NUTRITIONAL DEFICIENCY SYMPTOMS OF TEAK (*Tectona grandis* Linn. F) SEEDLINGS

By
VIJU VARGHESE

THESIS

Submitted in partial fulfilment of the
requirement for the degree

Master of Science in Forestry

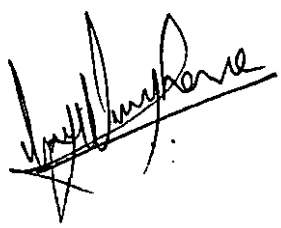
Faculty of Agriculture
KERALA AGRICULTURAL UNIVERSITY

Department of Silviculture and Agroforestry
COLLEGE OF FORESTRY
VELLANIKKARA, THRISSUR - 680654

1997

DECLARATION

I here by declare that this thesis entitled ***Nutritional deficiency symptoms of Teak (Tectona grandis Linn. f) seedlings*** is bonafide record of research work done by me during the course of research and that this thesis had not previously formed the basis for the award to me of any degree, diploma, associate ship, fellowship or other similar title of any other univsrsity or society.



VIJU VARGHESE

Vellanikkara,
9-06-1997

CERTIFICATE

Certified that the thesis entitled ***Nutritional deficiency symptoms of Teak (Tectona grandis Linn. f) seedlings*** is a bonafide record of research work done by Mr. Viju Varghese, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or accociateship to him.

Vellanikkara,
9 - 06 - 1997

Dr. K. GOPIKUMAR
Chairman, Advisory Committee
Associate Professor,
College of Forestry,
Vellanikkara, Thrissur.

CERTIFICATE

We, the undersigned members of the Advisory Committee of **Mr. Viju Varghese** a candidate for the degree of Mater of Science in Forestry, agree that this thesis entitled *Nutritional deficiency symptoms of Teak (Tectona grandis Linn. f) seedings* may be submitted by Viju Varghese in partial fulfillment of the requirement for the degree.

Dr. K. GOPIKUMAR
(Chairman, Advisory Committee)
Associate Professor
College of Forestry

Dr. A.I. JOSE
(Member, Advisory Committee)
Associate Dean
College of Forestry

Dr. LUCKINS C. BABU
(Member, Advisory Committee)
Associate Professor
College of Forestry

Dr. B. MOHAN KUMAR
(Member, Advisory Committee)
Associate Professor
College of Forestry

EXTERNAL EXAMINER

GRATITUDE

At this moment of fulfilment, my heart is overwhelmed with gratitude and I wish if these words could convey the feelings at present.

With great reverence and heartfelt gratitude, I would like to acknowledge the flawless guidance and propitious support of Dr. K. GOPIKUMAR, *Associate Professor, College of Forestry and Chairman, Advisory Committee with out which my work would not have been accomplished within the specific time limit. His critical suggestions and whole hearted encouragements, which made my endeavour bear fruits, is thankfully recollected. I once again expressing my deep respect and unfathomed obligation towards him.*

I extend my sincere gratitude to Dr. A.I. JOSE, *Associate Dean, College of Forestry and member of advisory committee for the valuable suggestions and constant inspiration rendered at different periods of my study.*

I express my sincere thanks to Dr. LUCKINS C. BABU, *Associate Professor, College of Forestry and member of advisory committee for timely help and valuable suggestions at different periods of my study.*

I place on record my sincere gratitude to Dr. B. MOHAN KUMAR, *Associate Professor, College of Forestry for facilities provided and valuable advice extended to me during the course of my study.*

I take this opportunity to extend my sincere thanks to Dr. N. K. VIJAYAKUMAR, Dr. K. SUDHAKARA and Dr. P.K. ASOKAN, Associate Professors, College of Forestry for their help and inspiring suggestions rendered during the course of this work.

Words can not express my gratitude to Sri. E.V. ANOOP, Assistant Professor, College of Forestry who helped me to widen my world and interests.

Thanks are also due to Smt. V.K. MALLIKA, Assistant Professor, College of Horticulture and Dr. P.A. WAHID, Professor, Radio Tracer laboratory, College of Horticulture, for providing necessary facilities for conducting the experiment at different periods of research work.

I am very much thankful to Dr. T. RADHA, Associate Professor, KHDP . Sri. A. AUGUSTIN, Assistant Professor, College of Horticulture and Dr. NANDAKUMARAN, Associate Professor, College of Veterinary and Animal Sciences for their sincere efforts to arrange all the facilities required for precise and timely conduct of chemical analysis.

I am very much indebted to all the staff members and non-teaching staff of College of Forestry for their sincere and whole-hearted co-operation through the course of my research work.

I am also deeply indebted to Mr. M.G. SURENDRAN, Mr. K. SATISHKUMAR and Mr. K.M. SUNIL, who were with me in field even during the odd hours of day and made my work momentous.

My sincere thanks are due to my beloved friends **VIMAL, SAJU VARGHESE, SUNIL KUMAR, MANOJ, JAYASHANKAR, CARMEL RANI, SMITHA, RESHMI** *and* **LAKSHMI** *who have contributed in some way or the other towards the completion of this work.*

The uninhibited and timely help by **Shri. B.N. NAGARAJ** *by way of the photographic work of the research work is warmly acknowledged.*

The study encountered no financial constraints for which the **JUNIOR RESEARCH FELLOWSHIP** *awarded by* **ICAR** *is duly acknowledged.*

I thank **Sri. K.C. SANTHOSH SAGAR**, *C/o. Zine graphics, Thiruvambady, Thrissur, for the neat and prompt execution of the typing works.*

My parents, brother and wife was always with me with their uninhibited moral support, blessings and boundless affection . I behold to them forever for all I am today and hope to be in future.

Last but no least, I bow my head before **THE ALIMIGHTY** *for enabling me to complete this endevour successfully.*

VIJU VARGHESE

Dedicated to my Family

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

Plate No.	Title
9.	Teak seedlings grown with nutrient solution lacking magenisum
10.	A leaf showing acute stage of magenisum deficiency
11.	Teak seedlings grown with nutrient solution lacking sulphur
12.	A leaf showing acute stage of sulphur deficiency
13.	Teak seedlings grown with nutrient solution lacking zinc
14.	A leaf showing acute stage of zinc deficiency
15.	Teak seedlings grown with nutrient solution lacking molybdenum
16.	A leaf showing acute stage of molybdenum deficiency
17.	Seedlings showing recovery of deficiency symptoms and improvement in growth after the application of complete nutrient solution

Introduction

INTRODUCTION

Teak (*Tectona grandis* Linn.f.) belongs to the family Verbenanceae, is a tree species of considerable economic importance. The chief importance lies in the fact that it is the principal timber tree of India and also one of the most important in the world. It is a large deciduous tree with rounded crown and a tall clean cylindrical bole, which is often buttressed at the base and some times even fluted (Troup, 1986)

Large scale plantations of teak are being grown in many parts of the country. In Kerala, teak is raised in plantations of the Forest Department over large areas. It is estimated that about 78,799 ha.of teak plantations are being maintained in Kerala (Forest Information Bureau, 1995). Despite its immense popularity and commercial importance, nutritional aspects of this species have seldom been studied, especially in the nursery stage.

The importance of mineral nutritoin in the production of healthy and vigorous seedlings in the nursery can not be over emphasized. The final performance of nursery stock largely depends on the nutrient composition of seed bed,soil or potting medium where the seedlings are grown. Severe nutritional disorders and deficiency symptoms have been reported in teak seedlings grown in Forest Department nurseries of Kerala, Tamilnadu, and Karnataka. The growth of seedlings had been also reported to be very poor in some private commercial nurseries.

The present study will help to characterise the importance of varoius nutrient elements in seedling nutrition of teak mainly based on the deficiency symptoms manifested as leaf discolouration,leaf area reduction, growth retardation, leaf

and stem deformation and poor root growth. The study will also establish a direct relation between nutrients applied and nutrients absorbed which in turn is responsible for the production of various nutritional disorders. This information will help to understand the importance of various nutrient elements on the growth of seedlings in the nursery. This in turn will enable the nursery men to produce healthy, vigorous seedlings of teak for varous commercial planting programmes. The visual symptoms of seedlings in the nursery is also expected to provide some guide lines to understand the nutritional disorders of teak even under the field conditions.

Hence, the present series of studies were undertaken to find out the visual deficiency symptoms of various nutrient elements to investigate the effect of nutrients on growth and vigour of teak seedlings and also to find out the uptake pattern of nutrients by seedlings grown in sand culture.

Review of Literature

REVIEW OF LITERATURE

Nutritional deficiency symptoms and disorders have been well studied and described in many tree species. However, most of these works are mainly limited to fruit plantation crops and spices. Though teak (*Tectona grandis* Linn.f.) is one of the most important timber species grown in India ; research information on the nutritiional aspects of this species is scanty. Literature pertaining to some of the most important nutritional aspects of tree species are reviewed and presented here under.

2.1.Role of mineral nutrient elements on plant growth and development

Apart from carbon, hydrogen and oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese, zinc, copper, molybdenum and boron are also recoganized as universally essential for plant growth and their development.

2.1.1.Nitrogen

Nitrogen is regarded as the fourth most abundant element in plants next to carbon, hydrogen and oxygen. Nitrogen content of the tissues was reported to control the use of carbohydrates and hence, determine whether the plant will produce vegetative or reproductive growth (Kraws and Kraybill, 1918). It is reported to be one of the most important structural constituents of the cell. Nitrogen containing compounds constitute 5 to 30 per cent of the dry weight of plants (Kramer and

Kozlowski, 1960). As much as 70 per cent of the leaf nitrogen is present in chloroplasts (Stocking and Origun, 1962). Ferrari and Varner (1969) reported that nitrogen as NO_3^- ions is involved in the activation of nitrate reductase enzyme. It plays an important role in the synthesis of proteins, chlorophyll and nucleic acids and is also associated with cell division and cell enlargment (Pandey and Sinha, 1972).

As a constituent of number of organic compounds including aminoacids,proteins,enzymes and cholorophyll,N is involved in various processes associated with protoplasm,enzymic reactions and photosynthesis (Gauch, 1972 and Greulach, 1973). Nitrogen has a major role in maintaining the phytochrome balance in plants. It favoured the synthesis of cytokinins in root meristems. An interruption in nitrogen supply enhanced the abscisic acid level and favoured leaf senescence in various tree species (Marschner, 1982).

2.1.2. Phosphorus

Phosphorus is known to be involved in photosynthesis associated with phosphorylation of various intermediates in CO_2 assimilation. In the two photochemical reactions occuring during photosynthesis, P is involved in the conversion of light into physiologically useful chemical energy by the formation of NADPH and ATP. Phosphate affects more directly the true photo chemical events of photosynthesis than does CO_2 (Arnon, 1959).

Phosphorus occurs as organic and inorganic forms and is translocated readily in both forms (Karmer and Kozlowski, 1960). Phosphorus is said to be essential for sugar starch transformation reactions in tree species (Edmond *et al.*, 1964). Phosphrous

is also a component of sugar phosphates, phytic acid and other components in plants (Evans and Sorger, 1966).

According to Pandey and Sinha (1972), P promotes healthy root growth and fruit ripening by helping translocation of carbohydrates. As a constituent of nucleoproteins, P constitute a major portion of protoplasm concerned with the cell division and the transfer of hereditory characteristics by the chromosomes (Gauch, 1972).

Like N, P also plays an important role as a structural component of the cell constituents and metabolically active compounds. Phosphorus acts as a structural component of the membrane system of the cell, the chloroplasts and the mitochondria. It forms the main part of the sugar phosphates - ADP, ATP, nucleic acids, nucleoproteins, purine and pyrimidine nucleotides, flavin nucleotides and several enzymes and co-enzymes (Greulach, 1973 and Agarwala and Sharma, 1976).

Phosphorus is reported to play a major role in energy metabolism of all living cells, even though the share of P is only 0.1 to 0.8 per cent of the total dry weight in plants (Epstein, 1978 and Jain, 1981). Marschner (1982) found that P favoured the movement of cytokinins from roots to other plant parts and hence, its deficiency resulted a decline in cytokinin content of tissues.

2.1.3. Potassium

Potassium is the only monovalent cation essential for all higher plants (Reed, 1942). It activates protein synthesis and N metabolism (Mulder and Bakema,

1956). It is an activator of the respiratory enzyme pyruvate kinase (Evans, 1963) and succinyl *COA* synthetase (Bush, 1969). Potassium also plays a role in the translocation of photosynthates from leaves to other portions of the plants (Spragu, 1964 and Hartt, 1969).

Although most plants require relatively large amounts of K, isolation of K containing compounds from plants has not yet become completely possible. More than 50 enzymes had been listed by Evans and Sorger (1966) which need K for maximal activitiy. Deficiency of K decreased starch synthesis as a result of reduced energy supply since K is necessary fo glycolysis, oxidative phosphorylation, photophosphorylation and for adenine synthesis (Evans and Sorger, 1966).

Potassium influenced stomatal opening and transpiration (Fischer and Hsiao, 1968). Potassium plays a prominent role in photosynthesis. Investigations have established the involvement of K in starch synthesis in various plant species (Murata and Akazawa, 1968 ; Nitsos and Evans, 1969 ; Rajput *et al.*, 1978). Pandey and Sinha (1972) observed that K is essential for the synthesis of chlorophyll, though it is not a constituent of chlorophyll.

Greulach (1973) stated that K deficiency may be expressed as water imbalance as this element is very important in regulating membrane permeability in plant cells. Ulrich and Ohki (1975) stated that the property of K to occur primarily in the ionic form or as charged particles on colioidal surfaces has made it most apt to function as a catalyst or as a co factor for many enzymatic reactions of the cell.

According to Agarwala and Sharma (1976) K increased the resistance power of plants to water stress , heat, pest and diseases. Potassium appears to be completely

water soluable in plants and is readily mobile within the plant tissues (Salisbury and Ross, 1977).

Capron *et al.* (1982) noted that though K activated synthesis of chlorophyll, an increased partitioning of K to the chloroplast in K deficient plants was the major reason for low substantial reduction in photosythetic rates during the initial stages of deficiency of this element .. Potassium was reported to have direct influence on cell division and higher cell number (Boringer and Schacherer, 1982). Marschner (1982) found that low K resulted in reduced transport of cytokinins from roots but enhanced ABA export to grains and caused accelerated senescence.

2.1.4. Calcium

Calicum is the major cation in the middle lamella and hence, supports the mechanical strength of tissues (Tagawa and Bonner, 1957 ; Cleland, 1960 and Rasmussen, 1967) Marinos (1962) reported that Ca is essential for the formation of cell membrane systems on which functional integrity and cellular metabolism are dependent.

Calcium is found to be immobile except when it is in xylem and is supposed to be very essential for root growth (Rios and Pearson, 1964). Paulson and Harper (1968) reported the involvment of Ca in metabolism. They concluded that Ca is involved in intra cellular transport of NO_2^- and not in the induction or activity of enzymes. Calcium provides a base for the neutralisation of organic acids and is essential for counteraction of metal toxicity. It also functions as an activator of enzymes like phosphatases, kinases and succinate dehydrogenases (Pandey and Sinha,

1972). It is an essential part of ∝ — amylase,a starch digesting enzyme in plant tissues (Salisbury and Ross, 1977).

Calcium ion itself is reported to be inactive, its activity being modified through a homologous class of Ca binding proteins. 'Calmodulin' is one among such proteins that control numerous key enzymes systems and cellular processes. The Ca-calmodulin complex bind the calmodulin dependent enzymes like NAD kinase thus turning them as active enzymes (Anderson and Cormier, 1978). Emanuelson (1984) has reported root development to have an exponential course at higher levels of Ca and was enhanced with increase in its concentration.

2.1.5. Magnesium

Magnesium is the sole cation present in chlorophyll and is constituting 2.7 per cent by weight of chlorophyll molecule. Thus, Mg plays a key role in photosynthesis. It is an activator of a number of enzymes including enolases, pyrophosphatases, hexokinases, carboxylases, phosphokinases, transketolases, fructokinases, glucokinases and pyrophosphorylases (Utter and Werkman, 1942 ; Bailey and Webb, 1944 ; Bailey and Webb, 1948 ; Dixon, 1949 and Mae, 1949). Magnesium plays a significant role as a co-factor required for oxidative de-carboxylation of pyruvic acid to form acetyl COA (Korkes *et al.*,1951).

According to Wallace and Muller (1962), there is a higher requirement for Mg at high temprature due to its significance in CO_2 fixation during photosynthesis. Magnesium also involved in various stages of fat and carbohydrate metabolism (Pandey and Sinha, 1972).

Magnesium is a constituent of chromosomes and plays a significant role in photosynthesis (Agarwala and Sharma, 1976). It acts as a carrier of P and helps in its sloubilisation (Ananthanarayan and Rao, 1979).

2.1.6. Sulphur

All plant proteins have S containing amino acids like cysteine, cystine and methionine. In many plants through the different amino acids, S participates in protein synthesis (Kramer and Kozlowski, 1960). Sulphur is essential for cell division and also for the synthesis of chlorophyll (Edmond *et al.*, 1964).

The importance of S is equal to that of N in its roll in protein synthesis and in total uptake it may exceed P by many times. Sulphur is a component of lipic acid, co-enzyme- A, thiamine, pyrophosphate, biotin, phosphosulphate and other compounds (Evans and Sorger, 1966). Thompson (1967) based on his studies on sulphur metabolism stated that from quantitative point of view the most important function of S metabolism in plants is to produce cysteine and methionine.

Sulphur deficiency causes poor quality crop products and is hence recoganised as a quality nutrient (Rajagopalan, 1987). It is found to enhance the efficiency of translocation of assimilates from leaf to fruits, particularly in annuals and vegetables (Thirumalaiswamy *et al.*, 1987).

2.1.7. Iron

Though Fe is described by various scientists as immobile inside the plant system, Branion and Jacobson (1962) and Brown (1965) have reported Fe to be

moderately mobile within the tissues. Foliar applied Fe was found to be translocated to meristematic tissue.

Iron exists as porphyrins in living cells. It acts as a catalyst and helps in electron carrier in respiration. The peroxidases, catalases and cytochrome oxidases which are widely distributed in plants are iron porphyrin containing enzymes that catalyse various chemical reactions. The transfer of electrons from substrates is mediated exclusively by the Fe porphyrin containing series of cytochromes (Nason and Mc Elory, 1963).

There exist non heme Fe proteins like ferrodoxine and mitochondrial Fe enzymes in plants (Burris, 1966). Iron actively participates in chlorophyll synthesis and much of the Fe in leaves is reported to be in the chloroplasts (Bogorad, 1966). Iron is reported to act as an activator of nitrate reductase and aconitase (Salisbury and Rose, 1978 and Alcaraz *et al.*, 1979) and played significant role in synthesis of nucleic acids and proteins.

2.1.8. Manganese

Manganese has been reported to act as an activator of carboxylase that catalyses assimilation of CO_2 that leads to the formation of di and tri-carboxylic acids. It is also directly involved in photosynthesis as an electron carrier participating in the reaction for release of oxygen (Mehler, 1951 ; Salisbury and Rose, 1978).

The highest concentration of Mn in plant cell is found in cytoplasm and the cell organelles and chloroplast is believed to be richest in Mn content (Levanidov, 1957). Manganese decreases the solubility of Fe by oxidation and hence, in certain cases

higher concentration of Mn leads to Fe deficiency in plants (Pandey and Sinha, 1972). Shkolnik *et al.*, (1975) has reported some of the hydrophytes and woody plants to be rich in Mn, which were related to their biochemical composition and were referred as manganophiles.

Manganese plays an important role in glycolysis and krebs cycle and hence its deficency results glucose accumulation. It is also essential for chlorophyll synthesis (Resh, 1978 ; Horiguchi and Fukomoto, 1987). Manganese content of various plant species exhibits wide varition and they show differential tolerance to Mn levels (Edwards and Asher, 1982).

2.1.9. Zinc

In most of the plants the concentration of zinc was found to be highest in leaves, generative organs and growth points compared to other parts (Riceman and Jones, 1960). Inside the cell, greater part of Zn occures in nuclei and mitochondria indicating its significant role in cell division (Kathore *et al.*, 1972).

Zinc is essential for the synthesis of tryptophane, a precursor for the synthesis of IAA, the principal hormone in higher plants (Tsui, 1948 ; Karmer and Kozlowski, 1960 ; Salami and Kenefick, 1970 ; Salisbury ans Ross, 1977). The large amount of tryptamine found in Zn deficient plants is an indication that Zn is absolutely essential for conversion of tryptamine to IAA (Takaki and Arita, 1986).

Epstein (1961) has reported Zn to have an apparent role in function of membranes. Zinc and Ca ions were found to regulate the ion transport across cell

membranes. Zinc is reported to be a constituent of carbonic anhydrase, lactic dehydrogenase and many respiratory enzymes (Price, 1962). Zinc plays a role in glycolysis and respiration being a constituent of many enzymes in these path ways (Nason and Mc Elroy, 1963) The respiration path ways strongly inhibited under inadequate Zn supply are due to decrease in activity of aldolase and a number of glycolytic enzymes (Shkolnik *et al.*, 1975).

Zinc is an essential constituent of alchohol dehydrogenase, alkaline phospatase and carboxy peptidase (Evans and Sorger, 1966). Zinc is found to be involved in the biosynthesis of porphyrins and haemo proteins, including cytochrome (Brown *et al.*, 1966). The involvement of Zn in nucleic acid metabolism is said to be the most important physiological role of Zn in living tissues. It is reported to be an integral part of RNA dependent DNA polymerases (Springate *et al.*, 1973). Deficiency of Zn serverly depressed the production of protein in meristamatic tissue resulting in accumulation of amino acids and amides (Kitagishi and Obata, 1986).

2.1.10. Copper

Copper plays a role in auxin metabolism which is evident from the high correlation existed between indole acetic acid content and activity of copper enzyme - as carbinate oxidase (Gamayunova, 1965). Nucleic acids and some nucleic acid precursors were found to have high affinity towards Cu ions. In many plant species biosynthesis of adenine, adenosine and adenosine monophosphates were enhanced by Cu ions (Okuntsov *et al.*, 1966).

A positive influence of Cu has been reported in building resistance to wilting in many plants. This effect is apparently related on the role of Cu in synthesising phenolic

inhibitor content in tissues (Prusakova, 1966). Chloroplasts of leaves contained more than 70 per cent of Cu and was found to be involved in bio-synthesis of proto-chlorophyll and Fe porphyrin complexes (Sorokina, 1967).

The nature and involvement of Cu in metabolic process is determined by the specific physico - chemical properties of this element. Copper ions reacts with amino acids, proteins and other polymers producing stable complexes and hence, was found to be more active than other metals. This also possess catalytic properties which were enhanced upon binding of this ion to protein molecule. Copper ions are reported to readily release or accept an electron, which accounts for the behaviour of Cu either as donor or as an acceptor of electrons in plant tissues (Frieden, 1968). According to Wishnick and Mildvan (1969), it was found to be a component in ribulose diphosphate carboxylase thus confirming its role in photosynthesis.

Endowed with the ability to change valency, Cu like Fe, Mn and Mo occupy central position in the mechanism of biological oxidation reduction reactions including those of respiration, photosynthesis and assimilation of molecular nitrogen (Shkolnik *et al.*, 1975).

2.1.11. Boron

Boron is neither a constituent of enzymes nor an activator. Starck (1963) stated that bulk of the B present in plants is mainly concentrated in cell walls. Although the exact physiological role of B is unknown, this element is said to be necessary for cell division, development of phloem and transport of plant hormones. In the absence of adequate supply of this element, the middle lamella of new cells develops poorly resulting break down of phloem tissues (Edmond *et al.*, 1964).

Lee and Arnoff (1967) reported that borate complex with 6- phosphogluconic acid; inhibiting the action of dehydrogenase and preventing the eventual synthesis of excessive quantities of phenolic acids will accumulate in B deficient plants resulting necrosis and death. The growth of vegetative shoots was observed to be retarted in B deficient plants due to the accumulation of pentose phosphate (Shkolnik and Illinskaya, 1975).

Lewis (1980) has illustrated the principle function of B in metabolism of phenolic acids and lignin biosynthesis and also in the mechanism of auxin action in the process of xylem development and differentiation. According to Pilbean and Kirkby (1983), the presence of B was found essential to maintain membrane structure and many of the deficiency symptoms were reported to be secondary effects caused by changes in membrane permeability.

3.1.12. Molybdenum

The requirement of Mo by plants is reported to be considerably lower than that of other trace elements. The highest requirement of Mo have been shown by plants of the family leguminosae (Hewitt and Jones, 1947).

The most significant physiological role of Mo is its involvement in N metabolism particularly in the reduction of nitrate and fixation of molecular N (Nichloas and Stevens, 1955). Molybdenum is important in energy metabolism and also stimulates respiration and phosphorylation (Hewitt, 1958).

According to Burkin (1968), Mo influenced the metabolism of vitamins in plants. A dramatic fall in ascorbic acid content occurred in Mo deficient plants.

Molybdenum also acts as a catalyst in various metabolic reactions (Shkolnik *et al.*, 1975). It forms complexes with RNA through phosphate groups (Ivchenko, 1981). He also reported that pectin metabolism has been influenced by Mo to some extent and a possible influence of Mo on cell membrance structure has also been observed.

2.2. Characteristic symptoms of deficiency of nutrient elements in tree species

2.2.1. Nitrogen

Visual symptoms of N deficiency has been described in various trees. Maskell *et al.*, (1953) reported stunted growth, yellowing of older leaves, dieback and reduced rate of leaf production in cocoa. Similar reports have been made in citrus (Jones and Embleton, 1959), coffee (Muller, 1966), avacado (Jones, 1975) and apple (Pant *et al.*, 1976).

Nitrogen being a mobile element, deficiency symptoms first appear on the older leaves (Gauch, 1972). The N deficiency resulted in chlorosis which generally reduced the rate of photosynthesis. Chlorosis was reported to be as a result of inadequate supply of N for chloroplast protein synthesis. Deficiency caused disproportionate amounts of secondary wall thickening due to carbohydrate accumulation that tend to make terminal growth slender and woody. Root growth was considerably better unless N was totally lacking in the media (Greulach, 1973).

Chlorosis, which was reported to be due to inadequate supply of N for chloroplast synthesis, was the most typical deficiency symptom in most of the tree species. The tissue analysis values for N were less firmly established compared to

other elements, because of wide variations in N level in a given plant in relation to plant parts, type and age of tissues, seasons and also due to its high mobility within the plant. However, tissue analysis values for indicating the deficiency, optimum and excess levels of N have been well developed for a number of temperate and tropical fruit tree species (Jones, 1975).

Pale green colour of older leaves which gradually changed to uniform yellow colour was the major symptom of N deficiency observed by cashew seedlings grown in nursery (Ohler, 1979 and Gopikumar and Aravindakshan, 1988). In white spruce, yellowing of needles and reduced height are typical symptoms of N deficiency (Hallett, 1985). Yellowing of older leaves, necrosis, premature leaf fall and substantial reduction in growth has been reported as symptoms of N deficiency in nutmeg (Philip , 1986).

According to Gopikumar and Aravindakshan (1988), visual deficiency symptoms such as leaf discolouration and stunting of growth of cashew seedlings associated with N deficiency was found to correlate with leaf content of this element. Similar observations were also made in cocoa seedlings grown in sand culture (Lockard and Asomaning, 1964).

Landis *et al.*, (1989) reported chlorosis of older leaves coupled with stunting of growth in seedlings of paper birch. They also noted that stunting due to N deficiency was usually easy to diagnose and subsequently to correct, because deficiency seedlings rapidly respond to application of N fertilizers. According to Driessche (1989), in Douglas-fir, the needles were pale yellow initially becoming brown at the tip and eventually dying while in white spruce the yellowing of needles finally lead to red or brown needle development.

Studies conducted in The College of Forestry, Vellanikkara , Thrissur, using *Ailanthus* seedlings showed that, N deficiency resulted in development of yellow chlorotic patches in the older leaves of seedling. At acute stages of deficiency, severe chlorosis of entire seedling followed by premature drying and defoliation was noticed (Anoop, 1993).

Nitrogen was reported to interact highly with several elements. In citrus, foliar level of Mg decreased with N deficiency (Lebanauskas *et al.*, 1958). They also found that uptake of Zn, Cu and B was improved by N deficiency. Antagonistic effect of N with P had been reported by Lockard and Asomaning, (1964) ; Smith (1966); Dewaard (1969) and Nybe (1986). The uptake of N was higher in the presence of S, indicating a positive interaction between N and S (Kandaswamy and Arulmozhiselvan, 1987).

2.2.2. Phosphorus

Varied symptoms were expressed by plants deficient in P. Haas (1936) observed dull bronze green older leaves with burned areas followed by shedding due to P deficiency in lemon and orange. In apple, P deficiency symptoms are expressed as small dark green leaves with bronze to purple tinge, sparse foliage and restricted branching (Wallace, 1953). Maskell, *et al.*, (1953) observed that P deficiency resulted in general stunting of cocoa plants. In older leaves, lose of green colour occurred in areas between the veins giving rise to a blotcky appearance and interveinal chlorosis. Lockard and Asomaining (1964) stated that in cocoa, reduced dry weight was noticed when P was deficient in tissues.

The element being mobile, lower leaves were the first to exhibit hunger signs. Phosphorous deficiency induced formation of anthocyanin pigmentation resulting in purple colouration (Muller, 1966 ; Gauch, 1972 and Resh, 1978). Childers (1966) reported restricted growth of root and shoot, small leaves with dull bluish green colour with purple tint followed by brown spotting and premature defoliation as the symptoms of P deficiency in avocado, citrus and strawberry. The lateral buds of P deficient plants remained dormant or sometimes dried resulting in reduced lateral shoots.

Phosphorus deficient plants accumulated carbohydrates to a higher level. Vascular tissues were found to be poorly developed and the nucleic acid synthesis was greatly reduced. The production of ATP, NAD and NADP was found to be reduced disrupting the metabolic path ways resulting in stunted growth of the plants (Greulach, 1973).

Swan (1971) observed remarkable difference in P deficiency symptoms in the two species of spruce studied. White spruce showed the characteristic stunting and purple leaf discolouration while red spruce, though stunted, exhibited no purpling. Bingham (1975) described the P deficiency symptoms in tree crops as slow growth and sparse foliage turning dull bronze to purple tinged resulting early dropping of leaves.

The root system of P deficient plants was found to be poorly developed. Length of primary and secondary roots was reported to be increased and that of tertiaries decreased in a study conducted by Narayanan and Reddy (1982). The dry weight decreased in 12 out of 14 species studied. Hormonal imbalance especially that of auxins and cytokinins was said to be the reason for increase in root elongation.

Hallett (1985) observed that in black spruce, primary needles, develop purplish tinge, a symptom called 'purple heart'. Bronze green lower leaves with purple and

necrotic blotches followed by defoliation has been described as symptoms of P deficiency in nutmeg (Philip, 1986).

Deficiency symptoms appeared first in the lower leaves indicating the mobile nature of P inside the plant. In the leaves of cashew seedlings when subjected to artificial P deficiency, a gradual transition from dark green leaves to bronze green was noticed (Gopikumar and Aravindakshan, 1988). Deficiency also caused reduction in height and leaf number in cashew, eventhough girth reduction was not considerable.

According to Driessche (1989) in Douglas-fir seedlings, phosphorus deficiency resulted in dull, greyish coloured foliage ; while in white spruce bright purple foliage, gradually turning darker was observed. Foliar deficiency symptoms of hard wood seedlings included the development of reddish- pink patches in red maple, general yellowing in white ash, marginal chlorosis in sugar maple and general chlorosis of the older leaves in paper birch (Landis *et al.*, 1989). In Ailanthus, phosphorus deficiency symptoms appeared first in older leaves as purple bronze patches. At later stages, these patches extended to the entire leaflet (Anoop, 1993).

Interaction of P with other elements had been reported by various workers. Phosphorus deficiency was found to be associated with a decrease in Mn (Lebanauska *et al.*, 1958) and N and Mg (Embleton *et al.*, 1958) content in tissues. According to Matsui *et al.*, (1977), P level was found positively correlated with Ca and Mg levels and negatively with K in apple. El-Gazzar *et al.*, (1979) after their experiments in orange, olive and guava have reported a positive relation between P and Mn and a negative trend with Fe and Zn whereas N and Cu remained without

much change. Phosphorus has been reported to interfere greatly with Zn and Fe uptake in many crop species (Gardner *et al.*, 1985). Philip (1986) has reported an increase in foliar concentration of N and Zn and a decrease in Mg and Mn in P deficient seedlings of nutmeg.

2.2.3. Potassium

Potassium being mobile inside the plant, the deficiency symptoms were first manifested on lower leaves. According to Eckstein *et al.*, (1937) in coffee, crowding of young leaves and darkening and irregular development of new growth were reported to be the characteristic symptoms of K deficiency. In coffee, Purseglove (1977) has observed scorching of entire leaf margins followed by defoliation when K was deficient in tissues. According to Muller (1966), necrosis of leaf margins of older leaves was the most conspicuous symptom of K deficiency in coffee. He also observed that K concentration was lowest near the leaf margins increasing gradually towards the midrib and K was readilly translocated from older leaves to younger growth.

Chapman *et al.*, (1947) described potassium deficiency symptoms in oranges as "fluting" or "tucking" of leaves with a variety of chlorotic spotting pattern. Potassium deficiency plants were found to produce and accumulate putriscine, a diamine that results necrosis in leaf lamina (Richards and Coleman, 1952). Evans and Murray (1953) described the K deficiency symptoms in cocoa as pale yellow areas with interveinal regions near leaf margins, quickly becoming necrotic. In cocoa, Lockard and Asomaning (1964) noted primary veins of older leaves first turning light green to yellow and then brown. The mid rib also was affected. They also noted that plants grown under K deficiency conditions were less severely stunted compared to those

grown under comparable deficiency levels of any other macronutrients. Leaf analysis of low yielders of mandarin with scorched leaves and non fruiting terminals showed more K and less Ca and Mg (Morchal and Laccevilhe, 1969).

The tip and marginal scorching of K deficiency in tree crops was reported by Ulrich and Ohki (1975). Development of necrotic older leaves associated with reduced height, number of branches and dry matter has been reported due to K deficiency in nutmeg (Philip, 1986). Acute deficiency of K in trees results in the entire plant showing typical symptoms including sèvere die back. Yellowing and necrosis of lower leaf tip which later spread to other portion of the leaves were the typical symptoms of K deficiency in cashew as observed by Gopikumar and Aravindakshan (1988).

In white spruce and Douglas-fir, K deficiency resulted in dull green seedling, lower needles turning purple at tips, then into yellow or brown (Driessche, 1989). According to Anoop (1993), in Ailanthus K deficient seedlings manifested chlorotic tips of the older leaves which in severe stages, turned completely chlorotic. Drying of terminal bud followed by death was also observed in many cases.

Potassium strongly antagonises with Ca and Mg (Cain, 1948 ; Smith, 1966; Dewaard, 1969 ; Hansen, 1970 ; Nybe, 1986 and Philip, 1986). Spiers (1987) reported reduced P, Ca and Mg uptake with increased K fertilization. In this study, high K content was found to decrease plant growth. Interactions involving K and other nutrients were studied by Tandon and Sekhon (1988). Potassium and Mg interactions were negative, which at times led to K induced Mg deficiency.

2.2.4. Calcium

In trees, Ca deficiency symptoms have been reported to appear first on roots. Root tips become slimy and turn black in cocoa (Murray, 1966). Lockard and Asomaning (1964) observed chlorotic symptoms in the first flushes of leaves immediately after germination in cocoa. However, no specific symptoms on leaves were noticed in the early stages of Ca deficiency (Chapman, 1975).

Being immobile inside the plant, deficiency symptoms are manifested on young leaves (Muller, 1966 and Chapman, 1975). This was followed by dieback of terminal buds. Franco and Mendes (1949) described the Ca deficiency symptoms in coffee as death of terminal buds and yellowing of leaf margins followed by browning and necrosis of margins of older leaves. In coffee, Muller (1966) observed the Ca deficiency as chlorosis of the youngest leaves. Light green to slightly yellowish chlorosis developed in the leaf margins and leaf tip and extended towards the midrib.

Lockard and Asomaning (1964) reported that seedling of tree species grown under Ca deficiency were more severely stunted compared to seedling grown under defeciency levels of N, P, K, Mg and S. According to Shear (1971) in apple, Ca deficiency was initially exhibited as cupping and chlorosis of developing leaves followed by necrosis of chlorotic area. Chapman (1975) reported dieback followed by chlorosis of leaves due to Ca deficiency in citrus.

Development of thick, brittle and small younger leaves with blunt end which later lead to crinkled appearance is the main symptom of Ca deficiency in nutmeg (Philip, 1986). In cashew, Ca deficiency did not produce any visual symptoms such as

leaf discolouration but growth of seedlings was found to be reduced (Gopikumar and Aravindakshan, 1988).

Calcium is reported to antagonise with K and Mg (Smith and Rasmussen, 1959 and Smith , 1966). High Ca was found to reduce leaf Mg, K, Na and P in citrus (Anderson and Martin, 1970). However, Lockard and Asomaning (1964) found that Ca deficiency did not affect significantly the levels of Mg or K in any plant part. Nybe (1986) has observed an increase in foliar K and Mg due to Ca deficiency in pepper. An incerase in levels of K, Mg, and Na and decerase in B was found to be associated with Ca deficiency in nutmeg (Philip, 1986).

2.2.5. Magnesium

Magnesium is mobile within the plant systems and hence, the deficiency symptoms first appear on older leaves (Embleton 1975 and Resh, 1978). In apple, older leaves of current season's growth appeared to develop green or grayish - green blotches between veins often extending upto margins. Under acute deficiency, fruits failed to ripen normally on tree, and were small, poorly coloured without any flavour (Wallace, 1953 and Wood bridge, 1955). The first sign of Mg deficiency noticed by Bull (1954) in African oil palm was the development of olive green area on leaves with no sharp boundary between lateral veins.

Boynton and Erickson (1954) reported that in cocoa, symptoms first appeared on older leaves as interveinal chlorosis and necrosis. Necortic spots frequently increase in size, join and progress to leaf margins resulting in premature defoliation. Magnesium deficiency increased the level of K in the leaves and Ca

in the roots and stems of cocoa (Lockard and Asomaning, 1964).

Embleton (1975) observed that Mg deficiency symptoms first appeared on older leaves. Characteristically there was a loss of green colour between the veins followed by cholorosis or development of brilliant colours.

In avocado, general chlorosis with veins remaining green, followed by dead lesions scatterd over the entire blade was the characteristic symptom of Mg deficiency (Bingham,1960). Magnesium deficiency in coffee was characterised by the development of olive green chlorosis near the midrib and laterals which gradually progressed towards the leaf margin (Muller, 1966). Abnormal K-Mg ratios in soil and leaves are supposed to be the factors causing deficiency of this element. Leaf fall was also reported to be accelerated by Mg deficiency (Sadowski *et al.*, 1976).

In black spruce, yellow tipped needles were observed due to deficiency of Mg (Hallett,1985). Pale yellow discolouration of midrib of older leaves followed by pale green, lemon and necrotic blotches towards margin, with upward cupping were the major symptoms of Mg deficiency in nutmeg (Philip, 1986). Severe inter veinal chlorosis of the older leaves was observed in cashew seedlings grown in sand culture due to the deficiency of this element (Gopikumar and Aravindakhan, 1988).

Inter veinal chlorosis was found to be the characteristic symptom of Mg deficiency in the seedlings of paper birch, a hard wood (Landis *et al.*, 1989). In norway spruce, Mg deficiency resulted in needle yellowing (Schaaf and Zech, 1993). In Ailanthus, Mg deficiency produced typical visual symptoms of interveinal chlorosis with reticulate pattern. In acute stages, these chlorotic patches between the

green, midrib and veins developed necrosis (Anoop, 1993).

The antogonistic effect of Mg with K and Ca has been reported by Emmert (1961) ; Dewaard (1969) ; Manicot *et al.*, (1980) and Nybe (1986). Magnesium deficiency was associated with a decrease in foilar concentration of Zn and Mn. However, foliar concentration of N, P, Fe and B in leaves was not affected by any level of Mg even under severely deficient conditions (Smith, 1966).

2.2.6. Sulphur

Though S is not a constituent of chlorophyll unlike N, it is reported to be very essential for the synthesis of chlorophyll (Eaton, 1975) and hence, it is very difficult to differentiate between N and S deficiencies, under conditions of diminishing supply of either element. Sulphur deficiency is best identified by determining the N/S ratio rather than S concentration in vegetative tissues (Rasmussen *et al.*, 1977). In nutrient solution lacking S, the newly formed youngest leaves in coffee show a uniform light green colour later turning to a more intensive chlorosis (Lott *et al.*, 1960). In coffee typical yellowing of the youngest leaves was observed due to deficiency of S (Muller, 1966).

Sulphur deficiency resulted in phloem breakdown, decrease in cambial tissues and an increase in leaf thickness . Increase in thickness of fibre, xylem and collenchyma cells has also been reported in many plants (Hewitt, 1963). Cocoa plants deficient in S were found to record significantly lower dry weight compared to treatments deficient in other macroelements, except Ca (Lockard and Asomaning, 1964). Childers (1966) reported that in fruit plants like apple, pear and grapes the

top most leaves on the shoots were first effected by S deficiency.

According to Gauch (1972) in many plants uniform yellowing of the youngest leaves was the characteristic symptom of S deficiency . Nybe (1986) studied the deficiency symptoms of S in pepper and reported initial symptoms of S deficiency appeared as pale green to silvery white discolouration of the younger leaves finally turning to uniform yellow.

Increase in foliar N and P was observed due to S deficiency in nutmeg (Philip, 1986). In cashew, the early symptoms of S deficiency appeared as pale green to greenish yellow discolouration of younger leaves which later turn to uniform yellow (Gopikumar and Aravindakshan, 1988). Small necrotic spots appeared on the affected leaves followed by the development of necrotic areas.

In Douglas-fir, S deficiency resulted in yellow needles like N deficiency but severe needle twisting was a distinguishing feature while in white spruce there was no obvious symptoms early in season, later needle extremities become golden particularly near shoot apex (Drieessche, 1989).

In Ailanthus, discolouration of leaves which advanced from the margin inwards was the initial symptom of S deficiency. This was followed by necrosis of the yellow areas and in the acute stage of deficiency the entire leaf became chlorotic (Anoop, 1993).

2.2.7. Iron

Iron is immobile in plant tissues and hence, the younger leaves are first affected by iron deficiency (Resh, 1978). However, the studies conducted by Branton and

Jacobson (1962) demonstrated the moderate mobility of Fe in plants. Deficiency manifests as intervenial chlorosis of leaves which in severe cases make the entire leaf blades yellow to whitish yellow (Gauch, 1972).

In cases of slight chlorosis, the general pale colour of leaves could be indistinguisable from N or Mg (Haas, 1942 and Wallihan, 1955). However, in lemon, leaves showing inter veinal chlorosis of an intermediate degree is reported to be a characteristics symptom of Fe deficiency (Wallihan, 1955). Childers (1966) reported that in fruit plants like avocado, citrus and strawberry, Fe deficiency appeared as a network of green veins on a yellowish green background. Severely affected leaves turned yellow and showed marginal and tip burning.

Iron chlorosis is a common disorder in forest nurseries and some species are found to be very sensitive for this (Bunt, 1976). In severe cases, the entire seedling becomes chlorotic and the disorder is almost impossible to correct at this stage (Hewitt, 1963). The entire younger needles were turning chlorotic in jackpine (Hallett, 1985). Straw coloured young flush with inter veinal chlorosis which later developed necrotic patches on leaf has been reported as the iron deficiency symptom in nutmeg (Philip, 1986) . He also observed size reduction and down ward cupping of leaves in Fe deficient plants. In white spruce needles turned pale green with yellow tips while in Douglas - fir, terminal needles were pale green to white with occasional spiraling of needle tips (Driesseche, 1989).

Iron is found to interact with several elements. High N, P and K have been reported in Fe deficient leaves of coffee (Muller, 1966). In citrus, Fe deficiency was reported to be associated with high content of N and low content of Ca in

leaves (Smith, 1966). Iron deficient plants of cocoa recorded very low content of element in roots compared to stems and leaves as stated by Lockard and Asomaning (1964). The Fe content in roots was redistributed to stems and leaves under its deficiency conditions. High foliar P, Zn and Mn and low K and Ca in leaves were associated with Fe deficiency in nutmeg (Philip, 1986).

2.2.8. Manganese

Manganese is an immobile element in the plant tissue (Shkolnik *et al.*, 1975 and Resh, 1978). Symptoms of Mn deficiency are well defined in most of the plants and if not masked by other deficiency or toxicity, tissue analysis to determine the Mn status is usually unnecessary (Lebanauskas, 1975).

In apple, leaves show interveinal chlorosis, beginning near margins and progressing towards the midribs (Wallace, 1953). In mango, leaves develop a yellowish green background with a fine network of green veins. Mature leaves deficient in Mn are thicker than normal, often with very blunt tips (Smith and Scudder, 1951). The fruit plants like citrus, walnut and plum produced small leaves with chlorosis between the main veins followed by die - back of twigs and branches under conditions of Mn deficiency (Childens, 1966).

Muller (1966) reported youngest leaves to be first affected by Mn deficiency in coffee. Affected leaves showed typical chlorosis with coarse reticulation. Similar observations have been made in mango by Agarwala *et al.* (1988). Manganese deficient plants exibited a reduction in chloroplasts resulting in low concentration of chlorophyll (Hofman, 1967).

Manganese at high levels has been reported to be toxic in various tree species. In citrus, toxicity symptoms were manifested as marginal yellowing and necrotic spots on leaves followed by excessive leaf fall. Tree growth and croping was also found to be greatly reduced (Ishihara *et al.*, 1968 and 1971).

In sandal, the younger leaves turned yellow and became brittle as the leaves expanded (Kamala *et al.*, 1986). Later, these leaves developed irregular patches and paired at some internodes and grew unequally. The seedlings died at severe stages. Application of Mn resulted in maximum height growth in *Dalbergia latifolia* followed by *Lagerstroemia lanceolata* and *Terminalia alata* (Kamala and Angadi, 1986).

Development of pale yellow chlorosis, water soaked necrosis, reduction in leaf size and torn off leaves were symptoms of Mn deficiency in nutmeg (Philip, 1986). Inter veinal chlorosis of younger leaves was the first visual symptom of Mn deficiency observed in cashew seedlings (Gopikumar and Aravindakshan, 1988) As the intensity of deficiency increased, chlorosis spread almost completely in the interveinal portion, making the major veins and laterals more pronounced.

Visual symptoms of Mn were also reported in tropical forests tree species by Kamala *et al.* (1988). In rose wood, chlorotic areas were observed between the veins of the leaves. Leaves became brittle with margins rolling and there was shortening of internodes. Deficiency of Mn resulted a reduction of leaf area, chlorophyll activity and photosynthetic efficiency in the leaves of *Cassia siamea*, *Eucalyptus tereticornis*, *Pterocarpus marsupium*, *Swietinia mahogany*, *Azadirachta indica*, *Dalbergia latifolia*, *Santalum album*, and *Tectona grandis*, as observed by Angadi *et al.* (1988).

According to Driessche (1989) in white spruce, slight grey colour coupled with reduced growth rate were the characteristic symptoms observed due to Mn deficiency. In the case of Douglas-fir, Mn deficiency resulted in overall reduction in growth of the seedlings while colour of the needles remained normal.

Shive (1941) and Somer and Shive (1942) reported Fe - Mn antagonism and a low Fe to Mn ratio in plant tissues to cause oxidation of ferrous ion to ferric form making it unavailable to plants. Manganese induced Fe deficiency has been reported in various tropical tree species (Hewitt, 1963 and Agarwala *et al.*, 1986).

2.2.9. Zinc

Typical inter veinal chlorosis termed as 'mottled leaf', reduced internodal length and 'little leaf' are the common symptoms of Zn deficiency (Gruelach, 1973 and Chapman, 1975b). This was reported to be largely due to inadequate supply of IAA as a result of Zn deficiency.

The Zn content in the plant tissues was found to range from 20 ppm to 10200 ppm (Holmes, 1944). Zinc deficiency was often associated with high content of N and K and low Ca in leaves (Smith, 1966). Foliar Zn absorption was said to be increased by higher Mn concentration but reduced by Fe and Ca in most of the plants (Arora *et al.*, 1970).

In many trees, root growth was found to be reduced by Zn deficiency (Mallik and Singh, 1959 and Millikan, 1963). Muller (1966) observed that due to Zn deficiency in coffee, the network of veins became elevated above the leaf surface and became dark green.

Lockard and Asomaning (1964) stated that in cocoa Zn deficiency inhibited plant growth to the highest extent compared to other micronutrients. In cacao, the width of leaf decreased progressively with the intensity of Zn deficiency and showed a high ratio of length to width (Murray, 1966). In citrus, Nair *et al.* (1968) decribed the visual symptoms of Zn deficiency as mottled-leaf, reduced leaf size and dieback of terminals.

Rosetting in apple is reported as mainly due to an imbalance of Zn nutrition (Naumov *et al.*, 1977). Little leaf, rosette and intervenial chlorosis of the younger leaves with a network of dark green veins were reported to be visual symptoms associated with Zn deficiency in pepper (Nybe, 1986). Marked reduction in inter nodal length, leaf area and drymatter has been reported due to Zn deficiency in nutmeg (Philip, 1986).

In sandal, Zn deficiency resulted in younger leaves turning yellow and subsequently becoming brittle as leaves expanded (Kamala *et al.*, 1986). Unequal growth at the internodes followed by stunting was also observed. In *Pterocarpus marsupium*, Zn application resulted maximum height increment compared to other nutrients (Kamala and Angadi, 1986). Angadi *et al.* (1988) observed that in most of the tree species except teak and mahogany the reduction in leaf area was the least in case of Zn defciency. Photosynthetic efficiency was also found to be less due to Zn deficiency in all the species except in the *Cassia siamea* and *Dalbergia latifolia*.

In mango, Zn deficiency was first noticed on young and middle leaves. These leaves turned olive green in colour and developed irregular brown spots near the tip (Agarwala *et al.*, 1988). Reduced internodal length, retarded terminal

growth and production of small leaves with inter veinal chlorosis were the symptoms of Zn deficiency noticed in cashew (Gopikumar and Aravindakshan, 1988). Inter veinal chlorosis with reduced inter nodal distances and progressively smaller new foliage were the symptoms observed in rose wood. Stunting of growth was also observed in *Cassia siamea* and *Azadirachta indica* (Kamala *et al.*, 1988).

Driessche (1989) reported spiraling of pale terminal needles and stunting of growth in Douglas-fir due to Zn deficiency. Apical needles were found to be twisted together and were clorotic. In white spruce, stunted growth with occasional dead needle tips towards shoot apex was the characteristic symptom observed due to Zn deficiency (Driessche, 1989).

2.2.10. Copper

Copper being immobile in plant system, the deficiency symptoms were first exihibited by new growth (Muller, 1966 and Resh, 1978). In most of the plants Cu deficiency has been reported to cause dieback of twigs and growing points (Anderson, 1932). Chlorosis, dieback of terminal shoots and shortening of internodes are the most common symptoms found in many plants (Reuther and Lebanauskas, 1975). Copper deficiency is reported to occur mainly when the seedlings are grown in peat based growing media (Landis *et al.*, 1989).

Lockard and Asomaning (1964) noticed development of small swellings above the node after the shedding of the small and immature leaf in plants of cocoa deficient in Cu. They also noticed that growth of cocoa seedlings was not affected significantly by the deficiency of Cu when grown in sand culture. Copper deficient plants recorded low osmotic pressure due to low level of sucrose and hence

are highly vulnerable to meteorological changes (Mizuno *et al.*, 1983). The leaf tip became dry, curled up and shows the deformation and dropping. Leaves also showed a marked decrease in moisture content.

Production of twisted chlorotic needles was the characteristic symptom of Cu deficiency observed in spruce (Hallett, 1985). Inter venial chlorosis, reduced size of new flush, downward cupping of leaf margins, coupled with reduced height and total dry matter production are the symptoms reported in nutmeg due to Cu deficiency (Philip, 1986). According to Kamala *et al.*, (1986), in sandal , Cu deficiency resulted in the development of white patches at the tip of the older leaves which gradually spread to other parts.

In *Pterocarpus marsupium*, the new leaves were found curling. The leaf size was reduced followed buy cupping of leaves (Kamala *et al.*, 1986). Inward curling of leaf edges and browning of tips which later spread to the entire leaf resulting in their death were the symptoms obsereved in rose wood. Copper deficiency significantly reduced the leaf areas, chlorophyll activity and photosynthetic efficiency in the leaves of most of the tropical tree seedlings (Angadi *et al.*, 1988).

In Douglas-fir seedlings grown in peat based growing media, Cu dificiency resulted in yellowing or chlorosis of needles. The needles were often twisted with spiralling of the terminal end (Driessche, 1989). In *Eucalptus nitens*, serious malformation of tree stems and branches was observed after seventeen months of planting in an improved pasture site in southern Tasmania. The concentration of Cu in the foliage was significantly lower in malformed trees compared to healthy ones (Turnbull *et al.*, 1994).

Physiological functions of Cu in plants are intimately associated with the type of interactions between Cu and other mineral elements. Antagonism was reported to occur between Fe and Cu (Gamayunova and Ostrovskaya, 1964). In Citrus, Cu deficiency had been found to be associated with high foliar N, K and low Ca content (Smith, 1966). Interaction between Ca and Cu was reported by Zhizhevskaya, (1972) in various plant species

2.2.11. Boron

Since B is highly immobile in plant tissues deficiency symptoms first appear on terminal growth (Muller, 1966 and Resh, 1978). Boron deficiency results in the degeneration of the meristematic tissues, including the cambium, breakdown of the walls of parenchyma cells and feable development of the vascular tissues (Bradford, 1975). Rosetting of terminal growth, die back, discolouration, thickening and brittling of leaves, curling, wrinkling and chlorosis are some of the general symptoms of B deficiency in various tree species.

Downward cupping of leaves and reflexing of leaf tips were the deficiency symptoms reported in cocoa (Maskell *et al.*, 1953). In addition to curling and twisting of leaves normally caused by B deficiency, numerous brown spots were also observed on the young leaves of cocoa (Lockard and Asomaning, 1964). Small young leaves with leathery texture, irregular leaf margin, and reduced internodal length were the results of B deficiency in coffee (Muller, 1966).

Boron deficiency in most of the plants was manifested when the tissue content was within the range of 15 to 20 ppm (Bradford, 1975). Boron deficiency in *Eucalyptus grandis* seedlings appeared first in the young apical leaves, resulting

wrinkling. As deficiency advanced, leaf blades became leathery and fragile, especially near the leaf apex (Rocha Filho *et al.*, 1979). In *Eucalyptus globulus*, the earliest visible sign of B deficiency was the upward cupping and rolling of leaves. Under acute conditions, development of leaves was impaired, resulting in the production of leaves with parts of the lamina missing (Dell and Malajczuk, 1994).

Tree seedling deficient in B showed a reduction in leaf area, decrease in chlorophyll content and photosynthetic efficiency of the leaves compared to plants grown in complete nutrient solution (Angadi *et al.*, 1988). Kamala *et al.* (1988) reported the presence of brown spots on the chlorotic leaves of rose wood. They also observed yellowing and development of wavy margin and conical shape of the leaves in *Pterocarpus marsupium*. This was followed by blackening of the leaf tip and margin. White spots with reduction in leaf size was the characteristic symptom observed in *Cassia siamea*. In *Azadirachta indica*, white and yellow spots developed in the leaves due to deficiency of B.

In mango, depressed growth, mild chlorosis, marked reduction in the length and width of the middle leaves were reported to be the common symptoms of boron deficiency (Agarwala *et al.*, 1988). At severe stages, the apex of the main stem turned black and necrotic and further growth was completely checked. In Douglas-fir, stunted growth with few branches coupled with reduction in needle size was the characteristic symptoms observed due to B deficiency (Driessche, 1989). In white spruce, he noticed stunted growth with poorly developed terminal buds. Apical needles were also short, twisted and necrotic.

Boron deficient plants had higher levels of P, Mg, Ca, Zn, and Mo . This demonstrates the antagonistic relation of B with other elements. In citrus, B deficiency was associated with high P and Mg and low K content in leaves (Smith, 1966). A decrease in foliar N and P was found associated with B deficiency in nutmeg (Philip, 1986).

2.2.12. Molybdenum

Plants growing in acidic soils usually exhibit Mo deficiency (Burkin, 1968). The initial symptoms of Mo deficiency appeared on younger leaves as yellowish green or pale orange interveinal spots. The Mo deficiency eventually results in poor flowering and fruting (Shkolnik *et al.*, 1975).

In orange and grape fruit, Mo deficiency first appeared as water soaked areas, subsequently developed into large interveinal chlorotic spots. These spots were bright yellow in colour and hence the name "Yellow-spot" has been given for this disorder (Vanselow and Datta, 1949). Lemon seedling grown in solution culture, developed rough textured and mottled leaves. At severe stages, the mottled spots became necrotic, enlarged and extended to margins resulting the edges to curl. These necrotic leaves usually drop off (Stewart and Leonard, 1952 and Hewitt, 1956).

Hewitt (1963) reported development of rough textured and mottled leaves in lemon. Lockard and Asomaning (1964) observed that in cocoa, when Mo was deficient, growth was least in terms of dry weights and leaf area compared to other trace element deficiencies. However, Mo deficient treatments did not reduce the tissue content of this element in any plant part studied.

The flowers produced under Mo deficiency usually lose their ability for anthesis. Severe disturbances in the formation of reproductive organs, especially in the development of pollen grains had been reported in various tree species (Agarwala *et al.*, 1979). Nutritional aspects of sandal was studied by Kamala *et al.*, (1986) and observed curling of leaves with older leaves showing cupping and formation of brown patches as defeciency of Mo.

Addition of Mo resulted maximum height increment in *Terminalia alata* while it was minimum in *Dalbergia latifolia* (Kamala and Angadi, 1986). Reduced leaf area, chlorophyll activity and Photosynthetic efficiency were observed in seedlings grown under Mo deficiency conditions (Angadi *et al.*, 1988).

Curling of the leaves was the characteristic symptom of Mo deficiency in various tropical tree species studied. Curling was associated with reduction in leaf size in *Dalbergia latifolia*. Necrotic areas were found to develop along the lamina but retaining the green veins. Chlorotic leaves with curled margins were the characteristic symptoms of Mo deficiency noticed in *Azadirachta indica*. In the leaves of *Cassia siamea*, white and black patches were developed while sickle shaped small leaves were produced in *Pterocarpus marsupium* (Kamala *et al.*, 1986).

Molybdenum and Al have been reported to be antagonistic in most of the tree species (Millikan, 1948). Barrocio (1962) observed synergism between Mo and K. Candela *et al.*, (1957) has reported that excess Mn will adversely affect the growth of plants suffering from Mo deficiency. Ishihara *et al.* (1968) in their studies using various plant species observed anagonostic relation between Mo and N

2.3. Diagnostic methods for detecting nutritional deficiencies and disorders in tree seedlings

Normally, diagnosis of the nutritional problems is more essential for the nursery managers to make sound decisions concering profitable and most effective use of manures and fertilizers (Pritchett, 1979 and Landis *et al.*, 1989). General diagnosis implies the determination of the nutritional status of the sites or trees (Bowen and Nambiar, 1984). This is very essential to make a qualitative appraisal of nutrient or nutrients limiting the growth. But, more often it is important to know how severe the deficiency is and also to predict the response to given quantities of nutrients applied to correct it (Evans, 1982 and Bowen and Nambiar, 1984).

The most common methods of diagnosis are based on visual symptoms, plant tissue analysis, soil analysis, pot cultures, bioassays, field trials and using indicator plants (Pritchett, 1979). Among these techniques, some have proved more useful and informative in certain situations compared to others and all have their own merits and demerits Hence, it is prudent to use a range of techniques for these types of studies (Gentle and Humphreys, 1984).

Visual growth symptoms have been studied and explained in many forest tree species and it had proved a useful method in diagnosing severe nutrient deficiencies Leaf (1968) pointed out that most of the essential nutrients perform such funtions in the tree that a characteristic symptom generally develops if one of the element is missing or deficient . Most of the visual growth symptoms were described based on observation on seedlings grown under stress in pots or sometimes on the basis of field experience (Binns *et al.*, 1980).

The deficiency symptoms of tree seedlings developed in pot studies do not always have an application under field conditions. Furthermore, visual symptoms of deficiencies developed in the field may be difficult to interpret because of environmental interactions climatic and soil conditions and also due to disease and insect problems (Pritchett, 1979).

Visual symptoms of deficiency or toxicity have been induced in several tree crops using sand and solution culture method (Will, 1961 ; Ingestad 1963 and Swan, 1972). Boussingault (1856) is believed to be the first to introduce the idea of growing plants in sand culture. Use of synthetic nutrient solutions for sand culture was first reported by Knop (1965). Hoagland (1919) attempted to provide the nutrients in amounts which resembled those in soil solution. Later, a nutrient formula was devised by Arnon and Hoagland (1940) and was subsequently modified by various workers to suit for various tree species. Leaf symptoms, stem malformations and changes in morphology and appearance are useful in qualitative diagnosis, but they are often readilly apparent only after the deficiency had already resulted in a reduction of growth or in malformation (Mead, 1984).

Generally, incipient deficiencies of many nutrients result mild chlorosis which make precise diagnosis difficult particularly in the case of micronutrients (Landis *et al.*, 1989). Visual symptoms varied with the intensity of deficiency or with tree species or even provenances and sometimes deficiency symptom of one element may be masked by another where multiple deficiencies occur (Walker, 1956 ; Leaf, 1968 ; Erdmann *et al.*, 1979 ; Pritchett, 1979 and Binns *et al.*, 1980).

Diagnosis on the basis of leaf colour relies on relationships between growth and pigmentation and also with leaf chemistry. These types of leaf discolourations were used to differentiate between deficiencies and or the degree of nutrient stress. Swan (1971) reported that infra red photography did not distinguish between the various macro nutrient deficiencies in conifer seedlings.

Lunkkonen *et al.* (1971) used Munsell colour charts to assess nutritional disorders in *Picea abies* seedlings and Haase (1984) reported good correlations between narrow band width reflectance, spectral intensity ratios and leaf N concentrations for a number of crops including citrus and avocado trees. Kamala *et al.* (1988) demonstrated that the presence and/or absence of a particular band in the zymogram of the peroxidase isoenzyme pattern in seedlings of *Dalbergia latifolia*, *Pterocarpus marsupium*, *Cassia siamea* and *Azadirachta indica* could be taken as a diagnostic index for nutritional deficiencies . This was particularly useful in sandal because the deficiency could be detected much before the manifestation of visual symptoms.

Diagnostic techniques based on visual symptoms often combined with plant tissue analysis are expected to give reliable information. The rationale behind the latter was that the concentration of nutrients or other extracts within a specified tissue reflects the nutritional status of that plant part and thus its growth potential (Princhett, 1979 and Marschner, 1986).

In tissue sampling, various tissues were used for determining nutrient uptake and distribution in trees. These include petioles, bark, latex, phloem, fruits or rootlets, but for most species tissue analysis refers to foliage analysis (Pritchett, 1979). In tree crops, foliage analysis is popularly used because it has proved to be reasonably sensitive for detecting deficiencies and also had the advantage of being directly related to productivity as foliage is the site of photosynthesis (Mead, 1984). The use of soil analysis for the estimation of nutritional deficiency was reported by Pritchett (1979), Evans (1982) and Alban (1984). However, in most of the tree crops, foliar deficiency symptoms along with tissue and soil analysis are mostly used for the detection of nutritional deficiencies and disorders.

Materials and Methods

MATERIALS AND METHODS

The present investigations relating to the nutritional deficiency symptoms of *Tectona grandis* Linn.f. seedlings were carried out in College of Forestry, Kerala Agricultural University, Vellanikkara during the period 1994 -1996. The study included two main parts ; the first part dealt with the induction of various nutrient deficiency symptoms in seedlings grown in sand culture while the second part aimed at diagnosis of these symptoms through analysis of growth behaviour and tissue nutrient status including chlorophyll content. An attempt was also made to find out the extent of recovery of nutrient deficiency symptoms in seedlings after the application of the concerned nutrient elements which were deficient earlier.

3.1. Development of nutrient deficiency symptoms

To induce the deficiency symptoms in the seedlings of *Tectona grandis*, sand culture experiments were carried out under controlled conditions inside a glass house attached to the College of Horticulture, Kerala Agricultural University main campus, Vellanikkara.

3.1.1. Preparation of sand

Pure quartz silica sand of 250 mesh obtained from ***M/s. Usha Mini Chem Industries, Bangalore*** was used for sand culture studies. The sand was first washed with tap water and then soaked in dilute hydrochloric acid for eight hours. The sand was then washed thoroughly with tap water and subsequently with deionized water until it became chloride free.

3.1.2. Preparation of experimental material

Seeds of *Tectona grandis* were collected from thirty five to forty year old plantations of ***Nilambur Forest Division, Kerala.*** Good quality uniform seeds were subjected to alternate wetting and drying for five days. After this seeds were spread in sand beds. The seeds were covered uniformly with a thin layer of sand. The seed beds were kept moist by regular watering.

Two months old seedlings of uniform growth in respect of height, collar diameter and leaf number were selected for the study.

Plastic containers of height 20cm, with a diameter of 18cm at the top and slightly tapering to 12cm at the base were used for the experiment. The containers were rinsed with dilute hydrochloric acid and then washed with deionised water. A drain hole plugged with a pad of lead free glass wool was also provided at the bottom of each container.

The containers were filled with acid washed sand to one-fourth of the volume prior to planting of seedlings. The seedlings were removed from the sand bed and the sand and soil particles adhering to the roots were washed off first with tap water and subsequently with deionised water.

After placing the seedling in the centre of a pot, the container was filled with acid washed sand leaving two and half inch space from the top. The pots were arranged on concrete benches inside the glass house at a distance of 10cm from one another (Plate 1).

Plate 1. Seedlings arranged for sand culture studies inside the glass house

The experimental seedlings were supplied with complete Hoagland No.2 (1948) nutrient solution for a period of one month till they established well in the sand. Before imposing the nutrient treatments, the sand was completely flushed with deionised water repeatedly for three to four times to wash away the nutrient residues.

3.1.3. Treatment details

The details of various treatments tried for the present study are furnished below.

1. Complete Hoagland nutrient solution
2. Nutrient solution lacking nitrogen
3. Nutrient solution lacking phosphorus
4. Nutrient Solution lacking potassium
5. Nutrient Solution lacking magnesium
6. Nutrient Solution lacking sulphur
7. Nutrient solution lacking zinc
8. Nutrient Solution lacking molybdenum

The chemical composition of complete Hoagland No.2 (1948) nutrient solution is given in table 1. From the stock solution, the required quantities of each nutrient as mentioned above were pipetted and made up to one litre. The nutrient solutions required for each treatment were carefully prepared in bulk by eliminating the desired nutrient from the stock. Analytically pure chemicals (AR grade) were used for the preparation of the solutions. Fresh nutrient solutions were prepared every week. Iron was added separately in order to avoid

Table 1.The composition of Hoagland No.2 (1948) nutrient solution

Complete solution (Stock solution)	Quantity pipetted (ml/litre) (Working solution)
$NH_4 H_2 PO_4$ (IM)	1
KNO_3/KCl (IM)	6
$Ca(NO_3)_2$ / $CaPO_4$ (IM)	4
$MgSO_4 . 7H_2O$ / $MgCl_2 . 6H_2O$ (IM)	2
Boric Acid (2.86g/l)	1
$MnCl_2 . 4H_2O$ (1 81 g/l)	1
$ZnSO_4 . 7H_2O$ / $ZnCl_2$ (0.28 g/l)	1
$CuSO_4 . 5H_2O/Cu(NO_3)_2 . 3H_2O$ (0.08g/l)	1
Molybdic acid (0.02 g/l)	1

precipitation when mixed with solution containing other nutrient elements. Every alternate day 50 ml of nutrient solution along with 2 ml of 0.1 per cent iron sulphate solution was added to each plant. On other days, 50 ml of deionized water was supplied to each pot.

The experiment was laid out in completely randomised design (CRD) with three replications and the total number of potted seedlings for the study was 360.

3.2. Diagnosis of nutrient deficiency symptoms

3.2.1. Visual symptoms

The seedlings were observed daily for the appearance of symptoms of nutrient deficiencies. The time taken for the manifestation of various visual symptoms was recorded and colour photographs were also taken.

3.2.2. Growth behaviour of seedlings

3.2.2.1. Shoot growth parameters

Observations were recorded on the following shoot growth parameters after imposing the teatments.

3.2.2.1.1. Height

The height of the individual seedling was measured from the soil surface upto the growing point using a scale at fortnightly intervals.

3.2.2.1.2. Collar diameter

The collar diameter of the individual seedling was measured using a vernier calliper at fortnightly intervals.

3.2.2.1.3. Number of leaves and leafarea

The number of leaves produced by the seedlings was recorded at fortnightly intervals. Leaf area was also found out using leaf area meter.

3.2.2.2. Root growth parameters

The following root observations were made at monthly intervals by taking representative samples from each treatment.

3.2.2.2.1. Root length

The length of the main root from collar to the tip was measured and expressed in centimeters.

3.2.2.2.2. Root number

The number of secondary roots araising from the main root was counted and recorded.

3.2.2.3. Fresh and dry weight

The Seedlings uprooted at monthly intervals for recording the root parameters were then separated into stem and root portions. These were cleaned free of dust and the fresh weights of stem and root were recorded separately.

These were then dried in cross flow air oven at $70^{o}C \pm 2^{o}C$ till constant dry weights were obtained. The dry weights of stem and roots were recorded separately using a precision balance.

3.2.3. Chemical analysis of leaf tissues

The following chemical analysis were carried out using experimetnal seedlings.

3.2.3.1. Chlorophyll content

Three seedlings from each treatment were uprooted at monthly intervals for analysis of the chlorophyll content of the leaves. The chlorophyll content of the leaf was estimated specro photometrically in a known aliquot of acetone (80 per cent) extract. The absorbance of the extract was measured at 645,663 and 652 nm for the estimation of chlorophyll- A, chlorophyll- B and total chlorophyll. The following formulas suggested by Starner and Hardley (1967) were used for the estimation of different fractions of chlorophyll.

$$\text{Chlorophyll - A} = 12.7\ (\text{Abs. at } 663\text{nm}) - 2.69\ (\text{Abs. at } 645\text{ nm}) \times \frac{V}{1000 \times W}$$

$$\text{Chlorophyll - B} = 22.9\ (\text{Abs. at } 645\text{ nm}) - 4.68\ (\text{Abs. at } 663\text{nm}) \times \frac{V}{1000 \times W}$$

$$\text{Total Chlorophyll} = 20.2\ (\text{Abs. at } 645\text{nm}) + 8.02\ (\text{Abs. at } 663\text{nm}) \times \frac{V}{1000 \times W}$$

Where

Abs = absorbance

V = Final volume of chlorophyll extract

W = Fresh weight of the leaf extract in grams

3.2.3.2. Nitrogen

Nitrogen was determined at monthly intervals by digesting 0.25 g of the samples in 5ml concentrated sulphuric acid and the nitrogen content in the digest was estimated by microkjeldhal distilation method (Jackson, 1958).

3.2.3.3. Phosphorus

Phosphorus was determined in a known aliquot of the acid extract colorimetrically by Vanado-molybdophosphoric yellow colour method (Jackson, 1958). The yellow Colour was read in a spectrophotometer at a wavelength of 470 nm.

3.2.3.4. Potassium

Potassium was estimated in a known volume of the acid extract using a flame photometer .

3.2.3.5. Calcium

Calcium was estimated at 422.7nm in diacid extract using Atomic Absorption Spectro photometer.

3.2.3.6. Magnesium

This was also estimated in Atomic Absorption Spectrophotometer at 285.2 nm using a known volume of the diacid extract.

3.2.3.7. Sulphur

Sulphur was estimated turbidometricaly at 400nm using diacid extract in presence of Ba Cl_2 (Jackson, 1958).

3.2.3.8. Zinc

Zinc was estimated using Atomic Absorption Spectro photometer. Zinc content in diacid extract was measured at a wave length of 213.9 nm using the hollow cathode tube.

3.3. Recovery studies

At the end of four months, after imposing various treatments representative seedlings from each replication showing nutrient deficiency symptoms were selected for the recovery studies. The nutrient element which was deficient earlier was supplied through complete Hoagland nutrient solution. The improvement in the growth of the seedlings and recovery of leaf discoluration was recorded . All the growth observatons made earlier were repeated here also. At the end of the study, these seedlings were analysed for various chemical constituents as per the standard procedures described earlier.

3.4. Statistical analysis

All the observations recorded were statistically analysed using analysis of various techniques as suggested by Panse and Sukhatme. (1978).

Results

RESULTS

The results relating to the study of nutrient deficiency symptoms of *Tectona grandis* Linn.f. seedlings grown in sand culture are described here under in various heads namely visual deficiency symptoms, growth behaviour of seedlings, chlorophyll content of leaves, tissue nutrient concentrations and recovery of deficiency symptoms.

4.1. Visual deficiency symptoms

The visual deficiency symptoms of seedlings grown in complete Hoagland nutrient solution and in nutrient solution lacking various nutrient elements are described below and depicted in plate 2.

4.1.1. Complete nutrients

The seedlings that received all nutrients through complete Hoagland nutrient solution were found to be very vigorous and healthy in growth and produced dark green normal shaped foliage throughout the period of study. These seedlings did not show any visual symptoms of deficiency.

4.1.2. Nitrogen

The symptoms of nitrogen deficiency appeared by the end of the first month after the commencement of treatment. During the initial stages, yellow patches appeared towards the margins in the older leaves. Later the entire lamina turned

Plate 2. Teak seedlings grown with nutrient solution lacking various elements

1. Control Seedling
2. Seedling lacking nitrogen
3. Seedling lacking phosphorus
4. Seedling lacking potassium
5. Seedling lacking magenisum
6. Seedling lacking sulphur
7. Seedling lacking zinc
8. Seedling lacking molybdenum


1
2
3
4
5
6
7
8

pale yellow. Stunting of seedlings was also noticed at this stage. In the acute stages of deficiency , the entire seedling appeared severely chlorotic compared to control (Plates 3 and 4). The completely chlorotic leaves gradually started premature drying also.

4.1.3. Phosphorus

Symptoms of phosphorus deficiency appeared roughly two months after the treatments were imposed. The first symptoms were appeared on oldest leaves. Initially purple bronze patches on the leaves which later changed to yellow chlorotic patches were observed (Plates 5 and 6). The new leaves were pale in colour. Gradually the bronze patches extended towards the entire leaf resulting premature defoliation. At the end of the study, the seedlings had sparse foliage and were stunted in growth compared to control.

4.1.4. Potassium

Deficiency symptoms of potassium started appearing by third month after the initiation of treatments. The symptoms were first manifested on the lower leaves. The leaves had chlorotic tips at the beginning. These chlorotic areas gradually spread through the margin upwards. The entire leaf developed chlorotic symptoms. The necrosis progressed from the lower part of the chlorotic leaves. This stage was noticed during the fifth month of starting the treatment (Plates 7 and 8).

4.1.5. Magnesium

Magnesium deficiency symptoms were noticed from the 50th day onwards. The older leaves produced small chlorotic areas during the initial stages of deficiency. Characteristic chlorotic pattern between the veins was noticed here. However, the midrib and veins remained green (Plates 9 and 10). At acute stages,

Plate 3. Teak seedlings grown with nutrient solution lacking nitrogen

1. Control Seedlings
2. Seedling lacking nitrogen

Plate 4. A leaf showing acute stage of nitrogen deficiency


1
2

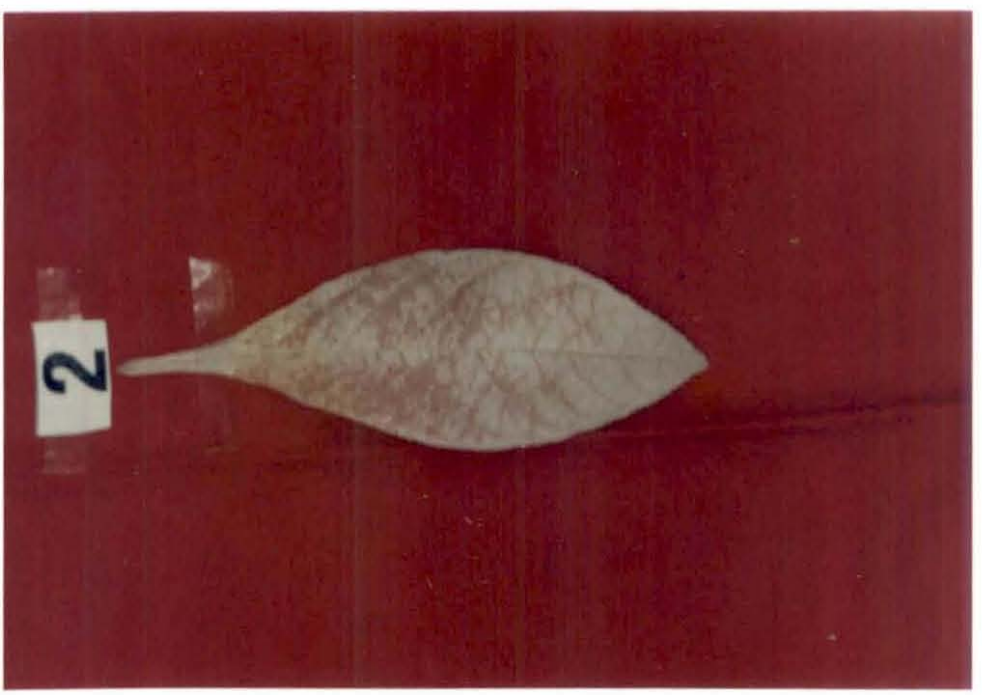

2

Plate 5. Teak seedlings grown with nutrient solution lacking phosphorus

1. Control Seedling
3. Seedling lacking phosphorus

Plate 6. A leaf showing acute stage of phosphorus deficiency


3
1
3


3

Plate 7. Teak seedlings grown with nutrient solution lacking potassium

1. Control Seedling
4. Seedling lacking potassium

Plate 8. A leaf showing acute stage of potassium deficiency


4
1
4

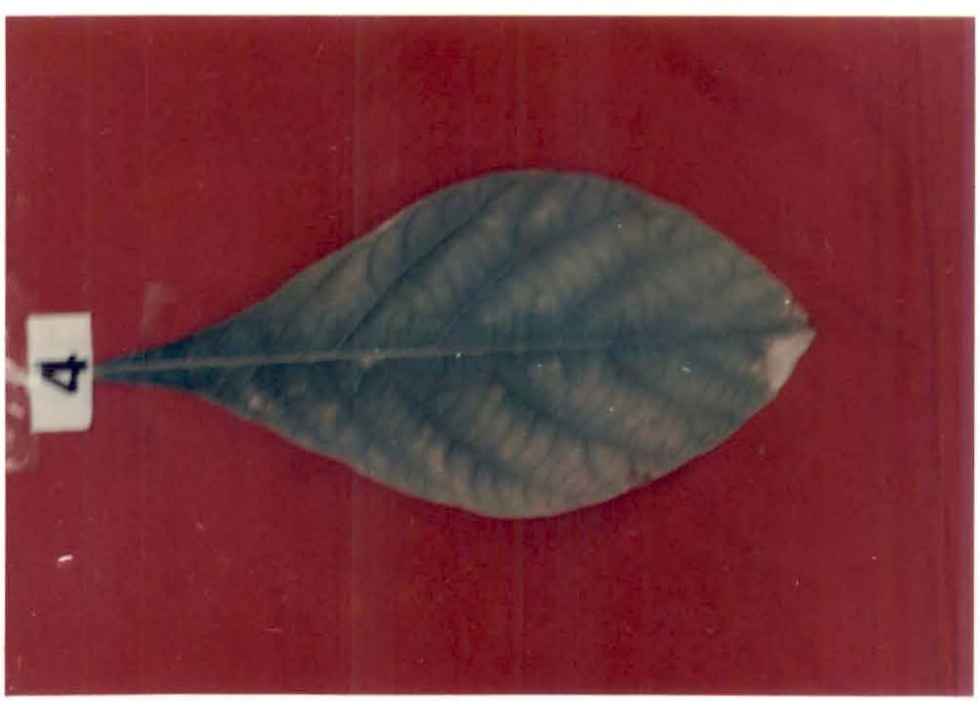
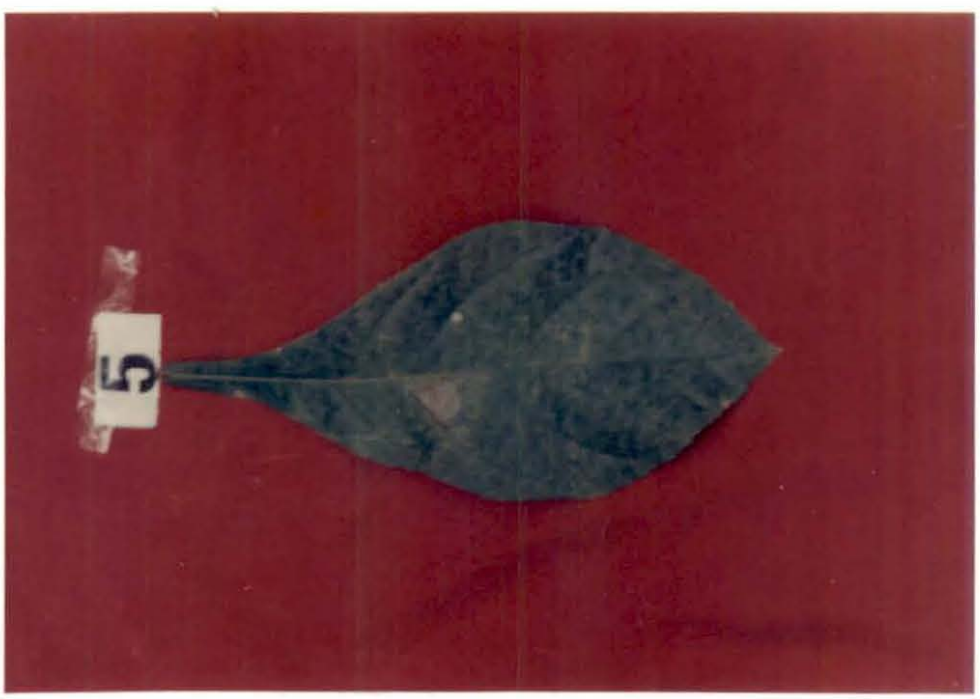

4

Plate 9. Teak seedlings grown with nutrient solution lacking magenisum

1. Control Seedling
5. Seedling lacking magenisum

Plate 10. A leaf showing acute stage of magenisum deficiency


1
5


5

the chlorotic areas developed into necrotic regions. Compared to control seedlings, Mg deficient seedlings were stunted in growth.

4.1.6. Sulphur

Seedlings which lacks S developed deficiency symptoms after three months. The symptoms first appeared on the terminal leaves as discolouration from dark green to pale green. The symptoms gradually advanced from margin inwards. At the moderate stages of deficiency, only the region close to midrib appeared green. Later, necrosis set in and at the acute stage the entire leaf developed chlorotic. The affected leaves were yellowish white in colour (Plates 11 and 12).

4.1.7. Zinc

Zinc deficiency symptoms were noticed from the fourth month onwards. The symptoms first appeared on the lower leaves as chlorotic patches. Seedlings were stunted in growth with short internodes, more number of branches and small clustered leaves. Later the leaves develop necrotic patches and at severe stages the leaves had a burned appearance (Plates 13 and 14).

4.1.8. Molybdenum

Seedlings which lacks Mo developed deficiency symptoms after five months. The symptoms first appeared on terminal leaves. The size of the terminal leaves reduced considerably. The leaves were narrow in appearance. At later stages interveinal chlorosis was also noticed (Plates 15 and 16).

Plate 11. Teak seedlings grown with nutrient solution lacking sulphur

1. Control Seedling
6. Seedling lacking sulphur

Plate 12. A leaf showing acute stage of sulphur deficiency


1
6


6

Plate 13. Teak seedlings grown with nutrient solution lacking zinc

1. Control Seedling
7. Seedling lacking zinc

Plate 14. A leaf showing acute stage of zinc deficiency


7
1
7

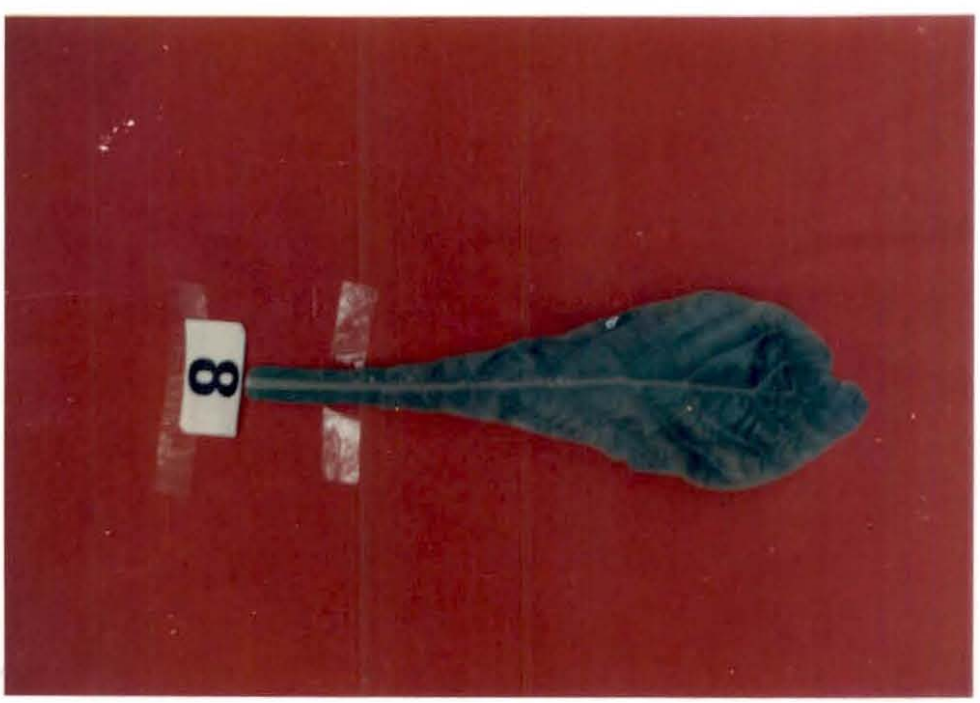

7

Plate 15. Teak seedlings grown with nutrient solution lacking molybdenum

1. Control Seedling
8. Seedling lacking molybdenum

Plate 16. A leaf showing acute stage of molybdenum deficiency


8
1
8


8

4.2. Growth behaviour of seedlings

The effect of nutrient deficiencies on the growth behaviour of seedlings grown in sand culture is presented below. Results on shoot growth parameters, root growth parameters and dry matter production of seedlings are presented separately.

4.2.1. Shoot growth parameters

The influence of various treatments on shoot growth parameters of seedlings like height, collar diameter, leaf number and leaf area is explained here under.

4.2.1.1. Height

The observations recorded on height of seedlings at fortnightly intervals are presented in table 2 and illustrated in figure 1. There was significant difference between various treatments with regard to the height of seedlings. At the end of the study period, seedlings grown with complete nutrient solution had the maximum height growth of 53.03 cm while the N deficient seedlings recorded the lowest height growth of 17.49 cm.

Among the various nutrient deficient seedlings, molybdenum generally produced maximum height growth (45.72 cm) during the last fortnight which was only 13.78 per cent less compared to control. This was followed by Zn and K deficient seedlings. It could also be seen from the table that S deficient seedlings were on par with Mg deficient seedlings in terms of height during the last two fortnights. At the end of study, the height increment was found to be relatively less in all the treatments compared to control

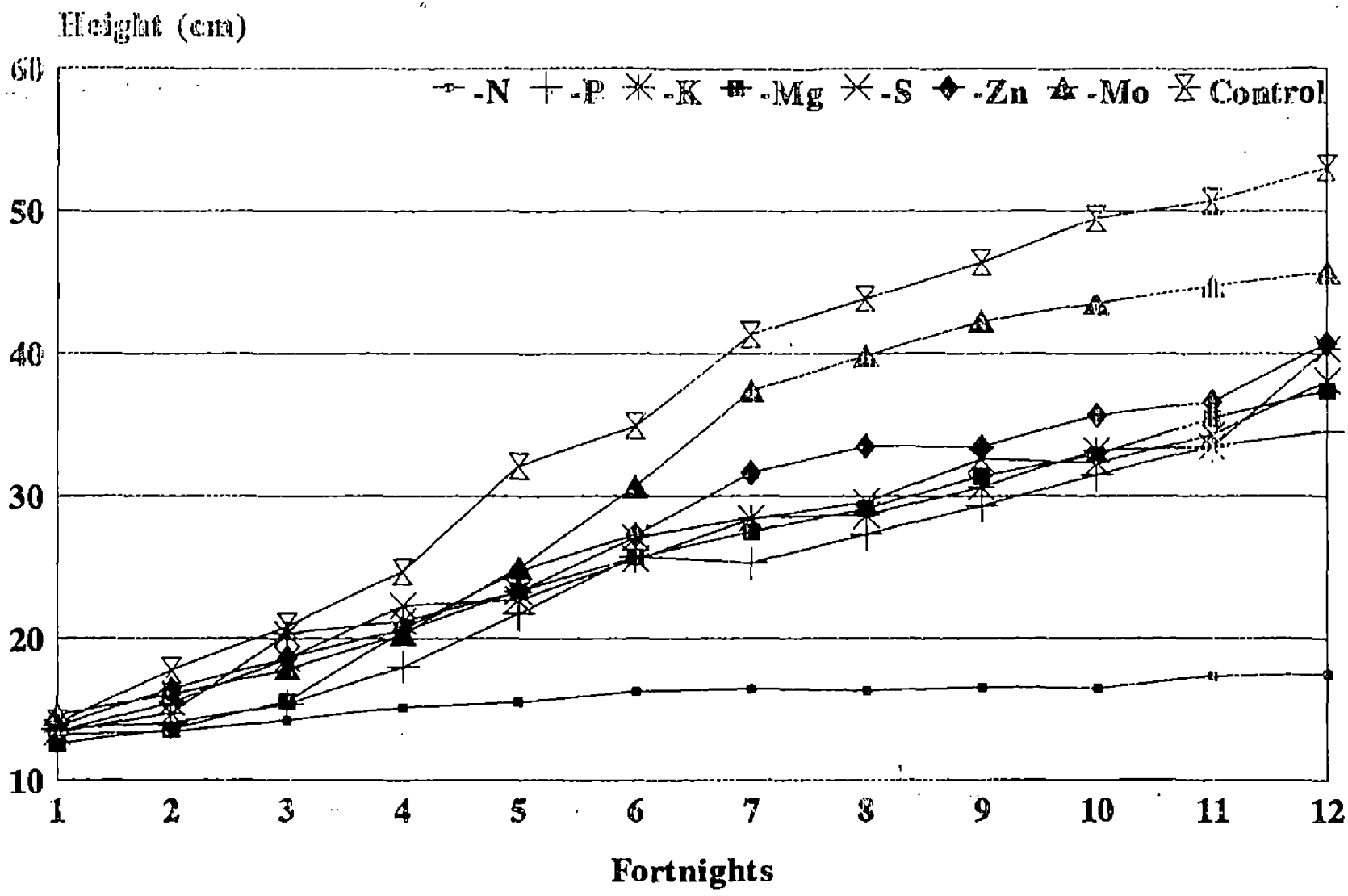
Table 2. Effect of nutrient deficiencies on the height (cm) of seedlings

Nutrient element deleted from complete solution	Fortnights											
	1	2	3	4	5	6	7	8	9	10	11	12
Nitrogen	13.20	13.38	14.21	15.12	15.51	16.28	16.43	16.31	16.54	16.50	17.32	17.49
Phosphorus	13.62	14.04	15.35	18.00	21.75	25.77	25.29	27.29	29.29	31.47	33.47	34.55
Potassium	13.41	14.70	20.35	21.24	23.33	27.12	28.47	28.66	30.64	33.21	33.45	40.34
Magnesium	12.59	13.59	15.59	20.51	23.36	25.73	27.50	29.14	31.40	32.88	35.47	37.41
Sulphur	13.46	15.46	18.56	22.32	22.73	25.60	28.41	29.59	32.58	32.32	34.29	38.09
Zinc	13.79	16.43	18.64	20.68	24.78	27.30	31.63	33.51	33.43	35.68	36.64	40.74
Molybdenum	14.65	16.02	17.83	20.29	25.01	30.68	37.38	39.86	42.26	43.52	44.74	45.72
Control	14.04	17.76	20.87	24.71	32.11	34.90	41.33	43.85	46.40	49.48	50.69	53.03
F-test	NS	**	**	**	**	**	**	**	**	**	**	**
SEM ±	0.41	0.34	0.38	0.36	0.68	0.39	0.29	0.45	0.50	0.39	0.39	0.56
CD (5%)	-	1.03	1.14	1.09	2.05	1.18	0.86	1.34	1.50	1 16	1.18	1.67

NS - Non Significant

** Significant at 1 per cent level

Fig.1 Effect of nutrient deficiencies on the height of seedlings



4.2.1.2. Collar diameter

Observations related to collar diameter of seedlings as influenced by various treatments are furnished in table 3 and illustrated in figure 2. It is evident from the data that there is significant difference between the various treatments in terms of collar diameter through out the study period. The seedlings grown in complete nutrient solution recorded the maximum mean collar diameter of 0.43 cm at the end of the study.

Nitrogen deficient seedlings tended to produce lowest diameter growth at the end of 12th fortnight (0.21cm). These seedlings were found to record relatively lower diameters beginning from the fifth fortnight onwards. The S deficient seedlings recorded the second lowest mean collar diameter of 0.26 cm at the end of study. It could be seen from the data that N deficient seedlings had 51.16 per cent lower diameter compared to control seedlings during the last fortnight while in the case of Mo deficient seedlings it was only 11.63 per cent lower compared to control at the end of study. For P and K the mean diameter was 0.29 cm each towards the last fortnight. In the case of Zn the mean collar diameter was found to be 0.34 cm at the end of 12th fortnight.

4.2.1.3. Number of leaves

The data given in table 4 and illustrated in figure 3 indicate the effect of various treatments on the number of leaves produced by seedlings. Treatment differences were found to be significant with regard to this parameter also. The seedlings receiving complete nutrient solution produced the highest number of leaves (25.70) towards the end of study.

Table 5. Effect of nutrient deficiencies on the collar diameter (cm) of seedlings

Nutrient element deleted from complete solution	Fortnights											
	1	2	3	4	5	6	7	8	9	10	11	12
Nitrogen	0.12	0.14	0.15	0.17	0.16	0.17	0.19	0.19	0.20	0.21	0.21	0.21
Phosphorus	0.13	0.14	0.16	0.19	0.19	0.21	0.22	0.24	0.26	0.25	0.27	0.29
Potassium	0.13	0.15	0.18	0.19	0.21	0.23	0.24	0.25	0.25	0.26	0.29	0.29
Magnesium	0.14	0.16	0.20	0.21	0.23	0.25	0.26	0.27	0.28	0.30	0.30	0.31
Sulphur	0.13	0.14	0.17	0.18	0.21	0.21	0.24	0.21	0.23	0.24	0.25	0.26
Zinc	0.14	0.16	0.18	0.20	0.22	0.24	0.26	0.27	0.29	0.31	0.32	0.34
Molybdenum	0.14	0.16	0.19	0.19	0.24	0.23	0.27	0.28	0.30	0.32	0.35	0.38
Control	0.15	0.18	0.20	0.22	0.24	0.26	0.30	0.33	0.34	0.36	0.39	0.43
F-test	NS	**	**	**	**	**	**	**	**	**	**	**
SEM ±	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
CD (5%)	-	0.08	0.05	0.05	0.05	0.05	0.08	0.08	0.05	0.05	0.05	0.05

NS - Non Significant

** Significant at 1 per cent level

Table 4. Effect of nutrient deficiencies on the leaves (number) produced by seedlings

Nutrient element deleted from complete solution	Fortnights											
	1	2	3	4	5	6	7	8	9	10	11	12
Nitrogen	10.00	10.14	11.35	11.75	11.22	11.54	11.72	11.52	11.73	11.11	10.67	10.30
Phosphorus	9.87	10.05	11.08	11.20	12.85	13.73	12.47	13.99	14.22	13.52	13.66	14.04
Potassium	9.17	10.73	13.72	14.47	16.59	17.81	18.74	18.38	19.34	19.81	18.01	18.89
Magnesium	9.45	10.59	12.83	13.23	15.10	15.79	16.92	16.71	17.33	17.29	16.29	16.47
Sulphur	9.47	10.50	12.21	13.54	14.35	15.92	16.32	17.11	18.32	19.83	20.75	20.35
Zinc	10.75	10.84	12.73	13.14	13.80	16.65	17.19	17.61	18.86	17.19	20.10	20.56
Molybdenum	10.54	10.86	12.88	13.71	15.50	15.34	16.96	17.53	18.88	19.80	20.96	22.22
Control	11.14	15.30	15.78	17.04	19.06	19.10	20.66	21.98	22.26	22.86	23.25	25.70
F-test	NS	NS	**	**	**	**	**	**	**	**	**	**
SEM ±	0.32	0.26	0.27	0.30	0.24	0.31	0.20	0.35	0.32	0.33	0.57	0.46
CD (5%)	-	-	0.81	0.91	0.71	0.93	0.60	1.06	0.97	0.99	1.70	1.38

NS - Non Significant

** Significant at 1 per cent level

Fig.2: Effect of nutrient deficiencies on the collar diameter of seedlings

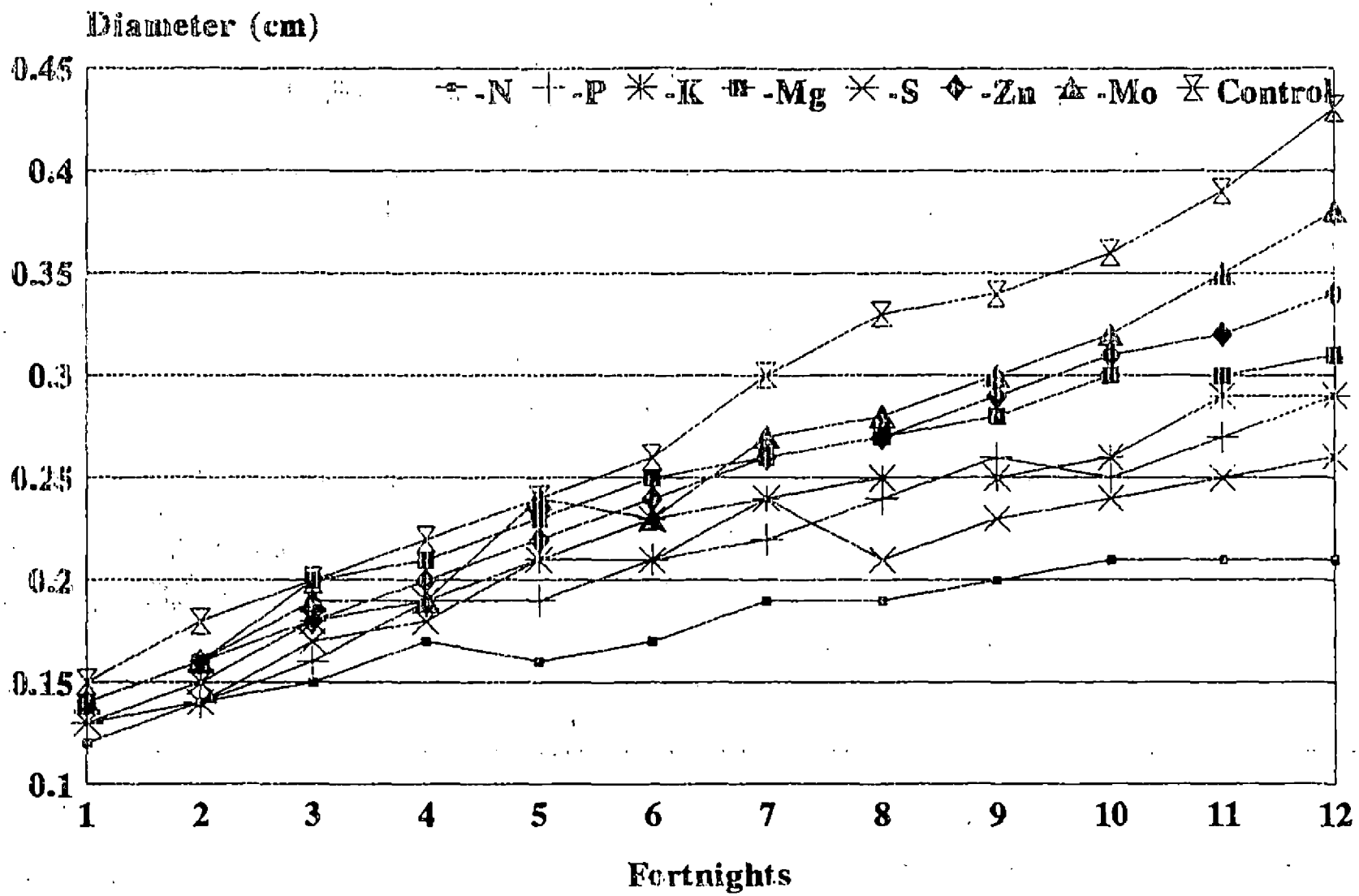
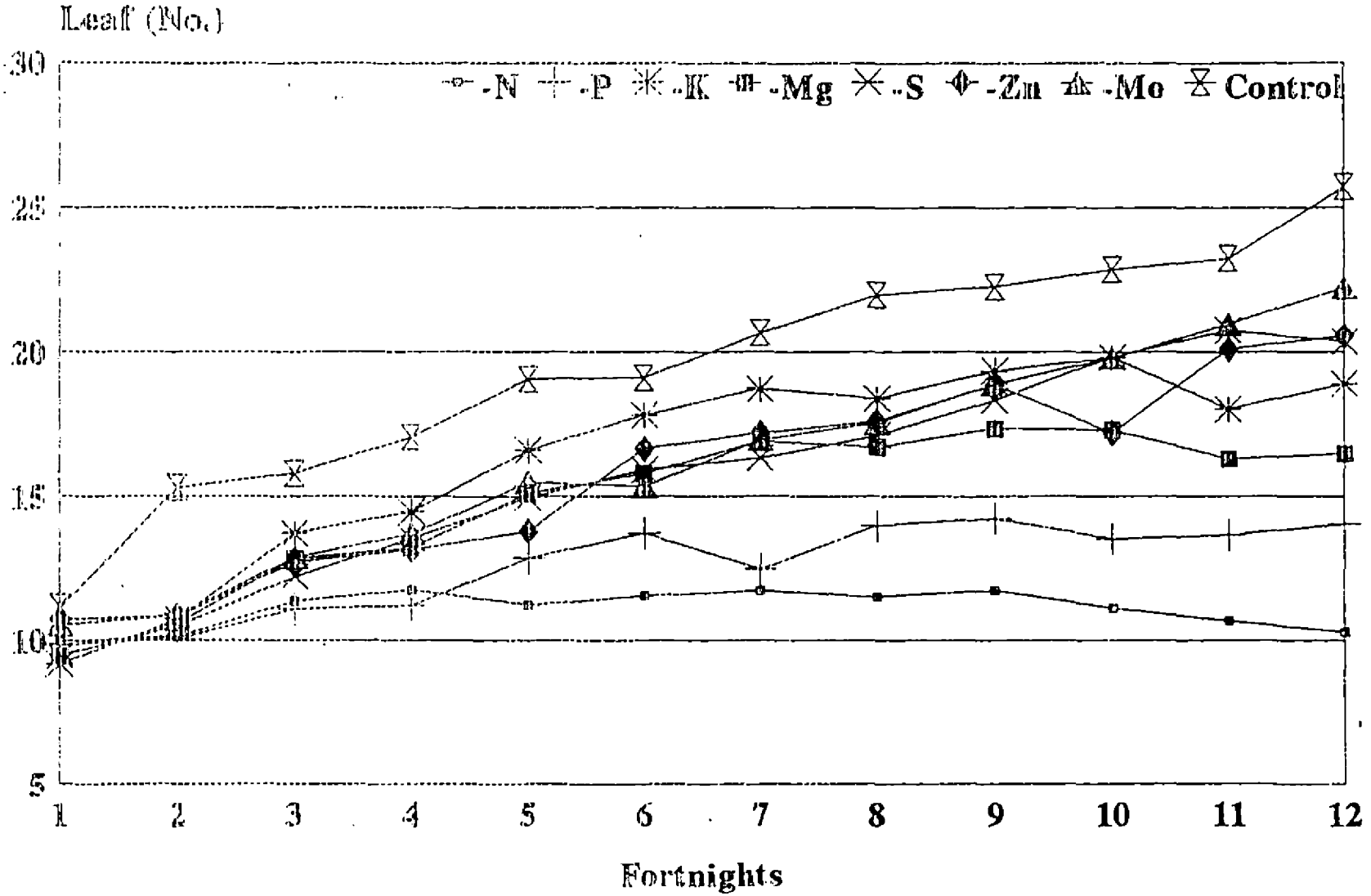


Fig.3 Effect of nutrient deficiencies on the number of leaves of seedlings



The seedlings receiving N deficient solutions were producing less number of leaves from the beginning onwards. Towards the end of the study, the N deficient seedlings had a leaf number of 10.30. This was followed by P deficient (14.04) and Mg deficient (16.47) seedlings.

In general, P and N deleted treatments produced the lowest number of leaves. The S and Zn deficient seedlings produced a leaf number of 20.35 and 20.56 respectively towards the end of the study.

4.2.1.4. Leaf area

The data furnished in table 5 and illustrated in figure 4 reflect the effect of various treatments on the leaf area produced by the seedlings. The maximum leaf area was recorded invariably by the seedlings grown in complete nutrient solution. It showed an increasing trend from 1506.45 cm^2 at the commencement of treatment to 3240.68 cm^2 at the end of the study.

The lowest leaf area (520.67 cm^2) was recorded by those seedlings which received nutrient solution lacking N. During the entire study period it never increased beyond 600cm^2. The second lowest was those seedlings which were deficient in P. At the end of the study they recorded a leaf area of 935.69 cm^2. In the case of S and Zn the leaf area was 2227 cm^2 and 2933.78 cm^2 respectively at the end of the study.

In the case of P deficient treatment, at the fourth month the leaf area was relatively high (1744.7cm^2) while the respective figure in control treatment was 2057.66 cm^2. In the case of K the leaf area was increasing upto the third month

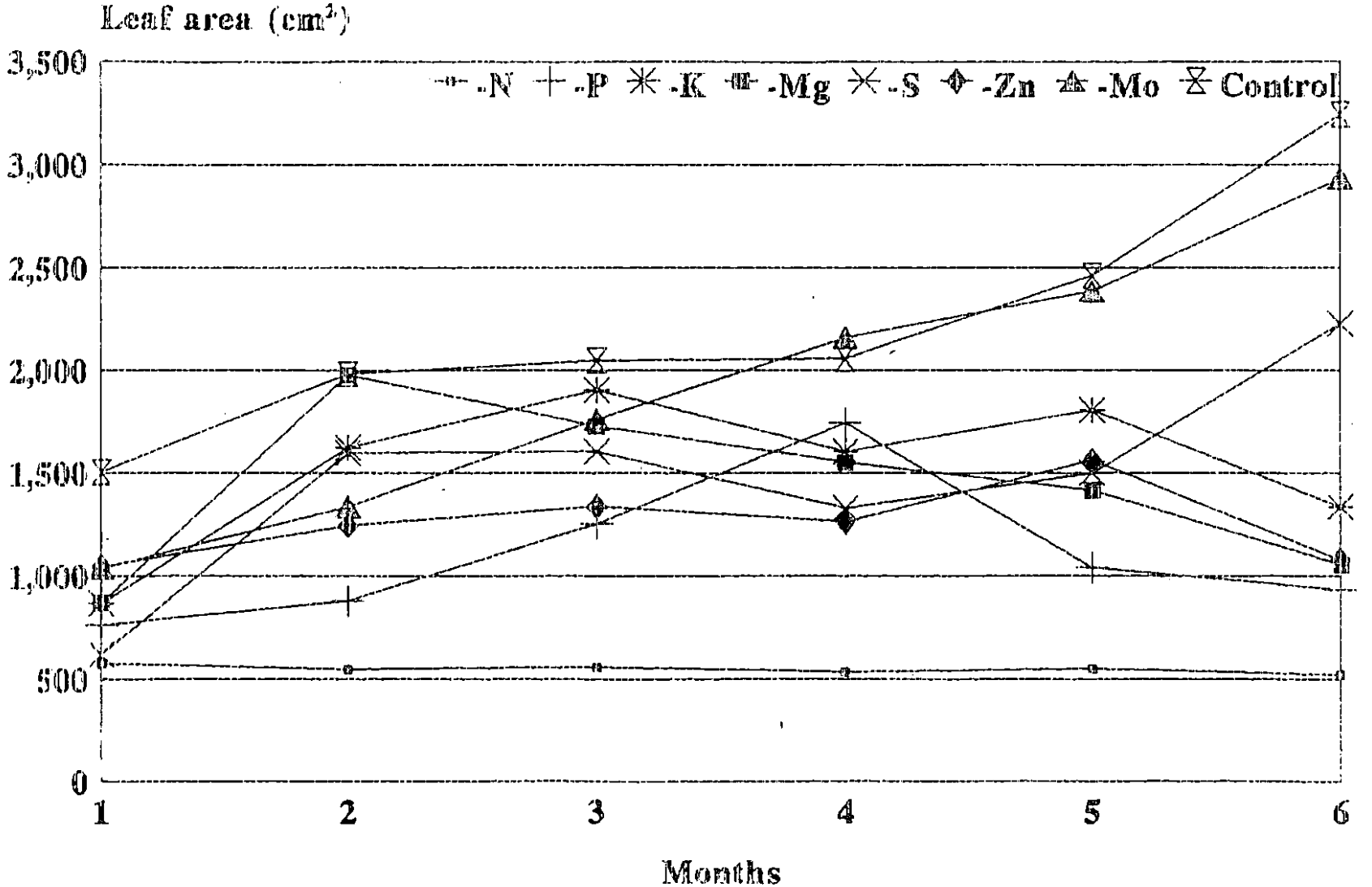
Table 5. Effect of nutrient deficiencies on the leaf area (cm^2) of seedlings

Nutrient element deleted from complete solution	Months					
	1	2	3	4	5	6
Nitrogen	576.27	547.58	559.11	534.00	550.11	520.67
Phosphorus	763.16	879.30	1255.67	1744.87	1044.22	935.69
Potassium	868.27	1625.46	1905.90	1606.56	1806.28	1339.90
Magnesium	872.15	1979.50	1731.56	1554.26	1417.56	1058.39
Sulphur	620.31	1600.25	1605.53	1332.78	1502.22	2227.00
Zinc	1048.35	1248.00	1343.22	1266.47	1563.26	1080.63
Molybdenum	1039.46	1339.69	1762.56	2160.44	2384.71	2933.78
Control	1506.45	1983.05	2048.78	2057.66	2461.11	3240.68
F-test	*	**	**	**	**	**
SEM ±	135.68	108.00	139.63	167.39	169.54	88.65
CD (5%)	406.8	323.8	418.6	501.8	508.3	265.80

* Significant at 5 per cent level

** Significant at 1 per cent level

Fig.4 Effect of nutrient deficiencies on the leaf area of seedlings



and recorded a value of 1905.90 cm^2. However, gradually this showed a decreasing trend and at the end of study it was 1339.90 cm^2. The difference in leaf area between Mg and Zn deficient seedlings during the last fortnight was not statistically significant.

4.2.2. Root growth parameters

The effect of different treatments on the root growth parameters like length of the main root and the number of secondary roots are described here under.

4.2.2.1. Length of the main root

Length of the main root did not show any significant differences due to the treatment application except for the last month (Table 6 and Figure 5). At the end of the study, the K deficient seedlings recorded the lowest root length of 16.79 cm compared to control (26.67 cm). Among the different treatments deleting various nutrient elements, Zn recorded the maximum root length of 24.35cm towards the end of the study. During this period N and P deficient seedlings recorded mean root length of 20.97 and 20.61 cm respectively. Seedlings grown under Mg deficiency produced roots of 19.20 cm long towards the end of the study.

4.2.2.2. Number of secondary roots

The effect of treatments on the number of secondary roots produced by the plants is given in table 7 and depicted in figure 6. Except at the end of sixth month, nutrient deficient treatments did not bring about any significant difference in the number of secondary roots produced by the seedlings. Mg deficient

Table 6. Effect of nutrient deficiencies on the length (cm) of the main root

Nutrient element deleted from complete solution	Months					
	1	2	3	4	5	6
Nitrogen	20.76	22.08	21.23	22.40	20.33	20.97
Phosphorus	19.33	22.84	21.18	22.30	21.67	20.61
Potassium	19.23	23.74	20.94	22.51	21.80	16.79
Magnesium	20.60	22.09	20.52	21.82	20.63	19.20
Sulphur	19.98	22.08	20.84	21.67	21.35	22.20
Zinc	19.81	22.36	20.18	22.65	20.73	24.35
Molybdenum	20.06	22.51	20.73	22.55	21.83	20.18
Control	29.13	25.13	24.73	26.18	24.90	26.67
F-test	NS	NS	NS	NS	NS	*
SEM±	2.03	1.78	1.21	1.48	1.26	1.78
CD (5%)	-	-	-	-	-	5.28

NS - Non Significant

* Significant at 5 per cent level

Table 7. Effect of nutrient deficiencies on the number of secondary roots

Nutrient element deleted from complete solution	Months					
	1	2	3	4	5	6
Nitrogen	29.55	42.46	34.67	35.67	34.00	32.14
Phosphorus	32.44	39.33	36.00	35.22	42.67	33.22
Potassium	31.11	41.33	37.82	34.22	36.67	37.78
Magnesium	28.55	35.00	34.00	35.22	34.23	28.78
Sulphur	30.44	39.89	33.11	32.56	36.34	31.89
Zinc	32.08	36.67	34.00	33.67	35.11	42.22
Molybdenum	32.67	35.12	38.55	39.67	41.78	40.78
Control	52.89	47.11	42.89	42.78	44.42	43.00
F-test	NS	NS	NS	NS	NS	*
SEM ±	2.09	1.98	2.32	2.62	2.14	3.13
CD (5%)	-	-	-	-	-	9.39

NS - Non Significant

* Significant at 5 per cent level

Fig.5 Effect of nutrient deficiencies on the length of roots

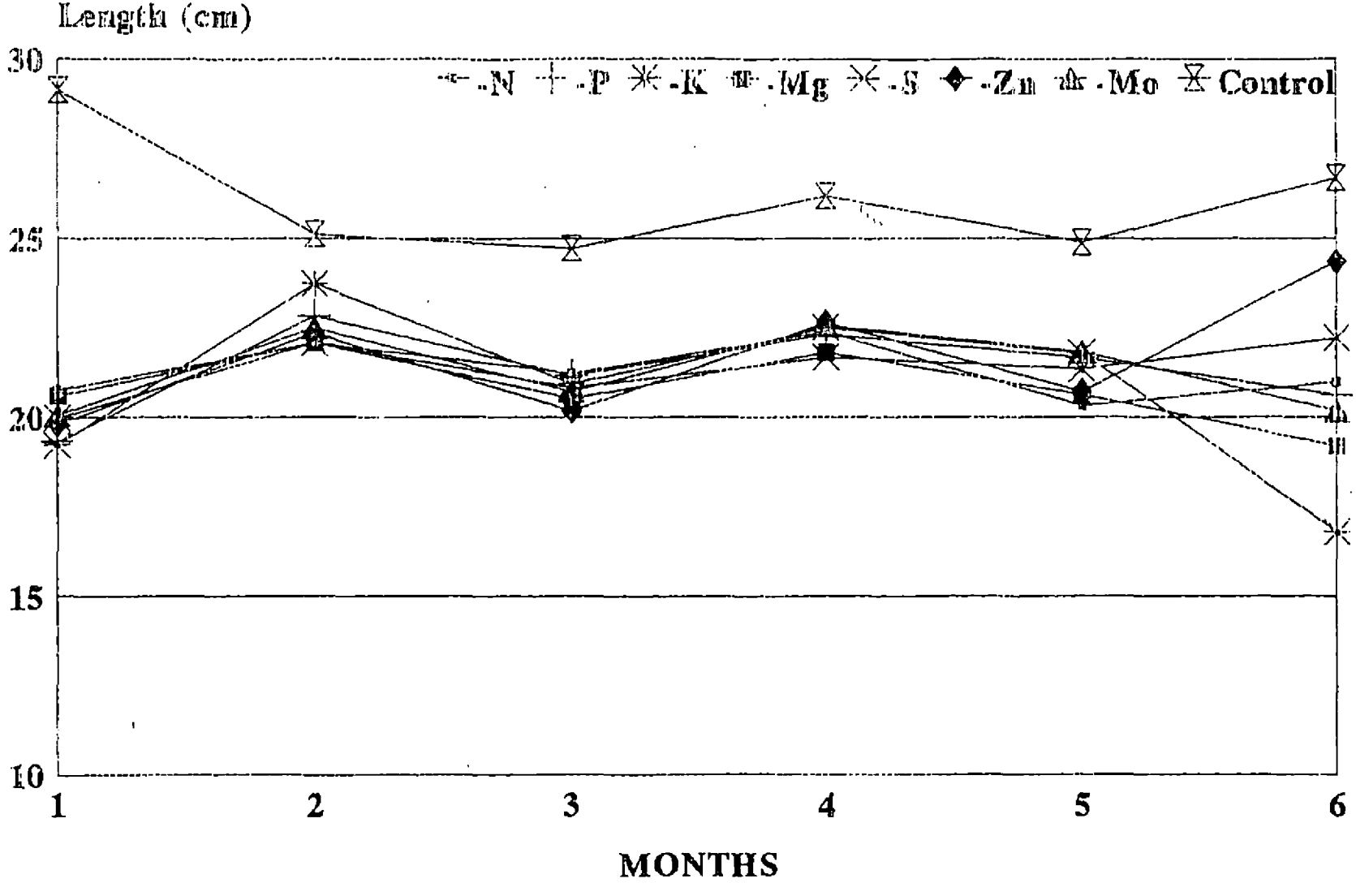
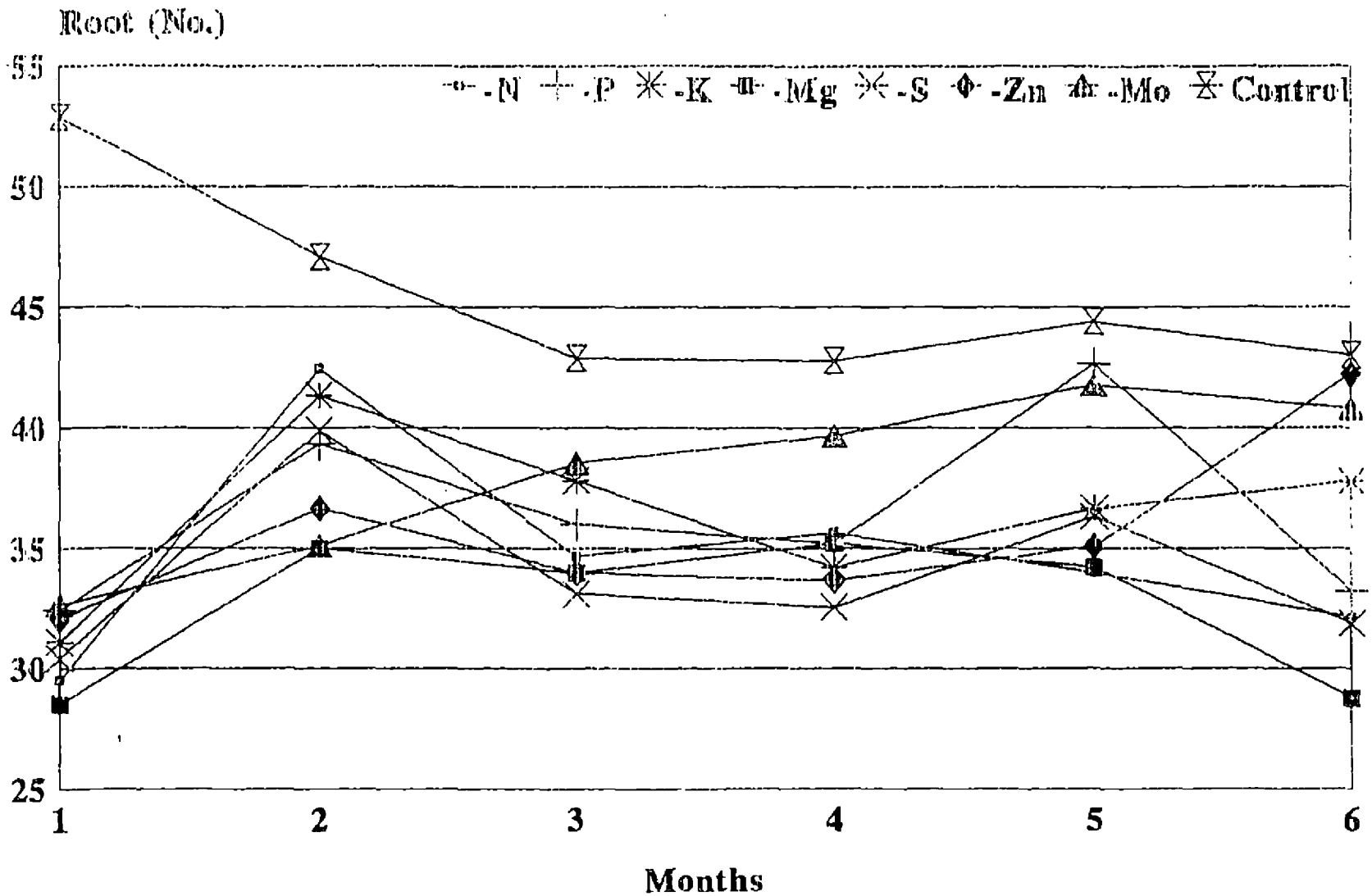


Fig.6 Effect of nutrient deficiencies on the number of secondary roots



seedlings had the lowest number of secondary roots in the first (28.55) and last months (28.78) of the study and these were respectively 46.02 per cent and 33.07 per cent lower when compared to control seedlings during the same periods. The seedlings grown in S deleted nutrient solutions had the second lowest number of secondary roots (31.89) towards the end of the study.

In general, Mo and Zn deficient seedlings continued to produce larger number of secondary roots through out the period of study. However, these were slighrly inferior compared to healthy seedlings grown in complete nutrient solutions.

4.2.3. Fresh and dry weights of shoots

The effects of nutrient stress on the fresh and dry weights of the shoots are clearly evident from the data tabulated in table 8. The various nutrient treatments significandy influenced the fresh and dry weight of the seedlings.

With regard to shoot fresh weights, treatment differences were very pronounced from the second month onwards. Seedlings that received complete nutrient solution recorded the highest shoot fresh weight from the beginning of the study itself. Among the nutrient elements, Mo deficient seedlings recorded the highest shoot fresh weights of 36.95 g and 45.72 g respectively during the fifth and sixth months. It could be seen from the table that the N deficient plants recorded the lowest shoot fresh weight through out the course of study. During the second month it was lowest (7.01 g) and towards the end of study these plants recorded a fresh weight of 11.39 g. The second lowest fresh weight was recorded by those seedlings grown in solution deficient in K (31.61 g).

Table 8. Effect of nutrient deficiencies on the fresh and dry weights (g) of shoots

Nutrient element deleted from complete solution	Months											
	1		2		3		4		5		6	
	Fresh Weight	Dry Weight	Fresh Weight	Dry Weight	Fresh Weight	Dry Weight	Fresh Weight	Dry Weight	Fresh Weight	Dry Weight	Fresh Weight	Dry Weight
Nitrogen	12.01	3.50	7.01	2.91	11.39	3.70	11.23	4.01	10.87	3.93	11.39	4.19
Phosphorus	10.63	3.05	12.82	4.23	23.85	7.58	31.51	11.75	27.48	11.57	33.69	10.17
Potassium	12.98	3.71	12.35	3.63	17.37	6.64	23.42	10.84	27.45	8.58	31.61	11.31
Magnesium	13.43	3.98	18.82	6.61	21.98	7.13	21.72	9.54	29.03	11.60	32.61	10.67
Sulphur	12.91	3.93	10.57	3.08	18.79	8.82	27.00	11.84	29.06	10.03	34.88	11.55
Zinc	12.55	3.84	14.31	4.35	21.02	9.44	25.20	10.92	31.21	11.26	35.35	11.61
Molybdenum	12.61	3.73	16.24	5.53	25.22	8.47	36.03	9.37	36.95	11.71	45.72	15.30
Control	14.20	4.04	20.99	7.40	35.03	10.58	47.12	12.96	50.60	14.38	65.84	18.23
F-test	NS	NS	**	**	**	**	**	**	**	**	**	**
SEM ±	0.68	0.26	0.51	0.39	0.99	0.41	0.66	0.44	0.91	0.61	0.92	1.07
CD (0.05)	-	-	1.54	1.17	2.96	1.25	1.97	1.31	2.73	1.84	2.77	3.20

NS - Non Significant

** Significant at 1 per cent level

The seedlings receiving complete nutrient solution recorded the highest shoot fresh weight through out the study period. During the sixth month they recorded a value of 65.84 g. The shoot fresh weights of the rest of the treatments were in the order - Mg < - P < - S < - Zn (Fig. 7).

Dry weight of the shoots produced by different nutrient treatments also differed significantly from the second month onwards. The results obtained were more or less similar to the shoot fresh weights. Here also the highest shoot dry weights were invariably recorded by those plants which received the complete nutrient solution. The N deficient seedlings recorded the lowest shoot dry weights through out the study period. This was lowest in the second month (2.91 g) and increased to 4.19 g towards the end. With regard to this parameter treatment were in the order -N<- P <- Mg<- K<- S<- Zn<- Mo< Control (Fig.8).

4.2.4. Fresh and dry weight of roots

Root fresh and dry weights were also found to be influenced by different treatments from the second month onwards (Table 9 and Fig.9). The seedlings grown in complete nutrient solution recorded the highest root fresh weights of 18.68 g during the sixth month. Among other treatments Zn deficient seedlings showed the highest root fresh weights during the sixth month (15.32 g) followed by Mo deficient seedlings (15.16 g). The N deficient plants invariably recorded the lowest root fresh weights through out the growth period. At the end of study, fresh weight of roots of N deficient plants was the lowest (10.73 g) followed by K deficient plants (12.39 g).

Table 9. Effect of nutrient deficiencies on the fresh and dry weights (g) of roots

Nutrient element deleted from complete solution	Months											
	1		2		3		4		5		6	
	Fresh Weight	Dry Weight	Fresh Weight	Dry Weight	Fresh Weight	Dry Weight	Fresh Weight	Dry Weight	Fresh Weight	Dry Weight	Fresh Weight	Dry Weight
Nitrogen	4.12	1.74	13.29	4.53	7.67	2.63	8.19	4.22	11.26	4.93	10.73	5.37
Phosphorus	4.18	1.87	6.23	2.05	7.99	3.01	10.90	5.19	12.17	4.80	12.87	5.73
Potassium	4.19	1.82	8.11	2.52	11.30	4.32	10.79	4.42	10.70	4.27	12.39	5.33
Magnesium	4.13	1.85	7.50	2.58	8.28	3.79	10.62	5.21	12.73	5.41	13.44	5.47
Sulphur	4.53	1.66	13.79	3.14	9.18	3.99	9.01	3.93	9.87	4.43	14.70	5.63
Zinc	4.47	1.54	14.78	3.17	10.06	3.78	10.40	4.42	13.52	5.38	15.32	6.32
Molybdenum	4.89	1.93	11.95	2.90	7.54	2.55	13.36	5.62	14.92	6.75	15.16	6.79
Control	4.98	1.76	10.73	2.44	13.24	3.98	15.57	7.19	16.26	7.54	18.68	7.43
F-test	NS	NS	**	**	**	**	**	**	**	**	**	*
SEM ±	0.23	0.11	0.68	0.23	0.35	0.31	0.71	0.40	0.68	0.50	0.73	0.44
CD (5%)	-	-	2.03	0.68	1.05	0.94	2.14	1.20	2.05	1.51	2.20	1.31

NS - Non Significant

* Significant at 5 per cent level

** Significant at 1 per cent level

Fig.7 Effect of nutrient deficiencies on the fresh weight of shoots

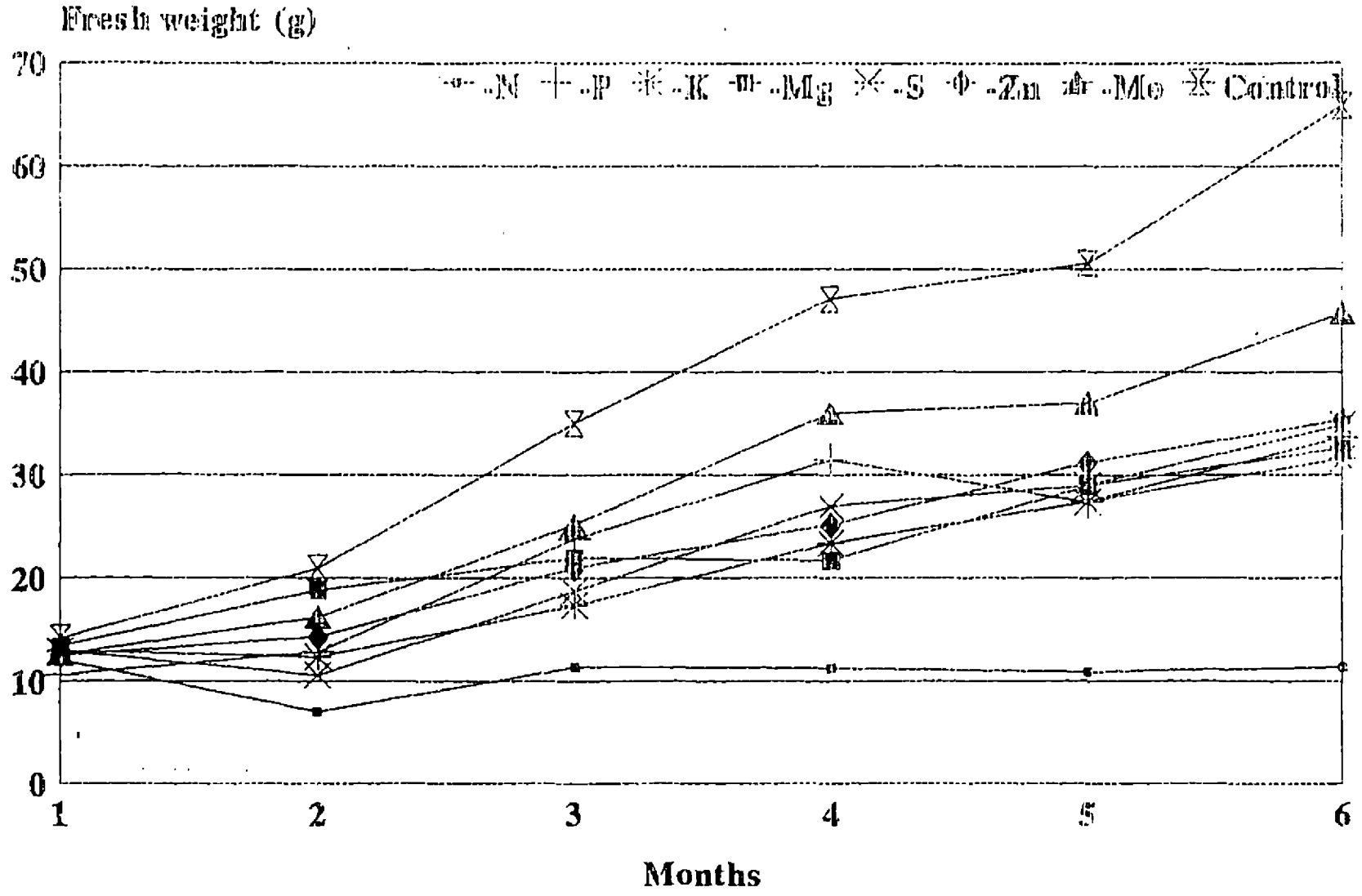


Fig.8 Effect of nutrient deficiencies on the dry weight of shoots

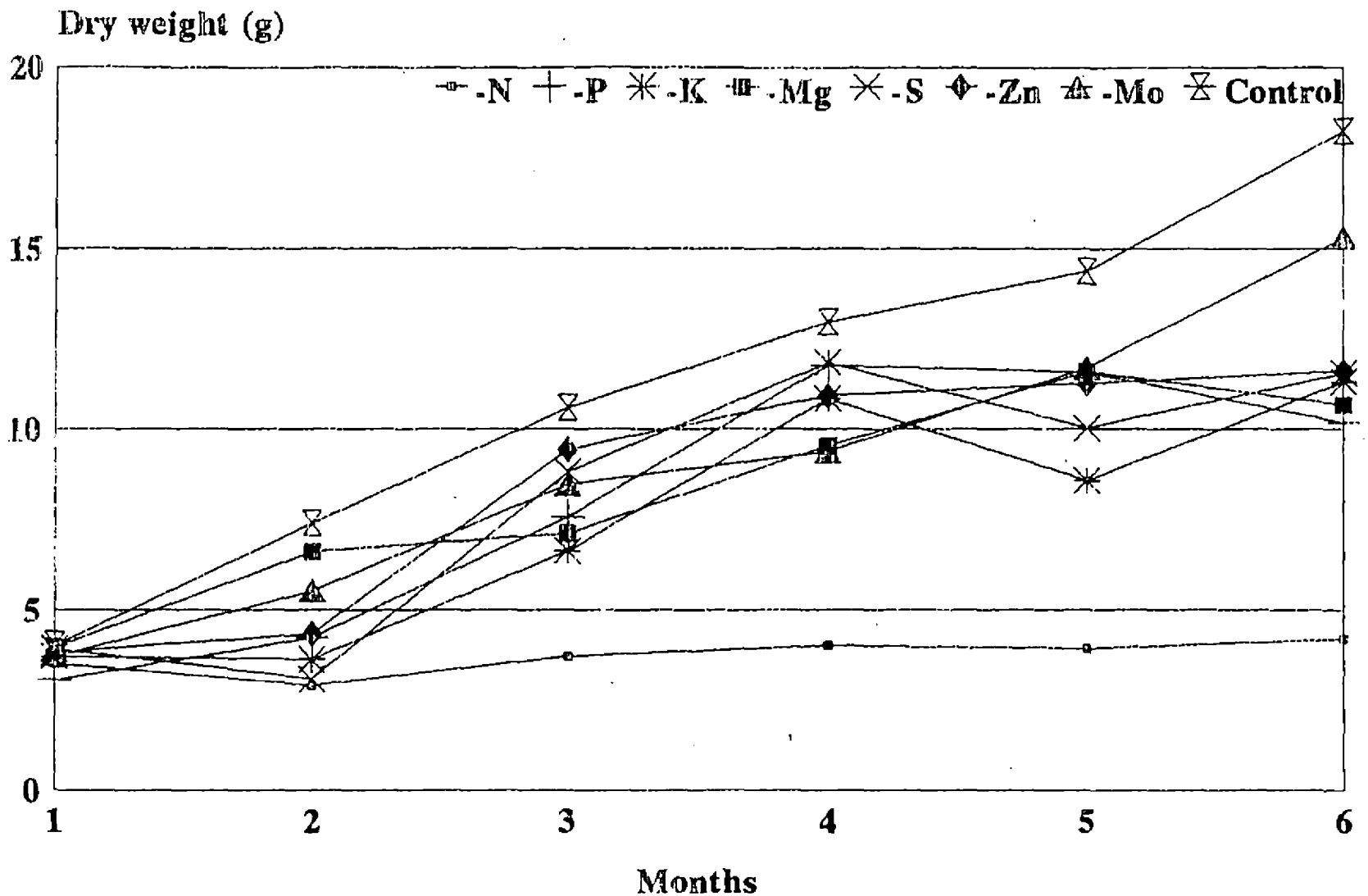
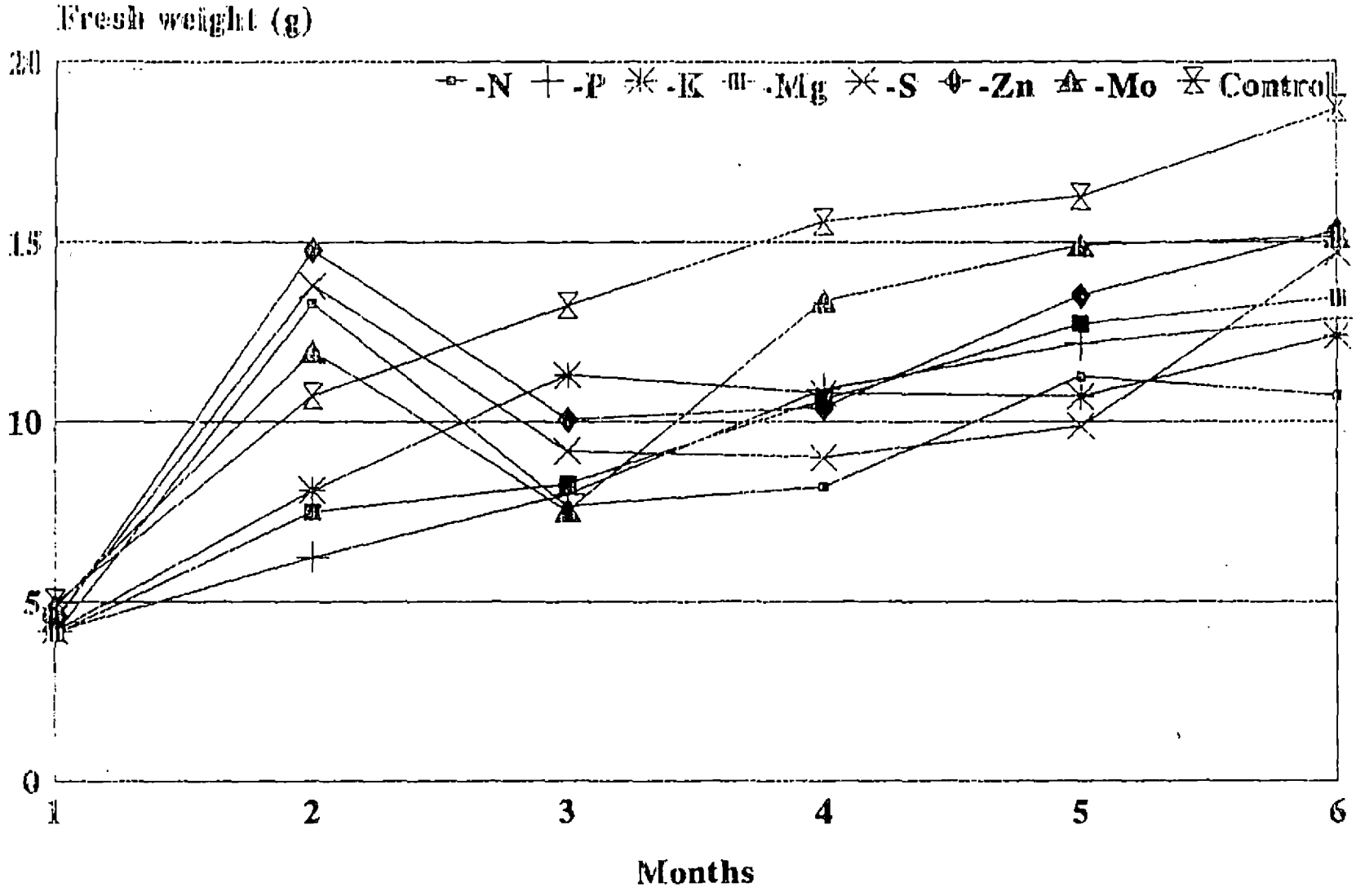


Fig.9 Effect of nutrient deficiencies on the fresh weight of roots



From the data it is also clear that root dry weights were significantly influenced by the nutrient treatments particularly from second month onwards. The root dry weights at the end of study were in the order - K <- N <- Mg <- S <- P <- Zn <- Mo < Control (Fig.10). At the end of study, the root dry weight of seedlings grown in complete nutrient solution was 7.43 g while it was only 5.33 g in K deficient seedlings.

4.3. Chlorophyll content

The chlorophyll content of leaves was found to be significantly influenced by the deficiency of various nutrient elements. The data related to chlorophyll content are tabulated in table 10.

The amount of chlorophyll - A in the leaves decreased gradually during the study period for most the treatments (Fig.11). The N deficient plants had the lowest chlorophyll - A content (0.42 mg g^{-1}) followed by P deficient seedling (0.56 mg g^{-1}) during the fifth month. The seedlings receiving complete nutrient solution and those lacking Mo have recorded the highest chlorophyll - A contents of 0.80 mg g^{-1} during this period.

Chlorophyll - B content also declined gradually for all the treatments except for K which showed a slight increase during the third month (Fig.12). The N deficient plants recorded the lowest content during the sixth month (0.31 mg g^{-1} of leaf tissue) while highest value during this period was recorded by K deficient plants (1.03 mg g^{-1}). Next to K was Mg deficient plants which recorded a value of 0.93 mg g^{-1}. The plants receiving complete solution were having a chlorophyll B content of 0.87 mg g^{-1} during the sixth month.

Table 10. Effect of nutrient deficiencies on the chlorophyll content of leaf tissue of seedlings

Nutrient element deleted from complete solution	Months														
	2	3	4	5	6	2	3	4	5	6	2	3	4	5	6
	Chlorophyll - A (mg g^{-1})					Chlorophyll - B (mg g^{-1})					Total chlorophyll (mg g^{-1})				
Nitrogen	0.89	0.72	0.63	0.42	0.32	1.50	0.69	0.65	0.44	0.31	2.39	1.41	1.28	0.86	0.63
Phosphorus	1.97	1.29	0.60	0.56	0.61	1.75	1.28	1.14	0.84	0.73	3.72	2.57	1.74	1.40	1.34
Potassium	1.59	1.29	1.17	0.69	0.58	1.26	1.35	1.24	1.11	1.03	2.85	2.64	2.41	1.80	1.61
Magnesium	2.07	1.60	0.88	0.68	0.71	1.45	1.19	1.16	1.11	0.93	3.53	2.80	2.04	1.79	1.64
Sulphur	2.06	1.10	0.91	0.64	0.33	1.71	1.38	1.14	0.90	0.74	3.77	2.48	2.05	1.54	1.07
Zinc	2.11	1.31	0.78	0.57	0.41	1.24	1.10	0.95	0.84	0.67	3.23	2.41	1.74	1.42	1.08
Molybdenum	1.81	1.29	0.91	0.80	0.62	1.32	1.09	0.83	0.81	0.67	3.13	2.38	1.74	1.61	1.29
Control	2.09	1.65	1.39	0.80	0.58	1.60	1 14	0.99	0.97	0.87	3.69	2.78	2.38	1.77	1.44
F-test	* *	* *	* *	* *	* *	* *	* *	* *	* *	* *	* *	* *	* *	* *	* *
SEM ±	0.05	0.03	0.06	0.03	0.04	0.09	0.03	0.04	0.03	0.03	0.09	0.03	0.05	0.04	0.04
CD (5%)	0.14	0.08	0.17	0.09	0.11	0.26	0.09	0.12	0.09	0.08	0.27	0.09	0.14	0.11	0.11

* * Significant at 1 per cent level

Fig.10 Effect of nutrient deficiencies on the dry weight of roots

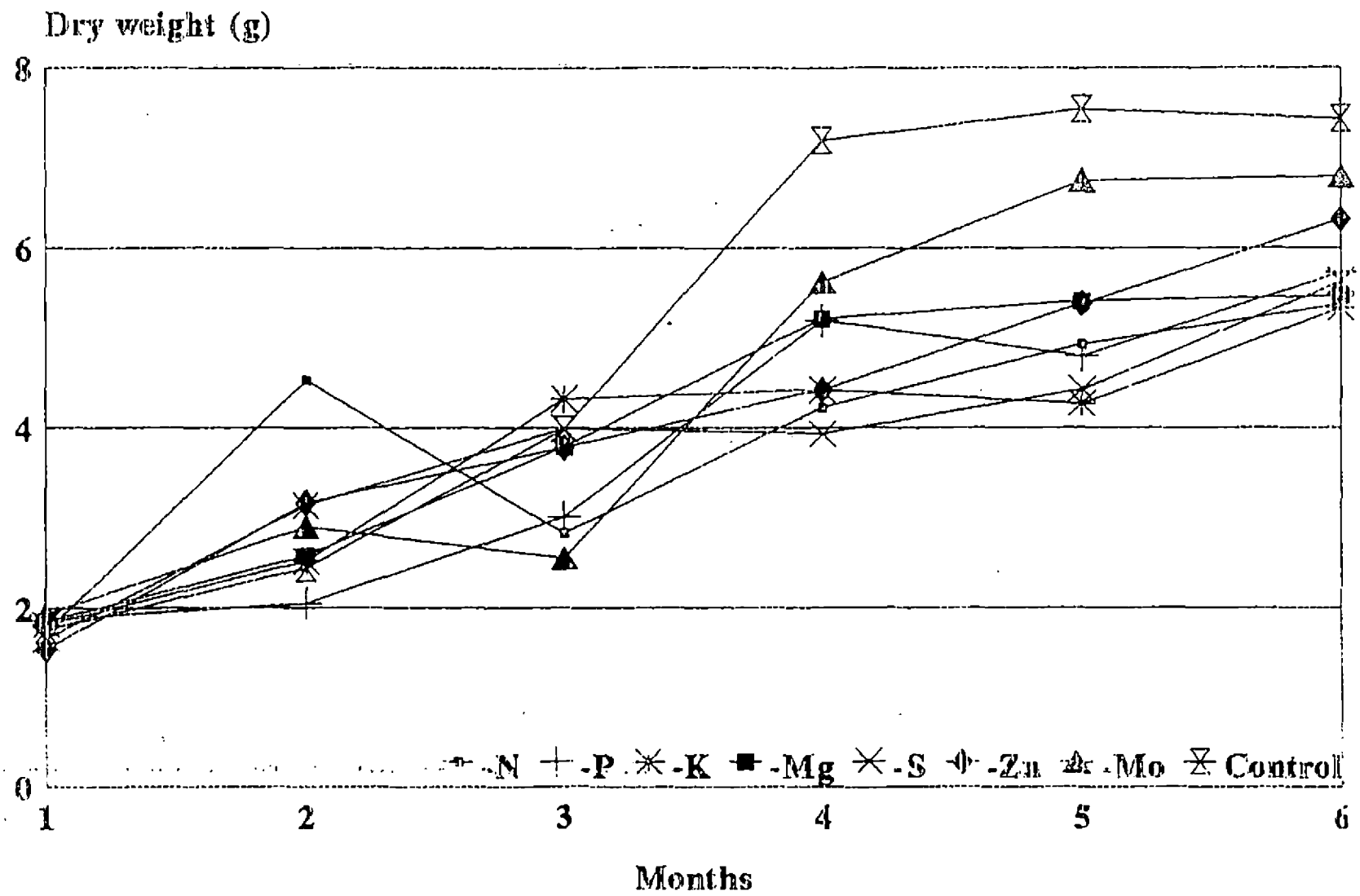


Fig.11 Effect of nutrient deficiencies on the chlorophyll- A content

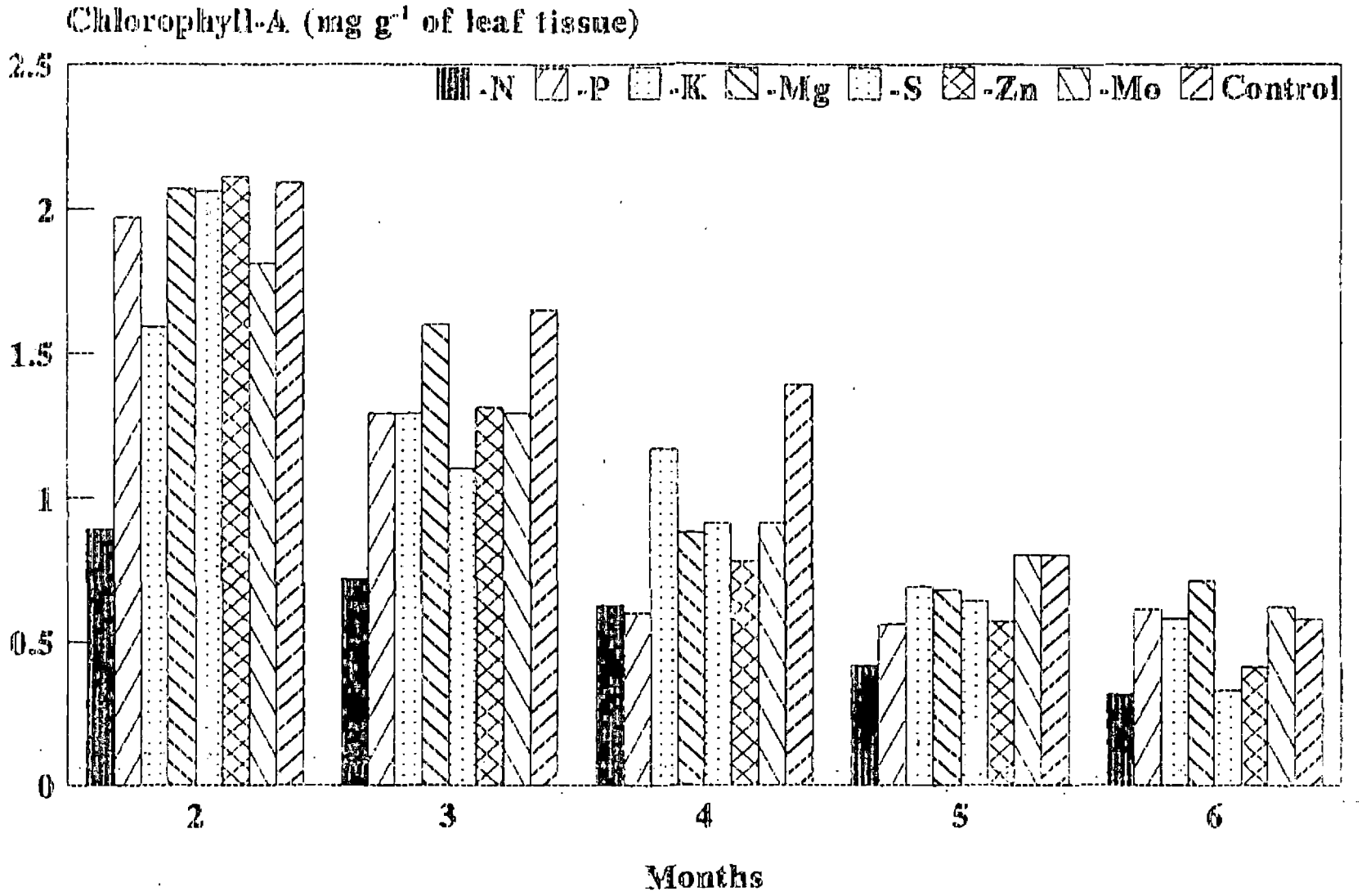
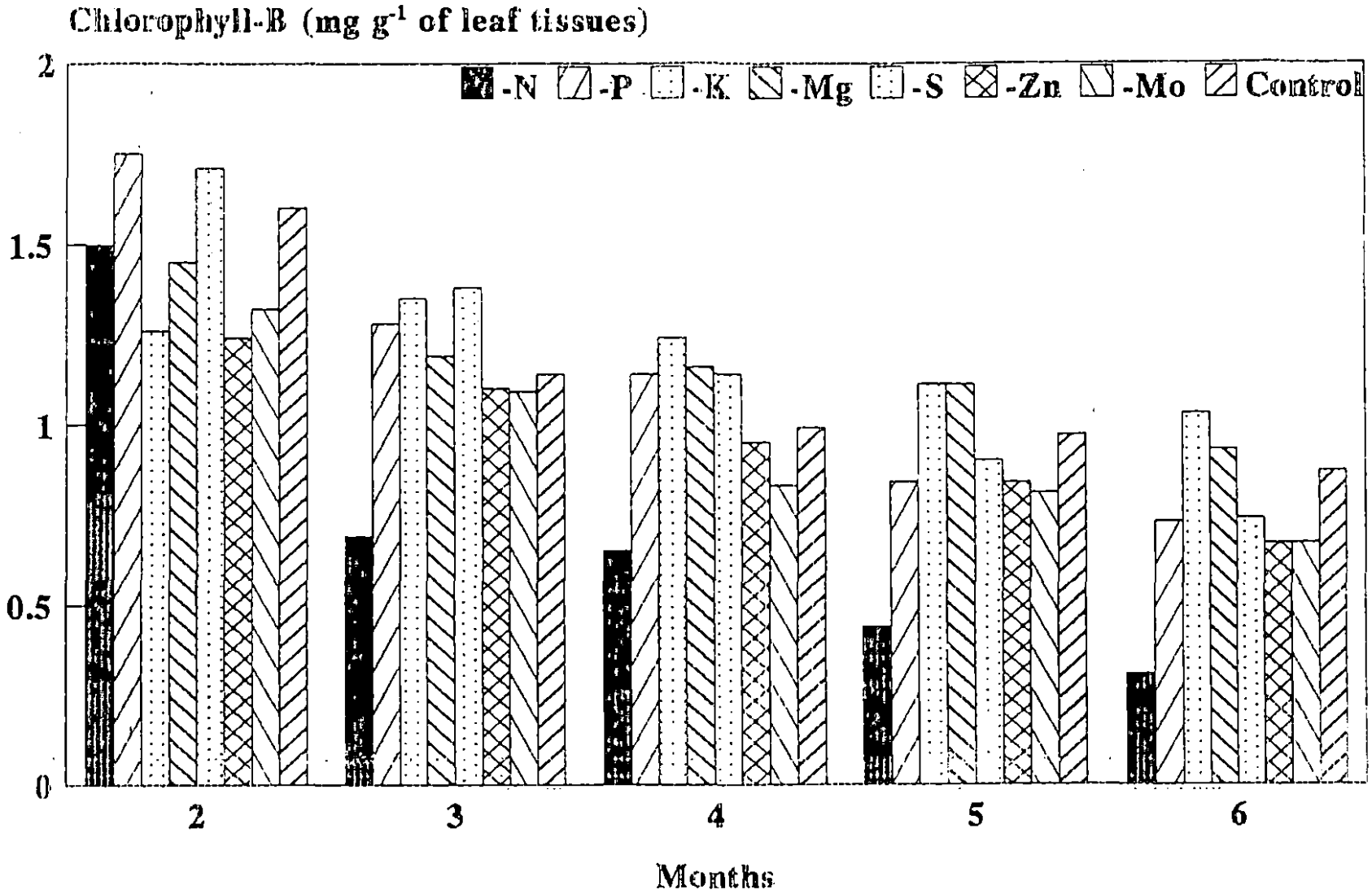


Fig.12 Effect of nutrient deficiencies on the chlorophyll- B content



In general, total chlorophyll content of the leaves was found to decrease with time (Fig.13). Seedlings subjected to N stress recorded the lowest total chlorophyll content throughout the period of study. Here also total chlorophyll content was found to decrease from 2.39 mg g^{-1} during the second month to 0.63 mg g^{-1} during the last month. The difference in total chlorophyll content between the seedlings receiving complete nutrient solution and those deficient in Mg and K was not significant during the fifth month.

4.4. Tissue nutrient levels

The effect of various treatments on the nutrient content of leaves of seedlings grown in sand culture is presented in this part.

4.4.1. Nitrogen

The N content of leaves was found to decrease in seedlings supplied with nutrient solution lacking N (Table 11). In these seedlings, the N content gradually decreased from 1.02 in the beginning to 0.56 per cent by the end of the sixth month when the study was completed. The seedlings receiving complete nutrient solution recorded highest N content during the sixth month (1.53 %). It could also be seen from the table that by the end of the study, P deficient seedlings had a N concentration to the tune of 1.34 per cent which was the second highest. At the end of sixth month, the second lowest value was recorded by those seedlings grown without K (1.08 %) followed by Zn (1.14 %). In the case of Mg and S deficient seedlings a moderate content of 1.23 and 1.24 per cent of N was recorded respectively.

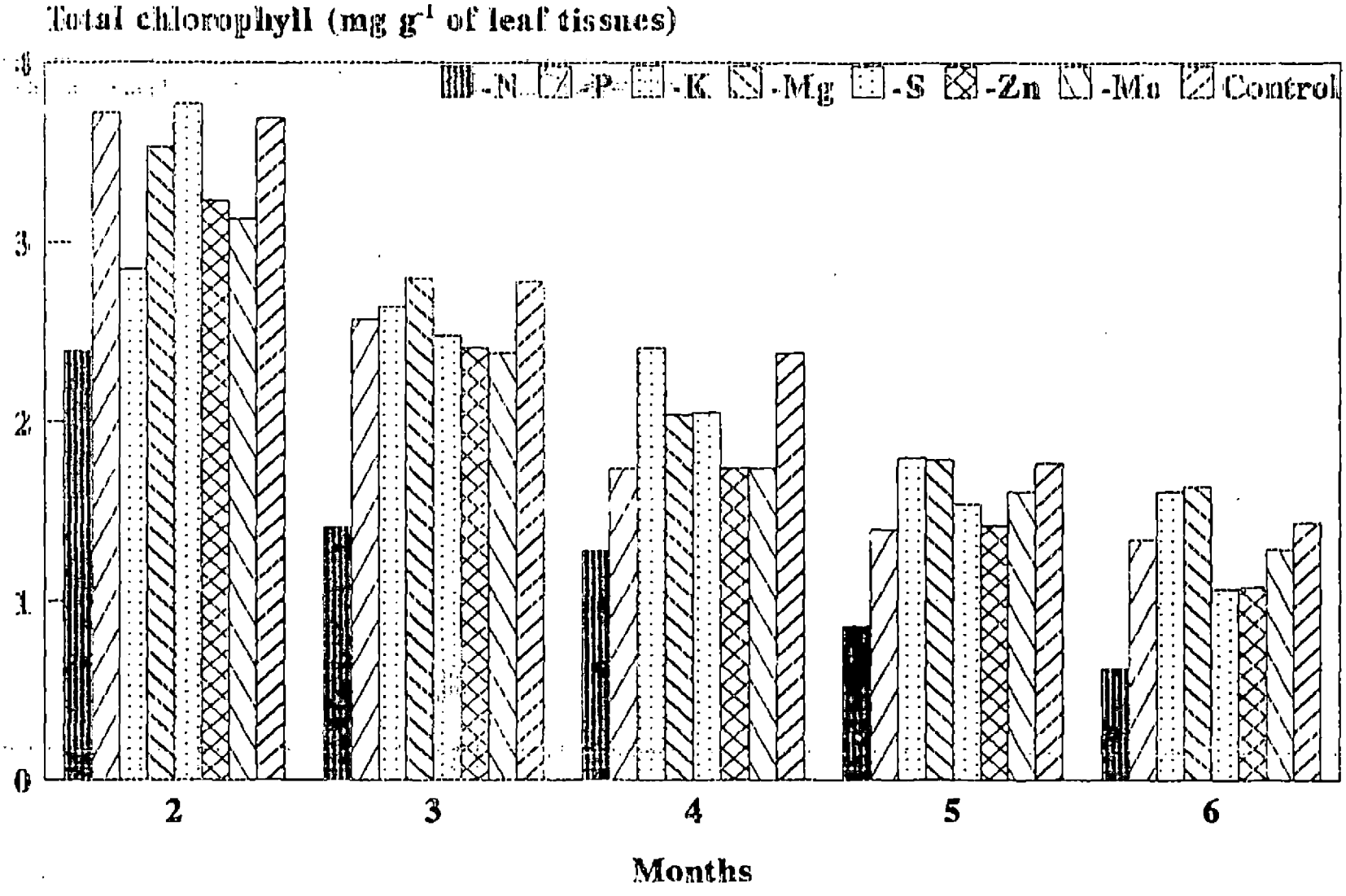
Table 11. Effect of nutrient deficiencies on the foliar concentration of nitrogen (per cent)

Nutrient element deleted from complete solution	Months					
	1	2	3	4	5	6
Nitrogen	1.02	0.95	0.74	0.62	0.60	0.56
Phosphorus	1.71	1.73	1.51	1.17	1.29	1.34
Potassium	1.47	1.48	1.13	1.20	1.48	1.08
Magnesium	1.62	1.39	1.31	1.26	1.44	1.23
Sulphur	1.59	1.29	1.09	1.27	1.50	1.24
Zinc	1.50	1.29	1.31	1.13	1.36	1.14
Molybdenum	1.32	1.17	1.47	1.12	1.32	1.30
Control	1.42	1.87	1.27	1.39	1.56	1.53
F-test	*	**	**	**	**	**
SEM ±	0.11	0.08	0.11	0.12	0.14	0.08
CD (5%)	0.34	0.25	0.32	0.36	0.43	0.25

* Significant at 5 per cent level

** Significant at 1 per cent level

Fig.13 Effect of nutrient deficiencies on the total chlorophyll content



4.4.2. Phosphorus

The effect of various treatments on the concentration of P in the seedlings is furnished in table 12. The tissue concentration P in plants supplied with nutrient solution lacking this element showed a gradual decline during the course of the study. At the end of the study, P concentration in these plants decreased to 0.42 per cent from the initial content of 1.26 per cent. The reduction was to the extent of about 66.67 per cent. A close examination of the data revealed that all the other nutrient deficient treatments also recorded lower levels of P during the course of the study. At the end of the study the seedling receiving complete nutrient solution recorded the highest value of 1.39 per cent.

4.4.3. Potassium

The K concentration of seedlings as affected by the various treatments is depicted in table 13 All the treatments were statistically significant with regard to their K content. The seedlings deficient in K showed a decreasing tendency from the initial content of 1.31 per cent to 0.28 per cent towards the end of study. At the end of study, the S deficient seedlings recorded the highest value of 1.54 per cent followed by seedlings receiving complete nutrient solution (1.51 per cent). However, the difference between the above treatments is not statistically significant. The seedlings which are deficient in N showed a decreasing tendency with regard to the K content except during the fifth month. At the end of study it recorded a mean content of 0.98 per cent of K. In the case of P, Mg and Mo deficient treatments, the seedlings recorded moderate values of 1.37, 1.33 and 1.30 per cent respectively towards the end of the study.

Table 12. Effect of nutrient deficiencies on the foliar concentration of phosphorus (per cent)

Nutrient element deleted from complete solution	Months					
	1	2	3	4	5	6
Nitrogen	1.28	1.27	0.83	1.05	0.89	1.21
Phosphorus	1.26	1.13	1.05	0.89	0.58	0.42
Potassium	1.98	2.04	1.31	1.05	1.32	1.13
Magnesium	1.52	1.58	1.24	1.28	0.86	1.23
Sulphur	1.99	1.83	1.36	1.43	1.39	1.15
Zinc	1.89	1.84	1.59	1.30	1.25	1.09
Molybdenum	2.07	2.01	1.72	1.78	1.35	1.20
Control	2.48	2.14	1.81	1.97	1.18	1.39
F-test	**	**	**	**	**	**
SEM ±	0.07	0.05	0.07	0.04	0.05	0.06
CD (5%)	0.20	0.15	0.21	0.11	0.13	0.18

** Significant at 1 per cent level

Table 13. Effect of nutrient deficiencies on the foliar concentration of potassium (per cent)

Nutrient element deleted from complete solution	Months					
	1	2	3	4	5	6
Nitrogen	1.78	1.86	1.33	1.06	1.28	0.98
Phosphorus	1.94	2.23	1.78	1.39	1.21	1.37
Potassium	1.31	1.14	0.62	0.34	0.41	0.28
Magnesium	1.96	1.94	1.71	1.31	1.58	1.33
Sulphur	1.72	1.86	1.75	1.50	1.70	1.54
Zinc	1.78	1.51	2.04	1.65	1.57	1.47
Molybdenum	1.80	1.66	1.77	1 41	1.37	1.30
Control	1.62	2.20	1.58	1.48	1.53	1.51
F-test	**	**	**	**	**	**
SEM ±	0.09	0.13	0.07	0.13	0.12	0.10
CD (5%)	0.26	0.38	0.21	0.38	0.36	0.31

** Significant at 1per cent level

4.4.4. Calcium

The leaf tissue concentration of Ca as influenced by nutrient stress in summarised in table 14. The data revealed that the treatments were having significant effect on the concentration of Ca in the seedlings through out the period of study. The seedlings grown using solutions deficient in K and Mo recorded more or less similar values with regard to Ca content while the seedlings deficient in N, P, Mg and Zn show a decreasing tendency as the study progressed. At the end of the study the seedlings receiving complete nutrient solution had the highest (1.22 %) and those which were deficient in Zn had recorded the lowest content (0.79%).

4.4.5. Magnesium

In seedlings supplied with nutrient solution lacking Mg, the concentration of Mg fell from an initial level of 1.27 per cent to 0.70 per cent towards the end of the study (Table 15). However, in the case of seedlings grown with nutrient solution lacking N, there was not much variation in the content of Mg through out the study period. With regard to most of the other treatments, the Mg content shown a decreasing tendency with the progress of study. In the case of seedlings receiving complete nutrient solution of the Mg content slightly increased towards the end of the study.

4.4.6. Sulphur

The data pertaining to the effect of nutrient stress on the concentration of S in the leaf tissues is tabulated in table 16. The difference in S content due to

Table 14. Effect of nutrient deficiencies on the foliar concentration of calcium (per cent)

Nutrient element deleted from complete solution	Months					
	1	2	3	4	5	6
Nitrogen	0.94	1.06	0.99	0.86	0.87	0.93
Phosphorus	1.24	1.18	2.55	1.20	0.95	0.92
Potassium	1.27	1.21	1.29	1.16	1.16	1.16
Magnesium	1.28	1.01	0.87	0.93	0.92	0.90
Sulphur	1.04	0.95	1.04	2.23	1.06	1.01
Zinc	1.12	0.83	1.03	0.74	1.13	0.79
Molybdenum	1.17	1.12	1.15	0.90	1.05	1.11
Control	1.41	1.08	1.32	0.90	1.54	1.22
F-test	**	**	**	**	**	**
SEM ±	0.07	0.06	0.05	0.06	0.04	0.04
CD (5%)	0.23	0.16	0.16	0.16	0.12	0.11

** Significant at 1 per cent level

Table 15. Effect of nutrient deficiencies on the foliar concentration of magnesium (per cent)

Nutrient element deleted from complete solution	Months					
	1	2	3	4	5	6
Nitrogen	0.78	0.91	1.04	0.99	0.87	0.94
Phosphorus	1.79	1.55	1.26	1.20	1.02	0.90
Potassium	1.34	1.58	1.24	1.01	1.07	1.18
Magnesium	1.27	1.07	1.06	0.94	0.82	0.70
Sulphur	1.91	1.40	1.86	1.45	1.30	0.97
Zinc	1.23	1.14	1.21	1.20	1.44	1.10
Molybdenum	1.13	1.62	1.77	2.16	1.94	1.63
Control	2.57	1.79	2.41	2.17	1.86	2.59
F-test	**	**	**	**	**	**
SEM ±	0.03	0.03	0.03	0.04	0.08	0.04
CD (5%)	0.08	0.09	0.08	0.12	0.24	0.11

** Significant at 1 per cent level

Table 16. Effect of nutrient deficiencies on the foliar concentration of sulphur (per cent)

Nutrient element deleted from complete solution	Months					
	1	2	3	4	5	6
Nitrogen	0.038	0.033	0.036	0.041	0.040	0.037
Phosphorus	0.047	0.045	0.045	0.032	0.049	0.037
Potassium	0.048	0.069	0.039	0.036	0.034	0.046
Magnesium	0.042	0.056	0.032	0.034	0.040	0.036
Sulphur	0.042	0.038	0.030	0.024	0.021	0.020
Zinc	0.040	0.050	0.050	0.041	0.044	0.034
Molybdenum	0.052	0.043	0.054	0.058	0.049	0.044
Control	0.047	0.072	0.033	0.060	0.057	0.058
F-test	**	**	**	**	**	**
SEM ±	0.00	0.01	0.00	0.00	0.00	0.00
CD (5%)	0.05	0.05	0.05	0.05	0.05	0.05

** Significant at 1per cent level

various treatments was statistically significant. The concentration of S was the lowest in seedlings that received nutrient solution lacking S. The initial content of S was 0.042 per cent and at the end of study it was 0.020 per cent. This decrease from initial value to final value is about 50 per cent. In all the other nutrient deficient seedlings there was not much fluxtuation in the content of S from beginning to end. At the end of the study, the highest value was recorded by those seedlings which were receiving complete nutrient solution (0.58%).

4.4.7. Zinc

The data on the effect of various treatments on the Zn concentration of the seedlings is tabulated in table 17. The seedlings which were deficient in Zn in the nutrient solution recorded the lowest value at the end of study (0.004 %). The difference between initial (0.013%) and final content is to the tune of 69.23 per cent. At the end of study the seedlings grown with nutrient solution deficient in P recorded the highest Zn content of 0.016 per cent. In most of the nutrient deficient treatments the value of Zn content shown a decreasing tendency with the progress of study.

4.5. Recovery studies using complete nutrient solution

4.5.1. Improvement of deficiency symptoms and growth

During the course of recovery studies, it was found that the foliar symptoms like leaf discolouration induced by the deficiency of various nutrients gradually disappeared. The new flushes of leaves produced were healthy, green and normally shaped. At the end of sixth month, the extent of recovery of seedlings from

Table 17. **Effect of nutrient deficiencies on the foliar concentration of zinc (per cent)**

Nutrient element deleted from complete solution	Months					
	1	2	3	4	5	6
Nitrogen	0.013	0.009	0.013	0.008	0.010	0.008
Phosphorus	0.013	0.012	0.011	0.008	0.009	0.016
Potassium	0.027	0.006	0.008	0.009	0.012	0.009
Magnesium	0.020	0.008	0.009	0.009	0.009	0.006
Sulphur	0.013	0.006	0.007	0.008	0.012	0.013
Zinc	0.013	0.005	0.009	0.005	0.006	0.004
Molybdenum	0.017	0.013	0.012	0.007	0.008	0.009
Control	0.033	0.030	0.013	0.013	0.008	0.013
F-test	**	**	**	**	**	**
SEM ±	0.00	0.00	0.00	0.00	0.00	0.00
CD (5%)	0.05	0.05	0.05	0.05	0.05	0.05

** Significant at 1per cent level

nutrient stress was remarkable (Plate 17). The seedlings recorded vigorous growth with dark green and thick foliage.

The effect of supplying complete nutrient solution on the increment in height, diameter and leaf production of nutrient deficient seedlings is clearly evident from the data furnished in table 18. Height differences were significant after the commencement of recovery studies. Application of complete nutrient solution to the nutrient deficient seedlings, resulted a considerable improvement in the height growth. The N deficient seedlings had recorded a height increment from 16.31 cm to 23.20cm while P deficient seedlings recorded the increment from 27.29 cm to 38.34 cm (28.82 % increase) at the end of the recovery studies. Like N and P all the other nutrient deficient seedlings also registered an improvement in height by the end of recovery studies as is evident from the data furnished in table 18. The mean height of control seedlings was found to be 53.35 cm at the end of study.

The difference in diameter was also significant during the recovery studies. Diameter increase was more pronounced for seedlings deficient in Zn and P. Here the increment was from 0.2 cm to 0.33 cm and 0.24 cm to 0.33 cm respectively.

With regard to leaf production also the treatments differed significantly during the recovery studies. The seedlings deficient in Mo have produced maximum number of leaves (24.76) with the application of complete nutrient solution while not much difference was observed in the case of seedlings deficient in K.

Table 18. Growth parameters of nutrient deficient seedlings after the application of complete solution

Nutrient element deleted from complete solution	Fortnights														
	Height (Cm)					Diameter (Cm)					Leaves (number)				
	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
Nitrogen	16.31	18.39	19.23	21.26	23.20	0.19	0.19	0.19	0.20	0.22	11.52	12.39	12.89	13.56	14.18
Phosphorus	27.29	33.42	35.08	36.62	38.34	0.24	0.30	0.31	0.32	0.33	13.99	16.64	17.64	17.58	19.33
Potassium	28.66	36.85	38.50	39.52	40.42	0.25	0.29	0.30	0.32	0.33	18.38	17.11	17.69	18.15	19.04
Magnesium	29.14	33.96	35.06	35.91	36.92	0.27	0.27	0.27	0.29	0.31	16.71	16.49	17.71	20.12	20.17
Sulphur	29.59	34.72	36.28	37.58	39.28	0.21	0.27	0.28	0.31	0.33	17.11	15.91	16.55	17.88	21.09
Zinc	33.51	36.88	38.04	38.87	40.19	0.27	0.30	0.31	0.33	0.36	17.61	17.44	17.73	19.60	20.74
Molybdenum	39.86	44.62	45.92	48.06	49.28	0.28	0.32	0.32	0.34	0.36	17.53	19.66	22.51	24.61	24.76
Control	43.85	47.92	49.35	50.76	53.35	0.33	0.33	0.34	0.36	0.40	21.98	22.07	23.62	24.34	24.41
F-test	**	**	**	**	**	**	**	**	**	**	**	*	**	**	**
SEM ±	0.45	1.82	1.86	1.66	1.65	0.00	0.02	0.02	0.01	0.01	0.35	1.61	1.32	1.48	1.21
CD (0.05)	1.34	5.47	5.59	4.98	4.94	0.08	0.05	0.05	0.05	0.05	1.06	4.83	3.96	4.45	3.64

* Significant at 5 per cent level

** Significant at 1 per cent level

Plate 17. Seedlings showing recovery of deficiency symptoms and improvement in growth after the application of complete nutrient solution

1. Control Seedling
2. Seedling selected from - N treatment
3. Seedling selected from - P treatment
4. Seedling selected from - K treatment
5. Seedling selected from - Mg treatment
6. Seedling selected from - S treatment
7. Seedling selected from - Zn treatment
8. Seedling selected from - Mo treatment


1
2
3
4
5
6
7
8

4.5.2. Improvement in leaf nutrient content

The chemical analysis of the leaf tissues at the end of the recovery studies revealed that there is much improvement in the concentration of major nutrients in the seedlings when compared to nutrient content before starting the recovery studies (Table 19). In the case of N deficient seedlings, the N content increased from 0.56 per cent to 1.34 per cent on receiving complete nutrient solution. With regard to P deleted seedlings there was an improvement from 0.42 to 1.22 per cent in P concentration. Similarly the K content of K deficient seedlings before recovery studies was 0.28 per cent and had been increased to 1.53 per cent after the recovery studies. It could be also seen from the table that the application of complete nutrient solution has increased the content of Mg, S and Zn in seedlings which were deficient in these elements before the commencement of recovery studies.

Table 19. Leaf tissue concentration of nutrient deficient seedlings after the application of complete solution

Nutrient element deleted from complete solution	Per cent						
	N	P	K	Ca	Mg	S	Zn
Nitrogen	1.34	1.93	2.17	1.04	1.95	0.057	0.020
Phosphorus	1.51	1.22	1.73	0.98	1.19	0.055	0.011
Potassium	1.40	2.01	1.53	1.39	1.57	0.063	0.016
Magnesium	1.40	1.48	1.30	1.32	1.86	0.067	0.024
Sulphur	1.23	2.27	1.75	1.21	1.94	0.050	0.032
Zinc	1.34	2.33	1.33	1.16	1.85	0.052	0.010
Molybdenum	1.29	2.30	1.55	1.12	1.29	0.051	0.026
Control	1.68	2.34	1.98	1.34	1.53	0.059	0.036

Discussion

DISCUSSION

The present series of studies relating to the nutritional deficiency symptoms of *Tectona grandis* were conducted with an objective of inducing and describing the symptoms of deficiency of various nutrient elements in the seedlings. This will also provide information to understand the importance of different nutrient elements, their actual role, quantity required and uptake pattern which will finally benefit the foresters and farmers for the production of healthy and vigorous seedlings for extensive planting programmes. The experiment was conducted in College of Forestry, Vellanikkara during the period 1994-96. The major results on the deficiency symptoms, growth behaviour, tissue nutrient concentration and recovery studies in relation to various nutrient elements are discussed here under.

5.1. Nitrogen

5.1.1. Visual deficiency symptoms and growth behaviour of seedlings

The initial symptom of N deficiency was the formation of yellow chlorotic patches in the older leaves of the seedlings. In acute stages, the entire seedling appeared severely chlorotic followed by premature drying and defoliation. The seedlings were also stunted in growth compared to control.

Chlorophyll content was found to decline gradually in these seedlings. Nitrogen deficient plants incidentally recorded the lowest chlorophyll- A (0.32 mg g^{-1}), chlorophyll- B (0.31 mg g^{-1}) and total chlorophyll content (0.63 mg g^{-1}). The reduction in the chlorophyll content of chlorotic leaves due to N deficiency

was also reported by Nazeem (1989) in clove and Anoop (1993) in Ailanthus. Chlorosis of the older leaves and stunting of the growth are the common visual symptoms of N deficiency observed in most of the tree crops. Typical chlorotic symptoms due to severe N deficiency were reported by Landis *et al.* (1989) in seedlings of paper birch and Driessche (1989) in seedlings of Douglas-fir and white spruce. Maskel *et al.* (1953) reported stunted growth, yellowing of older leaves, die back and reduced rate of leaf production in young seedlings of cocoa. Similar symptoms were also observed in citrus (Jones and Embelton, 1959), coffee (Muller, 1966), avacado (Jones, 1975), apple (Pant *et al.*, 1976), nutmeg (Philip, 1986), Cashew (Gopikumar and Aravindakshan, 1988) and Ailanthus (Anoop, 1993).

Nitrogen is reported to be mobile inside the plant system and hence, its deficiency leads to the movement of this element from older leaves to younger ones resulting in the development of symptoms first on the older leaves (Gauch, 1972). Chlorosis of older leaves was as a result of inadequate supply of N for chloroplast protein synthesis (Greulach, 1973).

Nitrogen deficiency had pronounced effect on the growth behaviour of seedlings particularly with regard to shoot growth. Shoot growth parameters like height, collar diameter and leaf production were lower in these seedlings compared to seedlings grown in complete solution. In fact, at the end of the study period, the height of these seedlings was found to be 67.02 per cent less compared to control. In cashew seedlings grown in sand culture, N deficiency resulted in reduced height, girth and leaf production of seedlings (Gopikumar and Aravindakshan, 1988). Similar observations were also made in Ailanthus by Anoop (1993).

In the present study, shoot fresh and dry weights were respectively 82.70 per cent and 77.02 per cent lower in N deficient seedlings compared to control. Lockard and Asomaning (1964) also observed low dry matter content in seedlings of cocoa grown under N stress. Similarly, in this treatment the fresh and dry weights of the root portion were also very low in relation to rest of the treatments. According to Kramer and Kozlowski (1960), N containing compounds constitute 5 to 30 per cent of the dry weights of plants.

The reduction in vegetative growth may be due to the fact that N supply largely controls the use of carbohydrate and hence determines whether the plant will make vegetative or reproductive growth (Kraws and Kraybill, 1918 and Jones, 1975). In addition, N is also reported to be involved in various other processes associated with protoplasm, enzymatic reactions and protein synthesis (Gauch, 1972; Pandey and Sinha, 1972 and Jones, 1975).

5.1.2. Tissue nutrient concentration

Visual deficiency symptoms produced by seedlings supplied with treatment solution lacking N concurred with a significant reduction in the foliar concentration of N in these seedlings. By the end of the study the N concentration fell to 0.56 per cent from the initial content of 1.02 per cent. This coincided with the severe stage of deficiency when the entire seedlings appeared chlorotic followed by premature drying and defoliation of leaves. The present observations are also in agreement with the finding of Lockard and Asomaning (1964), who observed typical symptoms of N deficiency in cocoa seedlings when the tissue content of

N was reduced to 0.96 per cent. Similar results were obtained with N deficient Ailanthus seedlings (Anoop, 1993) when the tissue content of N was reduced to 1.03 per cent.

Deletion of N from the treatment solution increased the P concentration (1.21%) of these seedlings at the end of the sixth month. Antagonistic effect of N and P has been reported in cocoa (Lockard and Asomaning, 1964), citrus (Smith, 1966) and pepper (Dewaard, 1969 and Nybe, 1986). The K concentration of N deficient seedlings recorded a decreasing tendency in the present study. However, foliar concentration of Mg showed a declining trend upon the deletion of N from the complete nutrient solution. Similar effects were also reported in citrus by Lebanauskas *et al.* (1958) and in pepper by Nybe (1986).

Interestingly the N deficient plants recovered from the visual symptoms of deficiency and produced green and healthy foliage by the end of the recovery studies when complete nutrient solution was again applied. There was also a rapid improvement in the height growth but improvement in collar diameter was relatively slow. The foliar concentration was also found to be increased remarkably with the application of complete solution. Landis *et al.* (1989) in paper birch noted that stunting due to N deficiency was usually easy to diagnose and

subsequently to correct, because deficient seedlings rapidly respond to application of N fertilizers.

5.2. Phosphorus

5.2.1. Visual deficiency symptoms and growth behaviour of seedlings

Phosphorus deficiency symptoms appeared first on the older leaves as purple bronze patches. As the level of deficiency advanced, these purple bronze patches extended to entire leaf and later changed to yellow chlorotic patches. In acute stages of deficiency seedlings had sparse foliage with stunted growth.

Like N, here also the chlorophyll content decreased gradually as the level of deficiency progressed. In tree seedlings similar symptoms were observed by other workers also. In apple, P deficiency symptoms are expressed as small dark green leaves with bronze to purple tinge, sparse foliage and restricted branching (Wallace, 1953). The study conducted at the University of Florida by Chiiders (1966) also revealed the development of bronze foliage in citrus and strawberry. Bingham (1975) explained the manifestation of P deficiency in tree species as slow growth, sparse, dull bronze to purple tinted foliage and early dropping of leaves. Development of bronze green lower leaves with purple and necrotic blotches followed by defoliation have been described as symptoms of P deficiency in nutmeg (Philip, 1986) while reddish pink colouration of older leaves and stunting of growth have been reported in red maple (Landis *et al.*, 1989). According to Driessche (1989) in Douglas-fir and white spruce seedlings,

P deficiency resulted in dull, greyish coloured or purple foliage. Appearance of purple bronze patches in older leaves which later extend to entire leaflet was the symptoms of P deficiency observed in Ailanthus (Anoop, 1993).

Since, P is a mobile element, deletion of this element from the nutrient solution resulted its translocation from older to younger tissues, manifesting the P deficiency symptoms to appear first in the older leaves. Phosphorus deficiency is reported to result in the formation and accumulation of anthocyanin pigments which results in the development of purple colouration (Muller, 1966; Gauch, 1972 and Resh, 1978). Greulach (1973) based on his studies stated that reduced quantities of ATP, NAD, NADP and various other P containing compounds resulted decrease and disruption of metabolic path ways resulting in stunted growth of the plant. It is also to be noted that P is an improtant structural component of the chloroplasts and hence its deficiency have contributed a lower content of chlorophyll in leaf tissues finally resulting in typical discolouration. Swan (1971) is of the opinion that P deficiency symptoms are extremely variable between species and some times even within the species and therefore this problem is difficult to diagnose from visual symptoms alone.

In the present study, shoot growth parameters such as height, collar diameter and leaf production were significantly affected by P deficiency. Height growth was lower in these seedlings (34.55 cm) compared to control (53.03 cm). Towards the end of the study, P deficient seedlings had 32.56 per cent lower collar diameter compared to seedlings that received complete nutrient solution. Leaf production was 45.37 per cent less compared to control seedlings. At the end of study, P defieient seedlings recorded a leaf area of 935.69 cm^2 which was 71.13 per cent lower compared to seedlings that received complete nutrient solution. The lower

number of leaves in P deficient plants might have resulted from the premature defoliation as has been reported by other workers. Childers (1966) has also observed early dropping of leaves in avocado, citrus and strawberry due to P deficiency. The sand culture studies conducted by Gopikumar and Aravindakshan (1988) in cashew and Anoop (1993) in Ailanthus also revealed similar outcome for P deficiency.

Like shoot growth parameters, the P deficient seedlings recorded lower shoot fresh and dry weights during the study period compared to control. Such reductions in shoot growth parameters have also been observed in cocoa (Lockard and Asomaning, 1964), cashew (Gopikumar and Aravidakshan, 1988), clove (Nazeem, 1989) and Ailanthus (Anoop, 1993). The retardation in growth could be explained by the fact that like N, P also plays an improtant role as a structural component of cell constituents and other metabolically active compounds (Greulach, 1973 and Agarwala and Sharma, 1976). It is also an established fact that P is the major controlling factor for energy in all living cells and as a constituent of nucleoproteins it is concerned with cell division also (Epstein, 1978).

5.2.2. Tissue nutrient concentration

In P deficient seedlings, the concentration of P in the leaf tissues decreased gradually as visual deficiency symptoms progressed. In the acute stage of deficiency, P concentration reduced to a very low value of 0.42 per cent. In cashew (Gopikumar and Aravindakshan, 1988), nutmeg (Philip, 1986), Douglas-fir and white spruce (Driessche, 1989) and Ailanthus (Anoop, 1993) also observed a gradual reduction in foliar concentration of P with the advancement of visual deficiency symptoms.

Phosphorus deficiency caused an increase in the foliar levels of N and K and a corresponding decrease in the levels of Ca and Mg. Similar results were reported in apple and nutmeg by different authors. In apple, Matsui *et al.*, (1977) noted a positive correlation of P level with Cu and Mg contents and a negative correlation with K while in nutmeg, Philip (1986) reported an increase in foliar concentration of N and a decrease in Mg when P was deleted from the nutrient solution.

In P deficient seedlings, the extent of recovery of visual symptoms was remarkable on application of complete nutrient solutions. There was also improvement in height, collar diameter and leaf production of the seedlings. Foliar concentration of P in these seedlings reached 1.22 per cent at the end of recovery studies. It is also interesting to note that the P content in these seedlings at the end of the recovery studies and before the development of visual symptoms was almost uniform there by indicating the possibilities of improving the seedling growth and the control of the deficiency by its proper application.

5.3. Potassium

5.3.1. Visual deficiency symptoms and growth behaviour of seedlings

The K deficient seedlings manifested chlorotic tips in the older leaves by third month after imposing the treatments. This later spread through the margin upwards. Gradually the entire leaf developed chlorotic symptoms with necrosis progressing from the lower part of the leaves. The symptoms observed in the present study also agree with the observations made by various workers on other tree species. Muller (1966) noticed necrosis of leaf margins of older leaves in

coffee. Purseglove (1977) reported browning and scorching of entire leaf margins and defoliation as typical visual symptoms of K deficiency in coffee. Necrotic older leaves have been reported by Philip (1986) in nutmeg. Yellowing and necrosis of lower leaf tip which later spread to other portion of the leaves were reported by Gopikumar and Aravindakshan (1988) in cashew and Anoop (1993) in Ailanthus. Ulrich and Ohki (1975) stated that in trees, since K moves to the growing point, the older leaves normally exhibit the most characteristic K deficiency symptoms as tip and marginal scorching.

Necrosis of leaf lamina at the acute stage of deficiency might have resulted from the accumulation of diamine and putriscine as reported by Richards and Coleman (1952). Even though there was a gradual decline in the chlofophyll- B and total chlrophyll content of K deficient seelings, they generally had higher concentration compared to other treatments particularly at the end of the study. Though K activated the synthesis of cholorophyll, an increased partitioning of K to the chloroplast has been reported as the reason for no substantial reduction in chlorophull content and photosynthetic rates in K deficient plants (Capron *et al.*, 1982).

In the present study, the reduction in height, collar diameter and leaf production was not found to be very severe in K deficient seedlings compared to other treatments. However, shoot growth parameter recorded lower values compared to control. In cashew, absence of K adversely affected all the shoot growth parameters except the girth of seedlings (Gopikumar and Aravindakshan, 1988). Similar trends in relation to height, leaf procution and drymatter as result of K deficiency have been reported in nutmeg (Philip, 1986) and Ailanthus (Anoop, 1993).

The property of K to occur primarily in the ionic form or as charged particle on colloidal surfaces has made it most apt to function as a catalyst or as a co-factor of one or more of many enzymatic reactions of living cells (Ulrich and Ohki, 1975). It also activates protein synthesis and N metabolism (Mulder and Bakema, 1956). This is reported to have a direct inflence on cell division resulting in a higher cell number as suggested by Boringer and Schacherer (1982).

5.3.2. Tissue nutrient concentration

Potassium deficiency was associated with a decrease in the initial foliar content of K from 1.31 to 0.28 per cent at the end of the study. Visual symptoms of K deficiency were reported to be concurred with reduced levels of K in foliages of cashew (Gopikumar and Aravindakshan, 1988), nutmeg (Philip, 1986) and Ailanthus (Anoop, 1993). A close observation of the data revealed that N and P levels were reduced while Mg and S levels increased on account of K deficiency. Among, all interactions, the antagonistic effect of K and Mg was most pronounced. Antagonistic effect of K with Mg have been also established in different crops by Cain (1948) in apple, Smith (1966) in citrus, Nybe (1986) in pepper, Philip (1986) in nutmeg and Anoop (1993) in Ailanthus.

On application of complete nutrient solution, seedlings recovered well from the visual symptoms and growth retardation induced by K deficiency. The tissue level of K also improved when K was supplied through complete nutrient solution.

5.4. Magnesium

5.4.1. Visual deficiency symptoms and growth behaviour of seedlings

Magnesium deficiency produced typical visual symptoms as inter veinal chlorosis with reticulate pattern. In the acute stage, these chlrotic patches between the green mid rib and veins developed necrosis. Growth was also stunted in these seedlings compared to control. Thus, Mg could be listed as another element, the deficiency of which produces a characteristic chlorosis which is generaly strongly patterned. Philip (1986) also noted symptoms similar to the ones obtained in the present study. In nutmeg, he observed the development of pale yellow colouration near midrib of older leaves followed by pale green, lemon and necrotic blotches towards marigin, with upward cupping, due to Mg deficiency. Such symptoms were also reported in citrus (Reitz, 1958 and Tanaka, 1960), coffee (Muller, 1966) and paper birch (Landis *et al.*, 1989).

Magnesium being a mobile element in plants, its deficiency resulted the movement of this element from older leaves to younger ones, inducing the symptoms to be developed first on older leaves (Embleton, 1975). Magnesium formed one of the major constituents in the pigment chlorophyll (2.7 % by weight) and hence, the removal of Mg from the treatment solution resulted in varying degrees of chlorosis. Magnesium is known to play a catalytic role as an activator of a number of enzymes, most of which were concerned with carbohydarate metabolism, phosphate transfer and decarboxylation (Dixon, 1949). So, the deficiency of this element might have disrupted the metabolic pathways and caused reduced growth as is evident from the present study.

5.4.2. Tissue nutrient concentration

Magnesium concentration in seedlings supplied with nutrient solution lacking Mg fell from 1.27 per cent in the beginning to 0.70 per cent by the end of the study period. The development of chlorosis between the veins of leaves occured when the Mg content of the tissue was declined to lower levels.

Antagonistic effect of Mg with all other elements except P is evident from the present study. Smith (1966) observed that in the leaves of citrus, P concentration was not affected by Mg level even in severely deficient trees. Antagonistic influences of Mg with K and Ca have been reported by various workers (Emmert, 1961 ; Dewaard, 1969 ; Manicot *et al.*, 1980, Nybe, 1986 and Ancop, 1993).

Magnesium deficient plants recovered well by the end of the recovery studies, when supplied with complete nutrient solution. Foliar concentration of Mg in seedlings kept for recovery studies increased from 0.70 per cent to 1.86 per cent at the end of the study when the growth of seedlings were normal.

5.5. Sulphur

5.5.1. Visual deficiency symptoms and growth behaviour of seedlings

Discolouration of terminal leaves from dark green to pale green which gradually advanced from margin inwards was the typical symptom observed in S deficient seedlings. In the moderate stage of deficiency the region close to midrib

appeared green and in the acute stage the entire leaf became chlorotic. This discolouration was associated with defoliation and the seedlings appeared to be lanky compared to control seedlings. The chlorophyll content of the S deficient seedlings decreased by the end of the study. Compared to control the S deficient seedlings had 25.69 per cent less total chlorophyll content during the last month.

The chlorotic nature of S deficent plants is due to the impaired phosynthesis attributed to the direct effect on the protein level and the chorophyll content in the chloroplasts. Since S is intimately associated with protein synthesis, its deficiency resulted in accumulation of carbohydrate and soluble N compounds, there by finally resulting a break down and decrease in cambial tissues. This might have contributed to the lanky appearance of these seedlings. Lott *et al.* (1960) in coffee observed the youngest leaves showing uniform light green colour later turning to more intensive chlorosis because of S deficiency. Overall yellowing of leaves similar to one appeared in the present study has also been reported in apple, pear, peach and grapes by Childers (1966).

There was no remarkable retardation in height and leaf production compared to control. At the end of the study the collar diameter was found to be 39.53 per cent lower when compared to control.

The shoot fresh and dry weights due to S deficiency was respectively 47.02 per cent and 36.64 per cent lower when compared to control. In cocoa seedlings grown in sand culture, deficency of S, recorded significantly lower dry weight compared to treatments deficient in other macro elements except Ca (Lockard and Asomaning, 1964).

5.5.2. Tissue nutrient concentration

Seedlings supplied with treatment solution lacking S developed chlorotic symptoms after three months. The S deficient seedlings recorded the lowest S concentration by the end of the study (0.02 per cent). In another study, Gopikumar and Aravindakshan (1988) also found that S deficiency coincided with low S levels in the foliage of cashew seedlings grown in sand culture.

Sulphur deficient plants recovered well by the end of the recovery studies when supplied with complete nutrient solution. Sulphur content in the foliages of the seedlings after the application of complete nutrient solution improved from 0.020 per cent to 0.050 per cent.

5.6. Zinc

5.6.1. Visual deficiency symptoms and growth behaviour of seedlings

The initial symptom of Zn deficiency appeared on the lower leaves as chlorotic patches. Seedlings developed short inter nodes, more number of branches and small clustered leaves. Later these leaves develop necrotic patches and at severe stages the leaves developed burned appearance. Chlorophyll content was also found to decline gradually in these seedlings as study progressed.

The leaf area of the Zn deficient seedlings was 66.65 per cent less compared to the control seedlings. The shoot fresh and dry weight also showed a reduction by 46.31 per cent and 36.31 per cent respectively compared to those seedlings receiving complete solution.

Typical inter veinal chlorosis termed as 'mottled leaf', reduced inter nodal length and 'little leaf', are the common symptoms of Zn deficiency as reported by Gruelach (1973). Zinc deficiency results in inadequate supply of IAA, a very important growth hormone. Philip (1986) in nutmeg also reported that, Zn deficiency resulted in reduction of internodal length, leaf area and dry matter content. In cashew seedlings, reduced internodal lenth, retarded terminal growth and production of small leaves with interveinal chlorosis are the symptoms observed by Gopikumar and Arvindakshan (1988).

5.6.2. Tissue nutrient concentration.

In Zn deficient seedlings, the concentration of Zn in the leaf tissues decreased gradually as visual deficiency symptoms progressed. The Zn content reduced from 0.013 per cent in the beginning to 0.004 per cent at the end of the study.

In nutmeg, gradual reduction in foliar concentration of Zn with the advancement of visual deficiency symptoms was reported by Philip, (1986). A close observation of the data revealed that N and K levels was high while Ca levels decreased on account of Zn deficiency. Smith (1966) in citrus reported that Zn deficiency was often associated with high content of N and K and low Ca in leaves.

On the application of complete nutrient solution, the seedlings recovered well from the visual symptoms and gowth retardation induced by Zn deficiency. The tissue level of Zn also improved significantly.

5.7. Molybdenum

5.7.1. Visual deficiency symptoms and growth behaviour of seedlings

Seedlings which were deficient in Mo developed symptoms only after five months of imposing the treatments. The symptoms appeared first on terminal leaves. The size of leaf reduced considerably. The leaves were narrow in appearnace. At later stages interveinal chlorosis was also noticed. With regard to the growth behaviour it was not much affected compared to other treatments. The reduction in height was only 13.78 per cent compared to control seedlings. In the case of collar diameter and leaf number the reduction was only 11.63 per cent and 13.5 per cent respectively compared to healthy seedlings.

In orange and grape fruit, Mo deficiency first appeared as water soaked areas, subsequently developed into large interveinal chlorotic spots (Vanselow and Datta, 1949). Curling of the leaves was reported by Kamala *et al.* (1988) in most of the tropical tree species. This was associated with reduction in leaf size in *Dalbergia latifolia*. In *Azadirachata indica* they noticed chlorotic leaves with curled margins. The changes in the isoenzyme pattern are the primary biochemical changes occuring at the cell level due to deficency of these trace elements and on account of these physiological changes, the plant finally shows its effect on the leaf anatomical and morphological character further expressing as visible deficiency symptom (Kamala *et al.*, 1988). Like other treatments Mo deficient plants recovered well by the end of the study, when supplied with complete nutrient solution. The growth was normal and there was improvement in discolouration and size of the leaves.

Summary

SUMMARY

The present investigations pertaining to the nutritional deficiency symptoms of teak (*Tectona grandis* Linn. f.) were taken up with the main objective of inducing and describing the symptoms of deficiency of various nutrient elements in the seedlings grown in sand culture. An attempt was also made to investigate the effect of nutrient elements on the growth behaviour of seedlings. Recovery studies with the application of complete nutrient solution was conducted to confirm the deficiency of various elements manifested by seedlings.

Sand culture experiments were conducted under controlled conditions inside a glass house attached to College of Horticulture, Kerala Agricultural University Main Campus, Vellanikkara, during the period of 1994-96. Two months old seedlings of uniform growth were planted in plastic containers filled with pure quartz sand. Hoagland No. 2 (1948) solution was used for supplying the nutrients. Treatment solutions were prepared in bulk by eliminating the desired nutrient element from the complete Hogland nutrient solution.

The salient results of the present studies are summarised below :

1. Characteristic visual deficiency symptoms were manifested by the seedlings at different levels of deficiencies of N, P, K, Mg, S, Zn and Mo.

2. For N, the initial visual symptom of deficiency was chlorosis of the older leaves. Later the entire lamina turned pale yellow. The acute stage of deficiency was characterized by severe chlorosis of the entire seedling followed by premature drying, defoliation, and stunting in growth. Phosphorus deficiency symptoms appeared first on the older leaves as purple bronze patches which later

changed to yellow chlorotic patches. In the acute stage of deficiency, the bronze patch extended towards the entire leaf resulting in premature defoliation. The seedlings had sparse foliage and were stunted in growth compared to control. Chlorotic tips in lower leaves were the initial symptoms of K deficiency. The chlorotic areas spread through the margin upwards. The entire leaf developed chlorotic symptoms. The necrosis progressed from the lower part of the chlorotic leaves.

3. Magnesium deficiency resulted in the development of small chlorotic areas in the older leaves as initial symptoms . Gradually, the chlorotic areas developed into necrotic regions. However, the mid rib and veins remained green. Compared to control, Mg deficient seedlings were stunted in growth. In the case of S deficiency, the symptoms first appeared on the terminal leaves as discolouration from dark green to pale green. The symptoms gradually advanced from margin inwards. At the moderate stage, only the region close to mid rib appeared green. At acute stage entire leaf turned chlorotic and developed necrosis. The affected leaves were yellowish white in colour.

4. The Zn deficiency symptoms first appeared on the lower leaves as chlorotic patches by the end of fourth month. The seedlings were stunted in growth with small clustered leaves. Later the leaves develop necrotic patches and at severe stages the leaves had a burned appearance. In the case of Mo deficiency, symptoms first appeared on terminal leaves. The size of the terminal leaves reduced considerably. The leaves were narrow in appearance. At later stages inter veinal chlorosis was noticed.

5. Vegetative growth was also affected by the deficiency of various nutrient elements. Among the shoot growth parameters height, collar diameter, leaf production and leaf area of the deficient seedlings were found to be seriously affected compared to control seedlings. Deficiency of N resulted maximum reduction in height compared to other elements which was followed by P. However, the effect of deficiency of Mo on the vegetative growth of seedlings was not as severe compared to deficiency of other elements. Nitrogen deficient seedlings produced the lowest diameter growth compared to all other treatments.

6. In the case of leaf production, N deficient seedlings recorded the lowest value followed by P deficient seedlings. The other treatments also recorded a value which was much lower compared to control. In the case of leaf area, N deficient seedlings recorded lowest leaf area followed by P deficient seedlings. In the case of K , the leaf area was increasing upto the third month and after that it showed a decreasing tendency. The maximum leaf areas was recorded invariably by the seedlings grown in complete nutrient solution.

7. Fresh and dry weights of the shoot portion were also found to be influenced by nutrient deficiency. The N deficient seedlings produced the lowest fresh and dry weights of shoots. Among the different treatments, Mo deficient seedlings recorded the highest shoot fresh and dry weights but lower compared to the seedlings that received complete nutrient solution. Root growth parameters were not significantly influenced by the deletion of nutrient elements except for their fresh and dry weights. Among the different treatments, Zn deficient

seedlings recorded the highest root fresh weight while N deficient seedlings recorded the lowest value. The dry weight of roots in K deficient seedlings was found to be the lowest compared to other treatments.

8. The chlorophyll content of the leaves was found to be significantly influenced by the deficiency of various nutrient elements throughout the study period. The amount of chlorophyll - A, Chlorophyll - B and total chlorophyll decreased gradually during the study period for all the treatments compared to control. The lowest chlorophyll content was recorded by those seedlings which were deficient in nitrogen.

9. Visual deficiency symptoms of seedlings were concurred with marked reduction in foliar levels of the concerned elements. Compared to seedlings that received all the nutrients through the complete solution, the seedlings showing deficiency symptoms recorded significantly lower levels of the concerned elements in their leaf tissues.

10. Foliar symptoms manifested by the seedlings due to the deficiency of nutrients gradually disappeared during the course of recovery studies. The new fleshes of leaves produced were healthy, green and normally shaped resulting vigorous growth. Chemical analysis of leaf tissues at the end of the recovery studies revealed that the elemental concentrations of most of the nutrients in these seedlings were also improved when compared to the initial nutrient contents at the beginning of recovery studies.

References

REFERENCES

Agarwala, S. C. , Chatterjee, C. and Natiyal, N. 1986. Effect of Mn supply on the physiological availability of Fe in rice plants in sand culture. *Soil Sci. Pl. Nutr.* **32** (2) : 169-178

Agarwala, S. C., Chatterjee, C., Sharma, P. N., Sharma, C. P. and Natiyal, B. D. 1979. Pollen development in maize plants subjected to molybdenum deficiency. *Can. J. Bot.* **570 :** 1946-1950

Agarwala, S. C., Natiyal, B. D., Chatterjee, C. and Sharma, C. P. 1988. Manganese, zinc and boron deficiency in mango *Scientia Horticulturae* **35 :** 99-107

Agarwala, S. C. and Sharma, C. P. 1976. Plant nutrients their function and uptake. *Soil Fertility - Theory and Practice*. Kanwar, J. S. (Ed.) ICAR, New Delhi, India, pp. 32-120

* Al-Abbas, A. H., Bass, R., Hall, J. D., Crane, F. L. and Baumgardner, M. F. 1974. *Agron. J.* **66:** 16-20

Alban, D. H. 1984. Soil and tissue analysis. *Nutrition of Plantation Forests*. Bowen, G. D and Nambiar, E. K. S. (Eds.) Academic Press, London, pp. 259-291

Alcaraz, C. F., Banet, E., Heliin, E. and Llorentes. 1979. Nitrate nitrogen and nitrate reducase activity in lemon tree leaves. *J. Pl. Nutr.* **1** (4) : 347-354

Ananthanarayan, R. and Rao, B. V. V. 1979. Studies on the dynamics of Mg in soils and crops of Karnataka . II. *Myrsore. J. agric. Sci.* **13:** 420-425

*Anderson, C. A. and Martin, F. G. 1970. Effects of soil PH and calcium on the growth and mineral uptake of young citrus trees. *Proc. Flo. St. Hort. Soc.* 82 : 7-12

*Anderson, F. G. 1932. Chlorosis of deciduous fruit trees due to Cu deficiency. *J. Pomol.* **10** : 130- 146

Anderson, J. M. and Cormier, M. J. 1978. Calcium dependent regulation of NAA Kinase in higher plants. *Biochem. Biophys. Res. Commun.* **34 :** 596 -602

Angadi, V. G., Kamala, B. S., Rai, S. N. 1988. Effect of deficiency of trace elements on leaf area, chlorophyll level and photosynthetic efficiency in tree seedlings. *My Forest* 24 (2) : 124-128

Anoop, E. V. 1993. *Nutritional deficiency symptoms of Ailanthus (Ailanthus triphysa (Dennst.) Alston) seedlings*. M.Sc. Thesis, Kerala Agricultural University, Vellanikkara, Kerala, pp . 140

*Arnon, D. I. 1959. Phosphorus and the biochemistry of photosynthesis. *Agrochimic.* 3 : 108-139

Arnon, D. I and Hoagland, D. R. 1940. Crop production in artificial solution and in soils with special reference to factors influencing yields and absorption of inorganic nutrients. *Soil. Sci.* **50:** 463-484

Arora, J. S., Yoshitake, T. and Matsumoto, K. 1970. Studies on the absorption and translocation of zinc chloride by satsuma orange leaves. *J. Jap. Soc. Hort. Sci.* 39 : 298-302

Bailey, K. and Webb, E. C. 1944. Purification and properties of Yeast pyrophosphatase. *Biochem. J.* **38:** 394-398

Bailey, K and Webb, E. C. 1948. Purification of yeast hexokinase and its reaction with beta-dichloro- diethyl- sulphide. *Biochem. J.* **42:** 60-68

*Barrocio, A. 1962. Fenomeni di singergismo molibdena potassio nella nutrizione potassica dello plaute. *Agr. ital.* 62 : 191-197

*Bingham, F. T. 1960. Magnesium deficiency of the Hass avocado tree. *Calif. Avocado Soc. year book* **44** : 101-105

Bingham, F. T. 1975. Phosphorus. *Diagnostic Criteria for Plants and Soils.* Chapman, H.D (Ed.) , Eurasia publishing House (P) Ltd., New Delhi, India. pp. 324-353

*Binns, W. O., Mayhead, G. J. and Mackenzie, J. M. 1980. *Brit. For. Comm. Leafl.* No. 76

Bogorad, L. 1966. *The Chlorophyllus.* Academic Press, New York. pp. 481-510

Boringer, H. and Schacherer, A. 1982. Influence of K nutrition on number of endosperm cells in barley. *Proc. Ninth. int. Pl. Nutr. Coll.*

*Boussingault, J. B. 1856. "Recherches sur la vegetation". *Agronome Chimie agricole et physiolgie.* Mallet Bachelier Paris : 1886-1891

Bowen, G. D. and Nambiar, E. K. S. 1984. Future directions in plantation nutrition research. *Nutrition of Plantation Forests.* Bowen, G.D. and Nambiar, E. K. S. (Eds.)., Academic Press, London. pp. 147-181

Boynton, D. and Erickson, A. 1954. A response of seedling cocoa trees under nursery conditions to magnesium and calcium. *Proc. Amer. Soc. Hort. Sci.* 64 : 15-20

Bradford, G. R. 1975. Boron. *Diagnostic Criteria for Plants and Soils.* Chapman, H.D.(Ed.) Eurasia Publishing House, New Delhi, India. pp. 33-55

Branton, D. and Jacobson, L. 1962. Iron transport in pea plants. *Pl. Physiol.* **37** : 539-545

Brown, J. 1965 Evidence of translocation of Fe in plants. *Plant Physiol.* **40** : 35-38

Brown, P. H., Capellini, R. A. and Price, C.A. 1966. Actinomycin D inhibitors of the Zn induced formation of cytokinin. *Plant Physiol.* **41:** 1543-1546

Bull, R. A. 1954. Studies on the deficiency diseases of the oil palm cultivation. III. Foliar analysis and mineral deficiency. *J.W. African Inst. Oil Palm Res.* **2** : 94-129

*Bunt, A. C. 1976. Modern potting composts. *A manual on the preparation and use of growing media for pot plants*. University park, PA ; Pennsylvania State University Press. p 277

Burkin, I. A. 1968. The *Physiological Role and the Agricultural Significance of Molybdenum*. Nauka, Moscow pp. 294

Burris, R. N. 1966. Biological nitrogen fixation. *An. Rev. Plant physiol.* **17** : 155-184

Bush, L. P. 1969. Influence of certain cations of succinyl COA synthatase from tobacco. *Pl Physiol.* **44** : 347-350

Cain, J. C. 1948. Inter-relationship between calcium, magnesium and potassium in one year old Mc Intosh apple trees grown in sand culture. *Proc. Armer. Soc. hort. Sci.* **51** : 1-12

Candela, M G , Fisher, E.G. and Hewitt, E. G. 1957. Molybdenum as a plant nutrient. *Plant. Physiol.* **32** : 280-288

Capron, S. J. M., Ludwig, C. J. and Flowers, I. T. 1982. Potassium deficiency and photosynthesis in Tomato. *Proc. Ninth. int. Pl. Nutr. Coll. CAB.* **1**: 78

Chapman, H. D., Brown, S. M. and Rayner, D.S. 1947. Effects of Potash deficiency and excess on orange trees. *Hilgardia* **17** (19): 619-650

Chapman, H. D. 1975. Calcium. *Diagnostic Criteria for Plants and Soils.*

Chapman, H.D. (Ed.) Eurasia Publishing House (P) Ltd., New Delhi, India. pp. 65-87

Chapman, H. D. 1975 b. Zinc. *Diagnostic Criteria for Plants and Soils*. Chapman, H. D. (Ed), Earasia Publishing House (P) Ltd., New Delhi. pp. 264-280

Childers, N. F. 1966. *Temparate and Tropical Fruit Nutrition.* Horticultural Publication, Ruteyers - The State University, New York pp . 391-489

Cleland, R. 1960. Effect of auxin upon loss of calcium from cell walls. *Pl. Physiol.* **35** : 581-584

Deli, B. and Malajczuk, N. 1994. Boron deficiency in eucalyptus plantations in China. *Cand. J. For. Res.* **24** (12) : 2409-2416

Dewaard, P. W. F. 1969. *Foliar Diagnosis, Nutrition and Yield stability of Black Pepper (Piper nigrum) in Sarawak.* Common wealth Department of Agricultural Research, Amsterdam pp. 1-149

Dixon, M 1949. *Multienzyme Systems*. Cambridge University Press, Cambridge, pp. 800

Driessche R-Van-den. 1989. Nutrient deficiency symptoms in container-grown Douglas-fir and white spruce seedlings. *FRDA- Report- Victoria, -B. C.* No. 100, vii + 29 pp

Eaton, F. M. 1975. Sulphur. *Diagnostic Criteria for Plants and Soils*. Chapman, H.D. (Ed.), Eurasia Publishing House (P) Ltd., New Delhi pp. 444

Eckstein, O., Bruno, A. and Turrentine, J. W. 1937. *Potash Deficiency Symptoms*. Webstermann and Company, New York. pp. 126

Edmond, J. B., Senn, T. L. and Andrews, F. S. 1964. *Fundamentals of Horticulture*. Tata Mcgraw-Hill Publishing Co. Ltd., Bombay, pp. 48-51

Edward, D.G. and Asher, C. J. 1982. Tolerance of crop and pasture species to Mn toxicity. *Proc. Ninth.int. Pl. Nutr. Coloq.* CAB. **1 :** 145-150

El-Gazzar, A. M., Taha, M. W. and Ghaly, E. 1979. Effect of different levels of P on growth and mineral composition of green house grown orange, olive and gauva. *Alexandria J. Agric. Res.* **27** (1) : 107-118

Emanuelson, J. 1984. Root growth and calcium uptake in relation to calcium concentration. *Plant and Soil* **78 :** 325-334

Embleton, T. W., Jones, W.W., Kirkpatrik. J. D. and Gregory Allen, D. 1958. Influence of sampling date, season and fertilization on macronutrients in avocado leaves. *Proc. Am. Soc. Hort. Sci.* **72 :** 309-320

Embleton, T.W. 1975. Magnesium. *Diagnostic Criteria for Plants and Soils*. Chapman, H. D. (Ed.) Eurasia Publishing House (P) Ltd., New Delhi, India. pp. 225-264

Emmert, F. H. 1961. *Plant Analysis and Fertilizer Problems*. American Institute of Biological Sciences, Washington. pp. 231-243

Epstein, E. 1961. The essential role of Ca in selective cation transport by cells. *Plant Physiol.* **36 :** 437- 444

Epstein, E. 1978. *Mineral Nutrition of Plants Principles and Perspectives*. Willey Eastern (Ltd.), New Delhi, India. pp. 285-313

*Erdmann, G. G., Metzger, F. T. and Oberg, R. R. 1979. Macro nutrient deficiency symptoms in seedlings of four northern hardwoods. *Gen. Tech. Rep*. NC-53. St. paul, MN: USDA Forest Service, North Central Forest Experiment Station. 36 p

* Evans, H. and Murray, D. B. 1953. A colour illustrated guide to the diagnosis of mineral deficiencies in cocoa. *Cocoa Res. A. Rep Trinidad, 1945*. **51 :** 65-66

Evans, H. J. 1963. Effect of potassium and other univalent cations on activity of pyruvate kinase in *Psium sativum*. *Pl. Physiol.* **38 :** 397-402

Evans, J. 1982. *Plantation Forestry in the Tropics*. Oxford University Press, New York. 472 p

Evans, H. T. and Sorger, G.J. 1966. Role of mineral elements with emphasis on the univalent cations. *A. Rev. Pl. Physiol.* **17 :** 47-76

Ferrai, T. E. and Varner, J. E. 1969. Substrate induction of nitrate reductase in barley aleurons layers. *Pl. Physiol.* **44 :** 85-88

Fischer, R. A. and Hsiao, T. C. 1968. Substrate induction of nitrate reductase in barley aleurone layers. *Pl. Physiol.* **44 :** 85-88

Forest Information Bureau, 1995. *Kerala Forests and Forestry Hand Book*. Kerala Forest Department 181 p

* Franco, C. M. and Mendes, H. C. 1949. *Sintomas de deficiencias minerais no cafeeiro. Bragantia (Brazil)* **9 :** 165-173

Frieden, E. 1968. The biochemistry of Copper. *Sci. Am.* **5:** 103-114

*Gamayunova, M. S. 1965. The principles of the pre-sowing treatment of seeds with trace element salts. *Abstract of Dissertation, Institute of Plant Physiology, Kiev*

Gamayunova, M. S. and Ostrovskaya, L. K . 1964. The effects of copper and iron on the early stages of plant development in relation to seed origin and pre- sowing treatment. *Biological Basis of Quality Improvement in Agricultural Plants*. Nauka Moscow pp. 107-113

Gardner, P. F., Pearce, R.B. and Mitchell, R.L. 1985. *Physiology of Crop Plants*. Scientific, Publisher, Jodhpur, India. pp. 98-132

Gauch, H. G. 1972. *Inorganic Plant Nutrition*. Dowden, Hutchinson and Ross Inc., Stroudsburg. pp. 205-291

Gentle, H. G. and Humphreys, F. R. 1984. Experiences with man made phosphatic fertilizers in forests of *Pinus radiata*. *Nutrition of Plantation Forests*. Bowen, G. D. and Nambiar, E. K. S. (Eds.), Academic Press, London. pp. 259-291

Gopikumar, K. and Aravindakshan, M. 1988. Sand culture studies in cashew. *Indian Cashew J.* 18 : 9 -14

Greulach, V A. 1973. *Plant function and structure*. Macmillan Publishing Co., Inc., Newyork. pp. 138

*Hass, A. R. C. 1936. Phosphorus deficiency in citrus. *Soil Sci.* 42 : 93-117

*Hass, A. R. C. 1942. Lime induced chlorosis of citrus in relation to soil factors. *Plant Physiol.* 17 : 27-51

Haase, T. V. 1984. Colour aerial photography in plant sciencies and related fields. *Nutrition of Plantation Forests*. Bowen, G. D. and Nambiar. E. K. S. (Eds.), Academic Press, London. pp. 259-291

*Hallett, R. D. 1985. Forest nursery practices in the maritimes. *Proceedings, Reforestation in the Maritimes, Symposium, Maritimes Forest Research Centre*. pp. 81-107

* Hansen, P. 1970. The effect of N, P, K, Ca and Mg on the nutrient content, growth and leaf development of Cox's orange pippin in sand cultures. *Tidsskr Planteavil* **74 :** 577-585

Hartt, C. E. 1969. Effect of potassium deficiency upon translocation of ^{14}C in attached blades and entire plants of sugarcane. *Pl. Physiol.* **44:** 1461-1469

Hewitt, E. J. 1956. Symptoms of molybdenum deficiency in plants. *Soil Sci.* **81 :** 159-171

Hewitt, E. J. 1958. The role of mineral elements in the activity of plant enzyme systems. *Encylopedia of Plant Physiology*. springer, Berlin. pp. 427-481

Hewitt, E. J. 1963. *Plant Physiology - A treatise.* Academic Press, New York. pp. 137-360

Hewitt, E. J. and Jones, E. W. 1947. The production of molybdenum deficiency in plants in sand culture with special reference to tomato and brassica crops. *J. Pomol.* **23 :** 254-262

Hoagland, D. R. 1919. Relation of concentration and reaction of the nutrient medium in the growth and absorption of the plant. *J. agric. Res.* **18 :** 73-117

Hoagland, D. R. 1948. *Inorganic Nutrition of Plants*. Chronica Botanica Company. Mass

Hofman, P. 1967. Studies on the manganese of the chloroplast. *Pl Physiol.* **42** : 997-1007

*Holmes, R. A. 1944. The effect of limiting the soil upon the availability to plants of zinc and copper. *US. Dep. agric. Bur. Pl. ind. Res. Rep. 23*

*Horiguchi and Fukomoto, 1987. Mechanism of Mn toxicity and tolerance of plants III. Effect of excess Mn on respiration rate and peroxidase activity of various plant species. *Jap. J. Soil Sci. Pl. Nutr.* 713-716

*Ingestad, T. 1963. Microelement nutrition of pine, spruce and brich seedlings in nutrient solutions. *Rep. For. Res. Inst. Sweden* **51** (7) : 150 p

*Ishihara, M., Hass, Y., Yokomizo, H. and Konno, S. 1968. Nutritional disorders of Satsuma mandarin trees in serpentine soil. I. Leaf and soil analyses in satsuma mandarin orchardes affected by nutritional disorder. *Bull. Hort. Res. Stat. Hiratsaka* 7 : 1-28

*Ishihara, M., Hass, Y., Yokomizo, H. and Konno, S. 1971. Studies on abnormal defoliation of satsuma trees. *Bull. Hort. Res. Stat. Hiratsaka* 16: 131-154

*Ivchenko, V. S. 1981. The significance of molybdenum for plants. *Abstract of Dissertation, Institute of Plant Physiology, Kiev.*

Jackson, M. L. 1958. *Soil Chemical Analysis*. Prentice Hall Inc. USA. p. 363

Jain, V.K. 1981. *Fundamentals of Plant Physiology*. S. Chand and Co. Ltd., New Delhi pp. 80-87

James, W. W. 1975. Nitrogen. *Diagnostic Criteria for Plants and Soils*. Chapman, H.D. (Ed.) Eurasia Publishing House (P) Ltd., New Dellhi, India. pp. 310-320

*Jones, W. W. and Embleton, T. W. 1959. The visual effect of nitrogen nutrition on the fruit quality of Valentia orange. *Proc. Amer. Soc. Hort. Sci.* **73 :** 234-236

Kamala, B. S. and Angadi, V. G. 1986. Effect of application of trace elements on seedling growth of some timber species. *Van Vigyan* **24** (3) : 110-112

Kamala, B. S., Angadi, V. G. and Parthasarathi, K. 1986. Symptoms and changes in the pattern of multimolecular forms of peroxidase associated with trace element deficiency in sandal seedlings. *Science and Culture* **52 :** 161-164

Kamala, B. S., Angadi, V.G. and Rai, S.N. 1988. Symptoms of deficiency of trace elements and the associated changes of peroxidase isoenzyme pattern in the seedlings of rosewood, honne, cassia and neem. *My Forest* **24** (4) : 307-311

Kandaswamy, P and Arulomzhiselvan, K. 1987. Effect of application of gypsum on availability and utilisation of S and N in rice. *Proc. Nat. Seminar on S. TNAU Coimbatore*. p. 176

Kathore, V. S., Bajaj, W. P. S. and Witwer, S .F. 1972. Sub cellular localization of Zn and Ca in bean tissues. *Pl. Physiol.* **49 :** 207-211

Kitagishi, K. and Obata, H. 1986. Effects of Zn deficiency on the N metabolism with special reference to protein synthesis. *Soil. Sci. Pl. Nutr.* **32** (3) : 397-405

*Knop, H. 1965. Quantitate unter suchury uber die Ernahrun gsprocess. derpflanzer, *Landwirtsch. Vers. Sta.* **7 :** 93-107

*Korkes, S., Campillo, A., Gunsalus, I. C. and Ochea, S. 1951. Enzymatic synthesis of citric acid. IV. Pyruvate as acetyl donor. *J. Biol. Chem.* **193 :** 721-735

Kramer, P. J. and Kozlowski, T. T. 1960. *Physiology of Trees*. Mc Graw Hill Co., Newyork. pp. 747

*Kraws, E. J. and Kraybill, H. R. 1918. Vegetation and reproduction with special reference to tomato. *Bullore Agric. Exp. Stn.* **149 :** 1-90.

Landis, T. D., Tinus, R. W., Mc Donald, S.E. and Barnett, J. P. 1989. Mineral nutrients and fertilization. *The Container Tree Nursery Manual.* USDA Forest Service, Agricultural hand book 674, pp. 7-13

*Leaf, A. L. 1968. Pottassium, magnesium and sulphur deficiencies in forest trees. *Forest Fertilization theory and practise*. Tennessee Valley Authority, knoxville. pp. 88-122

Lebanauskas, C. K. 1975. Manganese. *Diagnostic Criteria for Plants and Soils*. Chapman, H. D. (Ed.). Eurasia publishing House (P) Ltd., New Delhi. pp 264-265

Lebanauskas, C. K., Embleton, T.W. and Jones, W.W. 1958. Influence of soil application of N,K, dolomite and manure on the micronutrient content of avocado leaves. *Proc. Amer. Soc. Hort. Sci.* **71 :** 255-291

Lee, S. and Arnoff, S. 1967. Boron in plants- a biochemical role. *Science.* **58 :** 798-799

* Levanidov, L. Ya. 1957. Biological role of Mn in manganophilious plants. *Vehenye zapiski chelyabin skoyo. Pedagogi Cheskogo Institute.* **5 :** 267 -287

Lewis. D.H. 1980. Boron lignification and the origin of vascular plants-aunified hypothesis. *New phytologist.* **84 :** 209-229

Lockard, R. G. and Asomaning, E. J . A. 1964. Mineral nutrition of CaCao *(Theobroma cacao L.) Plant and Soil.* 21 (2) : 142-151

* Lott W. L., Mc clung, A. C. and Mead. calf. J. C. 1960. Sulphur deficiency in coffee. *Bull. Int. Basic. Economic Co-operation Res. Inst.* 22 : 21

*Luukkonen, O., Rasanen, P. K. and Yli-Vakkuri, P. 1971. *Silva Fenn.* **5 :** 297-313

Malik, P. C. and Singh, D.L. 1959. Deficiency symptoms in mango due to the absence of trace elements. *Indian J. Hort.* 16 : 228-232

Manicot, R., Ollagnier, M. and Ochs, R. 1980. Mineral nutrition and fertilization of the coconut around the world. Study of different elements. *Olea gineux* 35 : 13-27

Maskell, E. J., Evans, A. and Murray, D.B. 1953. The symptoms of nutritional dificiencies in cacao produced in sand and water cultures. *Report on Research on Cocoa*. Imperial College of Tropical Agriculture, Trinidad. pp. 54-64

* Matsui, J., Niizuma, T., Taguchi, K. and Yamazaki, T. 1977. The critical levels of P deficiency in apple trees and P application. *Bull. Akita Fruit Tree Expt. Stat.* (9) : 9-16

Marinos, N. G. 1962. Studies on submicorscopic aspects of mineral deficiencies .I. Calcium deficiency in the shoot apex of barley. *Am. J. Bot.* 49 : 834-841

Marschner, H. 1982. Effect of mineral nutrition on phytohormone balance in plants. *Proc. Ninth. Int. Pl. Nutr. Coloq.* CAB. pp . 354

Marschner, H. 1986. *Mineral Nutrition of Higher Plants*. John Wiley and Sons, Newyork. 629 p

Mead, D. J. 1984. Diagnosis of nutrient deficiencies in plantations. *Nutrition of Plantation Forests*. Bowen, G. D. and Nambiar, E. K. S. (Eds.) Academic Press, London. pp . 259-291

* Mee, S. 1949. A study of carboxylase in soyabean sprouts. *Arch. biocherm.* 22 : 139-148

*Mehler, A. 1951. Mechanism of reduction of O_2 and other hill reagents. *Arch. Biochem. Biophys.* 33 : 65-77

Millikan, C. R. 1948. Antagonism between molybdenum and certain heavy metals in plant nutrition. *Nature* 161 : 528

*Millikan, 1963. Effect of different levels of Zn and P on the growth of subterranean clover *(Trifolium subterrancum). Aust. J. agric. Res.* **14 :** 180-205

Mizuno, N., Inazu, O. and Dobasmi, K. 1983. Composition of carbohydrates and soluable solids, moisture and morphological changes in wheat plant grown on Cu deficient soil. *Soil Sci. Plant Nutr.* **29** (1) : 1-6

*Morchal, J. and Laccevilhe, J.J. 1969. Mineral balance of the Wilking mandarin : Influence of production and vegetative state of the tree on its mineral composition. *Fruits d' outre* **24 :** 299-318

Mulder, E.G. and Bakema, K. 1956. Effect of N,P,K and Mg nutrition of potato plants on the content of free amino acids and amino acid composition of protein of tubers. *Plant and Soil* **7:** 135-136

Muller, L. E. 1966. Coffee nutrition. *Temprate and Tropical Fruit Nutrition.* Childers, N. F. (Ed.) Horticultural publication. State University, USA. pp. 685-777

Murata, T. and Altazawa, T. 1968. Enzymic mechanism of starch synthesis in sweet potato root : I. Requirement of potassium ions for starch synthetase. *Arch. Biochem. Biophys.* **126 :** 837-879

Murry, D.B. 1966. Cacao nutrition. *Temprate and Tropical Fruit Nutrition.* Horticultural Publication, State University, USA pp. 530-609

Nair, P.C. S., Mukherjee, S. K. and Kathavate, Y.V. 1968. Studies on citrus dieback in India. Micro-nutrient status in soil and leaves of citrus. *Indian J. agric. Sci.* **38 :** 184-194

Narayanan, A. and Reddy, K.B. 1982. Effect of P- deficiency on the forms of plant root systems. *Proc. Ninth. Int. Pl. Nutr. Colog.* CAB. **1 :** 412-417

Nason, A. and Mc Elroy, W.D. 1963. Modes of action of essential mineral elements *Plant Physiology*. Steward, F. C. (Ed.) Academic Press, Newyork. pp. 451-536

*Naumov, V. D., Ganzhara, N. F., Tararov, V.M. and Naumov, L. M. 1977. The effect of soil characteristics on the occurrence of rosetting in apple trees. *Osobennosti Poecho. Derhono. Fodzolistpochv.* **139 :** 149-160

Nazeem, P. A. 1989. *Deficiency symptoms of mineral nutrients in clove (Syzigium aromaticum (L.) Merr. and Perry).* Ph.D. Thesis, Kerala Agricultural University, Vellanikkara, Kerala. pp. 185

Nichloas. D. J. D. and Stevens. H. M. 1955. Valency changes of molybdenum during the enzymatic reduction of nitrate reductase in cell free extracts. *Nature* **176 :** 1066-1067

Nitsos, R. E and Evans, H. J. 1969. Effects of univalent cations on particulate starch synthetase. *Pl. Physiol.* **44 :** 1260-1266

Nybe, E.V. 1986. *Investigation on the nutrition of black pepper (Piper nigrum L.)* Ph.D. Thesis submitted to Kerala Agricultural University, Vellanikkara, Kerala pp. 193

Ohler, J. G. 1979. *Cashew-Communication 11*. Department of Agricultural Research, Amsterdam. pp. 147-151

*Okuntsov, M. M., Vrublevskaya, V. G. and Zaitseva, T. A. 1966. The effect of copper on leaves of adenine, adenosine and adenosine triphosphate in plants. *Elements in Plants* Makeev, D.(Ed.) Buryatskoye Knizhonoye Izdatelstvo, Ulan-ude pp. 50

Pandey, S. N. and Sinha, B. K. 1972. *Plant Physiology*. Vikas Publishing House, Bangalore pp. 105-121

Panse, V. G. and Sukhatme, P.V. 1978. *Statistical Methods for Agricultural Workers*. ICAR, New Delhi. pp. 97-128

Pant, P. C., Singh, R. and Divakar, B. C. 1976. Deficiency symptoms of major nutrients in apple plants. *Prog. Hort.* 8 (2) : 93-101

Paulson, G. M. and Harper, J. E. 1968. Evidence for a role of calcium in nitrate assimilation in wheat seedlings. *Pl. Physiol.* **43 :** 775-780

Philip, J. 1986. *Mineral nutrition of nutmeg in relation to deficiency symptoms and flowering*. Ph.D. Thesis, Kerala Agricultural University, Vellanikkara, Kerala pp .188

Pilbean, D. J. and Kirkby, E. A. 1983. The physiological role of boron in plants. *J. Pl. Nutr.* 6 (*1*) . 563-582

*Price, C. A. 1962. Zinc dependent lactate dehydrogenase in *Euglena gracilis*. *Biochim. J.* 82 : 61-66

Pritchett, W. L. 1979. *Properties and Management of Forest Soils*. John Wiley and Sons, Newyork and Toronto 516 p

*Prusakova, L. D. 1966. The role of phenol compounds in the grass fall over. *Abstracts of the symposium on phenol compounds* Kursanov, A. L. and Zaprometov, M. N. (Ed.). Nauka, Moscow. p. 38

Purseglove, J. W. 1977. *Tropical Crops Dicotyledons* English language Book Society and Longman . pp. 477

Rajagopalan,V. 1987. Nutrient sulphur. *Proc. Nat. Seminar on Sulphur. TNAU, Coimbatore.* pp . 83-128

Rajput, C. B. S., Singh, N. P. a nd Tiwari, J. P. 1978. Effect of Potash on yield attributes of guava *(Psidium guajava.L.) Indian J. Hort.* **35** (1) : 19-22

Rasmussen, H. P. 1967. Calcium and strength of leaves. 1. Anatomy and histochemistry. *Bot. Gaz.* **128 :** 219-223

Rasmussen, P. E., Ramig, R. E., Ekin, L.G. and Rohde, C. R. 1977. Tissue analysis guidelines for diagnosing sulphur deficiency in white wheat. *Plant and Soil* **46 :** 153-163

Reed,H. S. 1942. *A Short History of the Plant Sciences.* Chronica Botanica C., Watham, Massachusetts, pp. 241-265

*Reitz, H. J. 1958. Magnesium deficiency. *Florida Guide to Citrus Insects, Diseases and Nutritional disorders in colour.* Florida University, Agricultural Experimental Station, Gainesville. pp. 44-55

Resh, H. M. 1978. *Hydroponic Food Production.* Woodbridge Press Publishing Co., Santa Barbara, California 93111, pp 30-59

Reuther, W. and Labanauskas, C. K. 1975. Copper. *Diagnositic Criteria for Plants and Soils,* Chapman, H.D. (Ed.) . Eurasia publishing house, New Delhi. pp. 157-159

Riceman, D. C. and Jones, G. B. 1960. Distribution of Zn in subterranean clover during on set of Zn deficiency as determined by the use of the radioactive isotope Zn. *Austr. J. agric. Res.* 2 : 887-893

Richards, F. J. and Coleman, R. G. 1952. Occurrence of putrescine in K deficient barley. *Nature.* (170) : 460

Rios, M. A. and Pearson, R. W. 1964. The effect of some chemical environmental factors on cotton root behaviour. *Soil Sci. Soc. Am. Proc.* **28** : 232-235

*Rocha Filho, J. V. de C., Haag, H. P., Oliveira, G. D. de. and Sarruge, J. R. 1979. Effect of boron on the growth and chemical composition of Eucalyptus grandis (In Protuguese.) *Bras. Flor.* **9** : 29-33

Sadowski, A., Pekacki, J., Szablowski, W. and Seilbrizm, K. 1976. Magnesium nutrition of apple trees. *Acta Agro botanica* **29** (2) : 157-177.

Salami, A. U. and Kenefick, D. G. 1970. Stimulation of growth in zinc dificient corn seedlings by the addition of tryptophan. *Crop. Sci.* **10** : 291-294

Salisbury, F. B. and Rose, R. W. 1978. *Plant Physiology 2nd ed.* Wadsworth Publishing Company INC . pp. 422

Salisbury, F. B and Ross, C. 1977. *Plant Physiology*. Prentice Hall of India Pvt. Ltd. New Delhi - 110001. pp. 204-209

*Schaaf, W. and Zech, W. 1993. Fertilization with Calcined magnesite and magnesium hydroxide for site amelioration in badly damaged Norway spruce ecosystem. *Zeitschrift fur Pflanzenerna Hrung und Bodenkunde.* **156** (4). 357-364

Shear, C. B. 1971. Symptoms of calcium deficiency on leaf and fruit of York Imperial apple. *J. Amer. Soc. Hort. Sci.* **96** (4) : 415-417

Stiive, J. W. 1941. Significant role of trace elements on the nutrition of plants. *Pl. Physiol.* **16** : 435-455

*Shkolnik, M. Y. A., Davydova, V. N. and Mochenyal, K. I. 1975. The effect of Zn on levels of gibberellin related substances in bean leaves. *Fiziologiya Rastenij*. 22 : 1021-1024

*Shkolnik, M. Y .A. and Ilinskaya, N. L. 1975. The effect of boron deficiency on the activity of glucose phosphate dehydrogenase in plants showing differential requirements for boron. *Fiziologiya Rastenij* 22 : 801-805

Smith, P. F. 1966. Leaf analysis of citrus. *Temprate and tropical fruit nutrition*. Childers, N. F. (Ed.) Rutgers State University, USA. pp. 208-228

Smith, P. F. and Rasmussen, G. K. 1959. The ralation of K nutrition to citrus fruit size and quality. *Proc. Amer Soc. Hort. Sci.* 74 : 261-265

*Smith, P. F. and Scudder, JR. G. K. 1951. Some studies of mineral deficiency symptoms in mango. *Proc. Florida State Hort. Soc.* 64 : 243-248

Somer, J. L. and Shive, J. W. 1942. The Fe-Mn relationship in plant metabolism. *Pl. Physiol.* 17 : 582-602

*Sorokina, G. I. 1967. The effect of copper on physiological processes and yield in potatoes. *Abstract of Dissertation*. Pedagogical Institute, Moscow

Spiers, J. M. 1987. Effect of K, Ca, Mg levels and N sources on growth and leaf element content of black berry. *Hort. Sci.* 22 (4) : 576-577

Spragu, H. B. (Ed.). 1964. *Hunger Signs in Crops*. American Society of Agronomy and the National Fertilizer Association, Washington

Springate, C. J., Mildvan, A. S., Abramson, R. and Engle, J. R. 1973. Deoxyribonucleic acid polymerase I, a zinc metallo enzyme. Nuclear quadrapolar relation studies of the role of bound zinc. *J.Biol. Chem.* **248 :** 5987-5993

Starck, K. 1963. Effect of boron on cell wall strcture of sunflower. *Acta. Bot.* **32 :** 3-15

Starner, W. J. and Hardley, H. H. 1967. Chlorophyll content of various strains of soyabeans. *Crop. Sci.* **5 :** 9-11

Stewart, I. and Leonard, C. D. 1952. Molybdenum deficiency in Florida citrus. *Nature* **170 :** 714-715

*Stocking, C. R. and Origun, A. 1962. The intracellular distribution of some metallic elements in leaves. *Am. J. Bot.* **49 :** 284-289

*Swan, H. S. D. 1971. Relationships between nutrient supply, growth and nutrient concentrations in the foliage of white and red spruce. *Point Claire, Quebec : pulp and paper research Institute of Canada. Woodlands paper No.29.* 27 p

*Swan, H. S. D. 1972. Foliar nutrient concentrations in red pine as indicators of tree nutrient status and fertilizer requirement. *Pulp. Pap. Res. Inst. Can., Woodlands Pap. 41.* 19 p

Tagawa, T. and Bonner, J. 1957 Mechanical properties of the avena coleoptile as related to auxin and to ionic interactions. *Pl. Physiol.* **32 :** 207-212

*Tanaka, S. 1960. Studies on citrus chlorosis in Japan *Bull. Tokai Kinki Exp. Stn.* **1 :** 1-83

Tandon, K. L. S. and Sekhon, G. S. 1988. Twenty years of research on soil and fertilizer potassium in India. *Fert. News.* **10 :** 21-31

Takaki, H. and Arita, S. 1986. Tryptamine in Zn deficient barley. *Soil Sci. Plant Nutr.* 32 (3) : 433-442

Thirumalaiswamy, K., Ramachandran, R., Sadasivan, P. and Srinivasan, S. 1987. Effect of sulphur fertilization on nutrient content, dry matter production and yield of pods in groundnut. *Proc. Nat. Seminar on Sulphur. TNAU,* Coimbatore. p . 178

Thompson, J. F. 1967. Sulphur metabolism in plants. *A. Rev. Pl. Physiol.* **18 :** 59-84

Troup, R. S. 1986. *The Silviculture of Indian Trees. Vol-II.* International Book Distributors, Dehra Dun, India pp . 697-705

Tsui, C. 1948. The role of zinc in auxin synthesis in the tomato plant. *Am. J. Bot.* **35 :** 172-179

Turnbull, C. R. A., Beadle, C. L., West, P. W. and Cromer, R. N. 1994. Copper deficiecy a probable cause of stem deformity in fertilized *Eucalyptus nitens. Canadian J. Forest Res.* **24** (7) : 1434-1439

Ulrich, A. and Ohki, K. 1975. Potassium. *Diagnostic Criteria for Plants and Soils.* Chapman, H. D. (Ed.). Eurasia Publishing House (P) Ltd., New Delhi, India pp . 362-386

*Utter, M. F. and Werkman, C. H. 1942. Effect of metal ions on the reactions of phosphopyruvate by *Escherichia coli. J. biol. Chem.* **146 :** 289-300

*Vanselow, A. P. and Datta, N. P. 1949. Molybdenum deficiency of the citrus plant. *Soil Sci.* **67 :** 363-375

Walker, L. C. 1956. Nutrient deficiencies. *Nutrient of Plantation Forests*. Bowen, G. D. and Nambiar, E. K. S. (Eds.). Academic Press, London. pp . 259-291

Wallace, A., and Muller, R. T. 1962. Effects of magnesium concentrations on in vitro CO_2 fixing reaction. *Pl. physiol.* **37** : 154-157

Wallace, T. 1953. *The Diagnosis of Mineral Deficiencies in Plants by Visual Symptoms - A Colour Atlas and Guide*. Chemical Publishing Co., Inc. Newyork

*Wallihan, E . F. 1955. Relation of chlorosis to concentration of iron in citrus leaves. *Amer. J. Bot.* **42** : 101-104

*Will, G. M. 1961. Mineral requirements of radiata pine seedlings. *NZ. J. Agr. Res.* **4** (3-4) : 309-327

Wishnick, M. and Mildvan, A. S. 1969. The presence of tightly bound Cu in ribulose diphosphate carboxylase from spinach. *J. Biol. Chem.* **244** : 5761-5763

*Woodbridge, C. G. 1955. Magnesium deficiency in apple in British Columbia. *Can. J. Agri Sci.* **35** : 350-357

*Zhizhevskaya, G. Y. A. 1972. *Copper, Mo and Fe in the N metabolism of legumes*. Nauka, Moscow. pp . 335

* Originals not seen

Appendices

APPENDIX - I

Abstract of analysis of variance for the effect of treatments on the height of seedlings

Source of variation	df	Mean square at fortnightly intervals											
		1	2	3	4	5	6	7	8	9	10	11	12
			**	**	**	**	**	**	**	**	**	**	**
Treatment	7	1.31	6.98	17.51	24.28	62.33	83.64	172.08	210.20	239.23	278.24	279.18	312.89
Error	16	0.35	0.35	0.44	0.39	1.40	0.47	0.25	0.60	0.75	0.45	0.47	0.93
Total	23	0.64	2.37	5.63	7.66	19.94	25.78	52.54	64.39	73.33	84.99	85.29	95.87

** Significant at 1 per cent level

APPENDIX - II

Abstract of analysis of variance for the effect of treatments on the collar diameter of seedlings

Source of variation	df	Mean square at fortnightly intervals											
		1	2	3	4	5	6	7	8	9	10	11	12
			**	**	**	**	**	**	**	**	**	**	**
Treatment	7	0.00	0.00	0.001	0.001	0.002	0.002	0.004	0.006	0.006	0.008	0.010	0.015
Error	16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	23	0.00	0.00	0.00	0.00	0.00	0.00	0.001	0.002	0.002	0.002	0.003	0.004

** Significant at 1 per cent level

APPENDIX - III

Abstract of analysis of variance for the effect of treatments on the leaves (number) of seedlings

Source of variation	df	Mean square at fortnightly intervals											
		1	2	3	4	5	6	7	8	9	10	11	12
				**	**	**	**	**	**	**	**	**	**
Treatment	7	2.34	8.58	6.47	9.47	16.92	16.42	26.65	28.42	31.88	43.47	53.07	70.60
Error	16	4.19	0.20	0.22	0.28	0.17	0.29	0.12	0.38	0.31	0.33	0.96	0.64
Total	23	0.89	2.75	2.12	3.08	5.27	5.20	8.19	8.91	9.92	13.46	16.82	21.93

** Significant at 1 per cent level

APPENDIX - IV

Abstract of analysis of variance for the effect of treatments on the leaf area of seedlings

Source of variation	df	Mean square at monthly intervals					
		1	2	3	4	5	6
		*	**	**	**	**	**
Treatment	7	262142.044	767649.98	670076.35	783785.34	1223383.29	3027802.11
Error	16	55226.174	34996.00	58486.05	84.54.86	86227.88	23578.68
Total	23	118200.570	257976.25	244622.23	297016.31	432318.65	937907.55

** Significant at 1 per cent level

* Significant at 5 per cent level

APPENDIX - V

Abstract of analysis of variance for the effect of treatments on the length of roots

Source of variation	df	Mean square at monthly intervals					
		1	2	3	4	5	6
Treatment	7	30.26	25.57	7.85	16.68	14.12	28.05*
Error	16	12.33	7.24	4.37	6.59	11.73	9.34
Total	23	17.78	12.82	5.43	9.66	12.46	15.03

* Significant at 5 per cent level

APPENDIX - VI

Abstract of analysis of variance for the effect of treatments on the number of secondary roots

Source of variation	df	Mean square at monthly intervals					
		1	2	3	4	5	6
Treatment	7	241.59	120.20	63.68	66.22	34.72	87.83*
Error	16	11.72	10.29	15.71	12.76	20.66	29.42
Total	23	81.68	43.74	30.31	29.03	24.94	47.19

* Significant at 5 per cent level

APPENDIX - VII

Abstract of analysis of variance for the effect of treatments on the fresh weight of shoots

Source of variation	df	Mean square at monthly intervals					
		1	2	3	4	5	6
			**	**	**	**	**
Treatment	7	45.16	60.75	140.76	339.67	366.10	937.37
Error	16	1.37	0.79	2.93	1.29	2.49	2.55
Total	23	14.70	19.04	44.88	104.28	113.16	214.02

** Significant at 1 per cent level

APPENDIX - VIII

Abstract of analysis of variance for the effect of treatments on the dry weight of shoots

Source of variation	df	Mean square at monthly intervals					
		1	2	3	4	5	6
			**	**	**	**	**
Treatment	7	6.82	8.11	13.09	22.74	28.45	49.53
Error	16	0.20	0.46	0.52	0.58	1.13	3.42
Total	23	2.22	2.79	4.34	7.32	9.45	17.46

** Significant at 1 per cent level

APPENDIX - IX

Abstract of analysis of variance for the effect of treatments on the fresh weight of roots

Source of variation	df	Mean square at monthly intervals					
		1	2	3	4	5	6
			**	**	**	**	**
Treatment	7	1.30	30.68	12.24	16.61	13.99	17.12
Error	16	0.16	1.37	0.37	1.53	1.40	1.62
Total	23	0.50	10.29	3.98	6.12	5.23	6.33

** Significant at 1 per cent level

APPENDIX - X

Abstract of analysis of variance for the effect of treatments on the dry weight of roots

Source of variation	df	Mean square at monthly intervals					
		1	2	3	4	5	6
			**	**	**	**	**
Treatment	7	0.184	1.71	1.24	3.29	3.94	1.77
Error	16	0.036	0.16	0.29	0.48	0.76	0.58
Total	23	0.081	0.63	0.58	1.33	1.73	0.94

** Significant at 1 per cent level

APPENDIX - XI

Abstract of analysis of variance for the effect of treatments on the chlorophyll content of the leaf tissues

Source of variation	df	Mean square at monthly intervals														
		2	3	4	5	6	2	3	4	5	6	2	3	4	5	6
		Chlorophyll - A					Chlorophyll - B					Total Chlorophyll				
		**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
Treatment	7	0.52	0.25	0.21	0.05	0.06	0.12	0.14	0.12	0.14	0.14	0.71	0.51	0.43	0.29	0.33
Error	16	0.007	0.002	0.01	0.003	0.004	0.02	0.003	0.005	0.003	0.002	0.02	0.003	0.007	0.004	0.004
Total	23	0.16	0.08	0.07	0.02	0.02	0.05	0.04	0.04	0.04	0.05	0.23	0.18	0.13	0.09	0.10

** Significant at 1 per cent level

APPENDIX - XII

Abstract of analysis of variance for the effect of treatments on foliar concentration of nitrogen

Source of variation	df	Mean square at monthly intervals					
		1	2	3	4	5	6
		*	**	**	**	**	**
Treatment	7	0.14	0.26	0.18	0.16	0.28	0.24
Error	16	0.04	0.02	0.03	0.04	0.06	0.02
Total	23	0.07	0.09	0.08	0.08	0.13	0.09

* Significant at 5 per cent level

* * Significant at 1 per cent level

APPENDIX - XIII

Abstract of analysis of variance for the effect of treatments on foliar concentration of phosphorus

Source of variation	df	Mean square at monthly intervals					
		1	2	3	4	5	6
		* *	* *	**	**	**	**
Treatment	7	0.54	0.41	0.34	0.42	0.26	0.25
Error	16	0.014	0.008	0.015	0.004	0.006	0.011
Total	23	0.17	0.13	0.11	0.13	0.08	0.08

* * Significant at 1 per cent level

APPENDIX - XIV

Abstract of analysis of variance for the effect of treatments on foliar concentration of potassium

Source of variation	df	Mean square at monthly intervals					
		1	2	3	4	5	6
		* *	**	**	**	**	**
Treatment	7	0.12	0.39	0.56	0.51	0.50	0.53
Error	16	0.02	0.05	0.02	0.05	0.05	0.03
Total	23	0.05	0.15	0.18	0.19	0.18	0.18

* * Significant at 1 per cent level

APPENDIX - XV

Abstract of analysis of variance for the effect of treatments on foliar concentration of calcium

Source of variation	df	Mean square at monthly intervals					
		1	2	3	4	5	6
		* *	**	**	**	**	**
Treatment	7	0.07	0.05	0.86	0.68	0.13	0.07
Error	16	0.02	0.009	0.009	0.009	0.005	0.004
Total	23	0.03	0.02	0.27	0.21	0.04	0.02

* * Significant at 1 per cent level

APPENDIX - XVI

Abstract of analysis of variance for the effect of treatments on foliar concentration of magnesium

Source of variation	df	Mean square at monthly intervals					
		1	2	3	4	5	6
		**	**	**	**	**	**
Treatment	7	0.94	0.29	0.70	0.69	0.55	1.15
Error	16	0.002	0.003	0.002	0.005	0.019	0.004
Total	23	0.29	0.09	0.22	0.22	0.18	0.35

** Significant at 1 per cent level

APPENDIX - XVII

Abstract of analysis of variance for the effect of treatments on foliar concentration of sulphur

Source of variation	df	Mean square at monthly intervals					
		1	2	3	4	5	6
		**	**	**	**	**	**
Treatment	7	0.00	0.001	0.00	0.00	0.00	0.00
Error	16	0.001	0.0001	0.00	0.00	0.00	0.00
Total	23	0.00	0.0002	0.00	0.0001	0.0001	0.0001

** Significant at 1 per cent level

APPENDIX - XVIII

Abstract of analysis of variance for the effect of treatments on foliar concentration of zinc

Source of variation	df	Mean square at monthly intervals					
		1	2	3	4	5	6
		* *	**	**	**	**	**
Treatment	7	0.00	0.00	0.00	0.00	0.00	0.00
Error	16	0.001	0.00	0.00	0.00	0.00	0.00
Total	23	0.0001	0.00	0.00	0.00	0.00	0.0001

* * Significant at 1 per cent level

APPENDIX - XIX

Abstract of analysis of variance for the effect of treatments on the height, collardiameter and leaf number of seedlings after application of complete nutrient solution

Source of variation	df	Mean square at fortnightly intervals														
		0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
		Height					Collar diameter					Leaf number				
		**	**	**	**	**	**	**	**	**	**	**	*	**	**	**
Treatment	7	210.20	231.53	239.46	236.75	239.81	0.006	0.006	0.006	0.007	0.008	28.42	23.78	34.20	40.01	33.13
Error	16	0.60	0.98	10.42	8.27	8.14	0.000	0.001	0.001	0.001	0.001	0.38	7.78	5.22	6.61	4.43
Total	23	64.39	77.41	80.13	77.63	78.65	0.002	0.002	0.002	0.003	0.003	8.91	12.65	14.04	16.77	13.16

* Significant at 5 per cent level

* * Significant at 1 per cent level

NUTRITIONAL DEFICIENCY SYMPTOMS OF TEAK (*Tectona grandis* Linn.f) SEEDLINGS

By

VIJU VARGHESE

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the

requirement for the degree

Master of Science in Forestry

Kerala Agricultural University

COLLEGE OF FORESTRY

VELLANIKKARA, THRISSUR

1997

ABSTRACT

Sand culture studies were conducted in College of Forestry, Kerala Agricultural University, Vellanikkara, Thrissur with an objective of inducing the symptoms of deficiency of various nutrient elements in seedlings of teak (*Tectona grandis* Linn. f.) grown in sand culture. The effects of nutrients viz., N, P, K, Mg, S, Zn and Mo on the growth, chlorophyll content and nutrient concentration of seedlings in the nursery were also studied. The results were finally confirmed by recovery studies by supplying the seedlings showing the symptoms of deficiency of various elements with complete nutrient solution. For the study, two months old seedlings of uniform growth were planted in containers filled with pure quartz sand and supplied with Hoagland No. 2 (1948) nutrient solution. The treatment solution was prepared by eliminating the desired nutrient from the complete Hoagland nutrient solution.

The characteristic deficiency symptoms produced by seedlings due to the deficiency of various nutrient elements include leaf discolouration, necrosis, scorching, defoliation and growth stunting. The seedlings showing visual deficiency symptoms were also photographed. Seedlings that received complete nutrient solution were healthy with dark green foliage. Vegetative growth of the seedlings was also found to be affected due to the nutrient stress. All the fractions of chlorophyll ie; chlorophyll - A, chlorophyll - B and total chlorophyll of the

treatment seedlings particularly N deficient seedlings declined considerably during the study period. Visual deficiency symptoms of the nutrient elements also coincided with a corresponding reduction in foliar levels of the concerned element. There was remarkable improvement in the growth and recovery of the visual symptoms when the deficient element was again supplied to the seedlings through complete nutrient solution. The foliar nutrient content of these seedlings was also found to be improved significantly on application of complete nutrient solution.