NUTRITIONAL DEFICIENCY SYMPTOMS OF AILANTHUS (*Ailanthus triphysa* (Dennst.) Alston) SEEDLINGS

By

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THESIS

Submitted in partial fulfilment of the requirement for the degree

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VELLANIKKARA THRISSUR

1993

Dedicated to
my Parents

DECLARATION

I hereby declare that the thesis entitled Nutritional deficiency symptoms of Ailanthus (*Ailanthus triphysa* (Dennst.) Alston) seedlings is a bonafide record of research work done by me during the course of research and that the theses has not previously formed the basis for the award to me of any degree diploma associateship fellowship or any other similar title of any other university or society

Vellanikkara
12.10.1993

ANOOP P V

CERTIFICATE

Certified that the thesis entitled Nutritional deficiency symptoms of Ailanthus (*Ailanthus triphysa* (Dennst) Alston) seedlings is a bonafide record of research work done by Mr Anoop E V under my guidance and supervision and that it has not previously formed the basis for the award of any degree fellowship or associateship to him

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Introduction

INTRODUCTION

Ailanthus triphysa (Dennst) Alston (Syn Ailanthus malabarica DC) is a fast growing tree species of considerable economic importance Locally known as matti perumaram pongilyam etc it is a large deciduous tree with cylindrical bole and is reported to be a strong light demander (Troup 1981) The wood of this tree is widely used in match packing case and paper pulp industries Large scale plantations of Ailanthus are being grown in many parts of the country (Sandhu 1984) This is a very important species being popularised for extensive planting programmes under various social forestry and agroforestry schemes In Kerala Ailanthus is raised in plantations of the Forest Department over large areas Of late it is also grown in many homesteads particularly in places where match industries are prevalent This also serves as a good standard for pepper in Northern Kerala 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 nutrition in the production of healthy and vigorous seedlings in the nursery need not be overemphasized It is a well established fact that the

ultimate performance of nursery stock is related to the nutrient composition of seed bed soil or potting medium where the seedlings are grown For the proper understanding of the mineral nutrition role of various elements their quantity required uptake pattern etc have to be well investigated It is with artificial nutrient cultures such as sand or solution cultures that the essential status of nutrient elements is established Severe nutritional disorders have been observed in Ailanthus seedlings grown in nurseries of the Forest Department as well as in other commercial nurseries An Ailanthus nursery showing the nutritional disorders are clearly depicted in Plate 1

The present investigations were taken up to understand the importance of various nutrient elements in the nutrition of Ailanthus seedlings The study is mainly based on the deficiency symptoms manifested on the seedlings as leaf discolouration growth retardation leaf and stem deformation and poor root growth An attempt was also made to establish a direct relation between nutrients applied and nutrients absorbed which in turn will reflect on the development of various nutritional disorders The information obtained will ultimately help us for the better understanding of the seedling nutrition of Ailanthus which in turn will help the farmers and foresters to produce healthy and vigorous

seedlings for extensive planting programmes The visual symptoms of seedlings in the nursery are also expected to provide some guidelines to understand the nutritional disorders of Ailanthus even under field conditions Hence the present series of studies were taken up with the following objectives

1 To induce the symptoms of deficiency of various nutrient elements in seedlings of Ailanthus grown in sand culture

2 To study the effect of various nutrient elements on growth and chlorophyll content of seedlings in the nursery

3 To find out the uptake pattern of nutrient elements at the seedling stage

Review of Literature

REVIEW OF LITERATURE

Nutritional deficiency symptoms and disorders have been well studied and described in many tree species These were based mostly on the observations on seedlings grown under stress in pots or on the basis of field experience However reported work in these lines in tropical trees is confined mostly to plantation crops Very little works were seen to be carried out on the mineral nutritional aspects of tropical forest tree species

2 1 Role of mineral elements in growth and development of plants

Apart from Carbon Hydrogen and Oxygen Nitrogen Phosphorus Potassium Calcium Magnesium Sulphur Iron Manganese Zinc Copper Molybdenum and Boron are also recognized as universally essential for plant growth

2 1 1 Nitrogen

Nitrogen is reported to be the most important structural constituent of the cell Nitrogen containing compounds constitute 5 to 30 per cent of the dry weight of plants (Kramer and Kozlowski 1960) Stocking and Orgun (1962) noted that as much as 70 per cent of the leaf nitrogen

was present in the chloroplasts Greulach (1973) found that nitrogen being a constituent of organic compounds such as amino acids proteins purines pyramidines chlorophyll and many co enzymes this element was found to be involved in all processes associated with enzyme reactions and photosynthesis Nitrogen supply was found to control the use of carbohydrates and hence determined whether the plant will make vegetative or reproductive growth (Kraws and Kraybill 1918) Marschner (1982) found that nitrogen has a major role in maintaining the phytohormone balance in plants An interruption in nitrogen supply enhanced the abscisic acid content of tissues which subsequently favoured the leaf senescence

2 2 2 Phosphorus

Phosphorus was reported to play a major role in energy metabolism of all living cells eventhough the share of phosphorus was only 0 1 to 0 8 per cent of the total dry weight in plants (Epstein 1978)

Greulach (1973) and Agarwala and Sharma (1976) noted that phosphorus acted as a structural component of the membrane system of the cell the chloroplasts and the mitochondria It formed the main part of sugar phosphates ADP ATP nucleic acids nucleoproteins purine and pyramidine

nucleotides flavin nucleotides and several other enzymes and co enzymes Being a component of nucleoproteins it is very important for cell division and transfer of hereditary traits as reported by Gauch (1972) Marschner (1982) found that phosphorus also favoured the movement of cytokinins from roots to other plant parts and hence its deficiency resulted in a decline in cytokinin content in these tissues

Phosphorus deficient plants produced purple bronze leaves since phosphorus played an important role in the synthesis of anthocyanin pigments (Gauch 1972)

2 1 3 Potassium

The property of potassium to occur primarily in the ionic form or as charged particles on colloidal surfaces has made it most apt to function as a catalyst or as a co factor for many enzymatic reactions of the cell (Ulrich and Ohki 1975) Evans and Sorger (1966) has reported the presence of more than 50 plant enzymes that need K for maximal activity

Potassium influenced stomatal opening and transpiration (Fischer and Hsiao 1968) Caporn et al (1982) noted that though potassium activated synthesis of chlorophyll an increased partitioning of K to the chloroplast in K deficient plants was the major reason for no substantial

reduction in photosynthetic rates during the initial stages of deficiency of this element

Marschner (1982) found that deficiency of potassium resulted in reduced transport of cytokinins from roots but enhanced ABA export to grains which caused accelerated senescence A higher cell number was associated with a higher K supply (Boringer and Schacherer 1982)

Gruelach (1973) stated that K deficiency may also be expressed as water imbalance as K is very important in regulating membrane permeability in plant cells

2 1 4 Calcium

Calcium is supposed to be the major cation in the middle lamella and hence supports the mechanical strength of tissues (Rasmussen 1967) Calcium functions as an activator of enzymes like phosphatases kinases and succinate dehydrogenases (Pandey and Sinha 1972)

Calcium is found to be immobile except when it is in xylem It is supposed to be very essential for root growth Emanuelson (1984) has reported root development to have an exponential course at higher levels of Ca and was enhanced with increase in Ca concentration

Anderson and Cormier (1978) found Ca ion to be inactive and its activity being modified through a homologous class of calcium binding proteins like Calmodulin These proteins control numerous key enzyme systems and cellular processes The Ca calmodulin complex bind the calmodulin dependent enzymes like NAD kinase thus turning them on

2 1 5 Magnesium

Magnesium is a major constituent of the most vital and widely distributed plant pigment chlorophyll This element is constituting 2 7 per cent by weight of chlorophyll It is an important activator of a number of enzymes most of which are concerned with carbohydrate metabolism phosphate transfer and decarboxylation (Dixon 1949)

Ananthanarayan and Rao (1979) have reported that Mg acts as a carrier of P and this helps in its solubilisation There was a higher requirement for Mg at high temperatures due to its role in Co_2 fixation during photosynthesis (Wallace and Muller 1962)

2 1 6 Sulphur

The most important role of sulphur in plants is its involvement in aminoacid synthesis (Kramer and Kozlowski 1960) Sulphur is considered equally important as nitrogen in

terms of protein synthesis and in total uptake it exceeds phosphorus sometimes Evans and Sorgor (1966) found that sulphur is essential for synthesis of chlorophyll and for cell division

Sulphur deficiency caused poor quality crop products and is hence recognised as a quality nutrient (Rajagopalan 1987) Thirumalaiswami et al (1987) found that sulphur enhanced the rate of translocation of assimilates from leaves to fruits particularly in annuals and vegetables

2 1 7 Iron

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

Several workers have stated that iron acted as an activator of nitrate reductase and aconitase and played significant role in synthesis of nucleic acids and proteins (Salisbury and Rose 1978 and Alcaraz et al 1979) Iron also plays a major role in the synthesis of chlorophyll and

much of the Fe in leaves is found to be present in the chloroplasts (Bogorad 1966)

Branton and Jacobson (1962) have reported that iron applied in the leaves was found translocated to meristematic tissue They found that Fe was moderately mobile in plants eventhough it is described by several workers as immobile inside the plant system

2 1 8 Manganese

The largest concentration of Mn in plant cell is found in the cytoplasm and the cell organelles chloroplast being the richest in Mn content Some of the hydrophytes and woody plants were found to be rich in Mn which was related to their biochemical composition (Shkolnik et al 1975) They were referred as manganophiles

Manganese has been reported to act as an activator of carboxylase that catalyses assimilation of carbondioxide that leads to the formation of di and tri carboxylic acids It was directly involved in photosynthesis as an electron carrier participating in the reaction for release of oxygen (Mehler 1951 and Salisbury and Rose 1978) Manganese was also found to be involved in many of the glycolysis and Kreb s cycle reactions (Horiguchi and Fukomoto 1987) The manganese

content of various plant species exhibits wide variation and they show differential tolerance to Mn levels (Edwards and Asher 1982)

2 1 9 Zinc

The concentration of Zn was found to be the highest in leaves generative organs and growth points compared to other parts (Riceman and Jones 1960) Inside the cell greater part of Zn occurs in nuclei and mitochondria indicating its significant role in cell division (Kathore et al 1972)

Zinc was found in plants mostly in the ionic form and less associated with complex compounds The metabolic functions of Zn have been reported to be more varied than any other trace element The principal respiration pathway was observed to be strongly inhibited by inadequate Zn supply as Zn is essential for the synthesis and activity of aldolase and a number of glycolytic enzymes (Shkolnik et al 1975)

Zinc played an important role in determining the auxin level in plants through its influence on the synthesis of tryptophan the precursor of IAA (Skoog 1940) Deficiency of zinc severely depressed the production of protein in meristematic tissues and brought about accumulation of amino acids and amides (Kitagishi and Obata 1986) This pointed to

the involvement of Zn in nucleic acid metabolism Springate et al (1973) has reported zinc to be an integral part of RNA dependent DNA polymerase which plays an important role in transcriptions

2 1 10 Copper

The nature and involvement of Cu in metabolic process was determined by the specific physico chemical properties of this element Copper ions reacted 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 a protein molecule Copper ions are reported to readily release or accept an electron which accounted for the behaviour of Cu either as a donor or as an acceptor of electrons (Frieden 1968)

Copper was found to be a component in ribulose diphosphate carboxylase thereby confirming its role in photosynthesis (Wishnick and Mildvan 1969) Copper was found to play a role in auxin metabolism which is evident from the high correlation existed between indole acetic acid content and activity of Cu enzyme ascorbinate oxidase (Gamayunova 1965) Endowed with the ability to change valency Cu like Fe Mn and Mo plays an important role in the biological oxidation

reduction reactions including those of respiration photosynthesis and assimilation of molecular nitrogen (Shkolnik et al 1975)

Nucleic acids and some nucleic acid precursors were found to have high affinity for Cu ions In many plant species biosynthesis of adenine adenosine and adenosine monophosphate were found to be enhanced by Cu ions (Okuntsov et al 1966)

2 1 11 Boron

Boron is neither a constituent of enzymes nor an activator Starck (1963) stated that bulk of the boron present in the plants was mainly concentrated in cell walls The growth of vegetative shoots was observed to be retarded in B deficient plants due to the accumulation of phenolic growth inhibitors which resulted in stimulation of pentose phosphate pathway in these cases (Shkolnik and Lilinskaya 1975) The principal function of boron as connected with the metabolism of phenolic acids and lignin biosynthesis and with the mechanism of auxin action in the process of xylem development and differentiation has been clearly illustrated in various plant species by Lewis (1980)

The presence of boron was found essential to maintain membrance structure and hence many of the common deficiency

symptoms were secondary effects caused by changes in membrane permeability (Pilbean and Kirkby 1983)

2 1 12 Molybdenum

Plants require molybdenum to a less quantity compared to other trace elements The most important physiological role of Mo is its involvement in nitrogen metabolism particularly in the reduction of nitrates and fixation of molecular nitrogen (Nicholas and Stevens 1955) Mo also acted as a catalyst in various metabolic reactions (Shkolnik et al 1975)

Molybdenum is important in energy metabolism Its role in vitamin metabolism and pectin metabolism was emphasized respectively by Burkin (1968) and Ivchenko (1981) Much of the functions of Mo in plants remain unexplored and further investigations are required to fully understand its functions in plants

2 2 Nutritional deficiency symptoms in tree seedlings

2 2 1 Nitrogen

Chlorosis which was reported due to inadequate supplies of nitrogen for chloroplast synthesis was the most typical deficiency symptom in most of the trees (Jones 1975) Nitrogen being a mobile element inside the plant the

deficiency was first manifested in the leaves due to its mobility from older to younger tissues as observed by Gauch (1972)

Visual symptoms of N deficiency has been described in various trees 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 deficient seedlings rapidly respond to application of N fertilizers

Hallett (1985) noted yellowing of needles and reduced height as typical symptoms of N deficiency in white spruce Pale green colour of older leaves which gradually changed to uniform yellow colour was the major N deficiency symptom in cashew seedlings grown in the nursery (Ohler 1979 and Gopikumar and Aravindakshan 1988) Similar symptoms were also observed in coffee (Muller 1966) citrus (Jones and Embleton 1959) avocado (Jones 1975) apple (Plant 1976) and nutmeg (Philip 1986)

The tissue analysis values for nitrogen are less firmly established compared to other elements because of wide variations in nitrogen level in a given plant in relation to seasons plant parts type and age of tissues and also due

to its high mobility within the plant However tissue analysis values for indicating the deficiency optimum and excess levels of nitrogen have been well developed for a number of temperate and tropical fruit tree species (Jones 1975)

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

Nitrogen was reported to interact highly with several elements Antagonistic effect of N with phosphorus has been reported by Lockard and Asomaning (1964) Smith (1966) Dewaard (1969) and Nybe (1986) In citrus foliar level of Mg decreased with nitrogen deficiency (Lebanauskas et al 1958) Kandaswamy and Arulmozhiselvan (1987) has reported that uptake of N was higher in the presence of sulphur indicating a positive interaction between nitrogen and sulphur

2 2 2 Phosphorus

Lot of variations have been reported in the symptoms of P deficiency While Hallett (1985) noted young black spruce germinants to have primary needles with a purplish

tinge a symptom called purple heart Swan (1971) observed remarkable differences in P deficiency symptoms for the two species of spruce studied White spruce showed the characteristic stunting and purple foliar symptoms while red spruce though stunted exhibited no purpling 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)

Deficiency symptoms appeared first in the lower leaves indicating the mobile nature of P inside the plant A gradual transition from dark green leaves to bronze green was noticed in the leaves of cashew seedlings subjected to P deficiency (Gopikumar and Aravindakshan 1988) Muller (1966) also noticed purple coloured leaves which was reported to be due to the P deficiency induced formation of anthocyanin Greulach (1973) reported reduced quantities of ATP NAD and NADP that contributed towards gradual decrease and disruption of metabolic pathways resulting in stunted growth of the plant

Childers (1966) reported restricted growth of root and top 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

Narayanan and Reddy (1982) reported that the root system of P deficient plants was also found to be affected While the root dry weight in 12 out of 14 species studied decreased the length of primary and secondary roots was found to be increased This type of increase in root length was mainly attributed to the imbalance of auxins and cytokinins

Phosphorus deficiency caused reduction in height and leaf number in cashew eventhough girth reduction was not considerable (Gopikumar and Aravindakshan 1988) In cocoa reduced dry weight was noticed when P was deficient in tissues (Lockard and Asomaning 1964) Interaction of phosphorus with other elements has been reported by various workers Phosphorus deficiency was found to be associated with a decrease in Mn (Lebanauskas et al 1958) N and Mg (Embleton et al 1958)

In nutmeg Philip (1986) has reported an increase in foliar concentration of N and Zn and a decrease in Mg and Mn in P deficient plants grown in sand culture Phosphorus level was found positively correlated with Ca and Mg levels and negatively with K (Matsui et al 1977)

2 2 3 Potassium

Deficiency symptoms of potassium appeared first on the recently matured leaves of the plant since potassium is mobile in the tissues Because of the tendency of K to move to the growing point the older leaves exhibit the most characteristic K deficiency symptoms as tip and marginal scorching in most of the trees (Ulrich and Ohki 1975) Acute deficiency of K in trees results in the entire plant showing typical symptoms including severe dieback 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)

Lockard and Asomaning (1964) noted primary veins of older leaves first turning light green to yellow and then brown in cocoa The mid rib also was affected

Potassium deficiency in orange has been described as fluting (Chapman et al 1947) Crowding of young leaves darkening and irregular development of leaves were reported to be the characteristic symptoms of K deficiency in coffee (Eckstein et al 1937) In coffee Purseglove (1977) has stated brown scorching of entire leaf margins followed by defoliation when K was deficient in tissues Potassium deficient plants accumulated putriscine a di amine that

favour necrosis in leaf lamina (Richards and Coleman 1952) Necrotic older leaves associated with reduced height number of branches and dry matter have been reported as a result of K deficiency in nutmeg (Philip 1986)

Plants grown under K deficiency conditions were less severely stunted compared to those grown under comparable deficiency levels of any other macronutrients (Lockard and Asomaning 1964) The scorched leaves and non fruiting terminals of low yielders of mandarin were found to contain more K and less Ca and Mg as evidenced by the tissue analysis (Morchal and Laccevilhe 1969)

Interactions involving K and other nutrients were studied by Tandon and Sekhon (1988) Potassium and Magnesium interactions were negative which even led to K induced Mg deficiency Potassium and calcium antagonism was also reported by several workers (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 was found to decrease plant growth

2 2 4 Calcium

Calcium deficiency symptoms have been reported to appear first on roots Murray (1966) has noted the root tips

becoming slimy and turning black in cocoa However no specific symptoms on leaves were noticed in the early stages of calcium deficiency (Chapman 1975)

Among leaves Ca deficiency symptoms were first to appear in younger ones The leaves were often distorted and small with irregular margin and necrotic spots (Muller 1966) This was followed by dieback of terminal buds

Chapman (1975) reported dieback followed by chlorosis of leaves due to Ca deficiency in citrus In apple Ca deficiency produced cupping and chlorosis of developing leaves followed by necrosis of chlorotic area in older leaves (Shear 1971) Calcium deficiency symptoms in cocoa were described by Murray (1966) as thickened midrib in younger leaves and shortened inter nodes However Lockard and Asomaning (1964) reported chlorotic symptoms in the first flushes of leaves immediately after germination in cocoa

In nutmeg Philip (1986) described Ca deficiency symptoms as thick brittle and reduced younger leaves with blunt end which later developed into crinkled appearance with necrotic areas

Eventhough Ca deficiency did not produce any visual symptoms such as leaf discolouration growth of seedlings was

found to be reduced in cashew (Gopikumar and Aravindakshan, 1988) Lockard and Asomaning (1964) reported that plants grown under Ca deficiency were more severely stunted compared to seedlings grown under deficiency levels of N P K Mg and S

The elements that are reported to antagonise with Ca are Mg and K (Smith and Rasmussen 1959 and Smith 1966) Anderson and Martin (1970) noted reduced leaf Mg K Na and P contents in citrus owing to higher calcium levels However Lockard and Asomaning (1964) found that Ca deficient treatments did not alter significantly the levels of Mg or K in any plant part An increase in levels of K Mg and N and a decrease in B were found to be associated with Ca deficiency in nutmeg (Philip 1986)

2 2 5 Magnesium

Magnesium is another important element the deficiency of which results in a characteristic severe chlorosis Interveinal chlorosis was found to be the characteristic Mg deficiency symptom in the seedlings of paper birch a hard wood (Landis 1989) In black spruce yellow tipped needles were also observed due to deficiency of Mg (Hallett 1985)

Magnesium being a mobile element in plants its deficiency resulted in the movement of magnesium from older

leaves to active younger ones and hence the symptoms to be developed first on older leaves (Embleton 1975) 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 Aravindakshan 1988) Ohler (1979) also reported similar symptoms in cashew

Magnesium deficiency in coffee was characterised by the development of olive green chlorosis near the midrib and laterals which gradually progressed towards leaf margins (Muller 1966)

Sadowski et al (1976) reported abnormal K-Mg ratios in soil and leaves to be the factors causing Mg deficiency Symptoms were more common in young trees compared to grown up ones Leaf fall was also reported to be favoured by Mg deficiency

In nutmeg pale yellow colouration of midrib of older leaves followed by pale green lemon and necrotic blotches towards margin with upward cupping were some of the symptoms recorded due to Mg deficiency (Philip 1986) The first sign of Mg deficiency noticed by Bull (1954) in African oil palm was the development of olive green area with no sharp boundary between lateral veins Some investigators have studied the ratio of magnesium in plant tissue to the other elements

present Chapman and Gray (1949) reported that the ratio of CaO/MgO in the ash of leaves of the oil palm was more correlated with magnesium chlorosis than the content of magnesium oxide alone in the ash However most reports show that the magnesium content of plant tissue is well correlated with the deficiency symptoms

Generally it is found that if the Mg content in mature leaves of plants is above 0 20 to 0 25 per cent the plant will not show any Mg deficiency symptoms (Embleton 1975) Mg deficiency increased the level of potassium in the leaves and calcium in the roots and stems of cocoa (Lockard and Asomaning 1964) Various other workers have also reported the antagonistic influence of Mg with K and Ca (Emmert 1961 De Waard 1969 and Nybe 1986) Magnesium deficiency was often associated with high K in leaves (Manicot et al 1980) Magnesium deficiency was associated with a decrease in foliar concentration of Zn and Mn in citrus However concentration of N P Fe and B in leaves was not affected by level of Mg even in severely deficient trees (Smith 1966)

2 2 6 Sulphur

Though sulphur is not a constituent of chlorophyll unlike nitrogen it is reported to be essential for the

synthesis of chlorophyll (Eaton 1975) and hence it is possible to differentiate between nitrogen and sulphur deficiencies under conditions of diminishing supply of either element Visual identification of sulphur deficiency in plants is difficult since deficiency symptoms are nearly identical with those of N deficiency Hence S deficiency is best identified by determining the total N/S ratio rather than sulphur concentration in vegetative tissues (Rasmussen et al 1977)

In cashew the early symptom of S deficiency appeared as pale green to greenish yellow discolouration of younger leaves which later turned to uniform yellow (Gopikumar and Aravindakshan 1988) Small necrotic spots appeared on the affected leaves followed by the development of necrotic areas

An overall yellowing of leaves occurred due to deficiency In fruit plants like apple pear peach and grapes the top most leaves on the shoots were the first to be affected by S deficiency (Childers 1966) Cocoa plants deficient in sulphur were found to record significantly lower dry weight than treatments deficient in other macroelements except calcium (Lockard and Asomaning 1964) Hewitt (1963) found that sulphur deficient plants were chlorotic and had an impaired photosynthesis attributed to direct effect on the protein level and the chlorophyll content of the chloroplasts

Tissue analysis values useful in indicating sulphur status have been reported in trees (Eaton 1975) Sulphur is known to interact with several elements Sulphur deficiency was associated with high N P and K contents in leaves of coffee (Lott et al 1960) and in citrus (Smith 1966) Philip (1986) observed an increase in foliar N and P content due to S deficiency in nutmeg

2 2 7 **Iron**

The most widespread symptom of iron deficiency in green plants is a reduced concentration of chlorophyll in young leaves resulting in chlorosis Iron chlorosis is relatively a common disorder in forest nurseries and some species are particularly sensitive (Bunt 1976) In severe cases the entire seedling becomes chlorotic and stunted and the disorder is almost impossible to correct at this stage (Hewitt 1963) The entire younger needles were found chlorotic in jack pine (Hallett 1985)

In cases of slight chlorosis the general pale colour of leaves may be indistinguishable from nitrogen or other elements (Haas 1942 and Wallihan 1955) However in lemon leaves showing interveinal chlorosis of an intermediate degree were diagnositic for iron deficiency (Wallihan 1955) When

chlorosis became very severe leaf tissues devoid of chlorophyll died resulting in complete defoliation

The youngest leaves showed severe chlorosis with the whole leaf turning yellow except the midrib and main veins in cashew seedlings grown in sand culture (Gopikumar and Aravindakshan 1988) In strawberry citrus and avocado severely affected leaves turned yellow and showed marginal and tip burning (Childers 1966) Dieback of shoots and branches was also reported in acute situations

Interveinal chlorosis followed by stunted growth and dieback of tips were found in cocoa trees deficient in Fe (Maskell et al 1953) Abnormal shooting of axillary buds and dieback of young shoots were also reported as characteristic symptoms

Straw coloured young flush with interveinal chlorosis which later developed necrotic patches on leaf lamina has been reported due to Fe deficiency in nutmeg (Philip 1986) Iron is found to interact with several elements In coffee Muller (1966) reported high N P and K contents in leaves deficient in iron Iron deficiency in citrus was reported to be associated with high N and low Ca contents in leaves (Smith 1966)

High foliar P Zn and Mn and low K and Ca in leaves were associated with Fe deficiency in nutmeg (Philip 1986) Iron deficient plants of cocoa recorded very low content of this element in roots compared to stems and leaves as reported by Lockard and Asomaning (1964) The iron in roots was redistributed to stems and leaves under its deficiency conditions The studies conducted by Branton and Jacobson (1962) also demonstrated the moderate mobility of iron in plants

2 2 8 Manganese

The symptoms of Mn deficiency are well defined in most of the plants and if not masked by other deficiency or toxicity supplemental tissue analysis to determine the manganese status is usually unnecessary (Lebanauskas 1975) Interveinal chlorosis of younger leaves was the first visual symptom of Mn deficiency in cashew seedlings as observed by Gopikumar and Aravindakshan (1988) As the intensity of deficiency increased the chlorosis also was found to spread almost completely in the interveinal portion making the major veins and laterals more pronounced

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 a severe stage

Visual symptoms of Mn deficiency were also reported in tropical forest 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 Yellowing of leaf margin which later spread to the midrib was the main symptom noticed in Pterocarpus marsupium

Seedlings of Cassia siamea produced leaves with white spots near the midrib and blackened leaf tips The leaves were sickle shaped on account of Mn deficiency In Neem yellowing and curling of the leaves were the main deficiency symptoms

Childers (1966) reported chlorosis between the main veins followed by dieback of twigs and branches under conditions of deficiency of Mn in fruit trees like citrus walnut and plum In coffee Muller (1966) reported youngest leaves to be affected first as a result of Mn deficiency The leaves showed typical chlorosis with coarse reticulation Studies by Agarwala et al (1988) also revealed similar symptoms in mango

Application of manganese resulted in maximum height growth in rose wood followed by Lagerstroemia lanceolata and Terminalia alata (Kamala and Angadi 1986)

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 compared to healthy plants (Angadi et al 1988)

Changes in peroxidase isoenzyme pattern were taken as diagnostic indices to find out the deficiency of manganese and other trace elements in a number of tropical forest tree seedlings (Kamala et al 1988) The presence and/or absence of a particular band in the zymogram of the peroxidase isoenzyme was particularly useful in diagnosing trace element deficiency much before the appearance of visual deficiency symptoms Manganese deficiency was manifested as reduction in height and number of leaves in cashew seedlings (Gopikumar and Aravindakshan 1988) Leaf analysis values of Mn were also low in these seedlings compared to seedlings grown with complete nutrient solution

Shive (1941) and Somer and Shive (1942) reported antagonism of iron and manganese and a low Fe to Mn ratio in

plant tissue to cause oxidation of ferrous iron to ferric form making it unavailable Hewitt (1963) and Agarwala et al (1986) have also reported Mn induced Fe deficiency in various plant species

2 2 9 Zinc

Gruelach (1973) has reported the major symptoms of Zn deficiency as reduced internodal length rosetting distorted and unusally small leaves This was reported to be largely due to inadequate supply of IAA as a result of zinc deficiency

Reduced internodal length retarded terminal growth and small leaves with interveinal chlorosis were the symptoms of Zn deficiency in cashew (Gopikumar and Aravindakshan 1988) Interveinal chlorosis with reduced internodal distances and progressively smaller new foliage were the symptoms observed in rose wood (Kamala et al 1988) They also reported yellowing and blackening of the leaf tip and also the development of uneven size and wavy margin of the new leaves associated with stunted growth in Pterocarpus marsupium Stunting of the growth was also observed in Cassia siamea and Azadirachta indica

In sandal zinc deficiency resulted in younger leaves turning yellow and becoming brittle as leaves expanded (Kamala

et al 1986) Unequal growth at the internodes followed by stunting was also observed

In citrus Nair et al (1968) have reported visual deficiency symptoms of zinc as mottled leaf reduced leaf size and dieback of terminals in field conditions Naumov et al (1977) reported rosetting symptoms in apple as mainly due to an imbalance of Zn nutrition Lockard and Asomaning (1964) stated that zinc deficiency inhibited plant growth to the maximum extent compared to other micronutrients particularly in cocoa Vegetative growth was found to be restricted in cashew also (Gopikumar and Aravindakshan 1988)

In Pterocarpus marsupium zinc application recorded maximum height increment compared to other nutrients (Kamala and Angadi 1986) Angadi et al (1988) observed that the reduction in leaf area was least in the case of zinc deficiency in the tree species they studied except in mahogany and teak Similar observations were made by Reuther and Burrows (1942) and Loustalot et al (1945) in young tung trees Photosynthetic efficiency was also less in the case of zinc deficiency in all the species studied except in Cassia siamea and Dalbergia latifolia

The zinc content in the plant tissues was found to range from 20 ppm to 10200 ppm (Holmes 1944) Deficiency of

zinc was coupled with a corresponding increase in all other elements in all plant parts except for sodium which was consistently found to be lower (Lockard and Asomaning 1964)

Zinc deficiency was often associated with high N and K and low Ca in leaves (Smith 1966) Foliar Zn absorption increased with higher Mn concentration However iron and calcium were found to reduce the absorption of Zn (Arora et al 1970)

2 2 10 Copper

Copper being immobile in the plant system the deficiency symptoms were first exhibited on new growth (Muller 1966) 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 in peat based growing media (Landis et al 1989)

Inward curling of leaf edges and browning of tips which later spread to the entire leaf resulting in their death were the symptoms observed in rose wood (Kamala et al 1988) In Pterocarpus marsupium the new leaves were found curling The leaf size was reduced and there was cupping of leaves also

In sandal copper deficiency resulted in the formation of white patches at the tip of the older leaves which gradually spread to the other part of the leaves (Kamala et al 1986) The seedlings were stunted in growth and died at the acute stage of deficiency Production of twisted chlorotic needles was the characteristic symptom of white spruce seedlings (Hallett 1985)

Lockard and Asomaning (1964) noticed the presence of a small swelling above the node after the shedding of the small immature leaf in plants of cocoa deficient in Cu In citrus production of large dark green leaves followed by gummosis and dieback of shoots were the initial symptoms as reported by Camp et al (1949) Philip (1986) reported interveinal chlorosis reduced size of new flush downward cupping of leaf margins coupled with reduced height and total dry matter as the symptoms associated with Cu deficiency in nutmeg

Copper deficiency significantly reduced the leaf area chlorophyll activity and photosynthetic efficiency in the leaves of tropical tree seedlings (Angadi 1988) The growth of cocoa seedlings was not influenced significantly by the deficiency of Cu when grown in sand culture (Lockard and Asomaning 1964)

Copper deficiency was characterized when its content fell less than 4 ppm in the dry matter of leaves The foliar content of the normal growth in most of the plants ranged from 5 to 20 ppm (Reuther and Labanauskas 1975)

Physiological functions of copper in the plants were normally associated with the interactions that take place between Cu and other elements Gamayunova and Ostrovskaya (1964) reported the antagonism of Cu with Fe Copper deficiency has been found associated with high foliar N and K and low Ca (Smith 1966) In nutmeg deficiency of Cu increased the uptake of Fe and Mg while the uptake of Ca was found to be reduced (Philip 1986)

2 2 11 Boron

Although the symptoms of boron deficiency vary from one plant species to another in general its deficiency leads to degeneration of the meristematic tissues including the cambium break down of the walls of parenchyma cells These internal symptoms are often accompanied by the manifestation of external symptoms like rosetting of terminal growth thickening brittleness and curling of the leaves and also thickening of petioles and stems (Bradford 1975) Kamala et al (1988) reported brown spots on the chlorotic leaves in rosewood They also observed yellowing 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 in Cassia siamea In Azadirachta indica white and yellow spots developed in the leaves due to deficiency of B

Maskell et al (1953) observed downward cupping of leaves and reflexing of leaf tips in cocoa as the deficiency of boron advanced in the leaves Small young leaves leathery texture irregular leaf margin and reduced internodal length were the results of B deficiency in coffee (Muller 1966) Crinkling of leaves premature shedding and dieback were the characteristic symptoms noticed in nutmeg (Philip 1986)

In addition to curling and twisting of leaves normally caused by boron deficiency numerous brown spots were also observed to appear on the young leaves of cocoa (Lockard and Asomaning 1964) The leaves of B deficient plants rarely abscissed and the symptoms remained on the plants almost indefinitely Plants deficient in boron showed a reduction in leaf area decrease in chlorophyll content and photosynthetic efficiency in the leaves compared to plants grown in complete nutrient solution (Angadi et al 1988)

Boron deficiency in a wide variety of plants was

characterized by levels less than 15 to 20 ppm in dry matter (Bradford 1975) Boron deficient plants had higher levels of P Mg Ca Zn and Mo This demonstrates the antagonistic relation of boron with other elements In citrus B deficiency was associated with a high P and Mg and low K content in leaves Philip (1986) reported a decrease in foliar Ca and K and an increase in foliar N and P content in nutmeg

2 2 12 Molybdenum

Curling of the leaves was the characteristic symptom of Mo deficiency in four tropical forest tree species studied by Kamala et al (1988) Curling was associated with size reduction of leaves in Dalbergia latifolia Necrotic areas were found to develop along the lamina but veins remained green In Pterocarpus marsupium sickle shaped small leaves were observed while white and black patches were noticed in the leaves of Cassia siamea In Azadirachta indica chlorotic leaves with curled margins were the specific symptoms of Mo deficiency While studying the nutritional aspects of sandal Kamala et al (1986) obtained curling of leaves with older leaves showing cupping and formation of brown patches subsequently turning white The seedlings died under the severest deficiency of Mo Hewitt (1963) observed rough textured and mottled leaves in lemon Plants growing in

acidic soils are reported to exhibit Mo shortage usually on account of its immobility in such soils (Burkin 1968)

In some cases Mo deficiency also appeared as yellowish green or pale orange interveinal spots The deficiency eventually resulted in a significant reduction in number of flowers produced by the plant (Skholnik et al 1975)

The flowers on Mo deficient plants are reported to lose their ability for anthesis Severe disturbances in the formation of reproductive organs especially in the development of pollen grains have been reported by Agarwala and Sharma (1976)

Reduced leaf area chlorophyll activity and photosynthetic efficiency were observed in seedlings grown under Mo deficient conditions (Angadi et al 1988) Lockard and Asomaning (1964) observed that in cocoa when Mo was deficient growth restriction was least in terms of dry weights and leaf area compared to other trace element deficiencies However its growth was significantly different from the plants receiving complete nutrient solution

Addition of Mo produced the largest height increment in Terminalia alata while it gave the smallest height growth

in Dalbergia latifolia (Kamala and Angadi 1986) Molybdenum deficient treatments did not reduce significantly the content of this element in any plant part studied (Lockard and Asomaning 1964)

Molybdenum have been reported to antagonise the toxic effects of Al and Cu (Millikan 1948) Barrocio (1962) reported synergism between Mo and K Candela et al (1957) reported excess Mn to adversely affect the growth of plants suffering from Mo deficiency

2 3 Diagnostic methods for nutritional deficiencies and disorders in tree seedlings

Generally diagnosis implies the determination of the nutritional status of the site or trees Diagnosis of nutritional problems was essential to make a qualitative appraisal of which nutrient or nutrients were limiting the growth But more often it was important to know how severe the deficiency was and also to predict the response to given quantities of nutrients applied to correct it (Bowen and Nambiar 1984) On the practical side diagnosis of the nutritional problems is essential for the nursery manager to make sound decisions concerning profitable and most effective use of manures and fertilizers (Landis et al 1989)

Diagnosis includes visual assessment based on symptoms plant tissue analysis soil analysis and biological estimations Among these techniques some have proved more useful in certain situations than others and all have their own merits and de merits Hence it is prudent to use a range of techniques and in general faster progress is made this way than by relying on a single technique (Gentle and Humphreys 1984)

Visual growth symptoms have been studied in many temperate forest tree species These were based mostly on observation with seedlings grown under stress in pots or sometimes on the basis of field experience as done in the case of British conifers (Binns et al 1980)

Visual symptoms of deficiency or excess have been induced in several tree crops using the sand and solution culture method Boussingalt (1856) was the first to introduce the idea of growing plants in sand culture Use of synthetic nutrient solutions for sand culture experiments 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 later modified by various workers which is now being used widely for sand culture studies

Leaf symptoms certain types of stem malformation and changes in morphology are useful in qualitative diagnosis but they are often readily apparent only after the deficiency has already resulted in a reduction in growth or in malformation (Mead 1984)

Generally incipient deficiencies of many nutrients caused mild chlorosis which made precise diagnosis difficult as in the case of micronutrients (Landis et al 1989) Deficiency symptoms varied with the intensity of deficiency or with tree species or even provenances and sometimes deficiency of one element may be masked by another where multiple deficiencies existed (Walker 1956 Erdmann et al 1979 Pritchett 1979 and Binns et al 1980)

Diagnosis on the basis of leaf colour relies on good 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) found that infra red photography did not always distinguish between the macronutrient deficiencies in conifer seedlings Studies of spectra of normal and nutrient deficient maize leaves suggested that different deficiencies

might be resolved by comparing reflectance spectra (Al Abbas et al 1974) The degree of nutrient stress was also determined

Luukkonen et al (1971) used Munsell colour charts to predict growth of 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 compared to control could be taken as a diagnostic index This was particularly useful in sandal (Kamala et al 1986) because the deficiency could be detected much before the manifestation of visual symptoms

Visual symptoms method was often combined with plant tissue analysis The rationale behind the latter was that the concentration of nutrients or other extracts within a specified plant part reflects the nutritional status of that plant and thus its growth potential (Marschner 1986)

In tree crops foliage analysis is popularly used because it has been shown to be reasonably sensitive for

detecting deficiencies and also has 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) and Alban (1984) However in most of the tree crops foliar deficiency symptoms along with tissue and soil analysis values are mostly used for the detection of nutritional deficiencies and disorders

Materials and Methods

MATERIALS AND METHODS

The present investigations pertaining to the nutritional deficiency symptoms of Ailanthus triphysa Dennst (Alston) seedlings were carried out in College of Forestry Kerala Agricultural University Vellanikkara during the period 1991-93 The study consisted of two main parts the first part involved the induction of nutrient deficiency symptoms in seedlings grown in sand culture while the second part aimed at diagnosis of these symptoms through analysis of growth behaviour chlorophyll and tissue nutrient levels The study also aimed at finding out the recovery of symptoms of the nutrient deficient seedlings after the application of the concerned elements which were deficient earlier

3 1 Development of nutrient deficiency symptoms

To induce deficiency symptoms in the seedlings of Ailanthus triphysa sand culture experiments were carried out under controlled conditions inside a glasshouse 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 Minichem Industries Bangalore was used for sand culture studies The sand was first washed with tap water and then soaked in dilute hydrochloric acid for about 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 planting material

Seeds of Ailanthus triphysa were collected from a single healthy mother tree of about eight years old from the main campus Vellanikkara during the last week of April 1991 The seeds were dried uniformly by spreading on the floor It was then soaked in tap water for 12 hours The seeds were then broadcasted in sand beds which were prepared under partial shade After sowing the seeds were covered uniformly with a thin layer of sand The seed beds were kept moist by regular watering The seedlings of about one month old were transplanted to polybags of size 16 x 18 cm They were also kept under partial shade and watered regularly

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

3 1 3 Selection of containers and planting of seedlings

Plastic containers of height 20 cm, with a diameter of 18 cm at the top and slightly tapering to 12 cm at the bottom 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 uniformly filled with acid washed sand to one fourth the volume prior to the planting of seedlings The seedlings were removed from the polybags and the sand and soil particles adhering to the roots were washed off first under tap water and then with deionised water

After placing the seedling in the centre of a pot the container was filled with acid washed sand leaving one inch space from the top The pots were arranged on concrete benches inside the glass house at a spacing of 20 cm from one another (Plate 2)

All the experimental seedlings were supplied with complete Hoagland No 2 (1948) nutrient solution for a period of 10 days till they established well in the sand Before imposing the nutrient treatments the growth media were completely flushed with deionised water repeatedly for three to four times to wash away the nutrient residues Deionised

Plate 1 An Ailanthus nursery showing severe nutritional disorders

Plate 2 Seedlings arranged for sand culture studies inside the glass house

water was prepared by passing tap water through an ion-exchange resin column

3 1 4 Treatments

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

The experiment was laid out in completely randomised design with three replications and the total number of plants for the study was 216

The chemical composition of complete Hoagland No 2 (1948) nutrient solution is furnished in Table 1 From the stock solution the required quantities of each nutrient as mentioned were pipetted and made 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

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

Complete solution (Stock solution)	Quantity pipetted ml/litre (Working solution)
$NH_4H_2PO_4$ (1M)	1
KNO_3\KCl (1M)	6
$Ca(NO_3)_2$\Ca PO_4 (1M)	4
$MgSO_4$ 7 H_2O (1M)	2
Boric Acid (2 86 g/l)	1
Mn Cl_2 4 H_2O (1 81 g/l)	1
Zn SO_4 7 H_2O (0 28 g/l)	1
Cu SO_4 5 H_2O (0 08 g/l)	1
Molybdic acid (0 02 g/l)	1

grade) were used for the preparation of the solutions Fresh nutrient solutions were prepared every week Iron was added separately in order to avoid 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 $FeSO_4$ solution was added to each plant On other days deionized water was supplied at the rate of 50 ml per plant Sand in each container was flushed with deionized water at the end of every month to prevent the possible salt accumulation which may result in root injury This was again followed by the application of fresh nutrient solution

3 2 Diagnosis of nutrient deficiency symptoms

3 2 1 Observation of visual symptoms

The seedlings under each treatment were observed daily for the appearance of symptoms of deficiency The time taken for the development of various visual symptoms was recorded and colour photographs were also taken The symptoms were confirmed only when at least one seedling in all the three replications coming under the same treatment developed identical symptoms For convenience an attempt was made to describe the symptoms during four stages of nutrient deficiencies viz initial moderate severe and acute

3 2 2 Growth behaviour of seedlings

3 2 2 1 Shoot growth parameters

Observations were recorded on the following shoot growth parameters after the commencement of the treatments

3 2 2 1 1 Height

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

3 2 2 1 2 Collar diameter

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

3 2 2 1 3 Number of leaves

The number of leaves produced by the seedlings was recorded at fortnightly intervals

3 2 2 2 Root growth parameters

Representative samples were selected and uprooted from each replication of all the treatments at monthly intervals for root observations

3 2 2 2 1 Root length

The length of the main root from collar to the tip was measured using a precise tape and expressed in centimetres

3 2 2 2 2 Root spread

The root spread was computed by measuring the spread along two axes at right angles to each other and the mean was calculated

3 2 2 2 3 Root number

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

3 2 2 3 Dry matter content

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°C $\pm$ 2°C till constant dry weights were obtained The dry weights of stem and root were also recorded A precise analytical balance was used for recording the weights of the samples

3 2 3 Chemical analysis of leaf tissues

The following chemical analyses were carried out in the laboratory

3 2 3 1 Chlorophyll content

Three seedlings each from a treatment were uprooted at bimonthly intervals for analysis of the chlorophyll content of the leaves The chlorophyll content of the leaf was estimated spectrophotometrically in a known aliquot of the 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 formulae suggested by Starner and Hardley (1967) were used for the estimation of different fractions of chlorophyll

Chlorophyll A

$$12\ 7\ (\text{Abs at } 663\text{ nm}) - 2\ 69\ (\text{Abs at } 645\text{ nm}) \times \frac{V}{1000 \times W}$$

Chlorophyll B -

$$22\ 9\ (\text{Abs at } 645\text{ nm}) - 4\ 68\ (\text{Abs at } 663\text{ nm}) \times \frac{V}{1000 \times W}$$

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 1 g of the samples in 5 ml concentrated sulphuric acid using hydrogen peroxide and the N in the digest was estimated colorimetrically using Nessler s reagent (Wolf 1982) The colour was read in a spectrophotometer at 410 nm

3 2 3 3 Phosphorus

Phosphorus was determined in a known aliquot of the acid extract colorimetrically by the Vanado molybdophos phoric 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 by Varsanate method A known

Hoagland nutrient solution The improvement in the growth of the seedling and recovery of leaf discolouration was recorded All the growth observations made earlier were repeated here also At the end of the study the 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 following the methods suggested by Panse and Sukhatme (1978) Square root transformed data were used wherever found necessary

RESULTS

The results of the study on the nutrient deficiency symptoms of Ailanthus triphysa Dennst (Alston) seedlings grown in sand culture are presented in this chapter The important findings are furnished under various heads viz 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 growth of seedlings that received complete Hoagland nutrient solution and the visual deficiency symptoms of other seedlings as influenced by various treatments are summarised below

4 1 1 Complete nutrients

The seedlings that received all nutrients through complete Hoagland nutrient solution were found to be very vigorous in growth and produced dark green foliage throughout the period of study The seedlings did not show any visual symptoms of deficiency or toxicity They had healthy dark green and normal shaped foliage at the end of the study period (Plate 3)

4 1 2 Nitrogen

Symptoms of N deficiency appeared by the end of the first month after imposing the treatment In the beginning patches of yellow colour began to appear in the oldest leaves Later the entire lamina turned pale yellow (moderate) stage This stage was followed by the severe stage of deficiency which appeared during the fourth month The leaves showing varying levels of yellowing with the gradual advancement of nitrogen deficiency are depicted in plate 4 Stunting of seedlings could also be noticed at this stage In the acute stage of deficiency which was evident at the end of five months of the study the entire seedling appeared severely chlorotic (Plate 5) The completely chlorotic leaves gradually started premature drying also

4 1 3 Phosphorus

Symptoms of phosphorus deficiency first appeared on the 40th day after the treatments were initiated Here the oldest leaves were affected first Initially purple bronze patches were observed on the lower halves of leaflets of these leaves The different stages of phosphorus deficiency are clearly illustrated in plate 6 The new leaves were of pale yellow colouration During the third month of the study the number of leaves with bronzing increased almost one third of

Plate 3 Ailanthus seedlings grown with complete nutrient solution

Plate 4 The stages of development of N deficiency symptoms in the leaflets

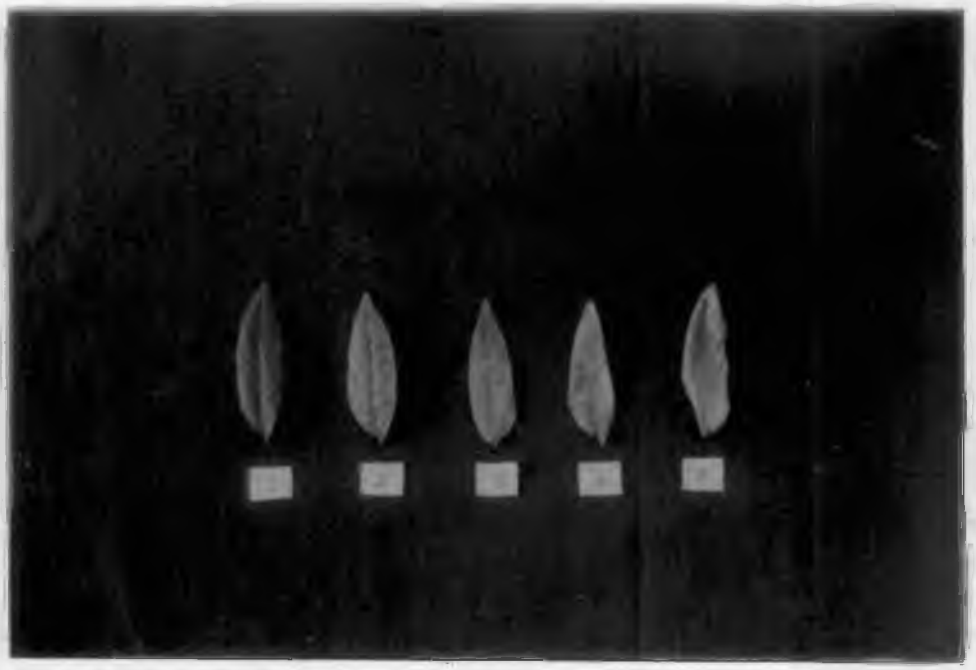


Plate 5 Seedings showing acute stage of deficiency of nitrogen

Plate 6 The stages of development of P deficiency symptoms in the leaflets


1
2
3
4
5

the leaf had purple bronze colouration (Plate 7) At the severe stage the bronze patch extended to the entire leaf Defoliation of such leaves was also noticed (Plate 8) In the acute stage of deficiency at the end of the study the seedlings had sparse foliage with necrotic patches The seedlings were also stunted in growth

4 1 4 Potassium

Potassium deficiency symptoms started appearing by the third month after imposing treatments The symptoms appeared first on the lower leaves The leaflets had chlorotic tips at the initial stage The chlorotic area gradually spread through the margin upwards (moderate stage) At the severe stage the entire margin of the leaflets had chlorotic symptoms (Plate 9) At the acute stage of deficiency the margins were crinkled and severely chlorotic Necrosis progressed from the lower part upwards in such leaves This stage was observed during the fifth month (Plate 10) Drying of the terminal buds was also observed in a number of seedlings at this stage This was followed by the gradual death of such seedlings (Plate 11)

4 1 5 Magnesium

Magnesium deficiency symptoms were noticed from the 60th day onwards The older leaves produced small chlorotic

areas during the initial stage of deficiency This later changed as a pattern with chlorotic area formation between the veins However the midrib and the veins remained green The various stages of deficiency of magnesium are clearly evident from Plate 12 Interveinal chlorosis with the reticulate pattern became marked when the deficiency was severe during the fourth month (Plate 13) At the acute stage this interveinal chlorotic area developed into necrotic regions The seedlings were also stunted in growth

4 1 6 Sulphur

Seedlings receiving the treatment solution lacking sulphur developed symptoms only by the fourth month The symptoms were first to appear on the lower leaves Leaf discolouration advanced from the margin inwards (Plate 14) At the moderate stage only the region close to midrib appeared green Later necrosis set in (severe stage) and at the acute stage the entire leaf became chlorotic This was followed by defoliation The seedlings generally had a lanky appearance and were completely chlorotic by the end of the study (Plate 15)

4 2 Growth behaviour of seedlings

The effect of nutrient stress on the growth behaviour of seedlings grown in sand culture is presented under three

Plate 7 Seedlings at an advanced stage of P deficiency showing a large number of leaves with purple bronze patches

Plate 8 Seedlings showing sparse foliage with necrotic patches in the acute stage of P deficiency

Plate 9 The stages of development of K deficiency symptoms in the leaflets

Plate 10 The seedlings at an advanced stage of K deficiency

Plate 11 Seedlings with dried terminal bud due to severe deficiency of potassium

Plate 12 The stages of development of Mg deficiency symptoms in the leaflets

Plate 13 Seedling at the severe stage of Mg deficiency

Plate 14 The stages of development of S deficiency symptoms in the leaflets

sections viz shoot growth parameters root growth parameters and drymatter production of seedlings

4 2 1 Shoot growth parameters

The influence of various treatments on shoot growth parameters of the seedlings like height, collar diameter and leaf number recorded at fortnightly intervals are explained hereunder

4 2 1 1 Height

The observations on the effect of various treatments on the height of the seedlings are presented in table 2 and illustrated in figure 1 There was no significant difference between various treatments with regard to height of seedlings till sixth fortnight Thereafter the seedlings showed significant differences due to treatment effect At the end of the study period seedlings grown with complete nutrient solution had the maximum height growth of 41 33 cm while P and N deficient seedlings recorded the lowest height growth of respectively 26 67 cm and 31 00 cm The retardation in height growth due to nitrogen deficiency is also evident from plate 18

In general N deficient seedlings had the lowest height growth particularly from the seventh fortnight

onwards By the twelfth fortnight of the study phosphorus deficient seedlings were found to record the lowest height and they continued to be so until the end of the study

Among the various nutrient deficient seedlings magnesium generally had the maximum height growth (37 43 cm) during the last fortnight which was only 9 44 per cent lower than control This was followed by the K deficient treatment It could also be seen that sulphur deficient seedlings were on par with Mg deficient seedlings in terms of height during the last two fortnights Potassium deficient seedlings showed wide variations in height throughout the period of study While K deficient seedlings tended to record the maximum height growth (28 41 cm) during the seventh fortnight they had the second lowest height during the 11th (24 50 cm) and 12th fortnights (27 33 cm) However at the end of the study the height was found to be relatively lower in all the treatments compared to control

4 2 1 2 Collar diameter

Observations related to collar diameter of seedlings as influenced by various treatments are furnished in table 3 and figure 2 In the present study it was found that there was no significant difference between the various treatments in terms of collar diameter throughout the study period All

the treatments were on par with regard to collar diameter of seedlings However during the latter half of the study beginning from the sixth fortnight sulphur deficient seedlings tended to produce the largest diameter growth The seedlings grown in complete nutrient solution and also those deficient in sulphur recorded a mean collar diameter of 0 70 cm at the end of the study

Potassium deficient seedlings tended to produce the lowest diameter growth at the end of the study (0 63 cm) These seedlings were recording relatively lower diameters beginning from the fourth fortnight onwards This was followed by P deficient seedlings during the 12th and 13th fortnights These seedlings had 7 14 per cent lower diameter compared to seedlings that received the complete nutrient solution during the last fortnight of study It was also observed that N deficient seedlings had 4 29 per cent lower diameter compared to control seedlings during this fortnight Magnesium deficient seedlings were slightly superior in terms of diameter when compared to N deficient seedlings though they were smaller compared to sulphur deficient seedlings and seedlings which received complete nutrient solution during the last three fortnights of the study

4 2 1 3 Number of leaves

The data furnished 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 During the third fortnight nitrogen deficient seedlings produced lowest number of leaves (10 24) followed by phosphorus deficient ones (11 33) though the difference was not statistically different During this period the rest of the treatments were found to be statistically on par with S deficient seedlings producing the highest number of leaves (12 51) immediately followed by the seedlings receiving complete nutrient solution (12 42)

From the tenth fortnight onwards until the end of the study a definite trend in leaf production was seen In general the P and N deleted treatments produced the lowest number of leaves though the difference was not significant The rest of the treatments did not show any statistical differences in leaf number At the end of the study the number of leaves produced by seedlings grown in sulphur deficient and complete nutrient solution were respectively 21 60 and 21 27 At this time the number of leaves produced by P deficient (8 20) and N deficient (10 90) seedlings were found to be the lowest Moreover during this fortnight the

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

Nutrient element deleted from complete solution	Fortnights													
	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Nitrogen	13.80	14.99	15.43	17.67	18.07	19.33	19.60	19.63	20.52	21.01	22.63	23.20	29.67	31.00
Phosphorus	12.88	13.17	15.20	18.11	19.17	20.84	21.25	21.38	22.30	20.87	24.57	25.37	26.37	26.67
Potassium	14.41	14.70	17.13	19.75	21.73	23.73	26.40	28.41	28.47	27.73	29.60	24.50	27.33	36.73
Magnesium	12.36	13.81	15.40	18.53	21.50	22.07	23.57	25.50	26.07	26.04	32.20	34.57	35.67	37.43
Sulphur	14.02	15.81	15.53	20.24	21.37	24.91	24.90	26.80	27.47	28.48	31.32	32.62	33.77	35.07
Control	13.43	15.23	18.80	18.82	21.27	23.29	25.87	27.08	27.54	27.98	35.25	38.67	40.12	41.33
F-test	NS	NS	NS	NS	NS	NS	NS	*	*	NS	*	**	*	*
SEm ±	1.07	1.74	2.15	2.31	2.61	2.43	2.71	2.78	2.49	3.10	2.60	3.08	5.21	3.62
CD (0.05)	--	--	--	--	--	--	--	4.95	4.43	--	4.64	5.48	9.29	6.45

* Significant at 5 per cent level

** Significant at 1 per cent level

NS - Non-significant

Table 3. Effect of nutrient deficiencies on the collar diameter (cm) of seedlings

Nutrient element deleted from complete solution	Fortnights													
	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Nitrogen	0.26	0.33	0.39	0.45	0.49	0.51	0.57	0.61	0.60	0.62	0.63	0.69	0.64	0.67
Phosphorus	0.25	0.32	0.37	0.44	0.47	0.52	0.57	0.60	0.63	0.63	0.60	0.59	0.63	0.65
Potassium	0.26	0.30	0.36	0.41	0.44	0.47	0.50	0.53	0.57	0.57	0.60	0.57	0.61	0.63
Magnesium	0.24	0.30	0.36	0.42	0.49	0.51	0.56	0.60	0.61	0.62	0.61	0.62	0.64	0.67
Sulphur	0.25	0.32	0.37	0.43	0.48	0.52	0.60	0.65	0.65	0.66	0.67	0.68	0.69	0.70
Control	0.24	0.31	0.35	0.40	0.47	0.53	0.55	0.59	0.60	0.62	0.67	0.66	0.68	0.70
F-test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SEm ±	0.01	0.04	0.04	0.05	0.06	0.07	0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08
CD (0.05)	--	--	--	--	--	--	--	--	--	--	--	--	--	--

NS - Non-significant

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

Nutrient element deleted from complete solution	Fortnights													
	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Nitrogen	8.50	9.22	9.57	10.24	10.95	11.48	11.45	11.44	11.24	11.05	10.30	11.33	11.40	10.90
Phosphorus	8.08	9.28	10.33	11.33	11.97	13.63	11.90	10.35	11.00	9.51	9.80	9.40	8.83	8.20
Potassium	8.53	9.31	10.57	12.00	13.11	14.48	15.13	16.04	16.23	16.81	17.73	17.33	18.20	18.33
Magnesium	7.97	9.36	10.21	11.76	13.27	14.63	15.40	15.92	16.77	15.28	17.42	17.75	18.33	18.60
Sulphur	10.56	9.81	11.12	12.51	13.17	14.96	15.03	16.37	16.75	15.66	18.13	19.47	20.52	21.60
Control	8.72	10.45	11.28	12.42	13.59	14.22	15.08	16.42	16.80	17.36	18.12	19.20	20.12	21.27
F-test	NS	NS	NS	*	*	*	**	**	**	**	**	**	**	**
SEm ±	1.12	0.53	0.92	0.61	0.88	1.19	1.18	1.06	1.14	0.85	1.32	1.77	1.65	2.16
CD (0.05)	--	--	--	3.79	2.63	2.27	4.67	13.62	12.67	28.63	16.73	11.75	17.74	13.48

* Significant at 5 per cent level

NS - Non-significant

** Significant at 1 per cent level

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

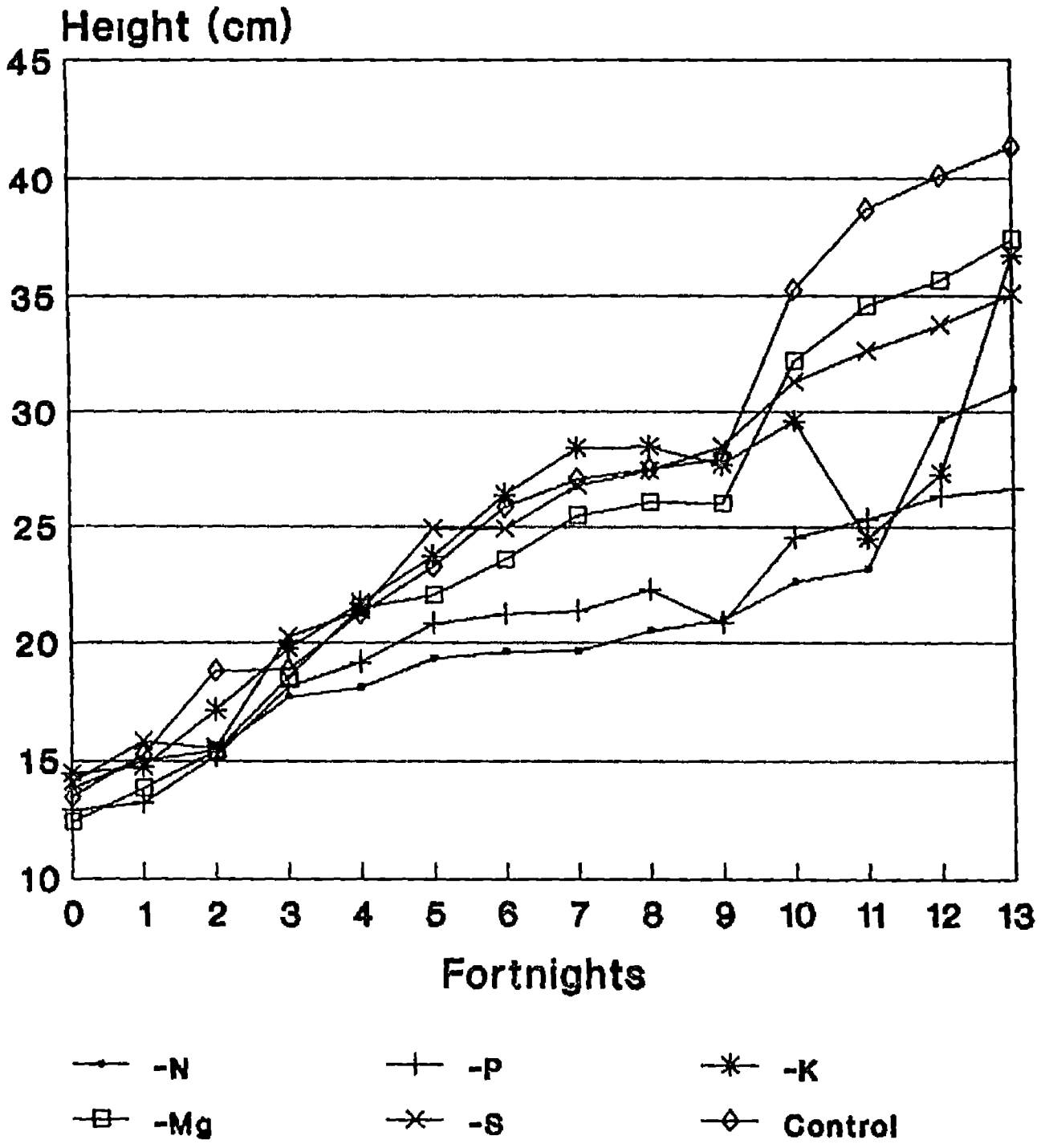


Fig.2 Effect of nutrient deficiencies on the collar diameter of seedlings

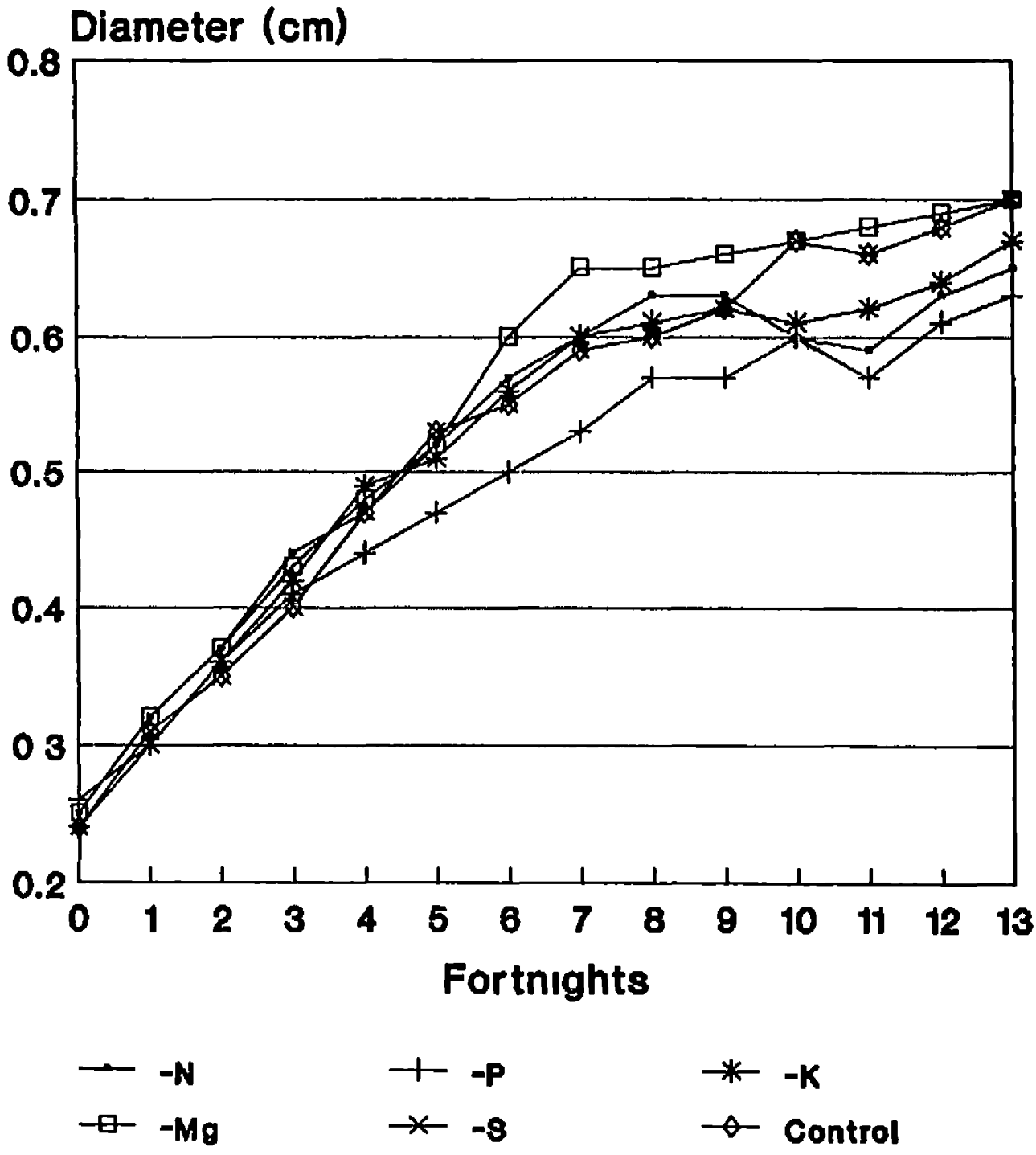
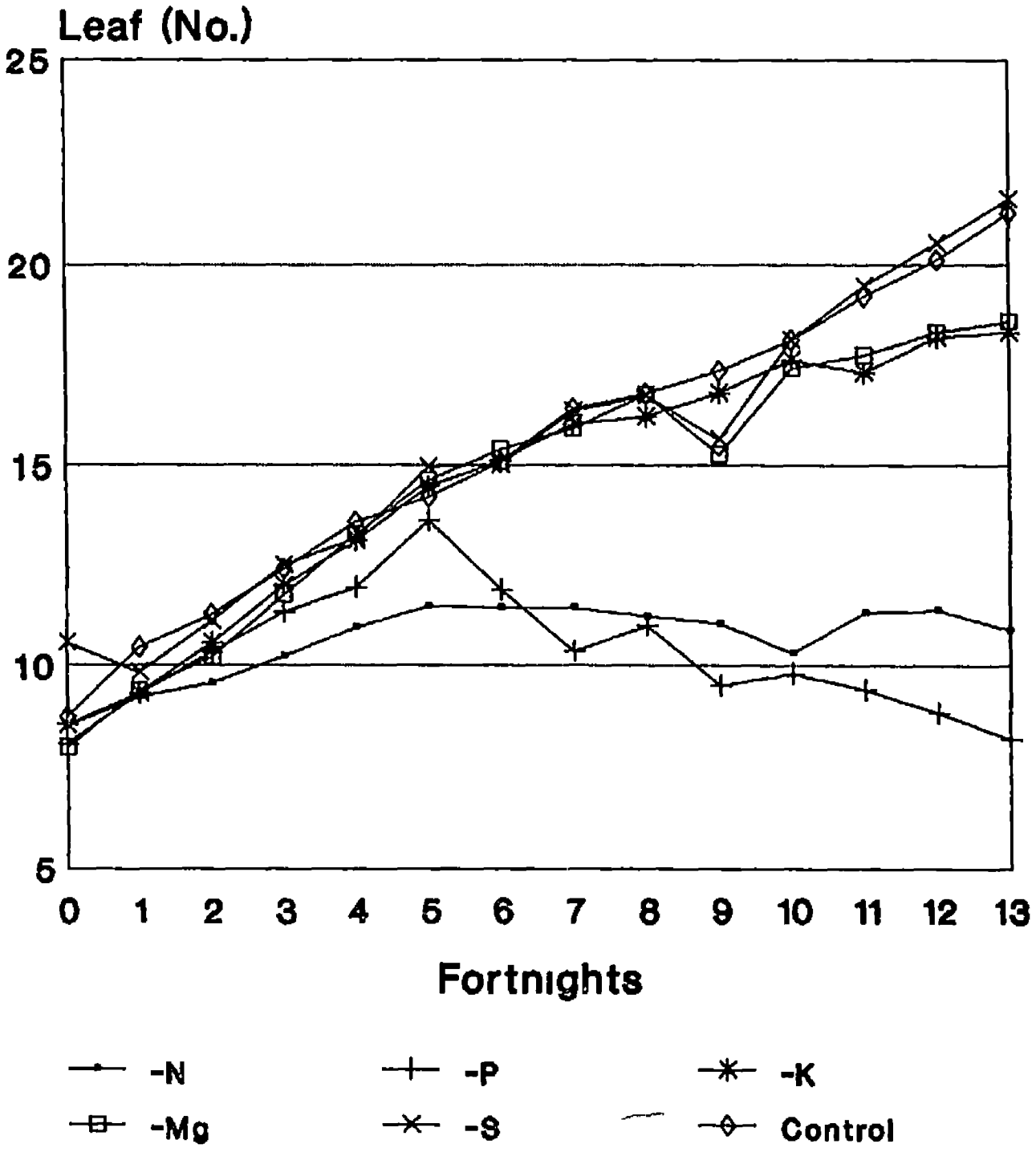


Fig.3 Effect of nutrient deficiencies on the number of leaves of seedlings



number of leaves produced by K and Mg deficient seedlings were respectively 18 33 and 18 60

4 2 2 Root growth parameters

The various root growth parameters like length of the main root spread of the root system and the number of secondary roots as affected by different treatments are presented here On the whole most of the root growth parameters were not found to be statistically influenced by deficiency of any of the elements in the nutrient solution

4 2 2 1 Length of the main root

Length of the main root did not show any significant differences due to treatment application throughout the period of study This is clearly evident from the data furnished in Table 5 and figure 4 However potassium deficient seedlings seemed to record the lowest root length during the last three months The mean length of the main root of K deficient plants in the sixth month was 10 40 cm compared to 10 89 cm in the seedlings that received complete nutrient solution

Sulphur deficient plants seemed to have the highest root length in the sixth month of the study (11 53 cm) which was 6 07 per cent higher than control However the difference between these two treatments was statistically

non significant These two treatments were not statistically influenced by deficiency of any of the elements in the nutrient solution Nitrogen deficient plants also had comparatively longer roots by the end of the study particularly in the last two months recording a mean value of 11 73 cm and 11 30 cm respectively

4 2 2 2 Root spread

Like root length the absence of different nutrient elements did not produce any significant differences in the spread of the root system also (Table 6 and Figure 5) At the end of the first month after the treatments were induced seedlings that received complete nutrient solution tended to produce the largest spread of roots (4 47 cm) while seedlings receiving nutrient solution without K had the lowest (3 18 cm) The difference was about 28 89 per cent At the end of the study however K deficient plants had the largest spread (5 50 cm) which was even 35 per cent higher than control Nitrogen deficient plants also had comparatively larger spread of roots

Phosphorus deficient plants had the lowest spread of roots at the end of the sixth month (2 83 cm) which was 30 47 per cent lower than control These plants also recorded low root spread values during the fourth and fifth months There

was no definite trend in root spread with regard to Mg deficient and S deficient plants However both treatments seemed to have lower root spread values compared to seedlings grown in complete nutrient solution especially at the end of six months

4 2 2 3 Number of secondary roots

The effect of treatments on the number of secondary roots produced by the plant is depicted in table 7 and figure 6 Except at the end of first month nutrient deficient treatments did not bring about any significant differences in the number of secondary roots produced by the seedlings Nitrogen deficient seedlings had the lowest number of secondary roots in the first (6 67) and last months (6 67) of the study which were respectively 42 8 per cent and 19 9 per cent lower compared to control seedlings during these periods The seedlings grown in P-deleted nutrient solutions had the second lowest number of secondary roots from the third month until the end of the study

Magnesium and sulphur deficient seedlings continued to produce larger number of roots throughout the period of study In fact S and K deficient seedlings had the maximum number of roots in the sixth month (8 67) while Mg deficient seedlings

Table 5 Effect of nutrient deficiencies on the length (cm) of the main root of seedlings

Nutrient element deleted from complete solution	Months 1	2	3	4	5	6
Nitrogen	15 97 (3 99)	11 83 (3 43)	9 17 (3 01)	10 17 (3 19)	11 73 (3 42)	11 30 (3 36)
Phosphorus	16 23 (4 01)	12 50 (3 48)	11 17 (3 34)	9 63 (3 10)	10 90 (3 30)	11 00 (3 30)
Potassium	17 00 (4 09)	9 67 (3 09)	11 67 (3 41)	9 37 (3 06)	10 20 (3 18)	10 40 (3 22)
Magnesium	17 28 (4 14)	8 77 (3 67)	10 67 (3 27)	12 70 (3 56)	10 73 (3 28)	10 90 (3 30)
Sulphur	9 70 (3 11)	13 67) (3 67)	10 63 (3 24)	11 17 (3 33)	11 00 (3 31)	11 53 (3 39)
Control	16 40 (4 04)	11 33 (3 35)	11 60 (3 40)	11 47 (3 41)	11 73 (3 41)	10 89 (3 29)
F-test	NS	NS	NS	NS	NS	NS
SEm ±	0 34	0 39	0 23	0 45	0 23	0 18
CD (0 05)	-	-	-			

* Significant at 5 per cent level

** Significant at 1 per cent level

NS Non-significant

Figures in parentheses indicate square root transformed values

Table 6 Effect of nutrient deficiencies on the spread (cm) of the root system of seedlings

Nutrient element deleted from complete solution	Months					
	1	2	3	4	5	6
Nitrogen	3 37 (1 82)	4 22 (2 04)	5 83 (2 40)	5 63 (2 37)	5 50 (2 33)	4 43 (2 08)
Phosphorus	3 37 (1 920	3 93 (1 98)	3 57 (1 87)	4 02 (2 00)	3 93 (1 98)	2 83 (1 68)
Potassium	3 18 (1 70)	3 77 (1 93)	4 83 (2 17)	4 30 (2 06)	4 02 (2 00)	5 50 (2 34)
Magnesium	4 35 (2 08)	3 85 (1 94)	3 42 (1 83)	3 18 (1 78)	4 45 (2 04)	3 67 (1 88)
Sulphur	3 93 (1 98)	3 77 (1 93)	7 33 (2 63)	4 38 (2 09)	3 78 (1 95)	3 92 (1 97)
Control	4 47 (2 10)	3 07 (1 75)	4 35 (2 08)	4 70 (2 16)	3 42 (1 85)	4 07 (2 01)
F-test	NS	NS	NS	NS	NS	NS
SEm ±	0 28	0 19	0 35	0 16	0 26	0 23
CD (0 05)	--	-	-		--	-

* Significant at 5 per cent level

** Significant at 1 per cent level

NS Non significant

Figures in parentheses indicate square root transformed values

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

Nutrient element deleted from complete solution	Months					
	1	2	3	4	5	6
Nitrogen	6 67 (2 54)	12 00 (3 40)	4 67 (2 10)	5 67 (2 38)	7 67 (2 76)	6 67 (2 58)
Phosphorus	9 67 (3 11)	8 33 (2 85)	4 00 (1 99)	5 67 (2 34)	7 00 (2 64)	7 00 (2 64)
Potassium	8 33 (2 82)	10 33 (2 30)	2 33 (1 22)	6 67 (2 55)	7 67 (2 77)	8 67 (2 91)
Magnesium	22 33 (4 70)	10 00 (3 15)	9 67 (3 05)	5 00 (2 20)	9 00 (2 98)	7 67 (2 75)
Sulphur	15 67 (3 94)	17 00 (4 11)	4 67 (2 16)	7 33 (2 70)	7 67 (2 72)	8 67 (2 94)
Control	11 67 (3 38)	9 67 (3 09)	5 00 (2 23)	6 67 (2 57)	4 33 (2 08)	8 33 (2 85)
F-test	**	NS	NS	NS	NS	NS
SEm ±	0 45	0 41	0 51	0 51	0 29	0 31
CD (0 05)	0 80	-	--		-	-

* Significant at 5 per cent level

** Significant at 1 per cent level

NS Non significant

Figures in parentheses indicate square root transformed values

Fig.4 Effect of nutrient deficiencies on the length of roots

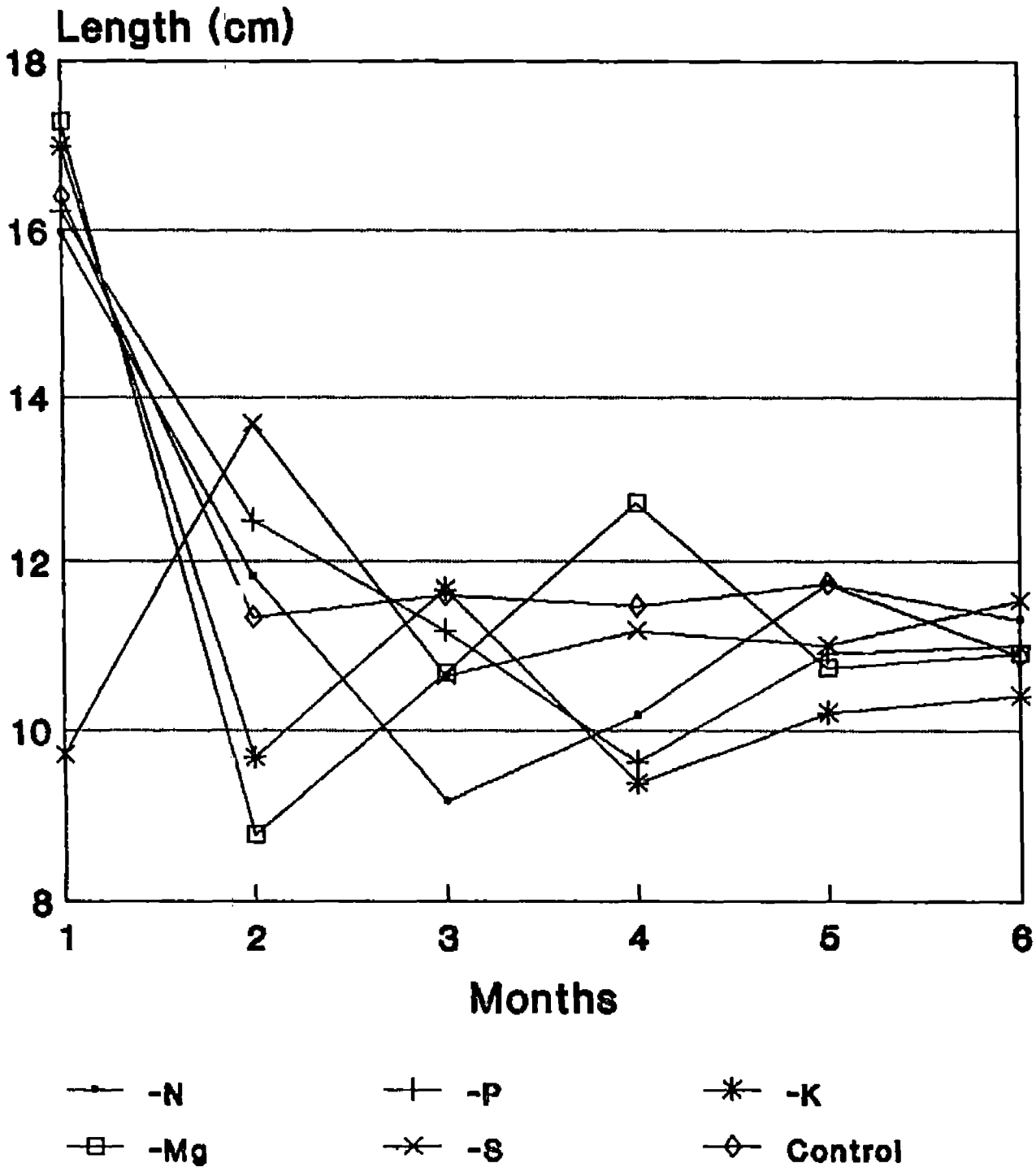


Fig.5 Effect of nutrient deficiencies on the spread of roots

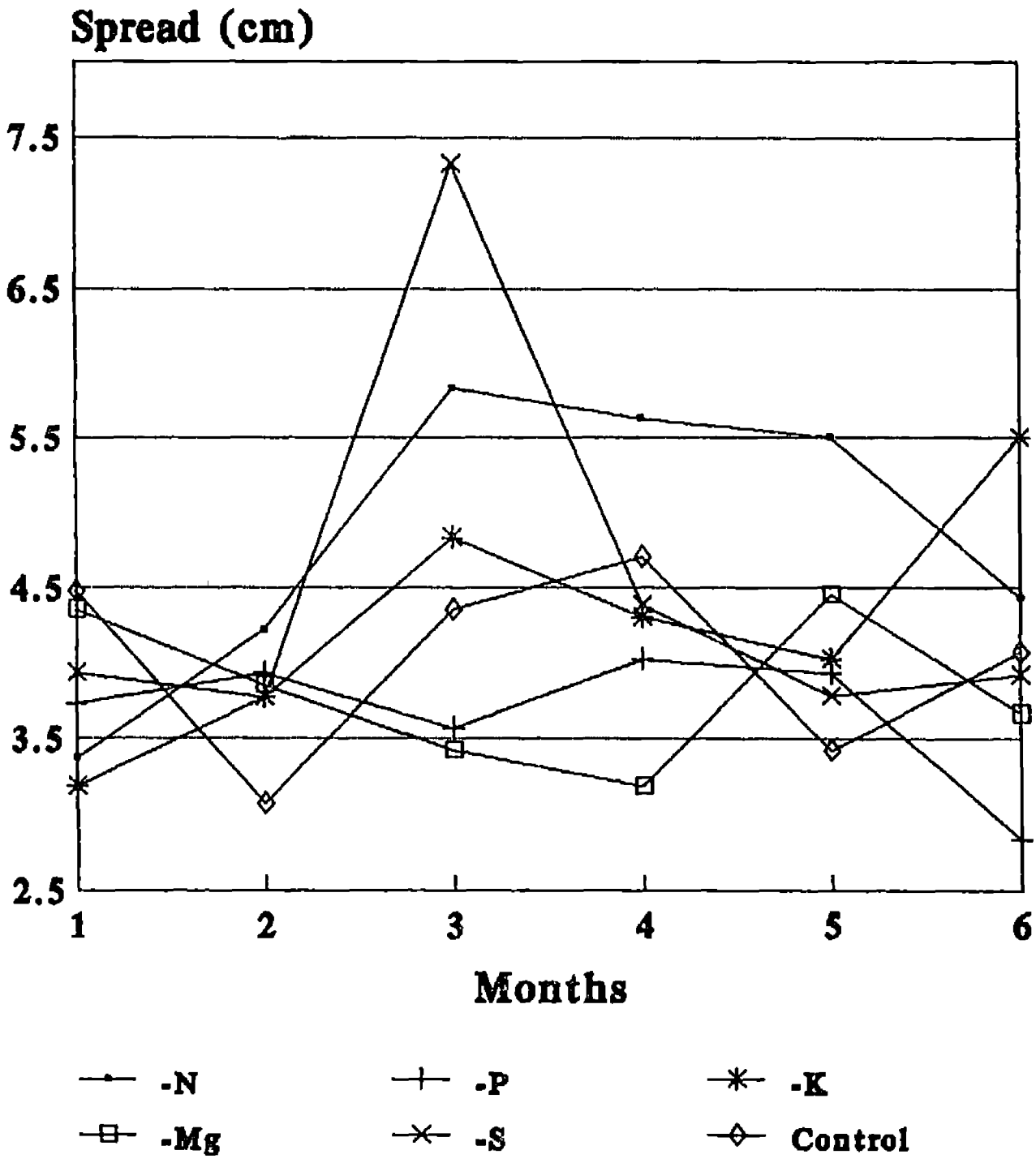
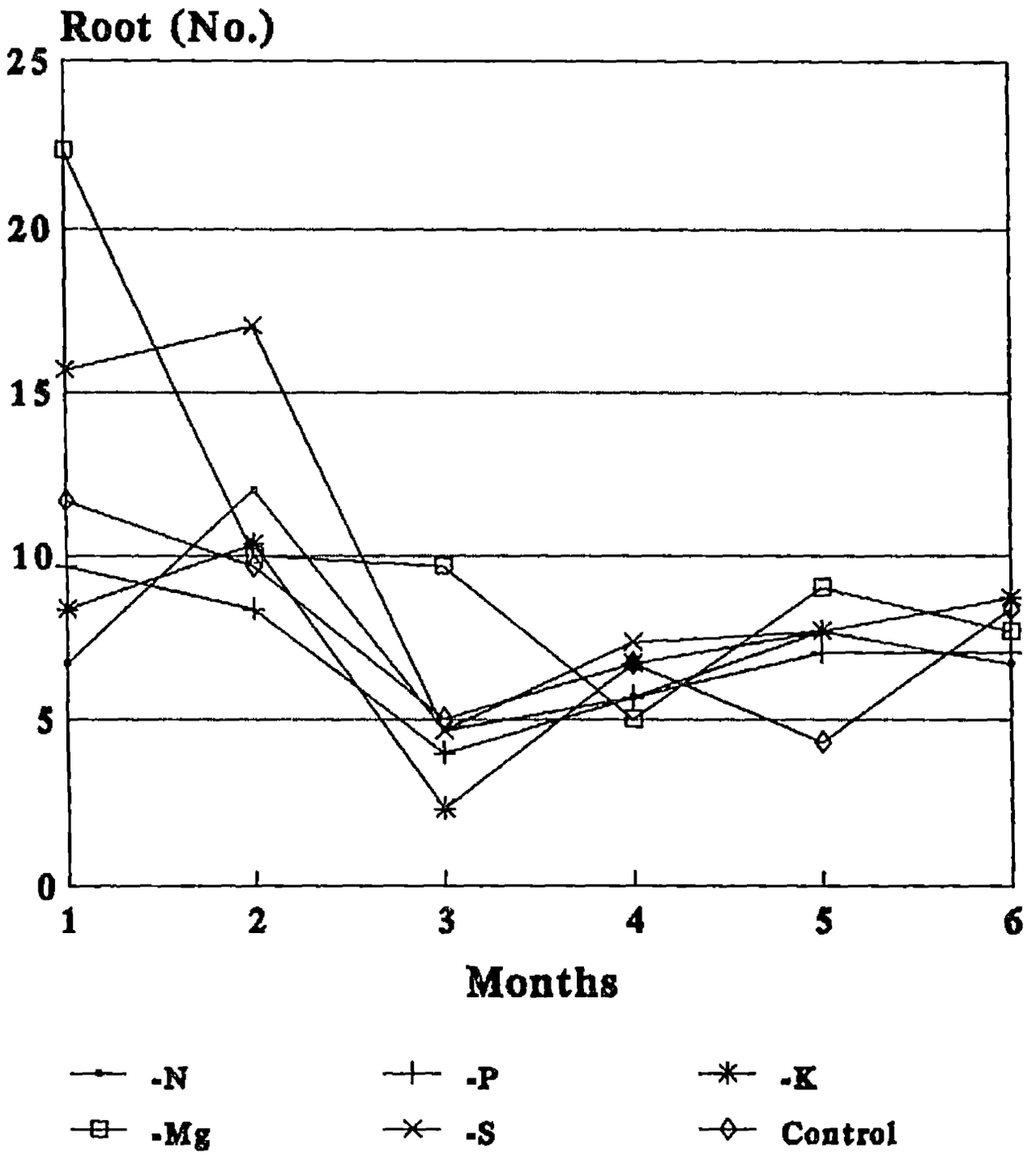


Fig.6 Effect of nutrient deficiencies on the number of secondary roots



had the largest number of secondary roots (9 00) at the end of the fifth month However this was on par with control

4 2 3 Dry matter of seedlings

The effects of nutrient stress on the fresh and dry weights of the shoot and root portions of the seedlings are clearly evident from the data tabulated in tables 8 and 9 The various nutrient treatments significantly influenced the dry matter of the seedlings especially towards the end of the study

With regard to shoot fresh weights treatment differences were very pronounced from the fourth month of the study Seedlings that received complete nutrient solution recorded the highest shoot fresh weight during the last two months of the study It was significantly different from the rest of the treatments during the sixth month Among the nutrient elements sulphur deficient seedlings recorded the highest shoot fresh weights of 12 15 g and 15 59 g during the fifth and sixth months respectively Nitrogen deficient plants also had low shoot fresh weights (11 41 g) and were significantly different from phosphorus deficient plants during the sixth month The shoot fresh weights of the rest of the treatments were in the order Mg< K< S< control (Fig 7)

Shoot dry weights of the different nutrient treatments also were significantly different by the fourth month of the study The results obtained were similar to the shoot fresh weights The highest shoot weights during the last three months were recorded for seedlings that received complete nutrient solution though they were significantly superior to rest of the treatments only in the last month (5 21 g) Here also it was observed that the P-deficient seedlings had the lowest dry weights during the last three months the value being 1 91 g during the sixth month which was significantly different from the rest of the treatments The rest of the treatments were in the order N< K< Mg<-S< control during the last month (Fig 8)

Root fresh weights were also found to be influenced by different treatments from the fourth month onwards The seedlings grown in the complete nutrient solution recorded the highest root fresh weights of 7 16 g during the fourth month Sulphur deficient seedlings showed the highest root fresh weights during the fifth (12 34 g) and sixth (10 63 g) months Nitrogen deficient plants were found to have the lowest root fresh weights of 5 52 g during the sixth month eventhough they were on par with P deficient and Mg deficient plants (Fig 9)

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	3 49 (1 87)	0 70 (0 84)	4 82 (0 84)	1 23 (1 10)	4 83 (0 42)	1 45 (1 18)	6 12 (2 18)	1 46 (1 19)	8 94 (2 97)	1 87 (1 36)	11 41 (3 38)	2 77 (1 66)
Phosphorus	4 19 (2 04)	0 83 (0 91)	3 86 (0 91)	0 77 (0 87)	6 54 (0 55)	1 77 (1 32)	3 47 (1 94)	0 58 (0 74)	5 57 (2 35)	0 36 (1 16)	8 32 (2 88)	1 91 (1 38)
Potassium	3 82 (1 95)	0 59 (0 76)	3 24 (0 76)	0 71 (0 86)	7 20 (0 42)	2 38 (1 54)	9 54 (1 30)	2 09 (1 44)	11 63 (3 35)	3 16 (1 77)	15 06 (3 88)	3 39 (1 84)
Magnesium	4 49 (2 12)	0 99 (0 99)	3 50 (0 99)	3 55 (0 73)	6 74 (0 54)	2 00 (1 41)	7 5 (1 87)	2 12 (1 40)	10 75 (3 27)	2 69 (1 64)	14 46 (3 80)	3 72 (1 92)
Sulphur	4 39 (2 09)	1 60 (0 99)	6 71 (0 99)	1 12 (1 00)	8 15 (0 55)	2 28 (1 49)	10 62 (2 51)	2 33 (1 50)	12 15 (3 47)	3 24 (1 790	15 59 (3 950	4 01 (2 00)
Control	3 82 (1 95)	0 78 (0 88)	5 15 (0 88)	1 03 (1 01)	9 81 (0 49)	2 83 (1 68)	10 65 (2 26)	2 96 (1 70)	15 37 (3 91)	4 14 (2 03)	18 29 (4 29)	5 21 (2 27)
F test	NS	NS	NS	NS	NS	NS	*	*	*	**	**	**
SEm ±	0 12	0 09	0 33	0 18	0 29	0 17	0 33	0 25	0 35	0 14	0 05	0 14
CD (0 05)							0 59	0 45	0 62	0 26	0 09	0 25

* Significant at 5 per cent level ** Significant at 1 per cent level

NS Non significant Figures in parentheses indicate square root transformed values

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

Nutrient element deleted from complete solution	Months 1 Fresh weight	1 Dry weight	2 Fresh weight	2 Dry weight	3 Fresh weight	3 Dry weight	4 Fresh weight	4 Dry weight	5 Fresh weight	5 Dry weight	6 Fresh weight	6 Dry weight
Nitrogen	1 34 (1 15)	0 18 (0 42)	2 31 (1 51)	0 52 (0 72)	2 37 (1 52)	0 79 (0 84)	4 37 (2 05)	0 23 (1 05)	5 87 (2 40)	1 62 (1 26)	5 52 (2 35)	1 45 (1 20)
Phosphorus	2 27 (1 49)	0 31 (0 55)	2 06 (1 33)	0 44 (0 66)	2 93 (1 64)	1 41 (1 15)	3 26 (1 76)	0 72 (0 78)	4 37 (2 09)	1 12 (1 06)	0 06 (2 46)	1 43 (1 18)
Potassium	1 64 (1 27)	0 18 (0 42)	2 47 (1 57)	0 35 (0 54)	1 75 (1 29)	0 93 (0 94)	3 51 (0 87)	0 61 (0 78)	7 10 (2 62)	3 11 (1 73)	9 37 (3 06)	4 35 (2 04)
Magnesium	2 19 (1 48)	0 35 (0 59)	2 50 (1 55)	0 35 (0 52)	1 79 (1 23)	1 50 (1 17)	4 98 (2 19)	1 75 (1 28)	4 98 (1 75)	2 77 (1 55)	6 70 (2 59)	3 43 (1 85)
Sulphur	1 89 (1 38)	0 31 (0 55)	4 15 (1 97)	0 64 (0 78)	3 11 (1 64)	1 54 (1 20)	6 13 (2 47)	1 91 (1 35)	12 34 (3 49)	5 14 (2 22)	10 63 (3 23)	5 54 (2 32)
Control	1 91 (1 38)	0 24 (0 49)	2 29 (1 48)	0 32 (0 56)	1 15 (1 05)	0 99 (0 99)	7 16 (2 61)	3 21 (1 65)	5 50 (2 31)	4 41 (2 03)	7 95 (2 78)	6 10 (2 47)
F test	NS	NS	NS	NS	NS	NS	*	NS	*	*	**	**
SEm ±	0 12	0 07	0 36	0 17	0 44	0 28	0 25	0 39	0 63	0 63	0 83	1 12
CD (0 05)			--				0 45		1 12	1 12	0 33	0 33

* Significant at 5 per cent level ** Significant at 1 per cent level

NS Non significant Figures in parentheses indicate square root transformed values

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

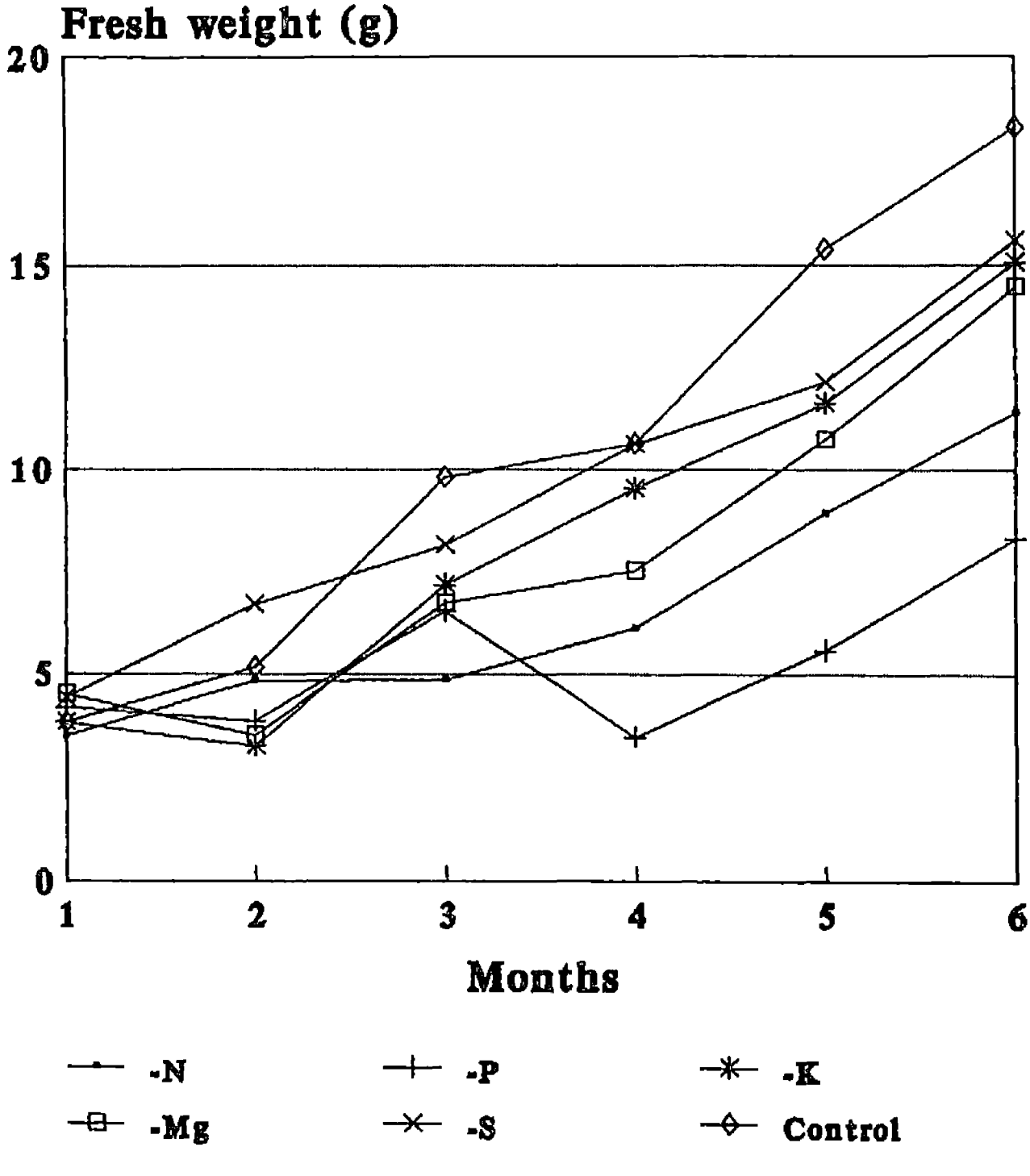


Fig.8 Effect of nutrient deficiencies on the dry weight of shoots

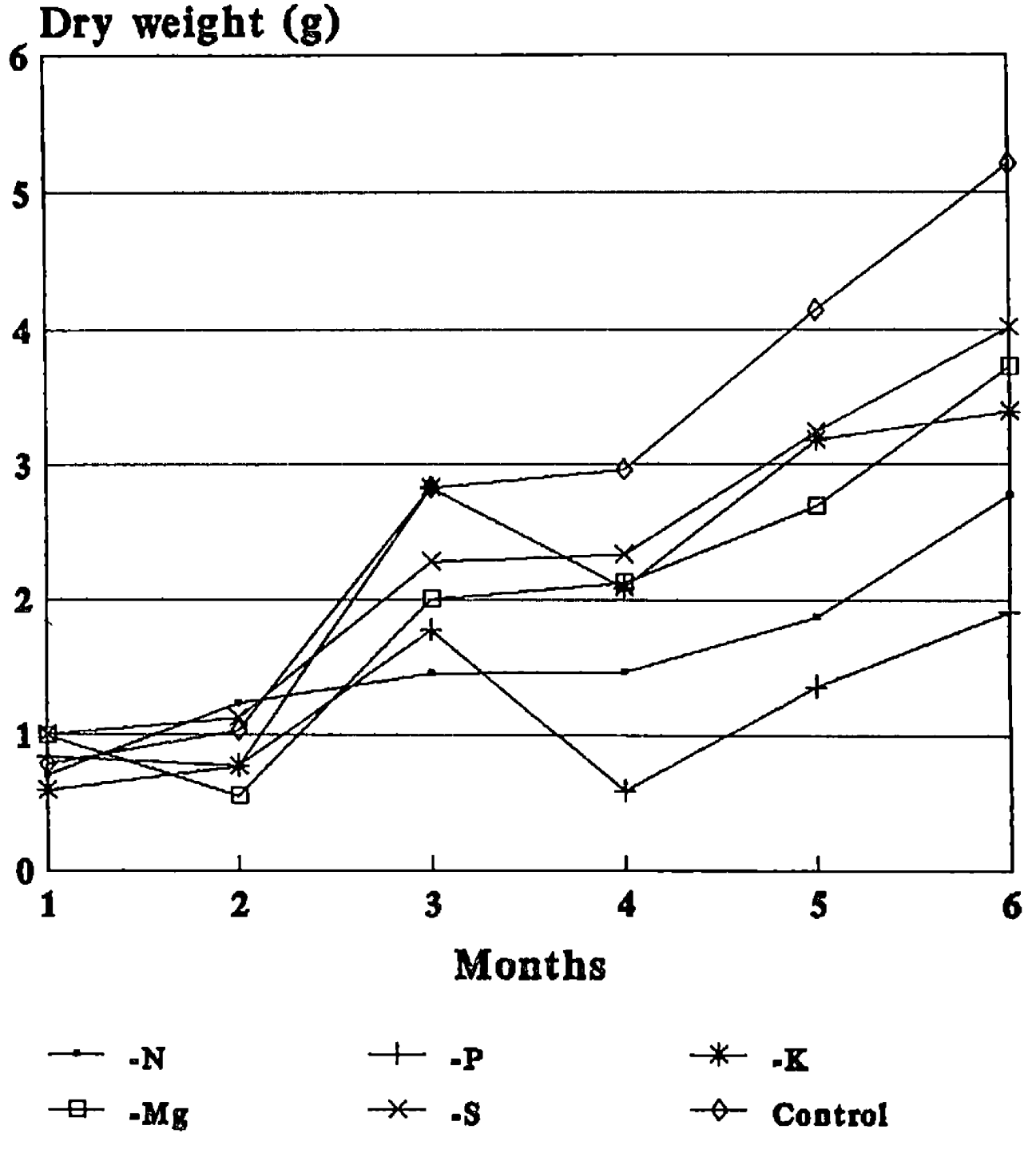


Fig.9 Effect of nutrient deficiencies on the fresh weight of roots

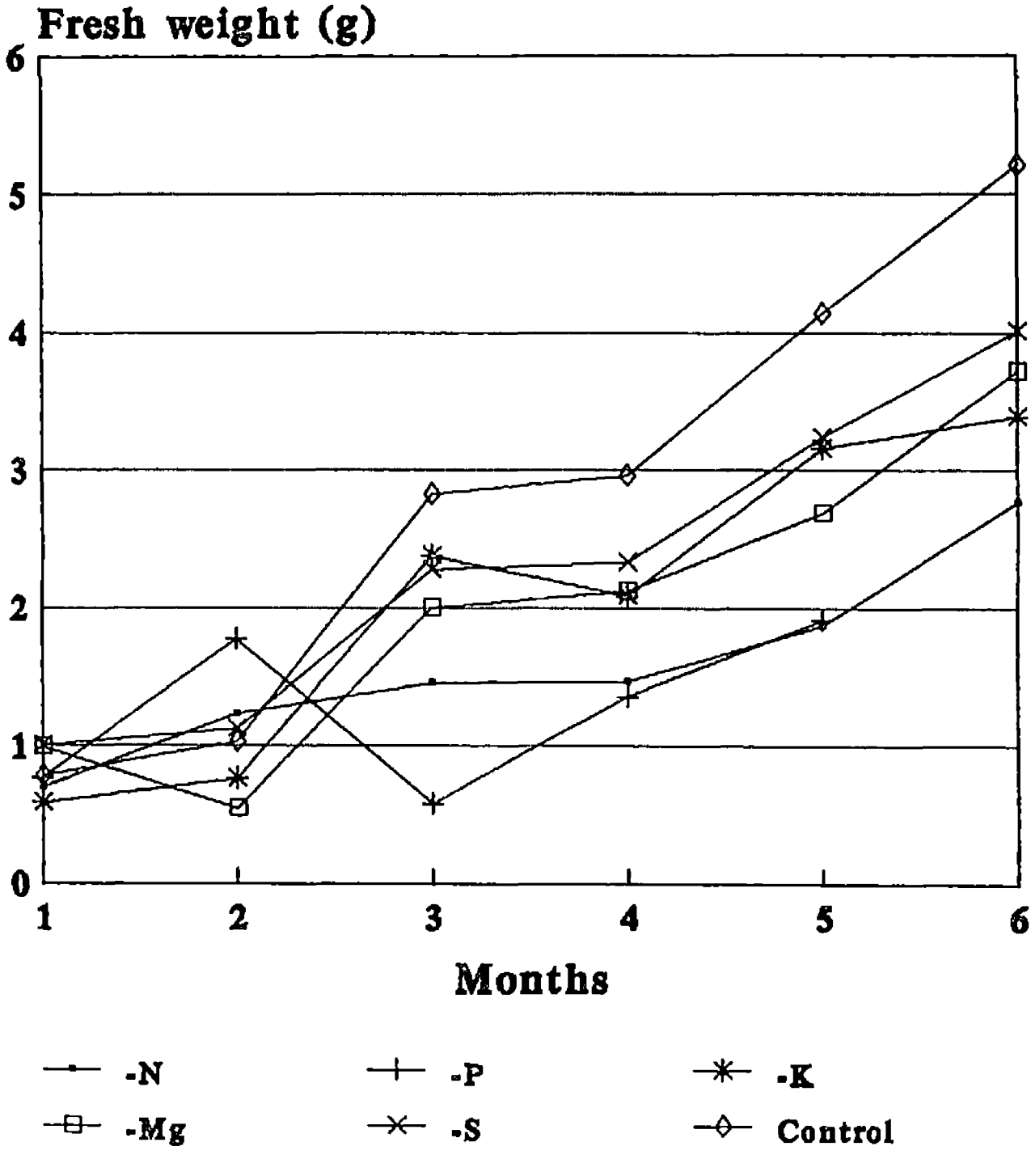
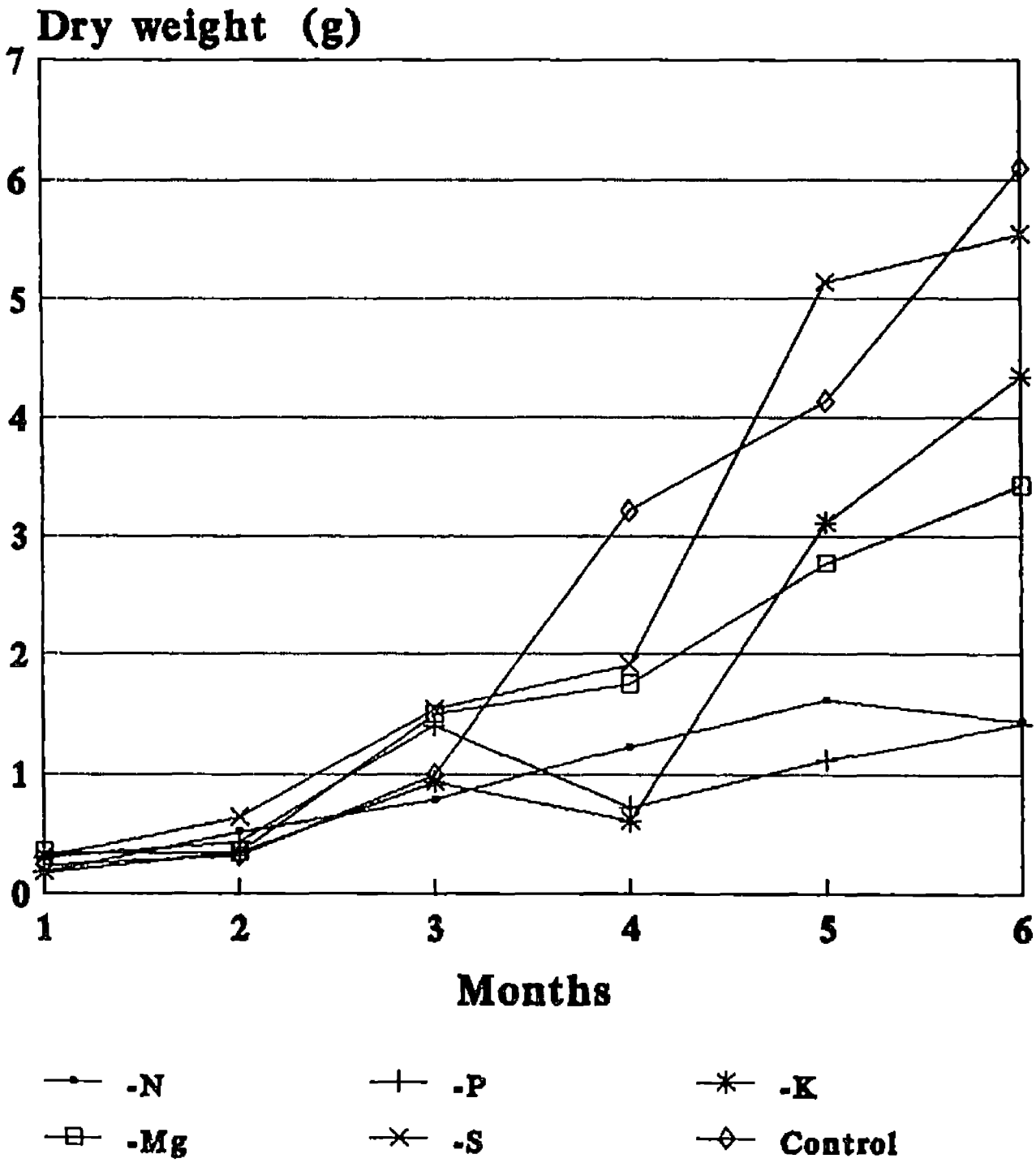


Fig.10 Effect of nutrient deficiencies on the dry weight of roots



From the data it is also clear that root dry weights were significantly influenced by the nutrient treatments during the last two months The root dry weights were in the order P< N< Mg< K<S< control during the fourth month Similar trend was observed during the last month also However P and N treatments did not differ significantly during these months Magnesium deficient seedlings and K deficient seedlings had intermediate root dry weight compared to rest of the treatments Among the various nutrient deficient treatments S deficient plants recorded the highest root fresh weights of 5 54 g which was 9 18 per cent lower than control while P seedlings had root dry weight of 1 43 g which was 76 55 per cent lower than control (Fig 10)

4 3 Chlorophyll content

The chlorophyll content of leaves was found to be significantly influenced by the deficiency of various nutrient elements especially during the last two periods of observations 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 all the treatments (Fig 11) The chlorophyll A content differed significantly between the various treatments during the fourth and sixth

months The Mg deficient plants had the lowest (0 51 mg/g of leaf tissue) and P deficient plants had the highest (0 85 mg/g) chlorophyll-A content in the fourth month Magnesium deficient plants were also found to record relatively low chlorophyll A content (0 30 mg/g of leaf tissue) during the last month However N deficient plants recorded the lowest (0 21 mg/g) and K deficient plants the highest (0 58 mg/g) values in the sixth month The treatments were in the order N< Mg< S< P< control < K during the sixth month Magnesium deficient plants were on par with S deficient and P deficient plants but differed significantly from nitrogen deficient potassium deficient and control plants during this month

Chlorophyll B content also declined gradually for all the treatments (Fig 12) and the trend obtained was almost similar to chlorophyll A The N deleted treatment recorded the lowest value during the fourth month while Mg deleted treatment recorded the lowest during the sixth month eventhough both were not significantly different from other treatments Potassium deficient plants recorded the highest chlorophyll B content of 1 41 mg/g and 1 20 mg/g respectively during the fourth and sixth months These were found to be higher when compared to the content obtained for plants receiving complete nutrient solution Phosphorus deficient plants recorded 28 89 per cent and S deficient plants recorded

Table 10. Effect of nutrient deficiencies on the chlorophyll content (mg/g) of leaf tissue of seedlings

Nutrient element deleted from complete solution	Months								
	1	4	6	1	4	6	1	4	6
	Chlorophyll-A			Chlorophyll-B			Total chlorophyll		
Nitrogen	0.54	0.52	0.21	1.13	0.84	0.55	1.66	1.36	0.76
Phosphorus	0.74	0.85	0.33	1.11	1.41	0.64	1.86	2.26	0.97
Potassium	0.92	0.72	0.58	1.85	1.41	1.20	2.76	2.14	1.78
Magnesium	1.19	0.51	0.30	1.07	0.86	0.54	2.26	1.36	0.84
Sulphur	0.97	0.62	0.33	1.42	0.12	0.56	2.39	1.74	0.89
Control	0.81	0.71	0.48	1.56	1.31	0.90	2.37	2.01	1.38
F-test	NS	*	**	NS	*	**	NS	*	**
SEm ±	0.19	0.10	0.03	0.32	0.20	0.04	0.35	0.30	0.04
CD (0.05)	--	0.18	0.05	--	0.36	0.08	--	0.53	0.08

* Significant at 5 per cent level
** Significant at 1 per cent level

NS - Non-significant

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

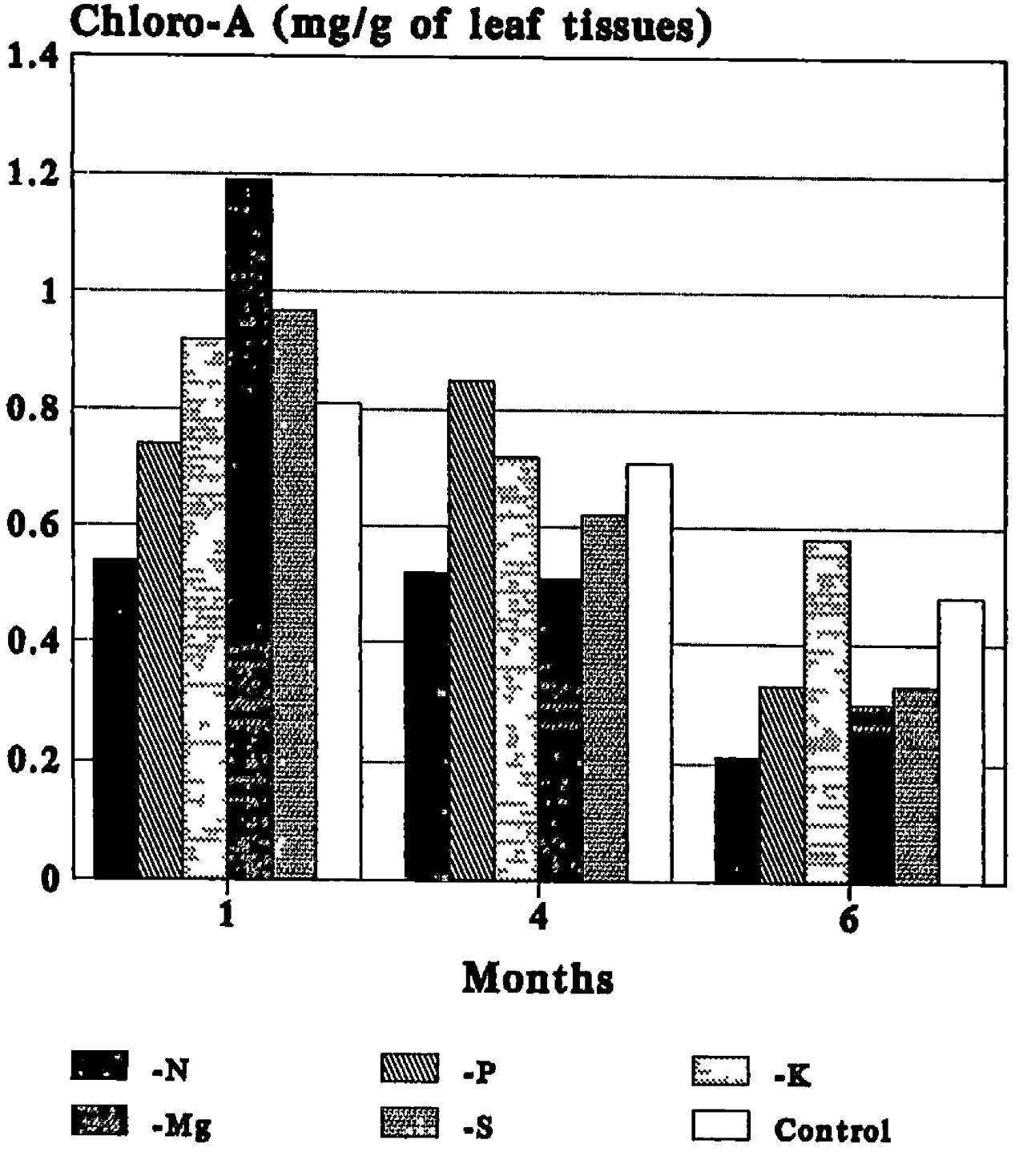


Fig.12 Effect of nutrient deficiencies on the chlorophyll-B content

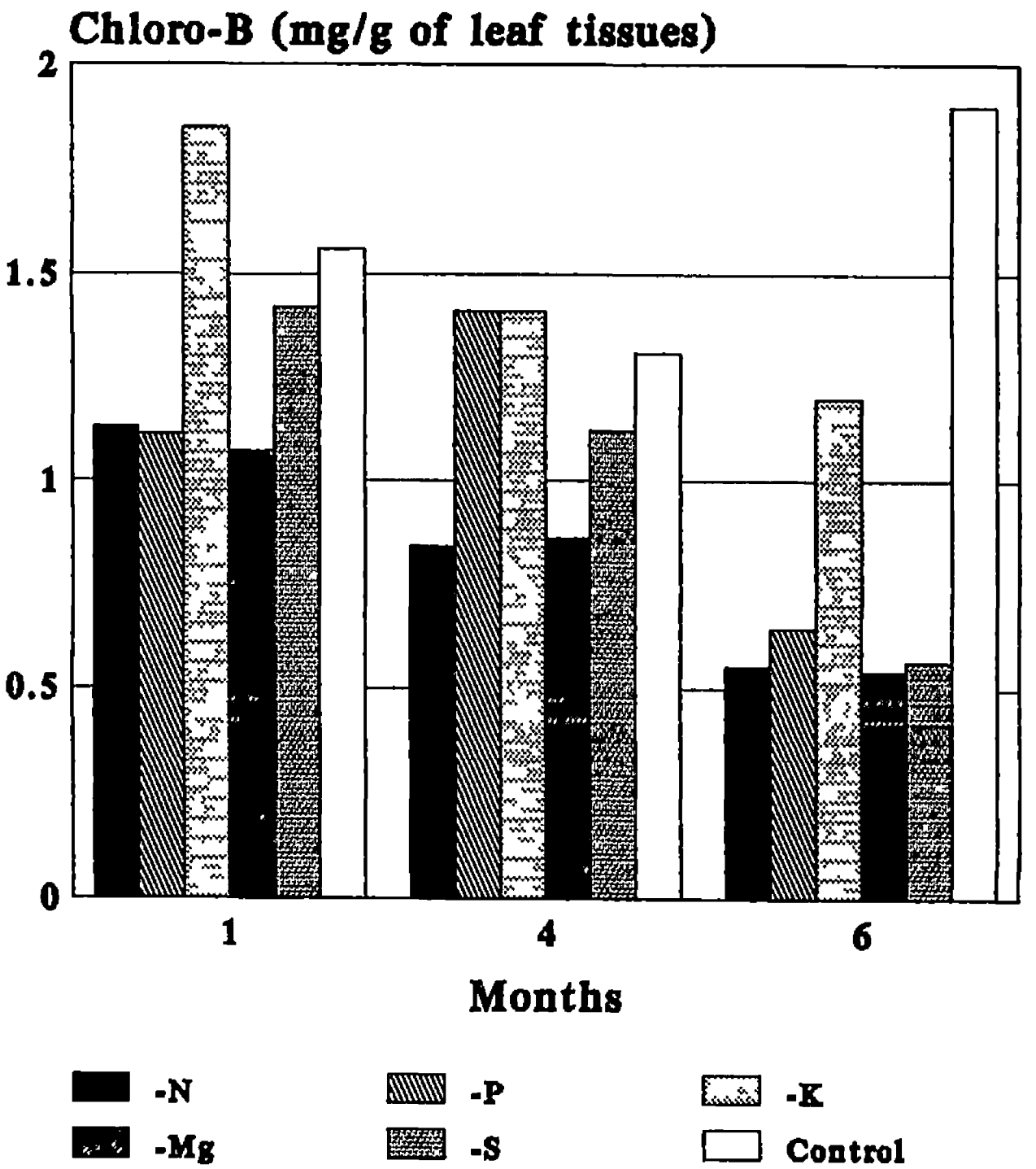
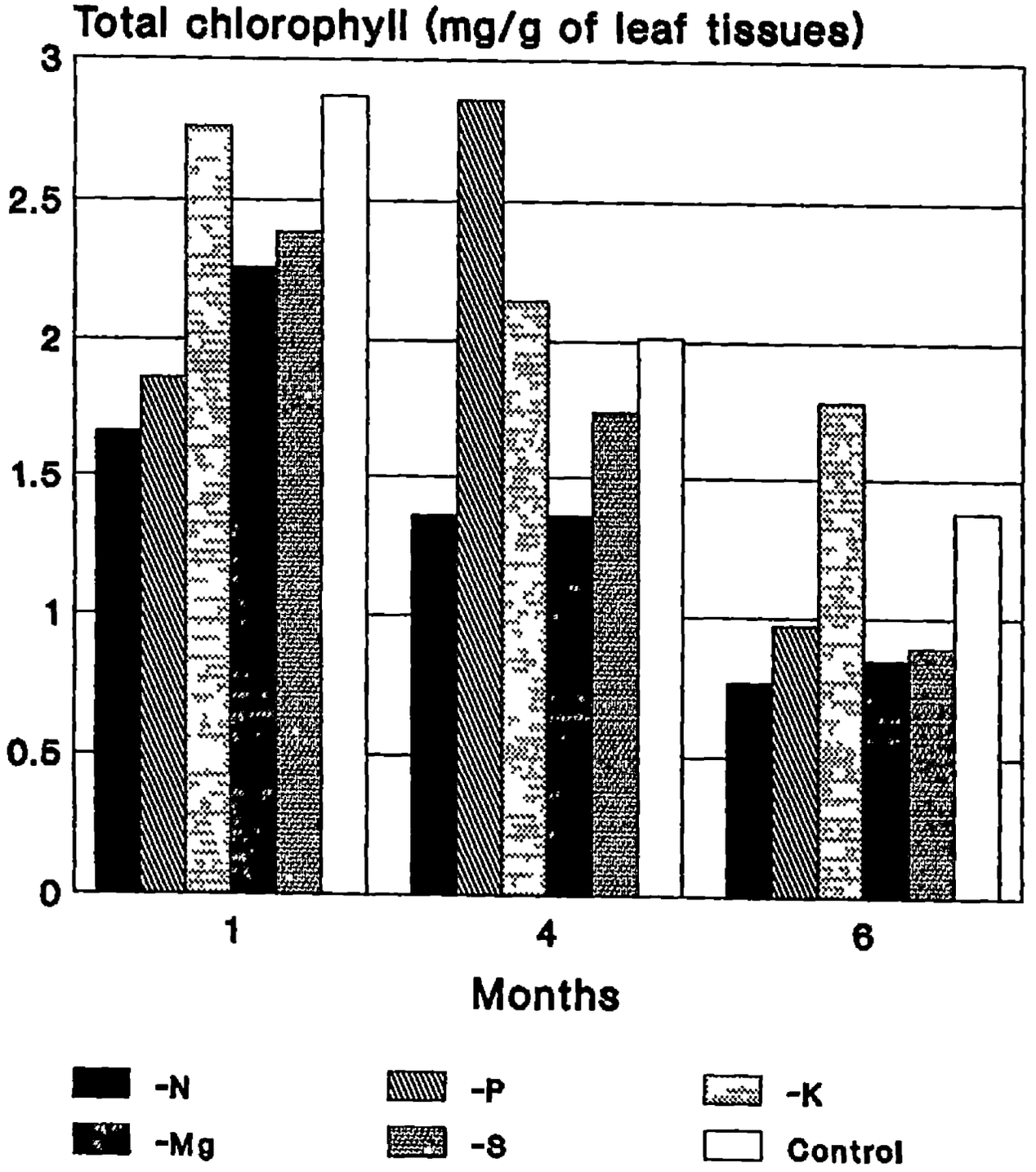


Fig.13 Effect of nutrient deficiencies on the total chlorophyll content



37 78 per cent lower chlorophyll B content during the last month though they were not statistically different

Total chlorophyll content of the leaves was also found to decrease with time (Figure 13) The effect of nutrient stress became more pronounced during the last three months when the treatment differences were significant with regard to this parameter Seedlings subjected to nitrogen stress recorded the lowest total chlorophyll content throughout the period of study The total chlorophyll content was found to decrease from 1 66 mg/g during the first month to 0 76 mg/g during the last month Moreover nitrogen deficient and magnesium deficient plants were statistically comparable during the fourth and sixth months Potassium deficient plants had the highest total chlorophyll content (1 78 mg/g) while N deficient plants had the lowest (0 76 mg/g) during the sixth month Seedlings that received all the nutrients (control) had relatively higher total chlorophyll content (1 38 mg/g) and this could be ranked next to potassium deficient seedling With regard to total chlorophyll content the treatments were in the order N< Mg< S< P< control < K in this 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 section

4 4 1 Nitrogen

The nitrogen content of leaves was found to decrease in seedlings supplied with nutrient solution lacking N (Table 11) In these seedlings the nitrogen content gradually decreased from 2 to 1 03 per cent by the end of the sixth month when the study was completed During this month the treatments differed significantly also Phosphorus deficient seedlings had the highest concentration of N (6 09 per cent) during the sixth month which was 50 5 per cent more than the control Seedlings grown in complete nutrient solution and solution lacking sulphur recorded a mean nitrogen content of 4 04 per cent at the end of the study It could also be seen from the table that magnesium deficient seedlings had a nitrogen concentration in their tissues to the tune of 4 96 per cent which was the second highest While P deleted and Mg deleted treatments recorded an increase in N concentrations during the course of six months the rest of the treatments showed a gradual declining trend with regard to this nutrient concentration

4 4 2 Phosphorus

The effect of various treatments on the phosphorus

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	2 00 (1 40)	2 21 (1 48)	2 09 (1 42)	2 19 (1 46)	1 33 (1 15)	1 03 (1 01)
Phosphorus	2 60 (1 41)	3 76 (1 94)	4 04 (2 00)	4 22 (2 05)	3 85 (1 70)	6 09 (2 47)
Potassium	4 50 (2 12)	3 64 (1 91)	4 89 (2 21)	2 25 (1 28)	5 08 (2 25)	4 41 (2 10)
Magnesium	4 60 (2 14)	3 04 (1 74)	2 60 (1 50)	5 38 (2 32)	5 49 (2 34)	4 96 (2 23)
Sulphur	4 98 (2 22)	3 04 (1 74)	4 80 (2 18)	5 17 (2 27)	6 65 (2 56)	4 04 (2 01)
Control	4 64 (2 15)	2 49 (1 58)	5 15 (2 27)	4 45 (2 11)	2 88 (1 51)	4 04 (2 01)
F-test	NS	**	*	NS	NS	**
SEm ±	0 35	0 06	0 28	0 42	0 53	0 05
CD (0 05)	-	0 11	0 51	--		0 91

* Significant at 5 per cent level

** Significant at 1 per cent level

NS Non-significant

Figures in parentheses are square root transformed values

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 72 (1 26)	0 63 (0 71)	1 07 (1 15)	0 58 (0 74)	0 89 (0 84)	1 52 (1 05)
Phosphorus	1 29 (1 07)	1 16 (0 86)	1 03 (1 00)	1 12 (1 04)	1 07 (1 15)	0 42 (0 41)
Potassium	2 99 (1 72)	1 38 (1 15)	1 12 (1 04)	0 52 (0 63)	1 47 (1 15)	0 91 (0 94)
Magnesium	2 59 (1 60)	1 12 (0 99)	0 98 (0 99)	1 25 (1 11)	0 89 (0 94)	1 25 (1 11)
Sulphur	2 95 (1 73)	1 25 (1 21)	1 12 (1 06)	1 30 (1 25)	1 03 (0 99)	1 27 (1 08)
Control	0 88 (0 84)	2 05 (1 40)	0 94 (0 96)	0 85 (0 92)	0 85 (0 92)	1 12 (1 05)
F-test	*	NS	NS	NS	NS	NS
SEm ±	0 91	0 27	0 13	0 28	0 18	0 14
CD (0 05)	1 62	-			--	-

* Significant at 5 per cent level

** Significant at 1 per cent level

NS Non significant

Figures in parentheses are square root transformed values

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 42 (1 19)	1 42 (1 19)	2 38 (1 54)	1 90 (1 38)	2 57 (1 58)	7 60 (2 76)
Phosphorus	1 53 (1 24)	1 07 (1 01)	1 90 (1 33)	1 37 (1 11)	2 11 (1 39)	4 63 (2 14)
Potassium	1 28 (1 13)	1 27 (1 12)	1 55 (1 24)	1 43 (1 13)	1 61 (1 27)	0 95 (0 92)
Magnesium	1 33 (1 15)	1 35 (1 16)	1 68 (1 27)	3 05 (1 76)	3 60 (1 90)	5 17 (2 27)
Sulphur	1 03 (1 01)	1 17 (1 08)	1 70 (1 30)	1 93 (1 37)	4 50 (2 12)	3 80 (1 87)
Control	1 33 (1 15)	1 80 (1 33)	1 82 (1 34)	2 29 (1 50)	3 60 (1 26)	5 27 (2 29)
F test	NS	NS	NS	NS	NS	**
SEm ±	0 10	0 12	0 18	0 22	0 45	0 14
CD (0 05)	-		-			0 25

* Significant at 5 per cent level

** Significant at 1 per cent level

NS Non-significant

Figures in parentheses are square root transformed values

concentration of seedlings is given in table 12 The tissue P concentration in plants supplied with nutrient solution lacking P showed a gradual decline during the course of the study At the end of the study phosphorus concentration in these plants decreased to 0 42 per cent from the initial content of 1 29 per cent The reduction was to the extent of about 67 44 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 However in seedlings supplied with complete nutrient solution there was a small increase in the P content by the end of the study Potassium deficient plants recorded the second lowest P content of 0 91 per cent in the last month while nitrogen deficient seedlings recorded the highest concentration of 1 52 per cent eventhough the treatment differences remained non significant during this month

4 4 3 Potassium

The potassium concentration of seedlings as affected by the various treatments is depicted in table 13 During most of the sampling time the differences in nutrient content as influenced by treatments was not found to be statistically significant However potassium deficient plants recorded the lowest K content (0 95 per cent) compared to all the other

treatments at the end of the study This is worked out to be about 25 78 per cent less when compared to the initial concentration of 1 28 per cent Nitrogen deficient treatment recorded the maximum increase in K content from 1 42 per cent to 7 6 per cent The rest of the treatments also had gradual increase in their K content during the study period The treatments differed significantly only on the sixth month of study During this month the seedling supplied with complete Hoagland solution had the second highest potassium content (5 27 per cent)

4 4 4 Calcium

The leaf tissue concentration of calcium due to the effect of nutrient stress is summarised in table 14 The data revealed that the tratments were having significant effect on the concentration of calcium in the seedlings throughout the period of study except the fourth month While K deficient treatments and Mg deficient treatments recorded an increased Ca content in their tissues the other treatments viz -N -P and S showed a declining trend In P deficient seedlings the S content reduced from 5 07 per cent to 2 53 accounting a percentage reduction of 50 1 while in S deficient treatments it reduced from 2 53 to 2 13 accounting for 15 81 per cent reduction The treatments that recorded an increase in Ca content include the control with largest increase (2 27 to

4 27 per cent) followed by K deficient and Mg deficient plants with almost similar increases in Ca content

4 4 5 Magnesium

In seedlings lacking Mg in nutrient solution, the concentration of Mg fell from an initial 0 56 per cent to 0 32 per cent by the second month Thereafter there was not much variation in the concentration (Table 15) Among the rest of the treatments except P treatment all the other treatments produced an increase in Mg content of seedlings Removal of P from the complete nutrient solution caused a decline in Mg content in the leaf tissues from 1 36 to 0 56 per cent accounting a decrease of about 58 82 per cent

Seedlings that received complete nutrient solution had the largest increase in Mg content from 0 64 to 2 08 per cent The other treatments resulted only a small increase in the Mg concentration Among all the treatments N produced the smallest increase in Mg content from 0 40 per cent to 0 56 per cent which accounted to a 40 per cent increase while K deficient seedlings resulted an increase of 66 67 per cent Mg in their leaf tissues

4 4 6 Sulphur

The effect of nutrient stress on the concentration of

Table 14 Effect of nutrient deficiencies on the foliar concentration of calcium

Nutrient element deleted from complete solution	Months 1	2	3	4	5	6
Nitrogen	1 87 (1 36)	1 60 (1 26)	2 80 (1 67)	2 27 (1 50)	2 80 (1 67)	1 33 (1 14)
Phosphorus	5 07 (2 24)	2 93 (1 71)	3 47 (1 65)	3 07 (1 75)	4 13 (2 03)	2 53 (1 59)
Potassium	1 60 (1 26)	2 40 (1 55)	3 73 (1 71)	2 67 (1 63)	1 20 (1 08)	2 27 (1 50)
Magnesium	1 87 (1 36)	2 80 (1 67)	2 00 (1 41)	2 27 (1 50)	2 80 (1 67)	2 40 (1 55)
Sulphur	2 53 (1 59)	2 53 (1 59)	1 47 (1 19)	2 00 (1 41)	2 27 (1 50)	2 13 (1 46)
Control	2 27 (1 50)	2 53 (1 59)	2 13 (1 44)	2 53 (1 57)	3 20 (1 79)	4 27 (2 02)
F test	**	*	**	NS	**	**
SEm ±	0 13	0 11	0 20	0 14	0 10	0 10
CD (0 05)	0 24	0 20	0 35	-	0 17	0 17

* Significant at 5 per cent level

** Significant at 1 per cent level

NS - Non significant

Figures in parentheses are square root transformed values

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 40 (0 63)	0 40 (0 63)	0 48 (0 68)	0 56 (0 72)	0 48 (0 65)	0 56 (0 74)
Phosphorus	1 36 (1 17)	0 40 (0 63)	0 88 (0 94)	0 48 (0 68)	0 36 (0 39)	0 56 (0 74)
Potassium	0 48 (0 68)	0 80 (0 89)	0 40 (0 63)	0 48 (0 68)	1 12 (1 65)	0 80 (0 88)
Magnesium	0 56 (0 74)	0 32 (0 56)	0 48 (0 68)	0 32 (0 56)	0 48 (0 68)	0 32 (0 56)
Sulphur	0 40 (0 63)	0 54 (0 63)	1 04 (1 01)	0 88 (0 92)	0 80 (0 85)	0 56 (0 69)
Control	0 64 (0 770	0 80 (0 89)	1 92 (1 38)	1 36 (1 17)	0 72 (0 56)	2 08 (1 44)
F test	**	**	**	**	NS	**
SEm ±	0 12	0 08	0 12	0 14	0 27	0 15
CD (0 05)	0 22	0 14	0 21	0 26	-	0 27

* Significant at 5 per cent level

** Significant at 1 per cent level

NS Non significant

Figures in parentheses are square root transformed values

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 17 (0 16)	0 45 (0 50)	0 09 (0 300	0 13 (0 35)	0 18 (0 42)	0 12 (0 41)
Phosphorus	0 09 (0 19)	0 10 (0 29)	0 15 (0 39)	0 20 (0 17)	0 36 (0 55)	0 26 (0 36)
Potassium	0 17 (0 26)	0 75 (0 68)	0 26 (0 51)	0 42 (0 65)	0 29 (0 54)	0 26 (0 50)
Magnesium	0 08 (0 86)	0 10 (0 31)	0 15 (0 39)	0 17 (0 40)	0 26 (0 51)	0 17 (0 41)
Sulphur	0 10 (0 30)	0 14 (0 37)	0 29 (0 53)	0 18 (0 42)	0 10 (0 32)	0 07 (0 27)
Control	0 04 (0 21)	0 20 (0 38)	0 28 (0 53)	1 28 (1 06)	0 38 (0 62)	0 23 (0 48)
F test	NS	NS	**	**	NS	**
SEm ±	0 21	0 09	0 04	0 16	0 11	0 06
CD (0 05)		-	0 08	0 29		0 10

* Significant at 5 per cent level

** Significant at 1 per cent level

NS Non-significant

Figures in parentheses are square root transformed values

sulphur in the leaf tissues is tabulated in table 16 The difference in sulphur content due to various treatments was not statistically significant during 1st 2nd and 5th months while it was significantly different during 3rd 4th and 6th months The concentration of sulphur was the lowest in seedlings that received nutrient solution lacking sulphur especially during the 5th and 6th months recording a mean sulphur content of 0 10 per cent and 0 07 per cent respectively Eventhough S deficient plants showed a decrease in the sulphur content the decrease was only very marginal (30 per cent) Sulphur concentration in seedlings that received treatment solution lacking N also had a decreasing trend (0 17 per cent to 0 12 per cent) In the rest of the treatments S concentration was found to be increased Seedlings receiving complete nutrient solution had the largest increase from 0 04 per cent to 0 23 per cent accounting about 475 per cent Compared to seedlings grown in complete solution the S deficient plants had 69 57 per cent lower sulphur content in the sixth month when treatments were highly significant

4 5 Recovery studies of visual deficiency symptoms, growth and tissue nutrient concentration

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 the sixth month the extent of recovery of seedlings from nutrient stress was remarkable (Plate 17) The seedlings had vigorous growth with dark green and thick foliage The effect of supplying complete nutrient solution on the increment of height diameter and leaf number of deficient seedlings is clearly evident from the data furnished in table 17

Height differences were however significant during the second and third months after the commencement of recovery studies Nitrogen and phosphorus deficient plants had the least height growth throughout the period of study Sulphur deficient plants had the maximum height growth (36 63 cm) in the third month of study At the end of the third month after applying complete nutrient solution the resultant height growth in -P K Mg S and control treatments were on par

The difference in diameter was also significant during the second and third months after the commencement of recovery studies Here also N deficient plants had the lowest diameter growth of 0 62 cm and 0 66 cm respectively during the second and third months of recovery studies Magnesium deficient plants were also significantly inferior to the rest

Plate 15 Seedling in the acute stage of S deficiency showing defoliation and chlorosis

Plate 16 Seedlings showing recovery of deficiency symptoms and improvement in growth after the application of complete nutrient solution

1 Seedlings selected from -N treatment
2 Seedlings selected from -P treatment
3 Seedlings selected from K treatment
4 Seedlings selected from -Mg treatment
5 Seedlings selected from S treatment


3

Table 17 Growth recovery of deficient seedlings after the application of complete nutrient solution

Nutrient element deleted from complete solution	Months								
	1	2	3	1	2	3	1	2	3
	Height (cm)			Collar diameter (cm)			Leaves (no)		
Nitrogen	21 63	25 23	28 83	0 69	0 62	0 66	6 67	11 00	16 00
Phosphorus	22 63	27 05	31 28	0 64	0 80	0 95	5 00	8 67	13 00
Potassium	28 23	30 91	33 58	0 63	0 75	0 87	16 00	18 33	20 33
Magnesium	24 90	29 03	33 17	0 60	0 70	0 80	12 00	15 67	15 67
Sulphur	26 13	31 39	36 63	0 64	0 78	0 91	10 67	15 33	15 33
Control	27 83	31 43	35 02	0 68	0 80	0 91	11 00	15 00	18 00
F test	NS	**	*	NS	**	**	NS	**	**
SEm ±	0 87	1 43	3 62	0 07	0 04	0 03	0 85	2 22	1 86
CD (0 05)		2 55	4 14		0 07	0 05	-	3 96	3 31

* Significant at 5 per cent level
** Significant at 1 per cent level

NS Non significant

Table 18 Leaf nutrient content of deficient seedlings after the application of complete nutrient solution

Nutrient element deleted from complete solution	Per cent					
	N	P	K	Ca	Mg	S
Nitrogen	3 99	2 05	2 20	2 00	1 20	0 33
Phosphorus	3 64	1 92	3 40	2 00	0 48	0 26
Potassium	3 78	2 32	2 90	3 20	0 96	0 35
Magnesium	4 68	2 05	3 90	2 00	0 94	0 16
Sulphur	3 64	1 25	3 30	2 40	0 48	0 21
Control	3 30	1 12	3 40	2 00	1 20	0 21

of the treatments in terms of girth Compared to control plants the girth increment in S P and K treatments due to the application of compelte nutrient solution was not significantly different Phosphorus deficient plants had the highest diameter of 0 95 cm at the end of the study

Treatments differed significantly in terms of leaf number also during the last two months of recovery studies Phosphorus deficient plants had consistent lower leaf number during the three months when recovery studies were made while K deficient plants generally had higher number of leaves Rest of the treatments did not differ significantly with regard to this attribute

4 5 2 Improvement in leaf nutrient content

The chemical analysis of the leaf tissues at the end of the recovery studies revealed that the elemental concentrations of major nutrients in these seedlings were higher when compared to nutrient content of deficient seedlings sampled during the same period The data furnished in table 18 indicate that in general the nutrient content of seedlings after the application of complete nutrient solution did not differ considerably

DISCUSSION

The investigations pertaining to the nutritional deficiency symptoms of Ailanthus grown in sand culture were taken up with the objective of inducing and describing the symptoms of deficiency of various nutrient elements in the seedlings The information gathered from the present study will help to understand the importance of various nutrient elements their role quantity required and uptake pattern which will ultimately benefit the farmers and foresters in the production of healthy and vigorous seedlings for extensive planting programmes Hence the present series of studies were conducted in College of Forestry Vellanikkara during the period 1991-93 The salient findings of the studies are discussed hereunder

5 1 Deficiency symptoms and uptake pattern of various nutrient elements

5 1 1 Nitrogen

5 1 1 1 Visual deficiency symptoms and growth behaviour

The initial symptom of nitrogen deficiency was the development of yellow chlorotic patches in the older leaves of the seedlings By the end of fourth month the entire lamina

of the lower leaves became pale yellow The acute stage of nitrogen deficiency was characterized by severe chlorosis of the entire seedling followed by premature drying and defoliation The seedlings were also stunted in growth compared to control plants

Chlorophyll content was also found to decline gradually in these seedlings Nitrogen deficient plants incidentally recorded the lowest chlorophyll A (0 21 mg/g) and total chlorophyll content (0 76 mg/g) Similarly the chlorophyll B content was also found to decline gradually in these seedlings throughout the study period The reduction in the chlorophyll content of chlorotic leaves due to N deficiency was also reported by Nazeem (1989) in nutmeg Chlorosis of the older leaves and stunting of the growth are the common visual symptoms of N deficiency observed in tree crops These types of visual symptoms were observed by Landis et al (1989) in seedlings of paper birch Maskell et al (1953) reported stunted growth yellowing of older leaves dieback and reduced rate of leaf production in young seedlings of cocoa Similar types of visual symptoms for nitrogen deficiencies were also reported in citrus (Jones and Embleton 1959) coffee (Muller 1966) avocado (Jones 1975) apple (Pant et al 1976) nutmeg (Philip 1986) and cashew (Gopikumar and Aravindakshan 1988)

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 supplies of nitrogen for chloroplast protein synthesis (Greulach 1973)

Nitrogen deficiency had pronounced effect on the growth behaviour of seedlings also particularly with regard to shoot growth Shoot growth parameters like height collar diameter and number of leaves recorded at fortnightly intervals were lower in these seedlings compared to seedlings grown in complete nutrient solution In fact at the end of the study period the height of these seedlings was found to be 25 per cent less compared to control In cashew seedlings grown in sand culture also N deficiency resulted in reduced height girth and leaf production of the seedlings (Gopikumar and Aravindakshan 1988)

In the present study shoot fresh and dry weights were respectively 37 62 per cent and 46 83 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 The number of secondary roots produced by N deficient seedlings in this

study was 19 92 per cent lower compared to control Similarly the fresh and dry weights of the root system in this treatment were also very low in relation to rest of the treatments

The reduction in vegetative growth may be due to the fact that nitrogen supply largely controlled the use of carbohydrates and determined whether the plant will make vegetative or reproductive growth (Kraws and Kraybill 1918 and Jones, 1975) In addition nitrogen is also reported to be involved in various other processes associated with protoplasm enzymatic reactions and photosynthesis (Gauch 1972 and Jones 1975)

5 1 1 2 Tissue nutrient concentration

Visual deficiency symptoms in seedlings supplied with treatment solution lacking nitrogen concurred with a significant reduction in the foliar concentration of N in these seedlings By the end of the study the nitrogen concentration fell to 1 03 per cent from the initial content of 2 per cent This coincided with the acute stage of deficiency when the entire seedlings appeared chlorotic followed by premature drying and defoliation of leaves The present results are also in agreement with the findings of Lockard and Asomaning (1964) who observed typical symptoms of

nitrogen deficiency in cocoa seedlings when the tissue content of N was reduced to 0 96 per cent

Deletion of N from the treatment solution increased the phosphorus concentration in the leaves of seedlings and interestingly it was the highest (1 52 per cent) in those seedlings at the end of the sixth month Antagonistic effect of nitrogen and phosphorus has been reported in various crops by several workers (Smith 1966 in citrus Dewaard, 1969 and Nybe 1986 in pepper) Similarly potassium concentration of N deficient seedlings also recorded the maximum increase in the present study However foliar concentration of calcium and sulphur showed a declining trend upon the deletion of N from the complete nutrient solution Similar effects were also reported in cocoa by Lebanauskas et al (1958) and in pepper by Nybe (1986)

The nitrogen deficient plants recovered from the visual symptoms of deficiency and produced green and healthy foliage by the end of the study period when complete nutrient solution was again applied However the improvement in height and collar diameter was somewhat slow The foliar concentration was also found to be increased remarkably with the application of complete solution

5 1 2 Phosphorus

5 1 2 1 Visual deficiency symptoms and growth behaviour

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 the entire leaflet In the acute stage of deficiency the seedlings had sparse foliage with necrotic patches and were also stunted in growth

Like nitrogen here also the chlorophyll content decreased gradually and they had comparatively lower chlorophyll content in their leaf tissues compared to healthy seedlings grown in complete Hoagland nutrient solution This was more pronounced by the end of the study In tree seedlings similar symptoms were observed by other workers also Reddish pink colouration of older leaves and stunting of growth have been reported in red maple (Landis et al 1989) while bronze green lower leaves with purple and necrotic blotches and defoliation have been described as symptoms of P deficiency in nutmeg (Philip 1986) Bingham (1975) explained P deficiency in tree species as slow growth sparse dull bronze to purple tinted foliage and early dropping of leaves A study was conducted at the University of Florida by Childers (1966) and he also observed the development of bronze foliage in citrus and strawberry

As we know since P is a mobile element deletion of this element from the nutrient solution caused its translocation from older to younger tissues resulting the P deficiency symptoms to appear in the older leaves Phosphorus deficiency is reported to result in the formation and accumulation of anthocyanin pigments which lead to the development of purple colouration (Muller 1966) Greulach (1973) from his studies stated that reduced quantities of ATP NAD NADP and various other P containing compounds contributed towards gradual decrease and disruption of metabolic pathways resulting in stunted growth of the plant It is also noteworthy that phosphorus is an important structural component of the chloroplasts and its deficiency might have contributed to the lower content of chlorophyll in the leaf tissues finally resulting in typical discolouration Swan (1971) is of the opinion that phosphorus deficiency symptoms are extremely variable between species and sometimes 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 collar diameter and leaf number were significantly influenced in seedlings subjected to P deficiency Height growth was the lowest in these seedlings (26 67 cm) compared to control (41 33 cm) Towards the end of the study P deficient

seedlings had 7 14 per cent lower collar diameter compared to seedlings that received complete nutrient solution Leaf production was also considerably affected due to P deficiency

Like shoot growth parameters the seedlings recorded lowest shoot fresh and dry weights during the latter half of the study Such reductions in shoot growth parameters have also been observed in cocoa (Lockard and Asomaning 1964) Cashew (Gopikumar and Aravindakshan 1988) and nutmeg (Nazeem 1989) The retardation in growth can be explained by the fact that like nitrogen phosphorus also plays an important role as a structural component of the cell constituents and other metabolically active compounds (Greulach 1973) It is also an established fact that phosphorus 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)

The lower number of leaves in P deficient plants might have resulted from the premature defoliation that was observed by the end of the study 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) also revealed similar outcomes for P deficiency in cashew seedlings

Length of the main root of seedlings was found to be affected due to P deficiency Compared to seedlings that received all the nutrients P deficient seedlings had longer roots eventhough their root spread number and dry weights were relatively less These results are in agreement with a study made by Narayanan and Reddy (1982) wherein they have observed an increase in length of primary and secondary roots and a decrease in dry weights in 12 tree species out of 14 studied Phosphorus was found to favour the export of cytokinins from roots and hence its deficiency could cause a decline in cytokinin content resulting in the elongation of the roots (Marschner 1982) Restricted root growth on account of P deficiency was also reported by Childers (1966) in avocado citrus and strawberry

5 1 2 2 Tissue nutrient concentration

In phosphorus deficient seedlings also 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) and nutmeg (Philip 1986) also there was 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 K and S 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 Ca and Mg contents and a negative correlation with K while in nutmeg Philip (1986) reported an increase in foliar concentrations of N and S when P was deleted from the nutrient solution

In P deficient seedlings also eventhough the extent of recovery of visual symptoms was remarkable improvement in height and leaf production was relatively low However P deficient plants exhibited the highest diameter of 0 95 cm at the end of the recovery studies Foliar concentration of P in these seedlings kept for recovery studies reached 1 92 per cent 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 thereby indicating the possibilities of improving the seedling growth and the control of the deficient element by its proper application

5 1 3 Potassium

5 1 3 1 Visual deficiency symptoms and growth behaviour

Initially potassium deficient seedlings manifested

chlorotic tips in the older leaves This later spread through the margin upwards and in severe stage the entire margins were chlorotic In the acute stage the margins became crinkled and necrotic Drying of terminal bud followed by death was also observed in number of cases The symptoms explained in this thesis also agree with the observations made by various workers on other tree species Purseglove (1977) noticed browning and scorching of entire leaf margins and defoliation as typical visual symptoms of potassium deficiency in coffee Necrotic older leaves have been reported by Philip (1986) in nutmeg

Ulrich and Ohki (1975) stated that in trees since potassium moves to the growing point the older leaves through depletion exhibit the most characteristic K deficiency symptoms of tip and marginal scorching They have also reported that extreme deficiency in trees results in the entire plant showing symptoms and ultimate dieback of twigs

Necrosis of leaf lamina at the acute stage of deficiency might have resulted from the accumulation of a diamine putriscine as reported by Richards and Coleman (1952) Eventhough there was a gradual decline in the chlorophyll content of K deficient seedlings they generally had a higher concentration compared to other treatments by the end of the study Though potassium activated the synthesis of

chlorophyll an increased partitioning of K to the chloroplast has been reported as the reason for no substantial reduction in chlorophyll content and photosynthetic rates in K deficient plants (Caporn et al 1982)

In the present experiment the reduction in height and leaf production was not found to be severe in K deficient seedlings compared to other treatments An almost similar trend was noticed with regard to fresh and dry weights of these seedlings However shoot growth parameters 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) In nutmeg Philip (1986) has reported similar trends in relation to height number of branches and drymatter as a result of K deficiency

The property of potassium 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 cofactor 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 element was reported to have a direct influence on cell division resulting in a higher cell number as suggested by Boringer and Schacherer (1982)

5 1 3 2 Tissue nutrient concentration

Potassium deficiency was associated with a decrease in foliar content of K from 1 28 to 0 95 per cent at the end of the study Visual symptoms of potassium deficiency were concurred with reduced levels of potassium in foliages of cashew (Gopikumar and Aravindakshan 1988) and nutmeg (Nazeem 1989) A close observation of the data also revealed that nitrogen and phosphorus levels reduced while Ca Mg and S levels increased on account of K deficiency Among all interactions the antagonistic effect of K and Mg was remarkable The Mg level in K deficient plants increased from 0 48 to 0 80 per cent with a corresponding decrease in K content from 1 28 to 0 95 per cent Antagonistic effects of K with Ca and Mg have been also established in different crops (Cain 1948 in apple Smith 1966 in citrus Dewaard 1969 Hansen 1970 and Nybe 1986 in pepper and Philip 1986 in nutmeg)

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 again through complete nutrient solution

5 1 4 Magnesium

5 1 4 1 Visual deficiency symptoms and growth behaviour

Magnesium deficiency produced typical visual symptoms of interveinal chlorosis with reticulate pattern particularly by the end of fourth month when the deficiency became severe In the acute stage these chlorotic patches between the green midrib and veins developed necrosis Growth was also stunted in these seedlings Chlorophyll content of the leaves of Mg deficient seedlings decreased markedly by the end of the study Chlorophyll A was 0 30 mg/g while chlorophyll B and total chlorophyll were respectively 0 54 mg/g and 0 84 mg/g in leaves during the period These values were incidentally the second lowest among all the treatments Magnesium deficiency induced chlorophyll decline was also observed in nutmeg seedlings grown in sand culture (Nazeem 1989)

Thus magnesium could be listed as another element whose deficiency produces a characteristic chlorosis which is generally strongly patterned Philip (1986) also noted symptoms similar to the ones obtained in this study in nutmeg He observed pale yellow colouration near midrib of older leaves followed by pale green lemon and necrotic blotches towards margin with upward cupping in the Mg deficient plants 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 the plants its deficiency resulted in movement of Mg 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 per cent by weight) and hence the removal of magnesium 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 carbohydrate 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 1 4 2 Tissue nutrient concentration

Magnesium concentration in seedlings supplied with nutrient solution lacking Mg fell from 0 56 per cent in the beginning to 0 32 per cent by the end of the second month The development of chlorotic area formation between the veins of leaves also occurred during the same period of the study

Antagonistic effect of Mg with all other elements except P is also evident from the present study Smith (1966)

also 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 other workers (Emmert 1961 Dewaard 1969 and Nybe 1986)

Magnesium deficient plants recovered well by the end of the study when supplied with complete nutrient solution Foliar concentration of Mg in seedlings kept for recovery studies was 0 94 per cent which represents a remarkable increase in Mg levels compared to the foliar levels of Mg during the third month when recovery studies first began

5 1 5 **Sulphur**

5 1 5 1 Visual deficiency symptoms and growth behaviour

In the investigations discolouration of leaves which advanced from the margin inwards was the initial symptom of sulphur deficiency This was followed by necrosis of the yellow areas and in the acute stage of deficiency the entire leaf became chlorotic This phenomenon was associated with defoliation and the seedlings appeared to be lanky compared to the control seedlings The chlorophyll content of the sulphur deficient seedlings decreased by the end of the study Compared to control sulphur deficient seedlings had 35 51 per cent less chlorophyll content during the last month

The chlorotic nature of S deficient plants was due to the impaired photosynthesis attributed to the direct effect on the protein level and the chlorophyll content in the chloroplasts Since sulphur is intimately associated with protein synthesis its deficiency resulted in accumulation of carbohydrates and soluble nitrogen compounds thereby finally resulting a breakdown and decrease in cambial tissues This might have contributed to the lanky appearance of these seedlings Overall yellowing of leaves appeared in the present investigations has also been observed in apple pear, peach and grapes by Childers (1966)

There was no remarkable retardation in collar diameter and leaf production in S deficient plants In fact S deficient plants possessed collar diameters and leaf number almost similar to control plants However height growth was slightly lower in these seedlings compared to control eventhough the difference was not statistically significant

Reduction in shoot dry and fresh weights was also low in sulphur deficient seedlings In cocoa seedlings grown in sand culture the extent of stunting in terms of dry weights due to the deficiency of different macro elements was the least in sulphur (Lockard and Asomaning 1964) Surprisingly it was found that root length number of secondary roots and root fresh and dry weights were higher in S deficient plants

compared to seedlings that received complete nutrient solution

5 1 5 2 Tissue nutrient concentration

Seedlings supplied with treatment solution lacking sulphur developed chlorotic symptoms only by the fourth month and these symptoms became marked by the end of sixth month Incidentally sulphur deficient plants had the lowest sulphur concentration in their foliage during this month (0 07 per cent) In another study Gopikumar and Aravindakshan (1988) also found that sulphur deficiency coincided with low S levels in the foliages of cashew seedlings grown in sand culture In the present study S deficiency caused an increase in K and Mg levels in seedlings Sulphur deficiency associated with high K content was noticed in leaves of coffee (Lott et al 1960) and citrus (Smith 1966) also

Seedlings deficient in sulphur recorded the maximum height growth by the end of the study Hence the extent of recovery of these seedlings in terms of height was slow compared to other treatments However recovery from visual deficiency symptoms and other growth parameters was remarkable in S deficient seedlings Sulphur content in the foliages of these seedlings after the application of complete nutrient

solution attained levels three times higher than deficient seedlings at the end of the study period

The basic information obtained from the present study on the characteristic visual symptoms growth behaviour and uptake pattern of elements as influenced by the deficiency of various nutrient elements will help us for the better understanding of the seedling nutrition of Ailanthus in nurseries This in turn will benefit research workers and foresters in the accurate diagnosis of the nutritional problems associated with the seedlings in commercial nurseries This will also provide valuable information necessary for carrying out manurial and fertiliser applications for nursery seedlings which will help in the production of healthy and vigorous nursery stock for extensive planting programmes The visual symptoms and growth retardation of seedlings due to the deficiency of various nutrient elements in the nursery are also expected to provide some useful guidelines to understand the nutritional disorders of Ailanthus even under field conditions

Summary

SUMMARY

The present investigations pertaining to the nutritional deficiency symptoms of Ailanthus (Ailanthus triphysa (Dennst) Alston) seedlings were taken up with the basic objective of inducing 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 in order to find out their uptake pattern The results were finally confirmed in recovery studies by supplying the seedlings showing the deficiencies of various elements with complete Hoagland nutrient solution

Sand culture experiments were carried out under controlled conditions inside a glasshouse attached to the College of Horticulture Kerala Agricultural University main campus Vellanikkara during the period 1991 93 Two months old seedlings of uniform growth were planted in containers filled with pure quartz sand Hoagland No 2 (1948) solution was used for supplying the nutrients Treatment solutions were prepared by eliminating the desired nutrient from the complete Hoagland nutrient solution

The salient results of the present investigations are summarised below

1 Characteristic visual deficiency symptoms were manifested by the seedlings at different levels of deficiencies of nitrogen phosphorus potassium magnesium and sulphur

2 For nitrogen the initial visual symptom of deficiency was chlorosis of the older leaves The acute stage of N deficiency was characterized by severe chlorosis of the entire seedling followed by premature drying and defoliation There was stunting of growth also Phosphorus deficiency symptoms also appeared first on the older leaves as purple bronze patches In the acute stage of deficiency the P deficient seedlings produced sparse foliage with necrotic patches Stunting was observed here also Chlorotic tips in lower leaves were the initial symptoms of K deficiency In the acute stage the margins became crinkled and necrotic Terminal bud drying was a prominent symptom noticed in some of the K deficient seedlings

3 Magnesium deficiency resulted in the development of typical visual symptom of interveinal chlorosis with a reticulate pattern by the end of fourth month when deficiency became severe Discolouration of leaves which advanced from the margin inwards was the initial symptom of sulphur deficiency This was followed by necrosis of the yellow areas and in the acute stage of deficiency the entire leaf became chlorotic These symptoms were associated with defoliation and the seedlings appeared to be lanky compared to the control Seedlings that received complete nutrient solution were vigorous in growth and produced dark green foliage throughout the period of study

4 Vegetative growth was also affected by the deficiency of various nutrient elements Among the shoot growth parameters studied height and the number of leaves produced by the seedlings were found to be statistically influenced especially towards the end of the study Deficiency of nitrogen and phosphorus resulted maximum reduction in height compared to other treatments However the effect of deficiency of potassium and magnesium on the vegetative growth of seedlings was not as severe compared to deficiency of other elements

5 Fresh and dry weights of the shoot portion were also found to be influenced by nutrient deficiency particularly towards the end of the study While nitrogen and phosphorus deficient seedlings had the lowest fresh and dry weights of shoots sulphur deficient seedlings had relatively higher values even compared to control

6 Root growth parameters were not statistically influenced by the deletion of these nutrient elements However P deficient seedlings had a tendency to result a slight elongation of their roots Nitrogen and phosphorus deficient seedlings recorded the lowest fresh and dry weights of the roots

7 The chlorophyll content of the leaves was found to be significantly influenced by the deficiency of various nutrient elements especially during the fourth and sixth month The amount of chlorophyll A chlorophyll-B and total chlorophyll decreased gradually during the study period for all the treatments except control The reduction in all fractions of chlorophyll content in the leaves with the advancement of chlorotic symptoms particularly due to nitrogen and magnesium deficiencies is very pronounced in the present study

8 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 had significantly lower levels of the concerned elements

9 Foliar symptoms manifested on the seedlings due to the deficiency of nutrients gradually disappeared during the course of recovery studies The new flushes of leaves produced were healthy green and normally shaped and seedlings had vigorous growth Chemical analysis of leaf tissues at the end of the recovery studies revealed that the elemental concentrations of major nutrients in these seedlings were higher when compared to the nutrient contents in deficient seedlings sampled during the same period

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Appendices

APPENDIX I

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

Source of variation	df	Meansquare at fortnightly intervals												
		0	1	2	3	4	5	6	7	8	9	10	11	12	13
Treatment	5	1 726	2 802	2 053	2 866	6 941	12 490	21 715	36 706 *	31 302 *	37 077	68 910 *	120 345 **	3 791 *	80 379 *
Error	12	1 717	4 532	6 957	8 034	10 199	8 824	11 014	11 586	9 287	14 396	10 159	14 208	2 364	19 659
Total	17	1 720	4 023	5 514	6 514	9 241	9 902	14 162	18 974	15 762	21 067	27 438	45 424	40 724	37 518

* Significant at 5 per cent level ** 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	Meansquare at fortnightly intervals												
		0	1	2	3	4	5	6	7	8	9	10	11	12	13
Treatment	5	0 0002	0 000	0 000	0 001	0 001	0 001	0 003	0 005	0 003	0 003	0 004	0 006	0 003	0 002
Error	12	0 0001	0 002	0 003	0 004	0 005	0 006	0 009	0 008	0 009	0 008	0 007	0 007	0 008	0 009
Total	17	0 0001	0 002	0 002	0 003	0 004	0 005	0 008	0 007	0 007	0 006	0 006	0 007	0 006	0 007

APPENDIX III

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

Source of variation	df	Meansquare at fortnightly intervals													
		0	1	2	3	4	5	6	7	8	9	10	11	12	13
Treatment	5	2 660	0 687	1 182	2 119 *	3 052 *	4 820 *	9 893 **	22 885 **	24 497 **	31 221 **	48 666 **	55 231 **	71 896 **	94 050 **
Error	12	1 870	0 419	1 262	0 559	1 162	2 128	2 105	1 683	1 933	1 091	2 599	4 701	4 076	6 976
Total	17	2 102	0 497	1 238	1 018	1 718	2 920	4 380	7 919	8 570	9 953	16 148	19 563	24 023	32 586

* Significant at 5 per cent level

** Significant at 1 per cent level

APPENDIX IV

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

Source of variation	df	Meansquare of fortnightly intervals					
		1	2	3	4	5	6
Treatment	5	0 454	0 207	0 066	0 109	0 024	0 010
Error	12	0 174	0 227	0 080	0 025	0 078	0 050
Total	17	0 256	0 221	0 76	0 049	0 062	0 038

APPENDIX V

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

Source of variation	df	Meansquare at monthly intervals					
		1	2	3	4	5	6
Treatment	5	0 070	0 029	0 286	0 111	0 082	0 144
Error	12	0 117	0 054	0 182	0 042	0 095	0 078
Total	17	0 103	0 046	0 213	0 062	0 091	0 097

APPENDIX-VI

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

Source of variation	df	Meansquare at monthly intervals					
		1	2	3	4	5	6
Treatment	5	1 890**	0 562	1 027	0 098	0 279	0 066
Error	12	0 300	0 254	0 385	0 150	0 127	0 135
Total	17	0 768	0 345	0 574	0 135	0 171	0 115

** Significant at 1 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	Meansquare at monthly intervals					
		1	2	3	4	5	6
Treatment	5	0 027	0 221	0 311	0 897*	0 830*	0 724**
Error	12	0 019	0 157	0 122	0 163	0 180	0 004
Total	17	0 021	0 176	0 178	0 379	0 371	0 216

* Significant at 5 per cent level

** 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	Meansquare at monthly intervals					
		1	2	3	4	5	6
Treatment	5	0 024	0 054	0 091	0 333 *	0 301 **	0 276
Error	12	0 011	0 047	0 044	0 094	0 031	0 030
Total	17	0 015	0 049	0 058	0 164	0 110	0 102

* Significant at 5 per cent level
** 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	Meansquare at monthly intervals					
		1	2	3	4	5	6
Treatment	5	0 050	0 139	0 174	0 329 *	1 053 *	0 362 **
Error	12	0 020	0 187	0 286	0 228	0 634	0 103
Total	17	0 029	0 173	0 253	0 258	0 757	0 179

* Significant at 5 per cent level
** Significant at 1 per cent level

APPENDIX-X

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

Source of variation	df	Meansquare at monthly intervals					
		1	2	3	4	5	6
Treatment	5	0 016	0 035	0 064	0 356	0 593 *	0 919 **
Error	12	0 007	0 045	0 117	0 228	0 189	0 051
Total	17	0 009	0 042	0 101	0 266	0 308	0 306

* Significant at 5 per cent level

** 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 variations	df	Meansquare of fortnightly intervals								
		1	4	6	1	4	6	1	4	6
		Chlorophyll-A			Chlorophyll-B			Total chlorophyll		
Treatment	5	0 147	0 051 *	0 540 **	0 288	0 208 *	0 214 **	0 476	0 454 *	0 472 **
Error	12	0 054	0 015	0 001	0 149	0 061	0 003	0 183	0 132	0 003
Total	17	0 082	0 025	0 016	0 190	0 104	0 065	0 269	0 227	0 141

* Significant at 5 per cent level

** Significant at 1 per cent level

APPENDIX XII

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

Source of variation	df	Meansquare at monthly intervals					
		1	2	3	4	5	6
Treatment	5	0 458	0 096 **	0 418 *	0 427	0 908	0 750 **
Error	12	0 185	0 006	0 121	0 270	0 415	0 004
Total	17	0 265	0 032	0 208	0 316	0 560	0 224

* 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 the foliar concentration of phosphorus

Source of variation	df	Meansquare at monthly intervals					
		1	2	3	4	5	6
Treatment	5	0 475	0 117	0 010	0 124	0 096	0 024
Error	9	0 125	0 111	0 024	0 117	0 046	0 025
Total	14	0 250	0 113	0 019	0 119	0 064	0 025

APPENDIX XIV

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

Source of variation	df	Meansquare at monthly intervals					
		1	2	3	4	5	6
Treatment	5	0 018	0 036	0 033	0 140	0 303	1 018
Error	12	0 017	0 022	0 046	0 074	0 300	0 032
Total	17	0 017	0 026	0 042	0 094	0 301	0 322

APPENDIX-XV

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

Source of variation	df	Meansquare at monthly intervals					
		1	2	3	4	5	6
Treatment	5	0 380 *	0 076 *	0 237 **	0 041	0 302	0 242
Error	12	0 027	0 019	0 058	0 031	0 014	0 057
Total	17	0 130	0 036	0 111	0 034	0 099	0 111

* Significant at 5 per cent level
** Significant at 1 per cent level

APPENDIX XVI

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

Source of variation	df	Meansquare at monthly intervals					
		1	2	3	4	5	6
Treatment	5	0 124	0 088	0 253	0 146	0 158	0 286
Error	12	0 023	0 009	0 021	0 031	0 106	0 035
Total	17	0 053	0 032	0 089	0 065	0 121	0 109

APPENDIX XVII

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

Source of variation	df	Meansquare at monthly intervals					
		1	2	3	4	5	6
Treatment	5	0 208 *	0 065	0 027 **	0 288 **	0 033	0 021 **
Error	12	0 065	0 140	0 003	0 039	0 019	0 005
Total	17	0 107	0 118	0 010	0 112	0 023	0 010

* Significant at 5 per cent level
** Significant at 1 per cent level

APPENDIX-XVIII

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

Source of variations	df	Meansquare of fortnightly intervals								
		Height			Collar diameter			Leaf number		
		1	2	3	1	2	3	1	2	3
Treatment	5	21 238	19 835**	22 762*	0 003	0 010**	0 042**	46 356	37 067**	18 856**
Error	12	16 313	3 080	6 203	0 007	0 002	0 001	18 278	7 309	5 167
Total	17	17 761	8 008	11 073	0 006	0 004	0 013	26 536	16 118	9 193

* Significant at 5 per cent level

** Significant at 1 per cent level

NUTRITIONAL DEFICIENCY SYMPTOMS OF AILANTHUS (*Ailanthus triphysa* (Dennst.) Alston) SEEDLINGS

By

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ABSTRACT OF A THESIS

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ABSTRACT

Sand culture experiments were carried out under controlled conditions inside a glasshouse attached to College of Horticulture, Kerala Agricultural University main campus, Vellanikkara during the period 1991-93 for inducing deficiency symptoms of various nutrient elements in the seedlings of Ailanthus (Ailanthus triphysa (Dennst) Alston) The effects of major nutrients viz , N, P, K, Mg and S on the growth, chlorophyll content and nutrient concentration of seedlings in the nursery were also studied The results were also 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 i e , chlorophyll-A chlorophyll-B and total chlorophyll of the treatment seedlings declined during the study period compared to control 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 visual symptoms when the deficient element concerned was again supplied to the seedlings through complete nutrient solution