.

Symptoms to be expected on shade leaves: boron.

**Key to nutrient deficiency symptoms on *Pueraria phaseoloides*,
Centrosema pubescens and *Calopogonium mucunoides***

| A. Symptoms found on older leaves | <i>Deficient element</i> |
|--|--------------------------|
| (i) Leaves chlorotic | |
| (a) Chlorosis commencing from tip and margins, followed by scorch | Potassium |
| (b) General chlorosis with development of necrotic patches in interveinal areas | Magnesium |
| (ii) Leaves not chlorotic | |
| (a) Small, dark green, lustreless leaves; very stunted growth | Phosphorus |
| B. Symptoms found on younger leaves | |
| (i) Leaves distorted, sometimes with scorch | |
| (a) Thick, brittle, dark green leaves, veins prominent; prostrate habit of growth | Boron |
| (b) Leaves very small, with marked necrosis of margins and over entire leaf | Zinc |
| (c) Leaves slightly elongated with tip 'cupping' and scorch | Copper |
| (ii) Leaves not distorted, but chlorotic | |
| (a) Tip and marginal scorch extensive, pale brown in colour | Molybdenum |
| (b) Marginal band of scorch with necrotic patches over entire leaf | Sulphur |
| (c) General leaf chlorosis with outlines of midrib and veins green; no marked reduction in size, and no scorch | Manganese |
| (d) General leaf chlorosis becoming pale lemon to white in colour; sometimes tip scorch and necrotic spots on leaf | Iron |
| (e) Ill-defined patchy chlorosis, leaving large portions of leaf green in colour | Calcium* |

* Unlike the other deficiencies, calcium deficiency has no single distinctive feature common to the three cover plants.

SOILS, MANURING AND THE CORRECTION OF NUTRIENT DEFICIENCIES

Malayan soils have been grouped into three main classes for the purposes of formulating general fertiliser programmes:^{60, 63, 69}

1. COASTAL ALLUVIAL CLAY SOILS

Rubber growing on coastal alluvial clay soils in Malaya seldom responds to fertiliser applications; however, sufficient responses to the application of nitrogenous fertiliser have been recorded to recommend that trial application of ammonium sulphate or urea be made on alternate tree rows in a field, particularly in the first year after planting in order to judge the advisability of applying a nitrogenous fertiliser throughout immaturity.

2. INLAND LOAM AND CLAY LOAM SOILS

Responses on these soils are mainly to nitrogen and phosphorus applications, and in consequence the fertiliser mixture recommended contains high proportions of nitrogen and phosphorus with only low potassium and magnesium contents.

3. INLAND SANDY SOILS

On these soils marked growth responses to potassium as well as to nitrogen and phosphorus are found, and a higher proportion of potassium is recommended than with the inland loams and clay loams.

The above classification of Malayan soils is retained for two main reasons despite the fact that a more detailed description of the main soil types and their derivation is available: firstly because experimental evidence of fertiliser responses on all soil types is not available and secondly because the three groups of soils can be easily understood and recognised. Soil series descriptions as related to the above broad soil classifications are given in *Table 1*.

TABLE 1. Summary of the main rubber-growing soils of Malaya, according to Owen⁵³

| Soil texture classification | Soil series name | Parent material |
|-----------------------------|---|--|
| Coastal alluvial clay soils | Selangor Kelantan | } Coastal deposits |
| Inland sandy soils | Sungei Buloh Tampin Chemor | Riverine alluvium Granite Terraced alluvium |
| Inland loams | Serdang Kedah Rengam Malacca Seremban | } Quartzite and quartzite/shale Granite Phyllite/shale Schist |
| Inland clay loams | Kuantan Segamat Batu Anam Perak | Basalt Andesite Shale Riverine alluvium |

Fertiliser applications to *Hevea* can be conveniently divided into two groups: the routine or maintenance application and the special additional application that may be required to correct a nutrient deficiency.

While the main purpose here is to deal with the second type of manuring, it is evident that whenever a special fertiliser is required consideration should be given to the suitability and the levels of application of the routine fertiliser. The use of suitable routine applications should reduce the likelihood of any special applications being required.

The 'complete' (i.e. containing N, P, K and Mg) fertiliser mixtures (*Table 2*) employed in the programmes given below are based on the use of mixtures of ammonium sulphate, potassium chloride, rock phosphate and kieserite. Mixtures based on other fertilisers could be formulated as simple physical mixtures or as granulated products; a further possibility is the combination of the component fertiliser materials by chemical reaction to give a granulated complete fertiliser as is the case with the nitrophosphates. Any complete fertiliser, whether formed by mechanical mixing or chemical reaction, should be assessed on its composition and cost when compared with the recommended mixture; other factors, such as the rate of solution of the fertilisers and its availability for uptake, should also be considered.

Routine fertiliser applications – immature rubber

Routine fertiliser applications are not intended to remedy particular deficiencies but are used to maintain vigorous tree growth and also soil fertility; a general fertiliser programme for immature rubber, based upon the results of fertiliser experiments, has been available in Malaya since 1953.⁶⁰ The programme was modified, in 1958⁶³ and again in 1963,⁶⁹ and the programme outlined in *Table 3* is based on data obtained from fertiliser experiments during the period 1937–63.^{3, 4, 19, 22, 39, 59} This programme is intended as a general recommendation for use on the majority of inland soil types, and is not meant to be rigidly adhered to under all conditions. It may be found that the recommended fertiliser applications will be inadequate for optimum growth on soils of low fertility, and the general field conditions and fertiliser history should be considered when preparing a fertiliser programme. The value of fairly generous fertiliser applications to ensure rapid growth of immature rubber, particularly during the first two years after planting or budding, is well established. Where there are vigorous pure leguminous creeping covers, regular fertiliser applications may not be required after the first two years. These covers give a very high return of nutrients, mainly of nitrogen and potassium, in the third and subsequent years after planting, with a consequent danger of excessive branching and leaf growth that may result in stem bending⁶⁶; in such cases a reduction or even complete cessation of fertiliser applications in the third, fourth and possibly also the fifth year might be justified. Trees with normal balanced growth should continue to be manured according to the programme.

TABLE 2. Composition of fertiliser mixtures in common use on rubber in Malaya
In parts per 100 by weight of individual fertiliser, and also in percentage nutrient content

| R.R.I.M. mixture | Ammonium sulphate (21% N) | Christmas Island rock phosphate (36% P ₂ O ₅) | Potassium chloride (60% K ₂ O) | Kieserite (26% MgO) | % N | % P ₂ O ₅ | % K ₂ O | % MgO |
|--------------------------|---------------------------|--|---|---------------------|------|---------------------------------|--------------------|-------|
| Magnesium M | 42 | 45 | 5 | 8 | 8.8 | 16.2 | 3.0 | 2.1 |
| Magnesium C ₂ | 62 | 24 | 6 | 8 | 13.0 | 8.6 | 3.6 | 2.1 |
| Magnesium X | 40 | 40 | 12 | 8 | 8.4 | 14.4 | 7.2 | 2.1 |
| Magnesium Y | 51 | 29 | 12 | 8 | 10.7 | 10.4 | 7.2 | 2.1 |

TABLE 3. Fertiliser programme for *Hevea brasiliensis*⁶⁹

| Time of application | Inland loams and clay loams | | | | Inland sandy soils | | | | | |
|--|--------------------------------|-----------|---------------------------------------|--------------------------|--------------------|---------------------|-----------|---------------------------------------|--------------------------|-------------|
| | Fertiliser mixture | N (oz) | P ₂ O ₅ (oz) | K ₂ O (oz) | MgO (oz) | Fertiliser mixture | N (oz) | P ₂ O ₅ (oz) | K ₂ O (oz) | MgO (oz) |
| <i>Seedlings and basket plants</i> | | | | | | | | | | |
| In planting hole | 4 oz rock phosphate | — | 1.5 | — | — | 4 oz rock phosphate | — | 1.5 | — | — |
| 1 month } after planting | 4 oz Magnesium M | 0.35 | 0.65 | 0.12 | 0.08 | 4 oz Magnesium X | 0.34 | 0.58 | 0.29 | 0.08 |
| 3 months } after planting | 4 oz " " | 0.35 | 0.65 | 0.12 | 0.08 | 4 oz " " | 0.34 | 0.58 | 0.29 | 0.08 |
| 5 months } after planting | 4 oz " " | 0.35 | 0.65 | 0.12 | 0.08 | 4 oz " " | 0.34 | 0.58 | 0.29 | 0.08 |
| 8 months } after planting | 6 oz " " | 0.53 | 0.97 | 0.18 | 0.13 | 6 oz " " | 0.50 | 0.86 | 0.43 | 0.13 |
| <i>Field budgrafts and budded stumps</i> | | | | | | | | | | |
| 2 months } after budding or planting | 4 oz Magnesium M | 0.35 | 0.65 | 0.12 | 0.08 | 4 oz Magnesium X | 0.34 | 0.58 | 0.29 | 0.08 |
| 5 months } after budding or planting | 6 oz " " | 0.53 | 0.97 | 0.18 | 0.13 | 6 oz " " | 0.50 | 0.86 | 0.43 | 0.13 |
| 8 months } after budding or planting | 6 oz " " | 0.53 | 0.97 | 0.18 | 0.13 | 6 oz " " | 0.50 | 0.86 | 0.43 | 0.13 |
| <i>Clonal seedlings and budgrafts</i> | | | | | | | | | | |
| 12 months } after planting or budding | 8 oz Magnesium M | 0.70 | 1.30 | 0.24 | 0.17 | 8 oz Magnesium X | 0.67 | 1.15 | 0.58 | 0.17 |
| 15 months } after planting or budding | 8 oz " " | 0.70 | 1.30 | 0.24 | 0.17 | 8 oz " " | 0.67 | 1.15 | 0.58 | 0.17 |
| 18 months } after planting or budding | 8 oz " " | 0.70 | 1.30 | 0.24 | 0.17 | 8 oz " " | 0.67 | 1.15 | 0.58 | 0.17 |
| 24 months } after planting or budding | 12 oz " " | 1.06 | 1.94 | 0.36 | 0.25 | 12 oz " " | 1.01 | 1.73 | 0.86 | 0.25 |
| 30 months } after planting or budding | 12 oz " " | 1.06 | 1.94 | 0.36 | 0.25 | 12 oz " " | 1.01 | 1.73 | 0.86 | 0.25 |
| 36 months } after planting or budding | 24 oz " " | 2.11 | 3.89 | 0.72 | 0.50 | 24 oz " " | 2.02 | 3.46 | 1.73 | 0.50 |
| 42 months } after planting or budding | 32 oz Magnesium C ₂ | 4.16 | 2.75 | 1.15 | 0.67 | 32 oz Magnesium Y | 3.42 | 3.33 | 2.30 | 0.67 |
| 54 months } after planting or budding | 32 oz " " | 4.16 | 2.75 | 1.15 | 0.67 | 32 oz " " | 3.42 | 3.33 | 2.30 | 0.67 |
| 66 months } after planting or budding | 32 oz " " | 4.16 | 2.75 | 1.15 | 0.67 | 32 oz " " | 3.42 | 3.33 | 2.30 | 0.67 |
| <i>Mature clonal seedlings and budgrafts</i> | | | | | | | | | | |
| Once annually, applied in wintering period | 32 oz Magnesium C ₂ | 4.16 | 2.75 | 1.15 | 0.67 | 32 oz Magnesium Y | 3.42 | 3.33 | 2.30 | 0.67 |

Routine fertiliser applications – mature rubber

No general fertiliser recommendations for mature rubber in Malaya have been published. This situation is very largely due to the difficulty of carrying out enough long-term experiments to cover all conditions; fertiliser response varies according to soil type, to the previous fertiliser and tapping history, and to the age and condition of the trees, so that any general recommendation must be based as much on sensible agricultural practice as on the response that is likely to be obtained. Since the majority of fertiliser experiments show a level of yield response that is more than sufficient to repay the cost of fertiliser application, it is considered sound practice, on the inland soil types of Malaya, to apply 2–3 lb of an N, P, K, Mg fertiliser per mature tree annually, up to ten years before replanting. In general no fertiliser is required for trees on coastal alluvial clays, but if the trees carry sparse foliage of a yellow-green colour and the drainage is not to blame, annual dressings of 2 lb per tree of ammonium sulphate may be of benefit.

Manuring of leguminous cover plants

Leguminous cover plants may show a marked response to phosphatic fertiliser applications, particularly in the first year after planting.^{41, 83} At sowing the seed is mixed with rock phosphate and the drills given a liberal dusting of the same fertiliser; thereafter the covers are dusted as a routine at intervals with rock phosphate, a total of 2 cwt per acre being applied in the first year and 1 cwt per acre in the second year after planting. Further dressings are unlikely to benefit the cover appreciably, but will of course build up the soil phosphorus content with eventual benefit to tree growth. Basic slag is an alternative phosphatic fertiliser that might be used in the first year after planting, at similar weights, with some advantage⁸³ in early growth.

There are indications that magnesium limestone applications result in improved growth and persistence of the leguminous covers⁸³: considering the low magnesium status of Malayan soils and the ease with which magnesium is lost by leaching, the application of magnesium limestone at the rate 1–2 cwt per acre to covers would appear to be sensible agricultural practice. Where leaf and soil analysis, or visual diagnosis, have indicated low levels of soil magnesium, such a dressing could be confidently recommended.

It is probable that on coarse sandy soils a response would also be obtained to application of potassium fertilisers.

Legumes are known to have a particular requirement for molybdenum, and pot tests have demonstrated a response of *Pueraria phaseoloides* and *Centrosema pubescens* to molybdenum in soil culture.⁷⁸ However as, field trials have not shown a similar effect,⁶⁴ there seem to be no grounds at present for applying molybdenum or any of the other minor nutrients as a routine dressing to leguminous cover plants.

Special fertiliser applications for the correction of nutrient deficiencies in Hevea

It might seem obvious that whenever symptoms of a particular deficiency are observed the first and correct step would be to apply a fertiliser containing the nutrient found to be deficient. There are, however, instances where matters are not so straightforward, for example:

1. Excessive application of a fertiliser that depresses uptake of another nutrient may induce a deficiency of the latter element, e.g. excessive potassium application may induce magnesium deficiency in this way, and elimination of the potassium application will result in correction of the deficiency, without the need for any special application of magnesium fertilisers.
2. There can be cases where soil conditions render a particular nutrient unavailable, in which case soil application is likely to be ineffective (this is often the case with iron deficiency).
3. Instances of transient deficiencies that can be expected to disappear as root growth improves

are known (e.g. budded stumps frequently possess yellow leaves and look markedly deficient when root development is very poor).

4. A deficiency may be only slight and perhaps not affect tree performance appreciably, e.g. manganese deficiency symptoms can be readily corrected by manganese sulphate application, but as yet no yield responses have been recorded: thus the high cost of treatment with manganese sulphate would only be justified in cases of acute deficiency.

It can thus be seen that a general appraisal of the situation should be undertaken in all cases of nutrient deficiency. It would of course be preferable to carry out leaf analysis and a detailed examination of the soil when diagnosing fertiliser requirements of all fields, and wherever possible this should be done. In the absence of such an approach, and when expert advice is not immediately available, the planter should attempt to correct a deficiency which he has diagnosed rather than allow the condition to deteriorate. In the following sections some of the basic factors that need to be considered when deciding upon a course of remedial action are discussed.

Recommendations are given on pages 65-70 for the correction of specific deficiencies in *Hevea* by the application of fertilisers; the levels of application are those which could be expected to induce a marked improvement in the content of the deficient nutrient element in the tree.

Only the fertilisers in common use in Malaya are listed in the tables; other fertilisers that have been used or are likely to be used on rubber in Malaya are also mentioned. Calculation of equivalent weights of other fertilisers can be easily made, taking into account their composition and also the composition and weight of the fertiliser quoted in the individual tables.

Time of application of fertilisers

Routine maintenance application to immature rubber will follow the timetable dictated by the planting date: for mature rubber it is considered preferable to apply fertiliser during the wintering period when the leaves are falling from the trees, for subsequent absorption at the time of refoliation when the tree has a relatively large requirement for nutrients.

These considerations apply particularly to ammonium sulphate and potassium chloride, from which nitrogen and potassium respectively may be rapidly absorbed in a matter of three to seven weeks after application.⁷⁰ Absorption of phosphorus from rock phosphate, as measured by increases in the leaf phosphorus level, is considerably slower, taking several months. Special fertiliser applications for remedying nutrient deficiencies should in general be applied as soon as is convenient after the diagnosis of the problem. A delay in application would be preferred only in the case of mature trees which go through a wintering cycle; when the deficiency is diagnosed in the months immediately prior to wintering (in Malaya, November, December or January) it is recommended that remedial fertiliser applications should not be applied until the wintering period has commenced.

Method of application of fertilisers

When applying fertilisers it is necessary to spread them in such a way that they will eventually come into contact with the maximum number of roots: this means that in rubber cultivation broadcast applications are recommended and that, apart from the recommended planting hole treatment of 4 oz rock phosphate, placement of fertiliser in pockets in the soil is not recommended. In experimental work satisfactory utilisation of rock phosphate has been obtained from broadcast applications and pocketed rock phosphate has not been found to be more effective than broadcast.

The method of application of fertiliser is particularly important in the first few years after planting, when the rubber plant has only a limited root system. In the period up to five months after planting the fertiliser should be evenly distributed over a circular area of about 18 inches diameter immediately around the base of the young plant: subsequent applications should be applied to areas of steadily increasing size around the young trees until at eighteen months after

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planting the fertiliser is broadcast over the whole area of the planting strip. Where pure leguminous creeping covers are being circle-weeded around the trees, the fertiliser can be applied directly over the covers. When grasses and other weeds occur, however, they should be sprayed out before manuring. This method of application should continue at least until the fifth year after planting, and longer if leguminous covers persist in the inter-row areas: in mature areas with a closed canopy and very little ground cover the fertiliser should be broadcast to cover as large an area of the ground as is conveniently possible. In terraced areas the application must be restricted to the actual terraces, to avoid fertiliser being washed down the slope.

Magnesium deficiency

FERTILISERS: Magnesium limestone (18–21% MgO and 34% CaO) the mineral form of the double carbonate of magnesium and calcium ($\text{MgCO}_3 \cdot \text{CaCO}_3$), is locally available in Malaya; magnesium limestone is also known as Dolomite, after the eighteenth-century French mineralogist Dolomieu.

Kieserite, crude magnesium sulphate, $\text{MgSO}_4 \cdot \text{H}_2\text{O}$ (26% MgO), named after a nineteenth-century German doctor Kieser.

Rates of application of Kieserite and magnesium limestone to correct magnesium deficiency

| Age of tree (years) | Quantity per tree (oz) | | |
|---------------------|------------------------|---------------------|----------|
| | Kieserite | Magnesium limestone | MgO* |
| 0–3 | 4 | 8 | 1.0–1.7 |
| 3–5 | 8 | 16 | 2.1–3.4 |
| More than 5 | 16–24 | 32–48 | 4.2–10.1 |

* The smaller quantity of MgO represents that supplied by Kieserite, and the greater quantity that supplied by magnesium limestone.

Magnesium limestone has to be applied at approximately one and a half times the level of kieserite application in order to provide the same quantity of magnesium. In view of the fact that magnesium limestone may not be as quick acting as kieserite, it is recommended that the levels of application of magnesium limestone should be raised to double those for kieserite. In acid soils magnesium is fairly quickly brought into solution from magnesium limestone, but the higher levels of application of the cheap and easily available magnesium limestone should be maintained, particularly in view of the generally low magnesium status of Malayan soils and also in view of the losses of magnesium and calcium from the soil by leaching following the use of acidifying fertilisers.

More than one application of magnesium may be required, depending upon the severity of the deficiency; such a decision can only be made by visual diagnosis in the field or by means of leaf analysis. Magnesium deficiency symptoms on mature rubber normally appear during the period September to November, which is thus the best time in the year to decide whether previous applications of magnesium have been sufficient to correct the deficiency.

In areas of known low magnesium status, routine use should be made of a complete fertiliser containing kieserite regardless of any special applications for the correction of obvious deficiencies. This inclusion of kieserite can be regarded as a maintenance dressing, and is of value in balancing the potassium component of the fertiliser which will tend to depress magnesium uptake by the tree.

It is possible for magnesium deficiency to be induced by heavy applications of potassium even though the soil magnesium status may be satisfactory: consideration should therefore be given to the fertiliser history of rubber showing magnesium deficiency, and if applications of potassium far in excess of those shown in *Table 2* have been given, the first stage towards correcting the magnesium deficiency should be the deletion of potassium from the fertiliser programme.

The correction of magnesium deficiency in cover plants has already been described under 'Manuring of Leguminous Cover Plants.'

Potassium deficiency

FERTILISERS: Potassium chloride, KCl (50% and 60% K₂O), 'muriate of potash.'

Potassium sulphate, K₂SO₄ (48-52% K₂O).

The lower grade of potassium chloride (50% K₂O) contains approximately 83.5% KCl and 16% NaCl, while the higher grade (60% K₂O) contains approximately 96% KCl and 3.5% NaCl.

Potassium sulphate is normally the more expensive fertiliser, and accordingly potassium chloride is used almost to the total exclusion of potassium sulphate in rubber cultivation. As there are no reasons for considering sodium to be important in the nutrition of *Hevea brasiliensis*, the higher grade (60% K₂O) potassium chloride is preferred.

Rates of application of potassium chloride to correct potassium deficiency

| Age of tree (years) | Quantity per tree (oz) | |
|------------------------|--|------------------|
| | Potassium chloride (60% K ₂ O) | K ₂ O |
| 0-3 | 4-8 | 2.4-4.8 |
| 3-5 | 8-16 | 4.8-9.6 |
| More than 5 | 16-32 | 9.6-19.2 |

More than one application may be made, depending upon the severity of the deficiency and recovery of the trees following the first application.

It is also recommended that the routine fertiliser used should be one containing a high proportion of K₂O (*Table 1*).

Nitrogen deficiency

FERTILISERS: Ammonium sulphate, $(\text{NH}_4)_2\text{SO}_4$ (21% N).

Urea, $\text{CO}(\text{NH}_2)_2$ (45% N).

Other nitrogenous fertilisers include Nitro-Chalk (formed by granulation of ammonium nitrate with calcium carbonate (15% N)), ammonium chloride (26% N) and various ammonium phosphates (e.g. mono-ammonium phosphate (11% N and 48% P_2O_5) and di-ammonium phosphate (21% N and 53% P_2O_5)).

For rubber cultivation the choice of nitrogen fertiliser generally lies between ammonium sulphate and urea. The decision depends largely on the saving in transport costs per unit of N when using urea, and the likelihood of losing N from urea by decomposition on the soil surface and subsequent volatilisation of ammonia into the atmosphere. A study has been made of the conditions under which such losses may occur and perhaps outweigh savings in transport costs.⁸² The main conclusions were that urea may be safely used on any soil when it is forked in, and can be safely broadcast on heavy clay soils: urea may only be used economically on loam and sandy loam soils, or applied to a surface covered by leaf litter, when the soil is either quite dry or saturated with water after heavy rain.⁶⁸ If light rain follows application to a dry soil surface there is a danger that some loss may occur.

Rates of application of ammonium sulphate and urea to correct nitrogen deficiency

| Age of tree (years) | Quantity per tree (oz) | | |
|------------------------|------------------------|------|---------|
| | Ammonium sulphate | Urea | N |
| 0-3 | 4-8 | 2-4 | 0.8-1.7 |
| 3-5 | 8-16 | 4-8 | 1.7-3.4 |
| More than 5 | 32 | 15 | 6.7 |

Two dressings of fertiliser applied within a period of six months should be sufficient to raise the tree nitrogen content appreciably. Since nitrogen deficiency is usually associated with a general lack of plant vigour and is indicative of poor growing conditions, it is recommended that after these special applications the rates of application of the routine fertiliser be increased to one and a half times that given normally.

Phosphorus deficiency

FERTILISERS: Rock phosphates, hydroxy fluorapatites of the general formula $\text{Ca}_{10}(\text{OH},\text{F})_2(\text{PO}_4)_6$ from Christmas Island (36% P_2O_5 and 42% CaO), Florida (36% P_2O_5) and North Africa (27% P_2O_5).

Superphosphate (16–18% P_2O_5) and double superphosphate (approximately 40% P_2O_5).

Other phosphatic fertilisers include the various grades of ammonium phosphates, e.g. mono-ammonium phosphate (48% P_2O_5 , 11% N), di-ammonium phosphate (53% P_2O_5 and 21% N), and basic slag (19% P_2O_5).

In contrast to the findings on neutral or slightly acid soils in temperate climates, it has been found with the generally acid and iron-rich Malayan soils that rock phosphate, which is insoluble in water, and the water-soluble ammonium phosphate and superphosphate are about equal in their efficiency as phosphate fertilisers for rubber.⁸¹ These findings can be extrapolated to include other fertilisers containing soluble forms of phosphate, and the choice of fertiliser should be made purely on the basis of cost per unit P_2O_5 . The unit cost of phosphate derived from rock phosphate is normally considerably less than that from other sources, and so rock phosphate is the generally preferred fertiliser for rubber. Naturally, when using ammonium phosphate as a source of phosphorus its nitrogen content should also be taken into consideration.

Basic slag is mainly used for broadcast application to leguminous covers; its high cost per unit P_2O_5 and its alkaline nature make it unsuitable for use in fertiliser mixtures with ammonium sulphate and for use in the planting hole.

Rates of application of rock phosphate to correct phosphorus deficiency

| Age of tree (years) | Quantity per tree (oz) | |
|------------------------|------------------------|--------------------------|
| | Rock phosphate | P_2O_5 * |
| 0–3 | 8–16 | 2.9–5.8 |
| 3–5 | 16–32 | 5.8–11.6 |
| More than 5 | 32–48 | 11.6–17.4 |

* Calculated from Christmas Island rock phosphate (36% P_2O_5).

It is recommended that a special phosphate application is made once only. Care should be taken to ensure that excessive localised application of phosphatic fertilisers containing water-soluble phosphate are not made to young trees (under 2 years), owing to the possibility of inducing a temporary minor nutrient deficiency.

The correction of phosphorus deficiency in cover plants has already been described under 'Manuring of Leguminous Cover Plants.'

Manganese deficiency

FERTILISER: Manganese sulphate, $\text{MnSO}_4 \cdot 4\text{H}_2\text{O}$ (30-32% Mn).

Manganese deficiency symptoms on *Hevea* can be corrected by soil applications of manganese sulphate,^{65, 72} and the following rates of application are used in cases of severe deficiency. It is considered that when the deficiency is only slight immediate correction is not imperative. Lower grades of manganese sulphate containing less than 30% Mn may at times be available: if they are employed the quantities to be applied should be adjusted according to the Mn content.

Rates of application of manganese sulphate to correct manganese deficiency

| Age of tree (years) | Quantity per tree (oz) | |
|------------------------|-----------------------------------|-----------|
| | Manganese sulphate (30-32% Mn) | Mn |
| 0-3 | $\frac{1}{2}$ -1 | 0.16-0.31 |
| 3-5 | 2-4 | 0.62-1.24 |
| More than 5 | 4-6 | 1.24-1.86 |

It is recommended that the above special application be used on only one occasion; a second application should be given only in cases of persistent and severe deficiency, following field inspection and leaf analysis. A noticeable improvement in the condition of the foliage following the application of manganese sulphate can only be expected after approximately five months. When a small quantity of manganese sulphate is required it should be mixed with the routine fertiliser dressings to ensure even application over the ground.

Calcium deficiency

Symptoms of calcium deficiency on rubber and cover plants have been observed in Malaya, and it is possible that with continued cultivation calcium application will eventually be required on the more highly leached soils.

The regular use of rock phosphate (with a calcium content of 42% CaO) and the occasional use of magnesium limestone (34% CaO) and possibly also of basic slag, make it unlikely that any special application of lime will prove generally necessary on rubber in Malaya. When soil and leaf studies show a particular need, however, ground limestone (CaCO_3 , about 50% CaO) could be applied at rates of up to 10 lb per mature tree. Broadcast over the ground, such an application will only have a small effect on the soil pH and should not raise it above the level normally tolerated by rubber.

Copper and molybdenum deficiency

No cases of copper or molybdenum deficiency requiring correction had been found in Malaya up to 1963. In experiments on mature trees applications of 2.5–5 oz of copper sulphate per tree and 2–6 grams of sodium molybdate have been effective in increasing the copper and molybdenum status of the tree respectively⁷⁰: these applications are not recommended for use unless indicated as necessary after detailed investigations of the soil conditions and of the plant nutrient status by leaf analysis.

Boron, zinc, sulphur and iron deficiency

No cases of boron, zinc or sulphur deficiency requiring correction have yet been found in Malaya. While iron deficiency is found under a few particular soil conditions, it is unlikely that a long-lasting and economic remedy can be effected. Spray applications of ferrous sulphate (0.2%) and of iron chelates (0.1%) could be tried both on rubber and covers; it is expected, however, that only a temporary relief, in terms of a change in colour of the sprayed leaves (as a green spotting where the iron has been absorbed), will be obtained. It is usually found that the iron-deficient trees grow to a reasonable size, although slowly, once a good root system has developed sufficiently to exploit a large volume of soil.

APPENDIX

TABLE 1. Leaf composition of healthy and deficient *Hevea brasiliensis*
Top and second whorl leaves taken from seedlings: results expressed on a dry weight basis

| Nutrient | Healthy | | Deficient | |
|-----------|-----------|--------------|-----------|--------------|
| | Top whorl | Second whorl | Top whorl | Second whorl |
| % Mg | 0.24-0.26 | 0.17-0.24 | 0.05-0.16 | 0.02-0.10 |
| % K | 1.10-1.60 | 1.00-1.40 | 0.40-0.50 | 0.30-0.40 |
| % Ca | 0.38-0.51 | 0.76-0.82 | 0.11-0.20 | 0.14-0.21 |
| % N | 2.90-3.50 | 2.60-3.50 | 2.80-3.00 | 2.60-2.70 |
| % P | 0.20-0.28 | 0.16-0.23 | 0.12-0.17 | 0.12-0.14 |
| % S | 0.14-0.24 | 0.18-0.26 | 0.12 | 0.12-0.14 |
| p.p.m. Mn | 11-35 | 16-38 | 6-8 | 9-14 |
| p.p.m. Fe | 66-85 | 80-86 | 53-58 | 65-104 |
| p.p.m. B | 20-68 | 7-181 | 1.2-12 | 0.4-14 |
| p.p.m. Mo | 1.71 | | 0.07 | |
| p.p.m. Zn | 21* | | 14* | |
| p.p.m. Cu | 13 | | 3 | |

* Composite sample of leaves taken from top and second whorls.

The above data are taken from the published work of E. W. Bolle-Jones^{13, 14} and refer to leaves from which the midribs were removed and discarded, taken from seedlings material (Tjir 1) grown under various deficiency conditions in sand culture: the values indicate the nutrient levels in healthy plants and those in deficient plants. Apart from the manganese concentration, which is here very low, and the upper limit of the boron concentration in healthy second whorls which is here very high, the concentrations of the individual nutrients are very similar to those found in samples collected in the field.

TABLE 2. Leaf nutrient composition of healthy and deficient *Centrosema pubescens*, *Pueraria phaseoloides*, *Calopogonium mucunoides*

Leaves taken from terminal half of the bine: results expressed on a dry weight basis

| Nutrient | <i>Pueraria phaseoloides</i> | | | <i>Centrosema pubescens</i> | | | <i>Calopogonium mucunoides</i> | | |
|-----------|------------------------------|---------------------|--------|-----------------------------|---------------------|--------|--------------------------------|---------------------|--------|
| | Healthy | Deficiency Moderate | Severe | Healthy | Deficiency Moderate | Severe | Healthy | Deficiency Moderate | Severe |
| % Mg | 0.38-0.60 | 0.14 | 0.07 | 0.30-0.46 | 0.18 | 0.07 | 0.20-0.35 | 0.06 | 0.04 |
| % K | 1.50-2.30 | 0.60 | 0.40 | 1.30-2.00 | 0.94 | 0.55 | 1.30-2.20 | 0.35 | 0.33 |
| % Ca | 0.60-1.00 | 0.14 | 0.11 | 0.55-1.00 | 0.20 | 0.10 | 0.50-0.90 | 0.18 | 0.09 |
| % N | 3.50-4.20 | — | — | 2.70-5.00 | — | — | 4.2-4.6 | — | — |
| % P | 0.40-0.45 | 0.13 | 0.10 | 0.35-0.50 | 0.19 | 0.12 | 0.30-0.32 | 0.16 | 0.07 |
| % S | 0.35-0.90 | 0.16 | 0.10 | 0.50-0.70 | 0.18 | 0.09 | 0.30-0.90 | 0.22 | 0.10 |
| p.p.m. Mn | 50-100 | 18 | 8 | 50-100 | 16 | 5 | 30-120 | 9 | 7 |
| p.p.m. Fe | 200-600 | 90 | 72 | 60-200 | — | — | 150-420 | 100 | 70 |
| p.p.m. B | 38-57 | 10 | 8 | 25-30 | 3 | 2 | 30-50 | 4 | 2 |
| p.p.m. Mo | 0.50-0.96 | 0.20 | 0.06 | 0.30-0.75 | 0.17 | 0.16 | 0.20-0.90 | 0.06 | 0.01 |
| p.p.m. Zn | 22-35 | 12 | 10 | 20-25 | 16 | 7 | 17-90 | 22 | 13 |
| p.p.m. Cu | 12-18 | 7 | 5 | 18-20 | 12 | 6 | 8-10 | 5 | 3 |

The above analytical data refer to composite samples of leaves taken from plants growing under various deficiency conditions in sand culture experiments: the individual values indicate the levels of nutrients in healthy plants provided with all nutrients and those in deficient plants. It is possible that greater emphasis may come to be placed on leaf analysis of cover plants, in which case a more precise method of sampling (e.g. taking a particular leaf on the bine) than that used here will be required.

APPENDIX

TABLE 3. Variations in the nutrient composition of light and shade leaves⁷³
 Basal four leaves taken from terminal whorls: results expressed on a dry weight basis

| | n | Light leaves | Low leaves shade | Spur leaves shade |
|-----------|----|--------------|------------------|-------------------|
| % K | 30 | 1.12 | 1.54 | 1.47 |
| % P | 30 | 0.20 | 0.24 | 0.24 |
| % Mg | 30 | 0.22 | 0.30 | 0.30 |
| % N | 30 | 3.25 | 3.39 | 3.34 |
| p.p.m. Cu | 9 | 12 | 14 | 14 |
| p.p.m. Zn | 3 | 20 | 27 | 28 |
| p.p.m. Mo | 3 | 0.21 | 0.50 | 0.49 |
| % Ca | 30 | 0.70 | 0.58 | 0.58 |
| p.p.m. Mn | 30 | 137 | 109 | 108 |
| p.p.m. B | 3 | 93 | 51 | 53 |
| % S | 10 | 0.26 | 0.27 | 0.26 |

n is the number of fields sampled. Results expressed on dry weight basis. These data are a summary of an investigation, reported fully elsewhere,⁴⁹ of the variation in nutrient composition of leaves (including midribs) exposed to full sunlight at the top of the canopy (light leaves), of leaves taken from short branches of limited growth in the shade (spur leaves shade) and of leaves taken from any low branch in the shade (low leaves shade).

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