## ECLARATION

I hereby declare that this thesis entitled **'Deficiency symptoms of mineral nutrients in clove (*Syzygium aromaticum* (L.) Merr. and Perry)'** is a bonafide record of research work done by me and that the thesis has not previously formed the basis for the award to me, of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

**(P. A. NAZEEM)**

Vellanikkara,
5th December, 1989.

## CERTIFICATE

Certified that this thesis entitled **'Deficiency symptoms of mineral nutrients in clove (*Syzygium aromaticum* (L.) Merr. and Perry)'** is a record of research work done independently by **Smt. P. A. Nazeem** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

**Dr. P. C. Sivaraman Nair**
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# CERTIFICATE

We, the undersigned members of the Advisory Committee of **Smt. P. A. Nazeem**, a candidate for the degree of Doctor of Philosophy in Horticulture, agree that the thesis entitled **'Deficiency symptoms of mineral nutrients in clove (*Syzygium aromaticum* (L.) Merr. and Perry)'** may be submitted by **Smt. P.A. Nazeem** in partial fulfilment of the requirement for the degree.

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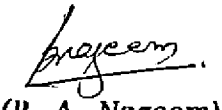

**(P. A. Nazeem)**

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# *Introduction*

# INTRODUCTION

The 'clove' of commerce is the dried flower buds of the clove plant, *Syzygium aromaticum* (L.) Merr. and Perry. The main producing countries in the world are Tanzania (Zansibar), Indonesia, Medagascar, Srilanka and India. The world production of clove is estimated to be around 40,000 tonnes per year. Indonesia is the largest consumer (30,000 tonnes) where it is used mainly for the production of kretek cigarettes. India produced 1300 tonnes in 1985-86 from an area of 1600 hectares. In addition, India imported 3053 tonnes of clove valued at Rs.1,698.16 lakhs during 1985-86 and 3239 tonnes valued at Rs.1,985.42 lakhs during 1986-87. The average domestic price per kg of clove varied between Rs.186 and 189 during these two years.

United States of America (1100 tonnes/year), West Germany and other European countries (1850 tonnes/year) are importing substantial quantities of this spice. In addition, there is also demand from Jamaica, Scandinavian countries, Japan and the Middle East.

Clove is largely used in the tobacco industries. It is otherwise used as a spice in confectionary, perfumery and pharmaceutical industries.

In Kerala, clove is being cultivated in an area of 883 hectares (1986-87) and it is mainly confined to Kottayam, Trivandrum and Ernakulam districts. Kerala has much potential in growing this crop as an inter crop in coconut and arecanut gardens. Tea and clove as a mixed crop combination holds considerable promise in Kerala and Tamil Nadu (Madhavan et al., 1984). The net income from the crop is reported to be very high compared to any other intercrop (Jacob and Alles, 1987). Long gestation period and lack of proper technology and extension service are the main constraints in production and productivity. Substantial increase in area, production and productivity of this crop is essential not only to meet our internal demand but also to earn foreign exchange by exporting the surplus quantity.

Balanced nutrition is one of the most important aspects for improving the production and productivity of any crop. Practically no work has been reported on the nutritional requirements of clove from India or other clove growing countries. In view of its importance, studies on certain nutritional aspects of clove has been taken up, with the main objectives of

(i) Inducing nutrient deficiency symptoms under controlled conditions.

(ii) Understanding the nutrient distribution and translocation pattern in deficient plants.

(iii) Assessing the nutrient removal from a bearing clove tree.

(iv) Evaluating the seasonal variations in foliar nutrient concentration.

# Review Of Literature

# REVIEW OF LITERATURE

The idea of growing plants in sand culture was first introduced by Boussingault in 1856. Nutrient solutions for sand culture experiments were first reported by Knop (1865). 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 is modified and used even now.

## 2.1 The essential elements

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

Reported work on mineral nutrition of clove is very little. Hence, a general review on mineral nutrition of crop plants is looked into.

### 2.1.1 Nitrogen

#### 2.1.1.1 Role in plant growth and development

Nitrogen is a major structural constituent of the cell. The cytoplasm and cell organells contained varying amounts of nitrogen largely in combination with carbon, hydrogen, oxygen, phosphorus and sulphur. Being a constituent of important organic compounds such as amino acids, proteins, purines, pyrimidines, chlorophyll and many co-enzymes, N was found involved in all processes associated with protoplasm, enzyme reactions and photosynthesis (Greulach, 1973).

Nitrogen containing compounds constituted 5 to 30 per cent of the dry weight of plant (Kramer and Kozlowski, 1960). As much as 70 per cent of the leaf nitrogen may be present in chloroplasts (Stocking and Origun, 1962).

According to Makino et al. (1984) the supply of nitrogen determined the content of ribulose biphosphate-carboxylase protein in leaf and consequently the rate of photosynthesis.

Nitrogen supply controlled the growth and fruiting of most plants. When other factors were not severely limiting, nitrogen supply largely controlled the use of carbohydrates and determined whether the plant will make vegetative, or reproductive growth (Kraws and Kraybill, 1918; Jones, 1975).

Nitrogen has a major role in maintaining the phytohormone balance in plants. It favoured the synthesis of cytokinins in root meristems. An interruption in nitrogen supply enhanced the abscisic acid level and favoured leaf senescence. Regular supplies of nitrogen was reported to cause constant levels of ABA but decline in GA level (Marschner, 1982).

2.1.1.2 Characteristic deficiency symptoms

Nitrogen being a mobile element in plants, deficiency resulted in movement of nitrogen from older leaves to active younger ones and the symptoms to be developed first on older leaves (Gauch, 1972).

The N deficiency resulted in chlorosis which generally reduced the rate of photosynthesis. Chlorosis was reported to result from inadequate supplies of N for chloroplast protein synthesis. Deficiency caused disproportionate amounts of secondary cell wall thickening due to carbohydrate accumulation that tend to make terminal growth slender and woody. Root growth was considerably better unless N was totally lacking in the media (Greulach, 1973). The deficiency of the element reduced leaf area resulting in lower interruption of radiation and lower crop yields.

Visual symptoms of N deficiency has been described in various crops. Maskell et al. (1953) reported stunted growth, yellowing of older leaves, die back and reduced rate of leaf production in cocoa. Similar reports have

been made in coffee (Muller, 1966), citrus (Jones and Embleton, 1959), avocado (Jones, 1975) and apple (Pant et al., 1976).

Sand culture experiments in citrus showed nutrient solutions lacking N, Mg and Ca to produce plants with less carbohydrates. Deficient plants showed high variation in morphology and growth rate compared to control plants (Maximos et al., 1980).

Yellowing of older leaves, necrosis, premature leaf fall and substantial reduction in growth has been reported as events of N deficiency in Nutmeg (Philip, 1986).

The nitrogen requirements for the crop varied with the species.

2.1.1.3 Interaction with other elements

Antagonistic effect of N has been reported on phosphorus (Smith, 1966; De Waard, 1969; Nybe, 1986). Zinc, Cu and B uptake was found improved by nitrogen deficiency (Lebanauskas et al., 1958). Foliar Mg level decreased with N deficiency (Embleton et al., 1958, Smith, 1966, Nybe, 1986). Similar response was exhibited with Ca (Lebanauskas et al., 1958) and Fe (Nybe, 1986).

High N application slightly increased the N, P and K contents and decreased the Ca contents of leaves and branches of orange trees (Glonti, 1970). Increased N levels raised the Ca, Mn and Zn contents in all parts of apple tree and lowered the K content. Magnesium and Fe content increased only in leaves whereas P and Cu increased in bark (Wenot, 1971). Stoilov and Lekhora (1974) has reported a negative relationship of N with P and K.

The ratio of leaf N to Ca appeared to be positively correlated with the level of K but not of Mg in the citrus leaf (Weir, 1969). Nitrate sources of N increased Ca and Mg and decreased Fe and Mn concentration in leaves of blackberry (Spiers, 1987). N recovery was reported to be higher in the

presence of S indicating a positive interaction between N and S uptake (Kandaswamy and Arulmozhiselvan, 1987).

### 2.1.2 Phosphorus

#### 2.1.2.1 Role in plant growth and development

Like nitrogen, phosphorus played an important role as a structural component of the cell constituents and metabolically active compounds. 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 etc., nucleic acids, nucleoproteins, purine and pyrimidine nucleotides, flavin nucleotides and several enzymes and co-enzymes (Greulach, 1973, Agarwala and Sharma, 1976).

Though the share of P was only 0.1 to 0.8 per cent of the total dry weight in plants, it was the major controlling factor of energy for all living cells. It was reported to play a key role in energy metabolism (Epstein, 1978, Jain, 1981).

Phosphorus was greatly involved in the photochemical reactions and $Co_2$ assimilation was found to be dependent on a preceding phosphate assimilation resulting in ATP formation at the expense of light energy. Being a constituent of nucleoproteins, it was concerned with cell division and transfer of hereditary traits (Gauch, 1972).

Phosphorus favoured the export of cytokinins from roots and hence, deficiency caused decline in cytokinin content (Marschner, 1982).

#### 2.1.2.2 Characteristic deficiency symptoms

Phosphorus deficient plants accumulated carbohydrates like the N deficient ones. Vascular tissues were poorly developed and the nucleic acid

synthesis was greatly reduced. 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 (Greulach, 1973).

The element being mobile, lower leaves were the first to exhibit hunger signs. Phosphorus deficiency induced formation of anthocyanin pigmentation resulting in purple coloured leaves (Muller, 1966).

Bingham (1975) explained P deficiency in tree crops as slow growth, sparse, dull bronze to purple tinted foliage and early dropping of leaves.

In apple, P deficiency symptom was expressed as small dark green leaves with bronze to purple tinge (Wallace, 1953).

The lateral buds of P deficient plants remained dormant or dried resulting in reduced lateral shoots. 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 symptoms of P deficiency in avocado, citrus and strawberry.

Bronze green lower leaves with purple and necrotic blotches and defoliation has been described as symptoms of P deficiency in nutmeg (Philip, 1986).

The root system of P deficient plants was found to get altered. Length of primary and secondary roots increased and that of tertiaries decreased. The dry weight decreased in 12 out of 14 species studied. Hormonal imbalance especially that of auxins and cytokinins was suggested to be the reason for increase in root elongation (Narayanan and Reddy, 1982).

2.1.2.3 Interaction with other elements

Phosphorus interaction with other elements has been reported by various workers. Phosphorus deficiency was found associated with a decrease in Mn,(Lebanauskas, 1958) N and Mg (Embleton et al., 1958).

Added N and K fertilizers were found to decrease P in leaves (Wenot, 1971). In apple, P level was found positively correlated to Ca and Mg levels and negatively to K (Matsui et al., 1977).

El-Gazzar et al. (1979) after their experiments in orange, olive and guava has reported a positive relation between P and Mn and a negative one with Fe and Zn whereas N and Cu remained without much change.

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

De Waard (1969) and Nybe (1986) reported that the foliar concentration of other nutrients were not influenced by P deficiency in pepper.

2.1.3 Potassium

2.1.3.1 Role in plant growth and development

Though potassium is present in all living cells, it is not associated with any specific compound within the cell. Potassium occurred primarily in the ionic form or as charged particle on colloidal surfaces. This property made it most apt to function as a catalyst or as a cofactor for one or more of many enzymatic reactions of living cell (Ulrich and Ohki, 1975). It activates protein synthesis and N metabolism (Mulder and Bakema, , 1956). The element

seems to be the most abundant of univalent cation to serve as an enzyme activator (Greulach, 1973). More than 50 enzymes has been listed by Evans and Sorger (1966) as those that need K for maximal activity. They have also reported its involvement in the incorporation of amino acids in proteins.

Influence of K on stomatal opening and transpiration has been reported by Fischer and Hsiao (1968) and Thomas (1970). Insufficiency of K resulted in reduced stomatal $CO_2$ conductance. Though potassium activated synthesis of chlorophyll, an increased partitioning of K to the chloroplast in K deficient plants has been reported as the reason for no substantial reduction in photosynthetic rates during initial stages of K deficiency (Caporn et al., 1982).

The element K was reported to have direct influence on cell division and higher cell number at higher K supply had been reported by Boringer and Schacherer (1982).

Low K was found to hinter transport of cytokinins from roots. Potassium deficiency enhanced ABA export to grains and caused accelerated senescence (Marschner, 1982).

As a consequence of the role in regulating membrane permeability, K deficient plants were found to express water imbalance (Greulach, 1973).

Potassium increased the resistance of plants to stress of moisture, heat, pest and diseases (Agarwala and Sharma, 1976).

2.1.3.2 Characteristic deficiency symptoms

Potassium being mobile inside the plant, the deficiency symptoms were first manifested on lower leaves. The tip and marginal scorching of mature leaf was the characteristic symptom of K deficiency (Ulrich and Ohki, 1975) in tree crops.

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 characteristic symptoms of K deficiency in coffee (Eckstein, et al., 1937). Purseglove (1977) has reported brown scorching of entire leaf margins and defoliation as K deficiency symptom in coffee.

Necrotic older leaves associated with reduced height, number of branches and dry matter has been reported as effects of K deficiency in Nutmeg (Philip, 1986).

Potassium deficient plants were found to produce and accumulate putriscine, a diamine that favour necrosis in leaf lamina (Richards and Coleman, 1952).

Analysis of low yielders of mandarin with scorched leaves and non fruiting terminals showed more K and less Ca and Mg in Scorched leaves (Morchal and Laccevilhe, 1969).

2.1.3.3 Interaction with other elements

Antagonistic effects of K with Ca and Mg has been established in different crops (Cain, 1948, Smith, 1966, De Waard, 1969, Hansen, 1970, Nybe 1986, Philip, 1986).

Leaf K was reduced in Washington navel orange by Mg sprays (Jones and Embleton, 1971). Wahid et al. (1974) demonstrated the effect of combined level of Na, Ca and Mg against the level of K in the leaf and suggested that critical levels of Na, Ca and Mg cannot be established in coconut with certainity. High K availability decreased Ca and Mg uptake in apple (Ludders and Bunemann, 1973). Sodium decreased the uptake of K. Calcium and Mg were found decreased concomittently with increased K uptake (Gardner et al., 1985). Spiers (1987) reported reduced P, Ca and Mg with increased

K fertilization. High K was found to decrease plant growth. Antagonistic influence existed for K and Mg on calcium concentrations.

Tandon and Sekhon (1988) studied the interactions involving K and other nutrients. Among the negative interactions, the important one reported was K x Mg, which even led to K induced Mg deficiency. Potassium and Ca antagonism occurred commonly and under conditions of moisture stress greater amounts of K supply was required to ensure K uptake by the crop.

Potassium, Ca and Mg played significant role in buffer system. Potassium increased membrane permeability whereas Ca and Mg decreased it. Hence, a K/Ca/Mg balance has to be maintained in plants (Greulach, 1973).

### 2.1.4 Calcium

#### 2.1.4.1 Role in plant growth and development

Calcium is found to be immobile except when in xylem. It is considered to be the only ion essential for root growth. It is reported not to get translocated in the phloem and to be continuously supplied to the meristem. This resulted in continuous uptake of Ca ions and a difference in water potential creating a flow of solutes and water in cell wall and in the xylem (Bangerth, 1979). Ferguson (1980) has reported Ca from wood to get remobilised to the developing shoots in Ca starved plants.

Emanuelson (1984) has reported root development to have an exponential course at higher levels of Ca and was enhanced with increased Ca concentration.

Being the major cation in middle lamella, Ca is supposed to support the mechanical strength of tissues (Rasmussen, 1967). Paulson and Harper (1968) reported synthesis of nitrate reductase to be reduced by Ca deficiency, but the activity of enzyme was found unaffected. Calcium functions as an activator of enzymes like phosphatase, kinases, and succinate dehydrogenases

(Pandey and Sinha, 1972). They have described calcium as a base for neutralisation of organic acids and essential for counteracting metal toxicity. Being a constituent of amylase - a starch digesting enzyme, it played an important role in binding of nucleic acids with protein.

Calcium ion itself is reported to be inactive, its activity being modified through a homologous class of calcium binding proteins. 'Calmodulin' is one among such proteins that control numerous key enzyme systems and cellular processes. The Ca calmodulin complex bind the calmodulin dependent enzymes like NAD kinase thus turning them 'on' (Anderson and Cormier, 1978).

Calcium ions and their acceptor calmodulin were found involved in diverse processes such as phototropism, photoperiodism, geotropism and hormonal regulation of growth (Cheung, 1980).

2.1.4.2 Characteristic deficiency symptoms

Calcium deficiency symptoms have been reported to appear first on roots. Root tips became slimy and turn black (Murray, 1966; Chapman, 1975).

Being immobile inside the plant, deficiency symptoms were first manifested in younger leaves. There may be dieback of terminal buds and the leaves may be often distorted and small, with irregular margin and necrotic spots (Muller, 1966).

Murray (1966) described Ca deficiency in cocoa as thickened midrib in young leaves and shortened internodes. Premature defoliation and die-back resulted in advanced cases.

In apple, Ca deficiency was exhibited as cupping and chlorosis of developing leaves, marginal chlorosis and necrosis of chlorotic area (Shear, 1971). Chapman (1975) reported dieback followed by leaf chlorosis as Ca deficiency symptom in citrus.

Thick, brittle and reduced younger leaves with blunt end which later developed to leaves with crinkled appearance and necrotic areas were the Ca deficiency symptoms reported in nutmeg (Philip, 1986).

2.1.4.3 Interaction with other elements

Calcium is reported to antagonise with K and Mg (Smith and Rasmussen, 1959; Smith, 1966). High Ca was found to reduce leaf Mg, K, Na and P in citrus (Anderson and Martin, 1970). Uptake of K, Rb, Br, Cl, $SO_4$ and $PO_4$ were found accelerated by Ca (Gardner et al., 1985). Nybe (1986) has observed an increase in foliar K and Mg due to Ca deficiency in pepper. An increase in levels of K, Mg and N and a decrease in B were found associated with Ca deficiency in Nutmeg (Philip, 1986).

2.1.5 Magnesium

2.1.5.1 Role in plant growth and development

Magnesium formed one of the constituents in the most vital and widely distributed plant pigment - chlorophyll. It constituted 2.7 per cent by weight of chlorophyll and hence, played a key role in photosynthesis. Magnesium was known to play a catalytic role as an activator of a number of enzymes most of which were concerned in carbohydrate metabolism, phosphate transfer and decarboxylation. The enzymes include enolases, pyrophosphatases, hexokinases, carboxylases, phosphokinases, transketolases, fructokinases, glucokinases and pyrophosphorylases (Dixon, 1949 and Agarwala and Sharma, 1976).

According to Wallace and Muller (1962), there was a higher requirement for Mg at high temperatures due to its significance in $CO_2$ fixation during photosynthesis.

Magnesium is reported to act as and helps in the solubilisation of P (Ananthanarayan and Rao, 1979).

2.1.5.2 Characteristic deficiency symptoms

Being mobile inside the plant, the deficiency symptoms first appeared on older leaves (Embleton, 1975).

The Mg deficiency in citrus was reported as chlorosis of older leaves which started at the tip and premature shedding of older leaves (Reitz, 1958; Tanaka, 1960). Tree growth and leaf fall during summer in citrus were closely related to leaf Mg content (Hansen, 1970).

Magnesium deficiency in coffee was characterised by an olive green chlorosis near mid rib and laterals which progressed to leaf margins (Muller, 1966).

In apple Mg deficiency occurred in young trees and was rare in grown up trees due to deep root penetration. Potassium-Mg ratio in soil and leaves was the factor causing Mg deficiency. Leaf fall is reported to be favoured by Mg deficiency (Sadowski et al., 1976).

Pale yellow colouration of mid rib of older leaves followed by pale green, lemon and necrotic blotches towards margin, with upward cupping were the major symptoms of Mg deficiency in nutmeg (Philip, 1986).

2.1.5.3 Interaction with other elements

Various workers have reported antagonistic influence of Mg with K and Ca (Emmert, 1961, De Waard, 1969, Nybe, 1986). Magnesium deficiency was often associated with high K (Manicot, et al., 1980).

2.1.6.2 Characteristic deficiency symptoms

Many of the symptoms of S deficiency were similar to that of N deficiency. Both N and S were constituents of protein and deficiency caused accumulation of carbohydrates and soluble nitrogen compounds. Increased protein hydrolysis and decreased synthesis has been reported in deficient plants (Greulach, 1973).

Sulphur deficiency resulted in phloem breakdown, decrease in cambial tissues and increase in leaf thickness. Increase in thickness of fibre, xylem and collenchyma cells has also been reported. 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 (Hewitt, 1963).

Cell division may become abnormal in sulphur deficient plants. The spindle movements and mechanism depend on the presence of thiol groupings which form cross linkages by oxidation and disulphide formation (Steffensen, 1954; Hewitt, 1963).

An overall yellowing of leaves occur due to S 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).

Lott et al. (1960) and Muller (1966) observed typical yellowing of youngest leaves as the S deficiency symptoms in coffee. The young leaves first expressed a uniform light green colour turning later to intensive chlorosis and leaves eventually becoming yellow. The areas along the mid rib were always green. The shoot growth was reduced.

Smith (1966) reported Mg deficiency to be associated with a decrease in foliar concentration of Zn and Mn in citrus. They also observed that, concentration of N, P, Fe and B in leaves were not affected by Mg level even in severely deficient trees.

Increasing Mg supply was found to lower K content in apple, (Hugriet, 1979) the effect being most evident in the epidermis and mesocarp. Leaf magnesium was usually negatively correlated with K.

### 2.1.6 Sulphur

#### 2.1.6.1 Role in plant growth and development

The importance of S is equal to that of N in terms of protein synthesis and in total uptake, it exceeds P at times.

The most important function of 'S' reported in plants is its participation in amino acid synthesis, which is the important building material of plant protein (Kramer and Kozlowski, 1960, Hewitt, 1963).

The SH group of proteins were found important in their enzymatic activities and also in cross bonding of protein molecules (Greulach, 1973). Sulphur deficiency resulted in poor quality crop products and is hence recognised as a quality nutrient (Rajagopalan, 1987).

Sulphur is a component of lipoic acid, Coenzyme - A, thiamine, pyrophosphate, biotin, etc. It is found essential for synthesis of chlorophyll and for cell division (Evans and Sorgor, 1966). It is found to enhance the efficiency of translocation of assimilates from leaf to fruits (Thirumalaiswami et al., 1987).

2.1.6.3 Interaction with other elements

Sulphur deficiency was associated with high N, P & K contents in leaves of coffee (Lott et al., 1960) and citrus (Smith, 1966).

Increase in foliar N and P was observed due to S deficiency in nutmeg (Philip, 1986).

Application of sulphur in the form of dust increased the total Ca in the stem as against the content in the leaves of groundnut (Thirumalaiswamy et al., 1987).

2.1.7 Iron

2.1.7.1 Role in plant growth and development

Iron in living cells is found chiefly in the form of porphyrins. Of the various metal porphyrins, Fe porphyrins (Hemes) and Mg porphyrins (chlorophylls) have been found in nature in abundance. Iron act as a calayst and electron carrier in respiration. The peroxidases, catalases and cytochrome oxidases which are widely distributed in plants are iron porphyrin containing enzymes that catalyse various chemical reactions. The transfer of electrons from substrates are mediated almost exclusively by the iron porphyrin containing series of cytochromes (Nason and McElroy, 1963).

There exist non heme iron proteins like ferrodoxine and mitochondrial Fe enzymes (Burris, 1966). Fe actively participates in chlorophyll synthesis and much of the Fe in leaves is in the chloroplasts (Bogorad, 1966).

Iron is reported to act as an activator of nitrate reductase and aconitase (Salisbury and Rosc, 1978; Alcaraz et al., 1979) and played significant role in synthesis of nucleic acids and proteins.

Though Fe is described by various scientists as immobile inside the plant system, Branton and Jacobson (1962) and Brown (1965) have reported iron to be moderately mobile in plants. Foliar applied Fe was found translocated to meristematic tissue.

2.1.7.2 Characteristic deficiency symptoms

The most characteristic effect of iron deficiency reported was the failure to produce chlorophyll in young leaves. The element being sparsly immobile, the younger leaves were the first affected by Fe deficiency. Leaves that had once obtained adequate iron for development, seldom developed chlorosis even when deficiency was subsequently severe to cause complete chlorosis of younger leaves (Hewitt, 1963).

Interveinal chlorosis appeared initially producing a fine reticulate pattern in partially expanded leaves. Necrosis reported was rare for iron deficiency. Chloroplasts were found decreased in size and the injury being irrevessible under severe conditions of iron stress (Jacobson and Oertli, 1957).

Chlorosis under Fe stress was associated with break down of chloroplasts in young leaves, with early lysis of starch grains. Vacuolation of chloroplasts has also been reported. Restricted growth was reported in iron deficient plants due to an abrupt cessation of cell division in the apical meristem (Brown and possingham, 1957).

Stunted growth and tip die back were found to follow intervenal chlorosis in Fe deficient cocoa trees (Maskell et al., 1953). They have also reported abnormal shooting of axillary buds and die back of young shoots as characteristic symptoms.

Childers (1966) reported iron chlorosis in strawberry, citrus and avocado. Severely affected leaves turned yellow and showed marginal and tip burning. Dieback of shoots and branches occurred in acute situations.

Muller (1966) described Fe deficiency symptoms in coffee as dark green veinal network on chlorotic parenchyma. General papery collapse of leaf margins or whole leaves followed by total bleaching has been reported as severe symptoms of Fe deficiency (Gauch, 1972).

Straw coloured young flush with interveinal chlorosis which later developed necrotic patches on leaf lamina has been reported as Fe deficiency symptom in nutmeg by Philip (1986). He has also reported reduced leaf size and downward cupping of leaves in Fe deficient plants.

2.1.7.3 Interaction with other elements

Iron deficiency was found to be induced due to the presence of Ca and Mg carbonates, deficiencies of K or Ca, excess P, Cu, Mn, Zn or Mo. High pH also induced Fe deficiency (Wallace and Hewitt, 1946).

High N, P and K have been reported in Fe deficient leaves of coffee (Muller, 1966). Iron deficiency in citrus was reported to be associated with a high content of N and low Ca in leaves (Smith, 1966). Iron was found to antagonise with P (Muller, 1966; Childers. 1966).

High Fe ratio has been reported to induce foliar symptoms of Mn deficiency in lemon. The leaf N, P and K rose along with Fe but Ca decreased in proportion to increase in Fe. Low Fe rate induced most rapid decrease in foliar N level. Similar trends were observed with P and K (Carpena et al., 1968).

High foliar P, Zn and Mn and low K and Ca in leaves were associated with Fe deficiency in nutmeg (Philip, 1986).

### 2.1.8 Manganese

#### 2.1.8.1 Role in plant growth and development

Largest amount of Mn in plant cell is concentrated in the cytoplasm and among cell organells, the chloroplasts are the richest in Mn. Manganese as an oxidator has been reported to counterbalance large amounts of tannides (Levanidov, 1957). Shkolnik (1984) has reported some of the hydrophytes and woody plants to be rich in Mn, which was related to their biochemical composition. They were referred as manganophiles and were reported to be rich in tannides and apparently alkaloids.

Manganese and iron are reported to regulate and maintain the activity of a particular oxidation reduction reaction. Mn acted as an activator of many enzymes including dehydrogenase, peroxidase and catalase. Increase in Mn content increased the peroxidase activity in leaves and this attributed to the necrotic browning in high Mn plants (Horiguchi, 1988).

Manganese has been reported to act as an activator of carboxylase that catalyse assimilation of $CO_2$ and lead 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 $O_2$ (Mehler, 1951; Salisbury and Rosc, 1978). It was found involved in many of the reactions in glycolysis and Krebs' cycle (Horiguchi and Fukomoto, 1987).

Wide variation has been reported in Mn content of plant species and crops exhibited differential tolerance to Mn levels (Edwards and Asher, 1982). Horiguchi and Fukomoto (1987) has reported that though Mn concentration of 200 to 300 ppm in plant parts were toxic in most cases, it was 1000 ppm for corn and 2000 ppm for rice. Mn toxicity level reported for sunflower was 5300 ppm (Edward and Asher, 1982). Wang (1987) has analysed rubber

plant parts collected from 46 countries and reported that the Mn content varied from 31 to 2167 ppm.

2.1.8.2 Characteristic deficiency symptoms

Manganese deficient plants exhibited either a reduction in number of chloroplasts or a disorganisation, resulting in low concentration of chlorophyll (Hofman, 1967). The deficiency symptoms first appeared on upper leaves and resembled iron deficiency characterised by irregular green bands and necrotic spotting (Shkolnik, 1984).

The fruit plants like citrus, walnut and plum exhibited young leaves with chlorosis between the main veins and die-back of twigs and branches under conditions of Mn deficiency (Childers, 1966). Citrus decline and leaf blight were found associated with Mn and Zn deficiency (Anderson and Calvert, 1970).

Muller (1966) reported youngest leaves to be first affected by Mn deficiency in coffee. Affected leaves showed typical chlorosis with coarse reticulation. Similar reports have been made in mango by Agarwala et al. (1988).

Pale yellow chlorosis, reduced size of young leaves, water soaked necrosis and torn off leaves were symptoms of Mn deficiency in nutmeg (Philip, 1986).

Mangansese at high levels has been reported to be toxic in various crops. Toxicity symptoms were expressed in citrus as marginal yellowing and necrotic spots on leaves. Excess application on Mn was found to increase abnormal leaf fall in citrus. Tree growth and cropping was greatly reduced (Ishihara et al., 1968 and 1971).

Manganese toxicity was found to be the main cause of internal bark necrosis of apple trees and that, low levels of boron supply was reported to be a modifying factor (Sadowski et al., 1981).

2.1.8.3 Interaction with other elements

Shive (1941) and Somer and Shive (1942) reported Fe-Mn antagonism and a low Fe to Mn ratio in plant tissue to cause oxidation of ferrous iron to ferric form making it unavailable to plants. Mn induced Fe deficiency has been reported by various workers (Hewitt, 1963, Agarwala et al., 1986).

Edward and Asher (1982) has reported Mn to have no effect on Ca and Mg content in tops of Mn tolerant plants. They have reported the concentration of Zn in leaves of Mn sensitive plants to increase with increase in Mn. Zn and K increased in shoots and decreased in roots. Islam (1986) has reported a reduction in Fe and Mg with increased Mn. He has also reported an interaction between Ca and Mn. An increase in Ca was effective in reducing Mn toxicity. Mn uptake was reduced by increase in Ca level in nutrient solution.

2.1.9 Copper

2.1.9.1 Role in plant growth and development

The presence of Cu in plants has been recognised as early as in 1816. The nature and involvement of Cu in metabolic processes was determined by the specific physico chemical properties of the metal. Copper ions reacted with amino acids, proteins and other polymers producing stable complexes and hence, was more active than other metals. Secondly, Cu ions possess catalytic properties which were enhanced upon binding of the ion to a protein molecule. Thirdly, Cu ions 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).

Chloroplasts contained more than 70 per cent of Cu content in leaves and was found involved in biosynthesis of proto-chlorophyll and iron porphyrin complexes (Sorokina, 1967). It was found to be a component in ribulose diphosphate carboxylase (Wishnick and Mildvan, 1969), confirming its role in photosynthesis.

Endowed with the ability to change valency, Cu like Fe, Mn and Mo occupy central position in the mechanism of biological oxidation reduction reactions including those of respiration, photosynthesis and assimilation of molecular nitrogen. Phenol oxidation was reported not to take place in the absence of Cu resulting in accumulation of gum on twigs and fruits (Shkolnik, 1984).

The protective action of Cu against destructive superoxide radicle has been established by Klyavinya and Ozollnva (1978). Hence, Cu deficiency resulted in reduced protection against ultraviolet rays, oxidation of lipids and chlorophyll and disintegration of membranes.

Nucleic acids and some nucleic acid precussors were found to have high affinity for Cu ions. Biosynthesis of adenine, adenosine and adenosine monophosphate were enhanced by Cu ions (Okuntsov et al., 1966).

Copper was found to play a role in auxin metabolism. High correlation existed between indole acetic acid content and activity of Cu enzyme - ascorbinate oxidase. It was found to enhance tryptophan synthesis (Gamayunova, 1965).

A positive influence of Cu has been reported on resistance to wilting. This effect is apparently related to the effects of Cu on the phenolic inhibitor content (Prusakova, 1966).

Copper was found to have variable phloem mobility from leaves; being retained while they are green and mobilised with N during senescence (Loneragan, 1982).

2.1.9.2 Characteristic deficiency symptoms

Copper being immobile in plant system, the deficiency symptoms were first exhibited on new growth (Muller, 1966). Die back of twigs and Chlorosis of young leaves have been reported as the characteristic symptoms in most of the plants (Anderson, 1932).

Production of large, dark green leaves followed by gummosis and die back of shoots were the initial symptoms reported in citrus (Camp et al., 1949). Later, twigs developed multiple shoots with small leaves that dropped shortly. Leaves were irregular with cupping of mid rib.

Copper deficient plants had leaves with low osmotic pressure due to low level of sucrose and hence showed its inability to adapt to meterological changes (Mizuno et al., 1983). The leaf tip became dry, curled up and showed deformation and drooping. They showed a marked decrease in moisture content.

Interveinal chlorosis, reduced size of new flush, downward cupping of leaf margins associated with reduced height, and total dry matter are the symptoms reported in copper deficient nutmeg plants (Philip, 1986).

2.1.9.3 Interaction with other elements

Physiological functions of Cu in plants were intimately associated with interactions that take place between Cu and other mineral elements. Antagonism was reported to occur between Fe and Cu (Gamayunova and

Ostrovskaya, 1964). In acid soils, tolerance of Cu content was low whereas in alkaline soils, plant tolerated upto 3| times that in acid soils (Plessis and Burger, 1971). No foliar accumulation of Cu has been reported.

Interaction between Ca and Cu was reported by Zhiznevskaya (1972). Copper acted as a regulator of Ca level in leguminous plants. In citrus, Cu deficiency has been found associated with high foliar N, K and Low Ca (Smith, 1966).

Copper deficiency was associated with an increase in foliar Fe and Mg and a decrease in Ca content of leaves of nutmeg (Philip, 1986). The N and $P_2O_5$ content were found to be doubled in Cu deficient wheat plants (Mizuno et al., 1983). No foliar accumulation of Cu has been reported (Burger et al., 1971).

2.1.10 Zinc

2.1.10.1 Role in plant growth and development

Within the plant, Zn concentration was high in leaves, ge
and growth points (Riceman and Jones, 1960). Zinc was found in plants mostly in the ionic form and less associated with complex compounds. Inside the cell, greater part of Zn occurs in nuclei and mitochondria (Kathore et al., 1972) associated with high molecular weight compounds suggesting its role in cell division.

Zinc was found incorporated in a multitude of metalloenzyme complexes and has the ability to activate a large number of enzyme complexes (Riordan, 1976). The metabolic function of Zn has been reported to be more varied than any other trace element.

Zinc is reported to be involved in the biosynthesis of porphyrins and haemo proteins, including cytochrome (Brown et al., 1966).

Zinc influenced glycolysis and respiration being a constituent of many enzymes in these pathways (Nason and McElroy, 1963). The principal respiration pathway was reported to be strongly inhibited under inadequate Zn supply (Shkolnik, 1984) due to decrease in activity of aldolase and a number of glycolytic enzymes.

Zinc was reported to be involved in the biosynthesis of chlorophyll precursors - protoporphyrins and porphobilinogen (Fugiwara and Tsutsumi, 1962).

Zinc has been reported to determine the auxin level in plants through their influence on tryptophan, the precursor of IAA (Skoog, 1940; Tsui, 1941). Tryptophan was converted to IAA through tryptamine. The large amount of tryptamine found in Zn deficient plants indicated that Zn is necessary for conversion of tryptamine to IAA (Takaki and Arita, 1986).

In the absence of Zn, glucose was found to get accumulated and synthesis of cellulose reduced. The osmotic pressure of cell was high and cell elongation reduced. Zinc was reported to influence gibberellin content in plants (Shkolnik et al., 1975) and the shortage of endogenous gibberellin during Zn deficiency may be one of the factors that inhibit stem growth resulting in shortening of internodes.

Evidence on the involvement of Zn in nucleic acid metabolism suggests the most important physiological role of Zn. It is reported to be an integral part of RNA dependent DNA polymerases (Springate et al., 1973) which plays an important role in transcriptions. Many of the enzymes needed for DNA duplications were found to contain Zn. Deficiency severely depressed the production of protein in meristematic tissue and brought about accumulation of aminoacids and amides (Kitagishi and Obta, 1986).

Epstein (1961) has reported Zn to have an apparent role in function of membranes. Zinc and Ca ions were found concerned in regulating ion

transport across cell membranes. Zinc deficient plant roots exhibited a greater leakage (Welch et al., 1982).

2.1.10.2 Characteristic deficiency symptoms

Reduced internodal length, rosetting, distorted and unusually small leaves are the major symptoms reported of Zn deficiency, all being largely due to inadequate supplies of IAA (Greulach, 1973).

Zinc deficiency symptoms have been reported in many crops under field conditions. Nair et al. (1968) has reported visual symptoms of Zn deficiency in citrus as mottled leaf, reduced leaf size and dieback of terminals.

Rosetting in apple is reported as mainly due to an imbalance of Zn nutrition (Naumov et al., 1977). In mango, among the minor elements studied, Zn deficiency appeared first on young and middle leaves (Agarwala et al., 1988). Marked reduction in length of vine, internodal length, leaf area and dry matter has been reported in Zn deficient pepper vines (Nybe, 1986). Similar reports were made in nutmeg by Philip (1986).

2.1.10.3 Interaction with other elements

Suggestions that Zn deficiency cause P to accumulate to toxic levels in older leaves have been confirmed in various crops (Johnson and Simons, 1979; Andrew et al., 1981; Welch et al., 1982).

In citrus, Zn deficiency was associated with high N and K and low Ca in leaves (Smith, 1966).

Foliar Zn absorption increased with higher Mn concentration whereas iron reduced it. Calcium was found to reduce foliar Zn absorption (Arora et al., 1970).

Increase of foliar P, Fe and decrease in Mg has been reported in Zn deficient nutmeg plants (Philip, 1986).

2.1.11 Boron

2.1.11.1 Role in plant growth and development

Unlike other essential trace elements, boron is neither a constituent of enzymes nor an activator. Bulk of boron present in plants was reported to be concentrated in cell walls (Starck, 1963). Lee and Arnoff (1967) reported that borates complex with 6 phospho gluconic acid; thus inhibiting the action of its dehydrogenase and preventing the eventual synthesis of excessive quantities of phenolic acids, which accumulate in boron deficient plants and cause necrosis and death.

Inhibition of growth of vegetative shoot as a result of boron deficiency was reported to be based on the accumulation of phenolic growth inhibitors which resulted in stimulation of pentose phosphate pathway in boron deficient plants (Shkolnik and Illinskaya, 1975).

Lewis (1980) has illustrated 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. It was found to regulate the hydrolytic and oxidative functions of phenolases, contributing to the biosynthesis of lignin precursors which are highly essential for vascular plants especially those with well lignified xylem.

Boron deficient plants exhibited a reduced rate of photosynthesis which was due to an alteration in chloroplast structure along with a reduction in galacto lipid content (Kibalenko, 1973). Boron was found to interfere

with the protein synthesis in ribosomes, the effect being reported only in dicot plants (Shkolnik, 1984).

Necrosis of apical meristem, the main site of IAA synthesis and synthesis of phenolics and inhibition of xylem and phloem differentiation acted behind all the external symptoms exhibited by boron deficient plants (Marschner, 1982).

According to Pilbean and Kirkby (1983), the presence of B was found essential to maintain membrane structure and many of the deficiency symptoms were secondary effects caused by changes in membrane permeability.

2.1.11.2 Characteristic deficiency symptoms

Boron deficiency lead to degeneration of meristematic tissue, breakdown of walls of parenchyma cells and poor development of vascular tissues. Phloem and xylem were poorly developed. Rosetting of terminal growth, die back, discolouration, thickening and brittleness of leaves, curling, wrinkling, chlorosis etc. are some of the general symptoms (Bradford, 1975).

Downward cupping of leaves and reflexing of leaf tips were the deficiency symptoms in cocoa (Maskell et al., 1953). Small young leaves, leathery texture, irregular leaf margin, and reduced internodal length were the results of boron deficiency in coffee (Muller, 1966).

Failure of apical bud, brittle upper leaves with mottled appearance followed by necrosis were the typical symptoms of boron deficiency in pepper (Nybe, 1986). Crinkling of leaves, premature shedding and die back were the characteristic symptoms in nutmeg (Philip, 1986).

2.1.11.3 Interaction with other elements

Boron interactions with other elements are quite scanty. In citrus B deficiency was associated with a high P and Mg and low K content of leaves (Smith, 1966). A decrease in foliar Ca and K and increase in foliar N and P was found associated with B deficiency in Nutmeg (Philip, 1986).

A synergistic relation between B and K has been reported by Sakal et al. (1988) based on their work in legumes.

2.1.12 Molybdenum

2.1.12.1 Role in plant growth and development

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

The most significant physiological role reported for Mo is its involvement in nitrogen metabolism particularly in the reduction of nitrates and fixation of molecular nitrogen (Nicholas and Stevens, 1955). The Mo containing enzymes reported are numerous. Shkolnik, 1984. has reported the role of Mo as a catalyst in various metabolic reactions.

Molybdenum is important in energy metabolism. Hewitt (1958) reported Mo to stimulate respiration and phosphorylation. It formed complexes with RNA through phosphate groups (Ivchenko, 1981).

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

Pectin metabolism has been reported to be influeced by Mo to some extent and a possible influence of Mo on cell membrane structure has been

suspected. Molybdenum has been reported to influence the phospholipid synthesis and thereby the cell membrane structure (Ivechenko, 1981).

Much of the activities of Mo in plants remain obscure and further investigations are needed to determine its activity in individual biochemical reactions.

2.1.12.2 Characteristic deficiency symptoms

Plants growing in acidic soils usually exhibited Mo shortage where this element is found in a largely immobile state (Burkin, 1968). The initial symptoms of Mo deficiency appeared as yellowish green or pale orange interveinal spots. The molybdenum deficiency eventually resulted in diminished number of flowers on the plant (Shkolnik, 1984).

The flowers on Mo deficient plants usually lost their ability to anthesis. Severe disturbances in the formation of reproductive organs, especially in the development of pollen has been reported (Agarwala et al., 1979).

2.1.12.3 Interaction with other elements

Molybdenum and Al has been reported to be antagonistic, the toxic influence of Al and Cu being counteracted by Mo (Millikan, 1948). Barrocio (1962) reported synergism between Mo and K. Candela et al. (1957) has reported excess Mn to adversely affect growth of plants suffering from Mo deficiency. Ishihara et al. (1968) has reported antagonistic relation between Mo and Ni.

## 2.2 Seasonal changes in foliar nutrient level

Since leaf is the principal site of plant metabolism, changes in nutrient supply are reflected in the composition of leaf. These changes are more pronounced at certain stages of development and concentration of nutrients in leaf at specific growth stages are related to the performance of the crop.

Seasonal influence on nutritional status of the plant has been reported in various crops. A significant negative correlation between light intensity and nutrient concentration has been reported in apple (Roger and Batger, 1952), rubber (Shorrocks, 1962), apricot (Malik, 1966) pepper (De waard, 1969), etc.

According to Ulrich (1952) best time for collecting leaf samples was between 8 AM and 12 Noon. Lin (1963) opined that leaf samples should be collected before noon to avoid diurnal variation in leaf N.

In citrus, the N, P and Mg contents of the tree were maximal as new shoots emerged and then decreased. The Ca content was lowest on emergence and then rose. Nitrogen absorption was greatest in December, $K_2O$ in June, Cao in November and Mgo in September - October. During winter, minerals were translocated to the roots (Hirobe and Ogaki, 1968).

In lemon, the nitrate nitrogen varied little from October to April, but rose between May and September with peak in July. High temperature brought the nitrate reductase activity lowest in July and Highest in October to April (Alcaraz et al., 1979).

Seasonal changes in Zn and water soluble phenolics has been reported in citrus by Nair and Mukherjee (1970). The contents were more in outer 2.5 cm trunk of orange trees in winter than in summer.

Ludders and Buneman (1973) have reported the highest uptake of nutrients in June to September in apple. The N content of apple trees has been reported to be highest early in the season, which declined sharply until mid summer and remained stable thereafter (Chuntanaparb and Cummings, 1980). Phosphorus concentration was the highest in early sample with slight variation after mid seasons. Magnesium was highest in leaf margins. No seasonal trend was reported for K and Mg. Calcium content increased non linearly throughout the season.

GuManru et al. (1981) has reported the N requirement for apple to be the greatest during March to May, least in September to March and a steady supply from May to September.

High N reserves and high N supply during the whole vegetative period were found necessary for a regular, annual bearing in apple (Faby, 1986). Nitrogen reserves in the trees from previous year's manuring were mobilised in spring and together with spring N application, were essential for flower bud initiation in early June.

Seasonal changes in N concentration has been reported in Avocado by Bar et al. (1987). Leaves from spring flush were sampled to interpret nutrient concentration.

Bargara and Chadha (1988) has reported the significance of standard leaf for leaf analysis. They have quoted the standard leaf for different crops which is of high significance in predicting the nutrient status of the crop. There existed a cyclic rythm to the elemental concentration in plants reflecting the interaction between uptake and translocation with changes in the dry matter accumulation. Elemental concentration varied with species. Of the 10 major and minor elements studied, only B and K was reported to be affected by rainfall and applied irrigation. Boron concentration increased during dry periods and decreased after rains and reverse was the case for K.

# Materials And Methods

# MATERIALS AND METHODS

The investigations pertaining to the nutritional aspects of clove (*Syzygium aromaticum* (L.) Merr. and Perry) reported herein consist of four main parts.

1. Induction of nutrient deficiency symptoms.
2. Nutrient distribution and translocation under nutrient stress condition.
3. Annual nutrient removal by a bearing clove tree
4. Seasonal variations in foliar nutrient concentration in bearing clove tree.

The first two aspects were studied with clove seedlings grown in pots and the latter two with field grown clove trees.

## 3.1 Induction of nutrient deficiency symptoms

To induce nutrient deficiency symptoms in clove seedlings, sand culture experiments were carried out in the green house of the Radio Tracer Laboratory, Kerala Agricultural University, Vellanikkara from July 1986 to August 1988.

### 3.1.1 Planting material

Clove seeds were collected from selected high yielding gardens in Nagarcoil, Tamil Nadu during June-July. The seeds were depulped and larger olive green ones without any discolouration were selected from single-seeded fruits. They were sown initially in germination beds of fine sand. Flat and shallow sowing with 5 cm spacing was adopted. The seed beds were kept moist by regular watering. The seedlings within 2 days of germination were transplanted in polythene bags of 25 x 15 cm size filled with potting mixture (1:1:1 sand soil and powdered cowdung). They were kept in shade and watered regularly.

the first two weeks of transplanting, the plants were supplied with complete nutrient solution for their establishment and thereafter, the nutrient treatments were imposed. Before starting the treatments, the growth media was flushed with deionised water repeatedly for three times to washaway the nutrient residues.

3.1.4 Treatments

The treatments tried were

1. Complete nutrient solution (C)
2. Nutrient solution minus nitrogen (-N)
3. Nutrient solution minus phosphorus (-P)
4. Nutrient solution minus potassium (-K)
5. Nutrient solution minus calcium (-Ca)
6. Nutrient solution minus magnesium (-Mg)
7. Nutrient solution minus sulphur (-S)
8. Nutrient solution minus iron (-Fe)
9. Nutrient solution minus manganese (-Mn)
10. Nutrient solution minus copper (-Cu)
11. Nutrient solution minus zinc (-Zn)
12. Nutrient solution minus boron (-B)
13. Nutrient solution minus molybdenum (-Mo)

There were fifty plants in each treatment and a total of 650 plants in the experiment. The plants under each treatment were grouped into three sets of 15 plants each and the remaining five plants were kept for observational purpose.

3.1.4.1Standardisation of nutrient solution composition

Preliminary studies were conducted with Hoagland and Arnon solution as modified by Loue (1962) for cocoa and by Philip (1986) for nutmeg to examine its suitability for growing clove seedlings.

When the Loue's solution (pH 6.5) was applied to the pots, the establishment was very poor and the plants developed leaf scorching within 15 days. Later, the plants became stunted in growth. Leaf samples were collected from these plants for chemical analysis and the foliar nutrient composition was compared with that of healthy plants growing in pot mixture.

The chemical analysis indicated a high content of K (1.83%) in the plants receiving the nutrient solution as against a foliar level of 0.91 per cent in healthy plants. Further the pH of the sand medium also varied markedly.

In view of these, trials were conducted to fix up the optimum level of K and pH of the nutrient solution.

Three levels of K viz. 1, 3 and 5 meq $l^{-1}$ and pH viz. 4.5, 5.5 and 6.5 were tried. Of these, the nutrient solution with 3 meq of K and pH 5.5 was found to be the best as its application resulted in maximum response and survival of the plants (98%). Further, the solution was safer to apply as the plants did not show scorching of the leaves. The leaf analysis of these plants indicated low levels of K but adequate for satisfactory growth.

From the results of these trials, the composition of the complete nutrient solution for clove was finally modified and fixed as given below:

Composition of complete nutrient solution

| Elements | meq $l^{-1}$ |
|---|---|
| $NO_3$ | 10 |
| $PO_4$ | 3 |
| K | 3 |
| Ca | 6 |
| Mg | 4 |
| $SO_4$ | 4 |

| Elements | Meq $l^{-1}$ |
|---|---|
| Fe | 0.180 |
| Mn | 0.005 |
| Cu | 0.010 |
| Zn | 0.004 |
| $BO_3$ | 0.050 |
| Mo | 0.03 ppm |

As far as possible, the relative proportion of the elements present in the complete nutrient solution and in the deficient solution were kept the same. The details of stock solution prepared and the quantity taken for preparing the final solution are given in Tables 1 and 2. Analytically pure chemicals (AR grade) were used for the preparation of the solutions. The water for the preparation of nutrient solution was filtered and demineralised by passage through an ion-exchange resin column. Fresh nutrient solutions were prepared every tenth day. The pH of the final solution was adjusted to 5.5 by the addition of 25per cent NaOH or 6N HCl.

Iron was added separately to the pots as it caused precipitation when mixed with solution containing other nutrient elements. Stock solution of Fe was prepared by dissolving the required quantity of $FeSO_4 . 7H_2O$ in distilled water and acidifying it with $H_2SO_4$ (0.5 ml $l^{-1}$) to avoid precipitation.

Every alternate day plants were supplied with 250 ml of respective nutrient solution. Sand in each container was flushed with deionised water at an interval of 15 days to prevent salt accumulation and was followed by the application of fresh nutrient solution.

3.1.5 Recording of deficiency symptoms

The aerial portion of plants under each treatment were carefully watched for the appearance of any visual symptom and the date of

Table 1. Composition of stock solution prepared for making the final solution

| Chemical used | Quantity $g\ l^{-1}$ | Molar concentration |
|---|---|---|
| $KNO_3$ | 101.00 | M |
| $HNO_3$ | 63.00 | M |
| $MgSO_4 \cdot 7H_2O$ | 246.50 | M |
| $Ca(NO_3)_2 \cdot 4H_2O$ | 236.00 | M |
| $KH_2PO_4$ | 136.00 | M |
| $Mg(NO_3)_2 \cdot 6H_2O$ | 256.00 | M |
| $MgCl_2 \cdot 6H_2O$ | 203.00 | M |
| $NaNO_3$ | 85.00 | M |
| $K_2SO_4$ | 87.00 | 0.5 M |
| $Na_2SO_4$ | 71.00 | 0.5 M |
| $Ca(H_2PO_4)_2 \cdot H_2O$ | 6.30 | 0.025 M |
| $CaSO_4 \cdot 2H_2O$ | 1.70 | 0.010 M |
| $FeSO_4 \cdot 7H_2O$ | 2.50 | 0.010 M |
| $Fe(NO_3)_3$ | 4.00 | 0.016 M |
| $H_3BO_3$ | 1.00 | 0.016 M |
| $ZnSO_4 \cdot 7H_2O$ | 0.56 | 0.002 M |
| $CuSO_4 \cdot 5H_2O$ | 1.25 | 0.005 M |
| $(CH_3COO)_2Zn$ | 0.44 | 0.002 M |
| $CuCl_2 \cdot 2H_2O$ | 0.85 | 0.005 M |
| $MnCl_2 \cdot 4H_2O$ | 0.50 | 0.0025 M |
| $H_2MoO_4 \cdot H_2O$ | 0.05 | 0.0003 M |

Table 2. Composition of the different stock solutions (ml) taken to make one litre of nutrient solution under each treatment

| Chemical | C | -N | -P | -K | -Ca | -Mg | -S | -Fe | -Mn | -Cu | -B | -Zn | -Mo |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $KNO_3$ | 2 | 0 | 2 | 0 | 2 | 0 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| $HNO_3$ | 2 | 0 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| $Ca(NO_3)_2$ | 3 | 0 | 3 | 2 | 0 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| $MgSO_4$ | 2 | 0 | 2 | 2 | 2 | 0 | 0 | 2 | 2 | 2 | 2 | 2 | 2 |
| $KH_2PO_4$ | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| $Mg(No_3)_2$ | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| $K_2SO_4$ | 0 | 3 | 1 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $Ca(H_2PO_4)_2$ | 0 | 20 | 0 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $CaSO_4$ | 0 | 200 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $H_3BO_3$ | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 |
| $MnCl_2$ | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 |
| $FeSO_4$ | 10 | 10 | 10 | 10 | 10 | 10 | 0 | 0 | 10 | 10 | 10 | 10 | 10 |
| $Fe(NO_3)_3$ | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 |
| $H_2MoO_4$ | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| $CuSO_4$ | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 |
| $ZnSO_4$ | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 |
| $(CH_3COO)_2Zn$ | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| $CuCl_2$ | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| $MgCl_2$ | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $NaNO_3$ | 0 | 0 | 0 | 4 | 6 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $Na_2SO_4$ | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

appearance of symptom suspected to be due to deficiency were recorded and colour photographs taken. The symptoms were however confirmed only when three plants receiving the same treatment developed identical symptoms.

3.1.6 Observations on growth parameters

Observations on the following growth parameters were recorded at monthly intervals after the commencement of the treatments. The observations were recorded for each plant in each group under a treatment so as to get three group means for each treatment.

3.1.6.1 Height of the plant

The height of the individual plant was measured from the soil surface upto the growing point using a flexible measuring tape.

3.1.6.2 Internodal length

The topmost four pairs of leaves were considered to obtain the internodal length. The total length of the stem supporting the four nodes divided by the number of nodes (4) was taken as the internodal length.

3.1.6.3 Number of leaves

Total number of leaves produced in a plant were counted and recorded separately and mean value for each group was calculated.

3.1.6.4 Leaf area

A method to compute the leaf area from length and breadth measurements was first standardised. For this purpose, actual areas of

100 clove leaves of varying maturity and size were calculated graphically and different equations were tried for their goodness of fit by least squares method. The function $X = 0.58\ lb$ where l is the maximum leaf length, and b is the maximum leaf width, was found to explain 98.8 per cent variations in leaf area ($R^2 = 0.988$). The relationship is shown in Fig. 1. The analytical values are furnished in Appendix 1. This equation has been used for computing the leaf area of the seedlings in all the experiments.

3.1.6.5 Dry matter content

Three plants from each treatment were marked out and uprooted at bi-monthly intervals for the first ten months and at monthly intervals thereafter. The uprooted plants were washed and separated into root, stem and leaf. They were cleaned free of dust and dried in cross flow air oven at 70° ± 2°C till constant weights were obtained. For the purpose of chemical analysis, the leaves from each plant were sorted into two as those from lower half of the stem (A) and those from upper half of the stem (B).

3.1.6.6 Leaf area ratio (LAR)

LAR was worked out by the formula suggested by whitehead and Mycersough (1962).

$$LAR = \frac{LA_1 + LA_2}{W_1 + W_2}$$

Where,

$LA_1$ and $LA_2$ = Leaf area per plant at two successive growth stages.

$W_1$ and $W_2$ = Total dry weight of the plant at two successive growth stages.

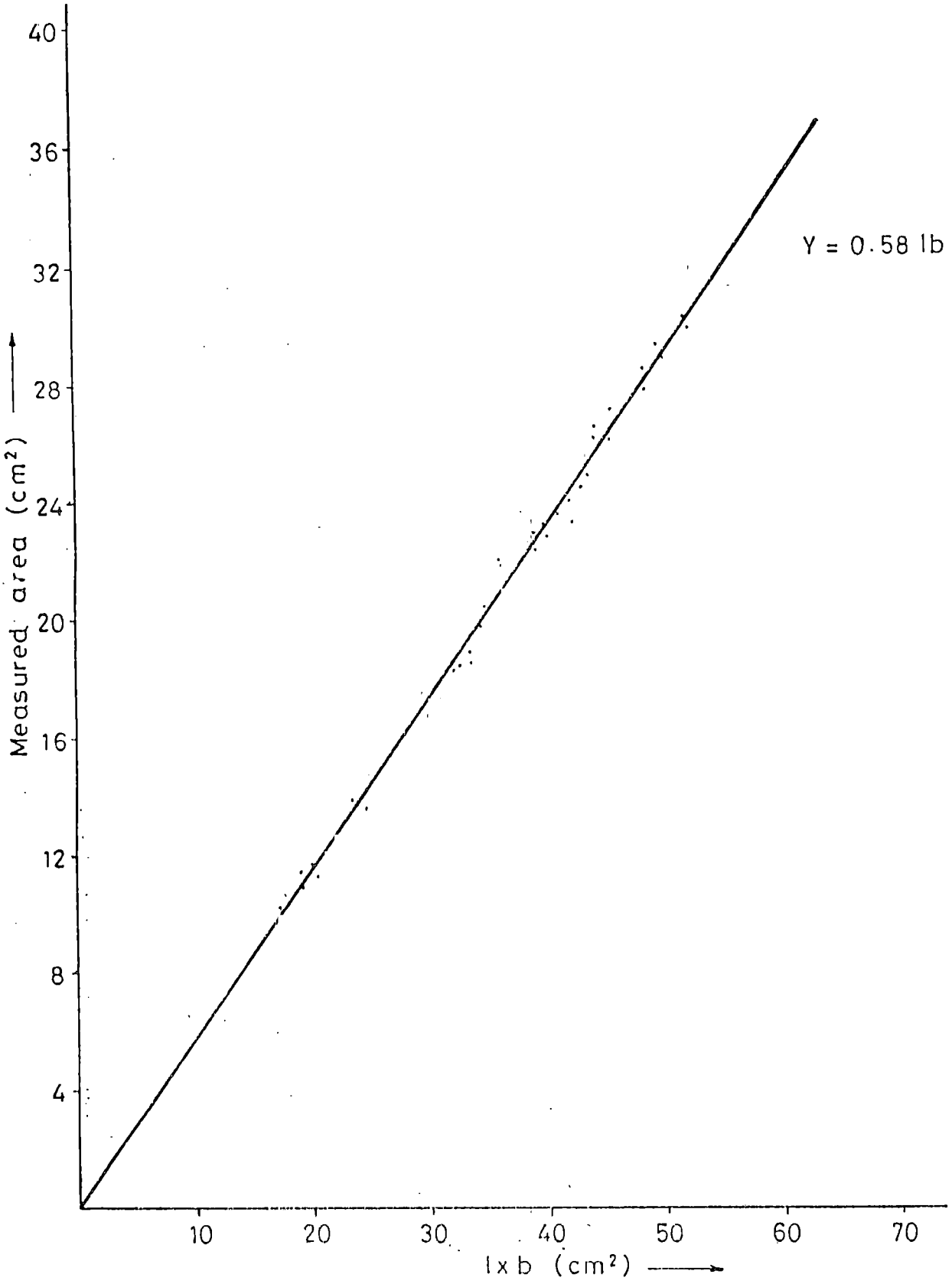



Fig. 1 Relationship between leaf area and the product of leaf length and breadth

3.1.6.7 Net assimilation rate (NAR)

It is the rate of increase in dry weight per unit leaf area per unit time. This was calculated by the formula of Gregory (1926) and was expressed as g per $m^2$ per day.

$$NAR = \frac{(W_2 - W_1)(\log_e LA_2 - \log_e LA_1)}{(t_2 - t_1)(LA_2 - LA_1)}$$

Where,

$LA_1$ and $W_1$ = Leaf area and weight of the plant respectively at time $t_1$

$LA_2$ and $W_2$ = Leaf area and weight of the plant respectively at time $t_2$

3.1.6.8 Absolute growth rate (AGR)

This gives an idea of daily growth rate. AGR was worked out by the formula suggested by Briggs (1920) and expressed as g per day.

$$AGR = \frac{W_2 - W_1}{t_2 - t_1}$$

Where,

$W_1$ and $W_2$ are the total plant dry weights at times $t_1$ and $t_2$ respectively.

3.1.6.9 Relative growth rate (RGR)

It is the ratio of increase in dry weight per unit dry weight per unit time. RGR was calculated by following the formula of Blackman (1919) and expressed as g per g per day.

$$RGR = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1}$$

Where,

$W_1$ = Dry weight of the plant at time $t_1$

$W_2$ = Dry weight of the plant at time $t_2$

## 3.2 Nutrient distribution and translocation under nutrient stress condition

The accumulation and distribution pattern of two anions ($H_2PO_4^-$ and $SO_4^{2-}$) and a cation (Ca) were studied under nutrient stress condition using radio isotopes.

Six month old seedlings were grown in quartz sand as in the previous study. For five months, the plants were supplied with deficient nutrient solutions which lacked the particular element whose distribution pattern was to be studied. At the end of five months' growth in nutrient deficient media, five plants were allowed to absorb the nutrient from a labelled solution of that particular nutrient. $^{32}$Phosphorus, $^{35}$S and $^{45}$Ca were used for the purpose. The plants receiving complete nutrient solution were also allowed to absorb the labelled nutrient solution in each case.

As the plants were shy absorbers of the nutrients and did not yield detectable radioactivity in the leaf in short term trials, longer periods were given for absorption of the labelled nutrient. For the very same reason, a larger initial activity in the solution was also found necessary. From the results of preliminary trials conducted for standardising the radioactivity requirement and feeding duration, the following quantities and durations were arrived at.

Dose and duration of isotope treatment

| Isotope | Concentration | Time allowed for absorption |
|---|---|---|
| $^{32}P$ | 0.04 $\mu$ci $ml^{-1}$ | 24 hrs |
| $^{35}S$ | 710 $\mu$ci $ml^{-1}$ | 30 days |
| $^{45}Ca$ | 418 $\mu$ci $ml^{-1}$ | 30 days |

Five plants each of the control and those under respective nutrient stress were utilised for the study. The plants were flooded and leached with deionised water before applying activity. Then they were kept in larger buckets (5 l capacity) so as to avoid the leaching loss of labelled solution. The activity was fed to all the treatments except $^{32}P$ along with 250 ml nutrient solution corresponding to each treatment. Once the isotopes were fed, no more nutrient solution was supplied to the plants. To compensate the evapo-transpirational losses, 100 ml deionised water was applied once in a week to each plant under the treatment.

For feeding $^{32}P$, the plants in silica sand media were uprooted and placed in 300 ml capacity solution bottles to which the 250 ml $^{32}P$ labelled solution (0.04 $\mu$ci $ml^{-1}$) was added. The plants were kept in position with cardboards provided with slits.

After the prescribed period of absorption as mentioned earlier, the aerial plant parts were detached, different parts separated, oven dried at 70 ± 2°C and radio assayed for arriving at the distribution pattern of respective elements.

### 3.2.1 Radio assay

For the determination of $^{32}P$ in plant samples, the Cerenkov counting method developed by Wahid et al. (1985) was followed. The method consisted of wet digestion of oven-dried and finely cut leaves with 2:1 nitric-perchloric acid mixture and determination of radioactivity in the digest after transfering it quantitatively into a scintillation counting vial. The radioactivity was determined in a microprocessor controlled liquid scintillation system (Rackbeta of Pharmacia, L.K.B.) adopting channel settings and computer programme recommended for tritium counting by liquid scintillation technique.

The $^{35}S$ and $^{45}Ca$ assays were performed after dry ashing the plant sample in silica crucible over direct flame. The ash was taken up in one ml 0.1 N HCl and transferred quantitatively into a 20 ml scintillation counting vial using 15 ml of a dioxane-based liquid scintillator (60 g Naphthalene, 4 g 2,5-diphenyl oxazole (PPO) and 0.2 g 1,4-bis (5-phenyl oxazolyl) benzene (POPOP), 100 ml methanol and 20 ml ethylene glycol brought to 1 lit with dioxane). The radioactivity was then determined by scintillation counting technique in a liquid scintillation system mentioned already.

### 3.2.2 Autoradiography

The plants that received $^{32}P$, $^{35}S$ and $^{45}Ca$ were cut at 5 cm above sand level and the leaves were detached from the stem by cutting at the leaf axes to prevent further translocation of the absorbed radiolabel in the plant. The plant parts were then arranged on an absorbant paper in their original position and secured with the aid of adhesive tape. The specimen sandwiched between absorbant paper sheets was then pressed in a herbarium press and dried in an oven at 70°C for 30 minutes. After

drying, it was autoradiographed by placing on an X-ray film of size 17.5 x 30 cm in dark. The X-ray film was exposed for a period of 20 days and then developed using a commercial X-ray film developer solution (Agfa-Geevaert India Ltd). The developed film was photographed by placing it against an illuminated white back ground.

### 3.3 Annual nutrient removal by adult clove trees

Three eight year old clove trees growing under uniform fertilizer and cultural management as recommended by KAU (1986) and at a spacing of 6 x 6 m at the Instructional Farm, Vellanikkara were used for studying the annual removal of major and minor nutrients by the new growth put forth in an year.

In March, 1987, when the apical buds were dormant, all the shoots of the plant were tagged serially on each tree. Next year, in April (i.e. after allowing the shoots to grow for one year) all the tagged shoots were collected from the tree. The harvested shoots from each tree were then separated into leaf and stem. The flower buds (the economic plant part) were harvested as and when they matured during the period. The plant parts from each tree were weighed immediately to get the fresh weights of each portion. The dry weight of these plant parts were worked out separately after drying sub samples of each portion in an oven at 70°C ± 2°C. The dried plant samples were used for major and micronutrient analysis after grinding them in a mill fitted with stainless steel blades. The samples were analysed for N, P, K, Ca, Mg, S, Fe, Mn, Cu, Zn, B and Mo.

### 3.4 Seasonal variations in foliar nutrient composition

Seasonal variations in foliar nutrient concentration were studied with bearing clove trees of eight years receiving uniform fertilizer and

cultural management as prescribed by KAU (1986) at the Instructional Farm, K.A.U., Vellanikkara. Inorganic fertilisers viz. Urea, Super phosphate and Muriate of potash were applied to supplement the mineral nutrients. Six rows of plants (spacing 6 x 6 m) with 10 plants in each row were made use of for collecting leaf samples. The leaves were sampled separately for first, second, third and fourth ranks starting from the first mature leaf at the shoot tip. The leaf samples were taken from shoots all round the tree. At a given sampling time three trees from each row were sampled in this manner to form a replication for each leaf rank. Thus, there were 6 replications (6 rows) and 24 samples (4 leaf position x 6 replication) for each sampling interval. Each leaf sample consisted of 50-70 leaves. The samples were collected for one year at monthly interval starting from November 1987. The leaf samples were cleaned with cotton piece soaked with deionised water, dried in an oven at 70°C ± 2°C and powdered in a mill with stainless steel blades, prior to chemical analysis.

### 3.5 Chemical analyses

The dried leaf samples were ground and chemically analysed for the macro and micro nutrients as detaild below.

Nitrogen was determined by digesting 0.1 g of the sample in 2 ml concentrated sulphuric acid using hydrogen peroxide and N was estimated in the digest colorimetrically using Nessler's reagent (Wolf, 1982). The colour was read in a spectrophotometer (Spectronic - 20) at a wave length of 410 nm.

Diacid extracts were prepared by digesting 1 g of the sample with 15 ml of 2:1 concentrated nitric acid - perchloric acid mixture (Johnson and Ulrich, 1959) and was made upto 100 ml. Aliquots from this solutions were taken for the analysis of P, K, Ca, Mg, S, Fe, Mn, Zn and Cu.

Phosphorus was determined colorimetrically by the Vanadomolybdo phosphoric yellow colour method (Jackson, 1958). The yellow colour was read in a spectrophotometer (Spectronic - 20) at a wave length of 470 nm. Potassium was estimated using a flame photometer (EEL make). Sulphur in the diacid digest, was determined turbidimetrically by barium chloride method (Hart, 1961) employing a spectrophotometer (Spectronic - 20).

Iron was estimated by the thiocyanate method and the colour was read in a spectrophotometer (Spectronic - 20) at a wave length of 490 nm (Jackson, 1958).

An atomic absorption spectrophotometer (Perkin-Elmer make) was used for determining Ca, Mg, Mn, Zn and Cu content of the digests. For the determination of Ca and Mg, $SrCl_2$ (1000 ppm Sr in the final solution) was used as the releasing agent.

Molybdenum was determined spectrophotometrically as the orange coloured complex which was formed when molybdenum react with iron and thiocyanate in the presence of a reducing agent. The coloured complex was extracted into di-isopropyl ether. The absorbance was read at 470 nm (FAO, 1982).

For boron estimation, plant samples were dry ashed and then analysed colorimetrically by using curcumin oxalic acid reagent (Jackson, 1958). The colour developed as a result of the formation of rosecyanine was read in a spectro photometer at a wave length of 540 nm.

The chlorophyll content of the deficient and normal leaves at the time of deficiency were analysed by the method suggested by Hiscox and Israelstam (1979) using dimethyl sulphoxide. The colour was read in a spectrophotometer (Spectronic - 20) at 645 and 663 nm.

For all the chemical analysis, analytically pure grades of chemicals and glass distilled water were used.

## 3.6 Statistical analysis

The recorded data were statistically analysed whereever found necessary by followiwng the methods suggested by Panse and Sukahatme (1978).

# Results

# RESULTS

The data generated from pot culture experiments with seedlings and from the investigations on the nutrient requirements of field-grown adult clove trees are presented in this chapter.

## 4.1 Nutrient deficiency symptoms

The results of the sand culture experiments to induce nutrient deficiencies in clove are presented under four major heads namely, visual deficiency symptoms, growth of clove under nutrient stress, nutrition of clove under stress condition and recovery of deficient plants.

### 4.1.1 Visual deficiency symptoms

The plants that received complete nutrient solution exhibited normal growth throughout the period of investigation. The mature leaves were dark green and the new leaves were light green with pink tinge. All the leaves had a glossy appearance due to high oil content. (Plate I).

#### 4.1.1.1 Nitrogen deficiency

The initial symptom of N deficiency was characterised by a change of normal dark green colour of the leaves to pale green. The symptom appeared first on the lower leaves (plate III). Initially, the leaves became chlorotic and turned slowly to yellow (plate IV) followed by shedding of the older leaves. The symptoms advanced from lower to upper leaves. New leaves formed were smaller in size and their growth was very much retarded. Nitrogen deficiency was unique with a general yellowing of older leaves. It took 10 months after starting the treatments, for the symptoms to first appear. The symptoms were severe by 15th month and within 16 months more than 50 per cent of the plants had shown the symptoms at varying degrees. Plate V expresses the different stages of foliar symptoms of N deficiency.

PLATE 1. Clove seeding receiving complete nutrient solution in sand culture


CONTROL

PLATE II. Clove seedling receiving complete nutrient solution, to compare the lower leaves with that of N-deficient plant

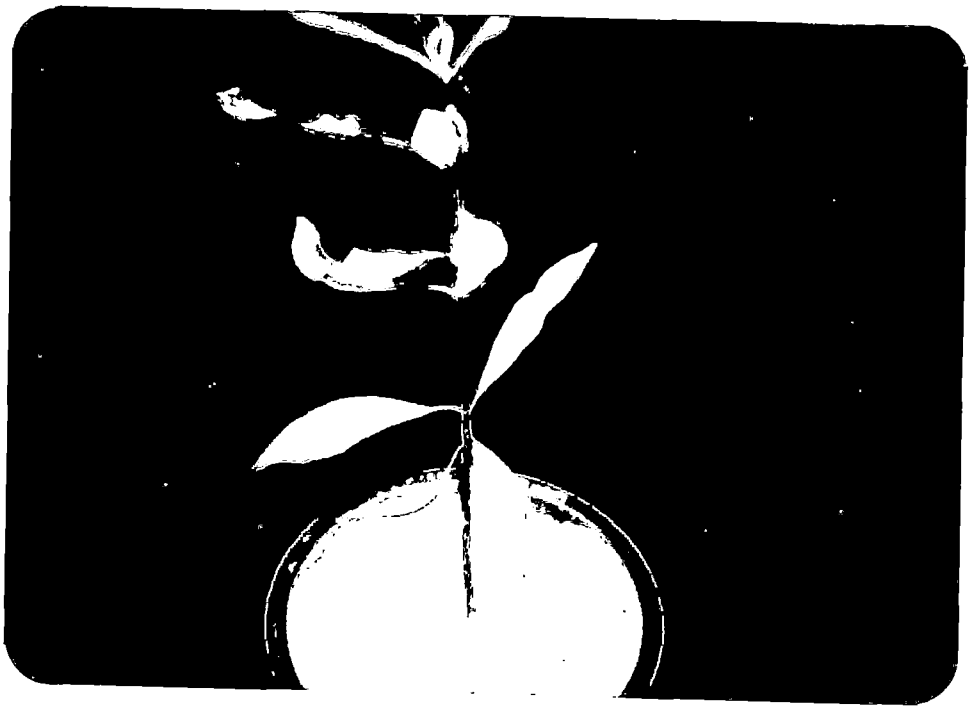
PLATE III. The N-starved seedling with deficiency symptoms expressed on lower leaves

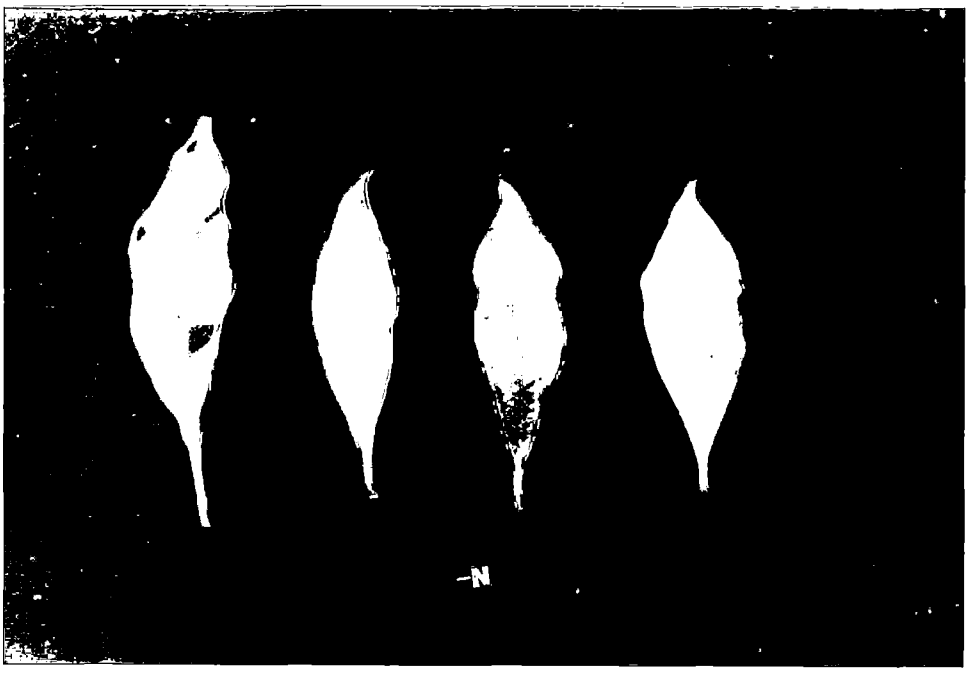

CONTROL


-N

PLATE IV. The N-deficient seedling showing early defoliation

PLATE V. The leaves showing different stages of N deficiency symptom




-N

4.1.1.2 Phosphorous deficiency

The plants under P stress showed stunted growth. The older leaves became dull green and small brownish spots appeared on leaf margins and lamina, mostly towards the basal part of the leaves (Plate VI). The adjoining necrotic spots coalesced and developed into bigger round spots to give a burnt appearance to the older leaves (Plates VII). The older leaves became chlorotic later and were shed resulting in sparse foliage on severely affected plants.

It took 13 months for the visual deficiency symptoms to first appear. The severe stage was reached within five months thereafter. More than 50 per cent of the plants showed the symptoms within this period.

4.1.1.3 Potassium deficiency

Mature and older leaves were the first to exhibit the visual symptoms of potash deficiency (Plates VIII and IX). Leaf tips and margins first turned brown, followed by drying-up of the tips. The symptoms progressed in ward until about half the leaf blade exhibited a scorched appearance (Plate X). The emerging leaves were pale green to yellowish green. The leaves fell off the plant only at a later stage.

Potassium deficiency symptoms were first observed, 12 months after the withdrawal of the nutrient. Symptoms became severe within another three months and by that time, majority of the plants under -K treatment had developed the characteristic symptoms.

4.1.1.4 Calcium deficiency

Reduced shoot growth with die-back of the tip was the most conspicuous symptom of Ca deficiency. The young leaves were affected first and were smaller in size. The upper mature leaves showed necrotic areas, especially near the tips and margins. The leaves later became chlorotic and fell off (Plate XI). The growing points of the plants remained dormant without further

PLATE VI. The leaves showing different stages of P deficiency symptom

PLATE VII. The P-starved seedlings showing the deficiency symptom on lower leaves

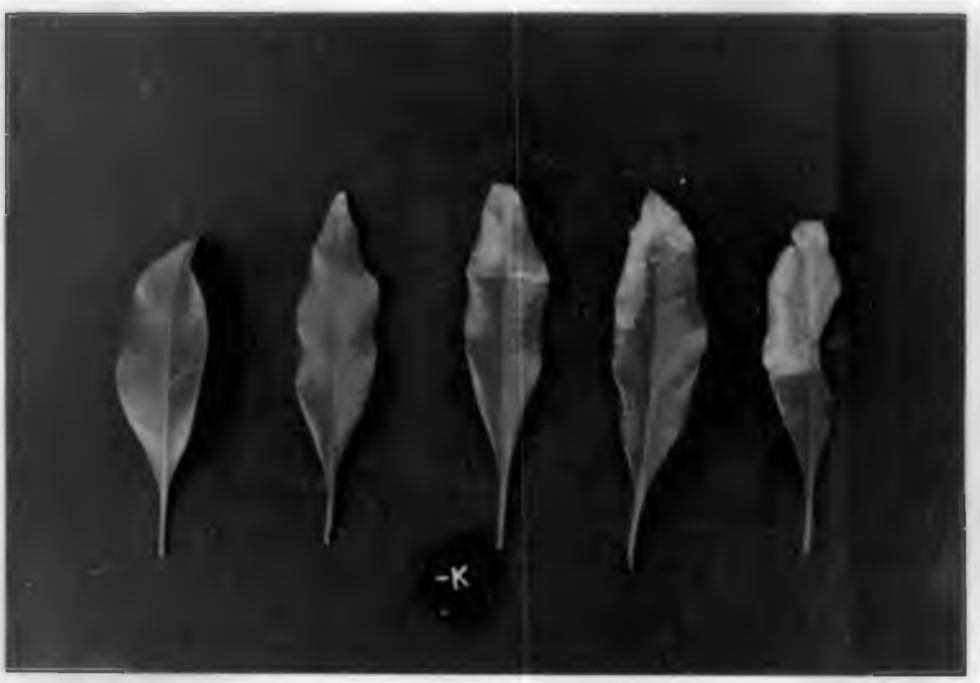
PLATE VIII. The K-starved plant expressing the deficiency symptom on older leaves

PLATE IX. The K-starved plant at advanced stage of K deficiency


-K


-K

PLATE X. The leaves showing different stages of K deficiency symptom


-K

growth. Later they became necrotic and fell off leaving a bare tip (Plate XII). The affected plants failed to putforth new growth. The visual symptoms were evident 12 months after the treatment and majority of the plants exhibited severe symptoms within 16 months.

4.1.1.5 Magnesium deficiency

As a consequence of Mg stress, older leaves became yellowish green due to the chlorosis spreading from the margins towards the midrib. It took 12 months for the symptom to appear, after the withdrawal of the element from the nutrient solution. The leaves became increasingly chlorotic as the deficient plant put forth newer flushes. At the later stages, the young developing leaves failed to develop normal size and colour (Plate XIII). Necrosis of the leaf tip and margins as well as downward curling of the lamina, were also seen on deficient plants (Plate XIV and XV). The leaves remained chlorotic for about two months, prior to defoliation. The plants were stunted. The symptoms of severe deficiency were expressed by 18 months after the commencement of the treatment.

4.1.1.6 Sulphur deficiency

Symptoms of sulphur deficiency were first observed on the plants 10 months after imposing -S treatment. The newly produced leaves were the most affected by S deficiency. They were pale green in colour and failed to attain normal size (Plate XVI). The older leaves remained unaffected. The young leaves also showed marginal necrosis and a tendency to drop off from the plant prematurely. Later growth produced still smaller leaves with shorter internodes (Plate XVII). The die-back of the tips and complete cessation of growth marked the severe stage of deficiency. These symptoms were observed 15 months after the commencement of the treatment.

PLATE XI. The leaves showing different stages of Ca deficiency symptom

PLATE XII. The Ca starved plant showing stunted growth


-Ca


-Ca

PLATE XIII. The Mg-starved plant with lower and upper chlorotic leaves

PLATE XIV. The Mg-starved plant with the leaves showing chlorotic and necrotic symptom

PLATE XV. Leaves showing different stages of Mg deficiency symptom

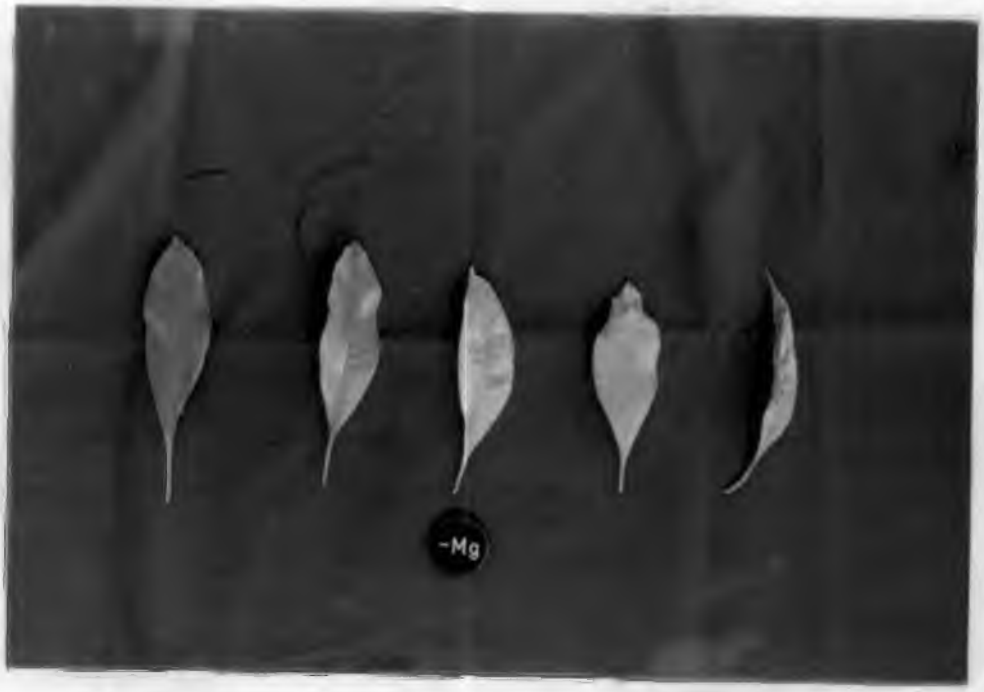

-Mg

PLATE XVI. The S-starved plant with chlorotic upper leaves

PLATE XVII. The S-starved plant expressing severe stage of deficiency

4.1.1.7 Iron deficiency

Plants under Fe stress showed interveinal chlorosis on younger leaves as initial symptoms of the deficiency (Plate XVIII). These symptoms appeared 12 months after commencement of the treatment. The new leaves were yellowish white with the midrib remaining green. The leaves failed to produce chlorophyll at normal rate and were papery white in many cases (Plate XIX). The newly produced leaves were shed soon, ultimately resulting in sparse foliage on the plant. The developing shoots showed tip die-back. The plants almost stopped its growth by 15 months after starting the treatment. The symptoms were very severe by the 16th month. The various stages of foliar symptom of Fe deficiency are presented in Plate XX.

4.1.1.8 Manganese deficiency

The initial symptoms of Mn deficiency resembled those of Fe. The symptoms first appeared on young leaves as interveinal chlorosis by 12 months after starting the treatment. The plants exhibited not much reduction in growth but leaves were smaller and distorted in subsequent flushes (Plate XXI).

In advanced stages of deficiency the growth became stunted with practically no new flush. Curling and cupping of leaves were also observed on severely affected plants. Symptoms of severe deficiency were observed by the 15th month after withdrawing the element from the nutrient solution.

4.1.1.9 Copper deficiency

Growth reduction due to Cu stress became evident initially by 15 months after starting the treatment. Older leaves did not show any visible deficiency symptom. The new leaves produced were small, narrow and chlorotic (Plate XXII). Loss of turgor, bending of lamina and drying of the tips were associated with Cu deficiency (Plate XXIII). Such shoots were short-lived and soon defoliated giving a barren appearance. The growth was stopped eventually. The symptoms of Cu deficiency became severe within three months of their initial appearance.

PLATE XVIII. The Fe-starved plant expressing interveinal chlorosis.

PLATE XIX. The Fe-starved plant showing papery white upper leaves

PLATE XX. Leaves showing different stages of Fe deficiency


-Fe

PLATE XXI. The Mn-starved plant expressing the deficiency symptoms

PLATE XXII. The Cu-starved plant with narrow, chlorotic and short lived upper leaves

PLATE XXIII. The Cu-starved plant expressing the deficiency symptoms

4.1.1.10 Zinc deficiency

Clove seedlings grown under Zn stress for 13 months developed the characteristic deficiency symptoms on their new flushes. There was a reduction in internodal length resulting in rosette condition (Plate XXIV). Leaves failed to develop the normal green colour (Plate XXV). The petioles and laminae showed a tendency to curl downward giving a sickle-like appearance (Plate XXVI). The symptoms became severe within three months of the appearance of the initial symptoms. Unlike in the case of Cu deficiency, the curled leaves were stiffer and sickle shaped in Zn-deficient plants. Moreover, the leaves were retained on the plant for a longer period. At severe stage of deficiency, the growth of the plant was considerably reduced. Visual symptoms of Zn deficiency were absent on the older leaves.

4.1.1.11 Boron deficiency

The clove seedlings became stunnded after 14 months' growth under B stress. The upper leaves failed to develop dark green colour and were slightly chlorotic. The symptoms became severe by 17 months. The leaves had a hard, and brittle appearance with occasional tip and marginal necrosis (Plate XXVII). New growths were small and often aborted. The leaves dried off prematurely (Plate XXVIII) leaving a barren top. By 17 months of B stress, more than 50 per cent of the plants developed identical B deficiency symptoms.

4.1.1.12 Molybdenum deficiency

The clove plants grown in -Mo solution failed to develop any characteristic visual deficiency symptom for 2 years. The growth of treated and control plants were almost identical.

4.1.2 Growth of clove under nutrient stress

The growth parameters found affected by nutrient stress are presented in this section. The relevant data on the effect of nutrient stress on vegetative growth of clove are furnished in Table 3 to 10 and Fig. 2 to 9.

PLATE XXIV. The Zn-starved plant expressing the deficiency symptoms

PLATE XXV. The Zn-deficient plant with reduced internodal length and sickle shaped chlorotic leaves as compared with healthy plant

PLATE XXVI. Leaves showing different stages of Zn deficiency

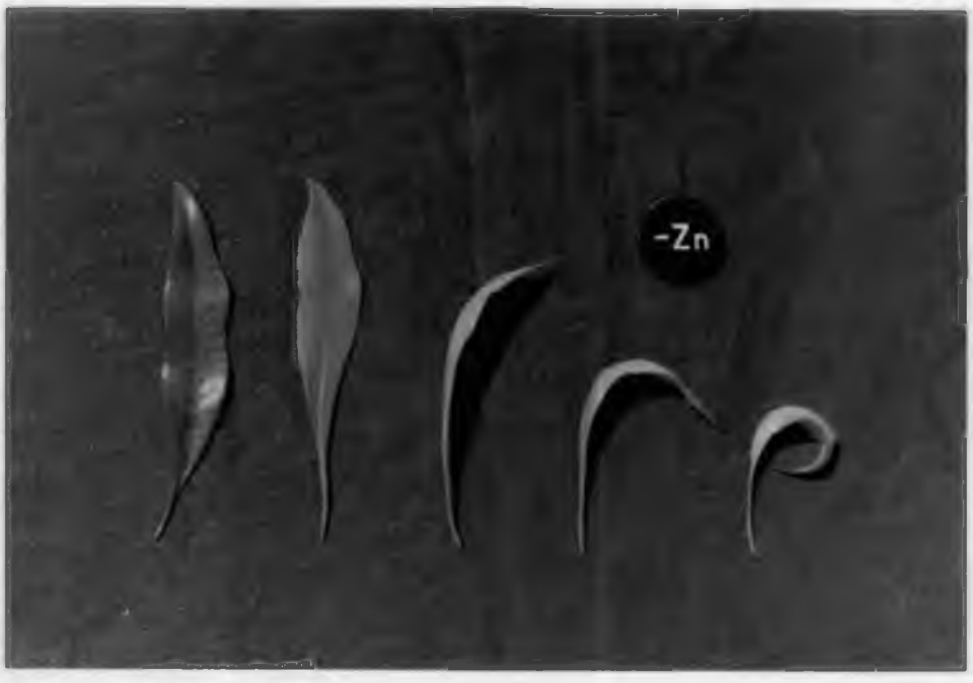

-Zn

PLATE XXVII. The B-starved plant with necrotic, brittle leaves

PLATE XXVIII. The B-starved plant with the young growth drying prematurely

4.1.2.1 Deficiencies of major nutrients (N, P and K)

Deficiency of N, P or K had a pronounced effect on height of the plant, leaf production, leaf area, root growth and biomass production (Table 3). The efects were more pronounced when the plants started showing symptoms of severe deficiency between 15 to 18 months after withdrawal of the nutrients from the nutrient solution. The manifestations of deficiency in terms of reduced growth rate was observed as early as 7 to 8 months after withdrawing a major nutrient (Fig. 2, 3 and 7). Further, the deficiency of N was found to affect the plant growth most (Fig. 7). The plants under N-stress had a height of 35.23 cm at the end of 15 months stress period as against 44 cm for the control. Reduction in the number of leaf for N deficient plants was much more, to the extent of 46 per cent. The total leaf area also declined drastically (53 per cent) and the root mass reduced to 40 per cent. The chlorophyll level at starved condition is depicted in Fig.8.

The reduction in growth parameters due to P stress were to the tune of 13 per cent in height, 31 per cent in leaf area and 24 per cent in total biomass produced, by the time the plants expressed severe foliar symptoms of P deficiency.

Potassium stress for a period of 15 months reduced the height of the plants by 15 per cent, leaf area by 32 per cent and total dry matter by 18 per cent (Table 3).

The influence of major nutrients on physiological parameters is presented in Table 4. Stress induced by withdrawing any one of the major nutrient from the nutrient solution reduced the LAR, NAR, AGR and RGR as compared to control plants. The adverse effects were more pronounced towards later stages of growth and was more due to N starvation.

4.1.2.2 Deficiency of secondary nutrients (Ca, Mg and S).

Growth retardation in clove plants following withdrawal of Ca, Mg or S from the nutrient solution occurred in varying degrees. Calcium

Table 3. Effect of major nutrient (NPK) stress on growth of clove seedling

| Element under stress | Stage* of deficiency | Months after treatment | Treat-ment | Growth parameters | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Height (cm) | Number of leaves | Inter-nodal length (cm) | Leaf area ($cm^2$) | Root dry weight (g) | Shoot dry weight (g) | Total dry weight (g) |
| N | Initial | 10 | -N | 28.53 (17) | 27 (33) | 2.43 (13) | 272 (42) | 1.12 (22) | 4.05 (29) | 5.17 (28) |
| | | | C | 34.30 | 40 | 2.80 | 469 | 1.43 | 5.73 | 7.16 |
| | Severe | 15 | -N | 35.23 (20) | 33 (46) | 2.70 (20) | 358 (53) | 1.20 (40) | 5.20 (39) | 6.40 (39) |
| | | | C | 44.00 | 61 | 3.36 | 766 | 2.00 | 8.46 | 10.46 |
| P | Initial | 13 | -P | 39.17 (7) | 43 (20) | 2.90 (9) | 535 (19) | 1.50 (4) | 5.77 (23) | 7.27 (20) |
| | | | C | 42.30 | 54 | 3.20 | 660 | 1.56 | 7.49 | 9.05 |
| | Severe | 18 | -P | 42.10 (13) | 52 (22) | 2.93 (15) | 632 (31) | 1.83 (20) | 7.17 (25) | 9.00 (24) |
| | | | C | 48.10 | 67 | 3.43 | 909 | 2.30 | 9.53 | 11.83 |
| K | Initial | 12 | -K | 36.47 (10) | 37 (21) | 2.50 (17) | 435 (26) | 1.20 (18) | 5.50 (17) | 6.70 (17) |
| | | | C | 40.40 | 47 | 3.00 | 590 | 1.47 | 6.63 | 8.10 |
| | Severe | 15 | -K | 37.40 (15) | 46 (25) | 2.30 (32) | 518 (32) | 1.47 (27) | 7.10 (16) | 8.57 (18) |
| | | | C | 44.00 | 61 | 3.36 | 766 | 2.00 | 8.46 | 10.46 |

* Corresponds to the stage when deficient plants started showing foliar symptoms.
Parentheses indicate percentage reduction from healthy plants.

Table 4. Effect of major nutrient (NPK) stress on LAR, NAR, AGR and RGR of clove seedling

| Parameter | Treatment | Period (days) 0-180 | 180-360 | 360-540 |
|---|---|---|---|---|
| Leaf area ratio ($cm^2/g$) | C | 45.12 | 66.64 | 75.21 |
| | -N | 36.38 | 50.39 | 58.24 |
| | -P | 33.51 | 60.73 | 71.25 |
| | -K | 41.61 | 58.97 | 64.82 |
| Net assimilation rate ($g/m^2/day$) | C | 0.7802 | 0.7351 | 0.2800 |
| | -N | 0.6635 | 0.6534 | 0.1110 |
| | -P | 0.7375 | 0.6770 | 0.2309 |
| | -K | 0.6717 | 0.6688 | 0.2384 |
| Absolute growth rate (g/day) | C | 0.0087 | 0.0255 | 0.0207 |
| | -N | 0.0062 | 0.0138 | 0.0039 |
| | -P | 0.0067 | 0.0182 | 0.0128 |
| | -K | 0.0072 | 0.0183 | 0.0119 |
| Relative growth rate (g/g/day) | C | 0.0033 | 0.0047 | 0.0021 |
| | -N | 0.0024 | 0.0032 | 0.0006 |
| | -P | 0.0024 | 0.0037 | 0.0016 |
| | -K | 0.0027 | 0.0038 | 0.0015 |

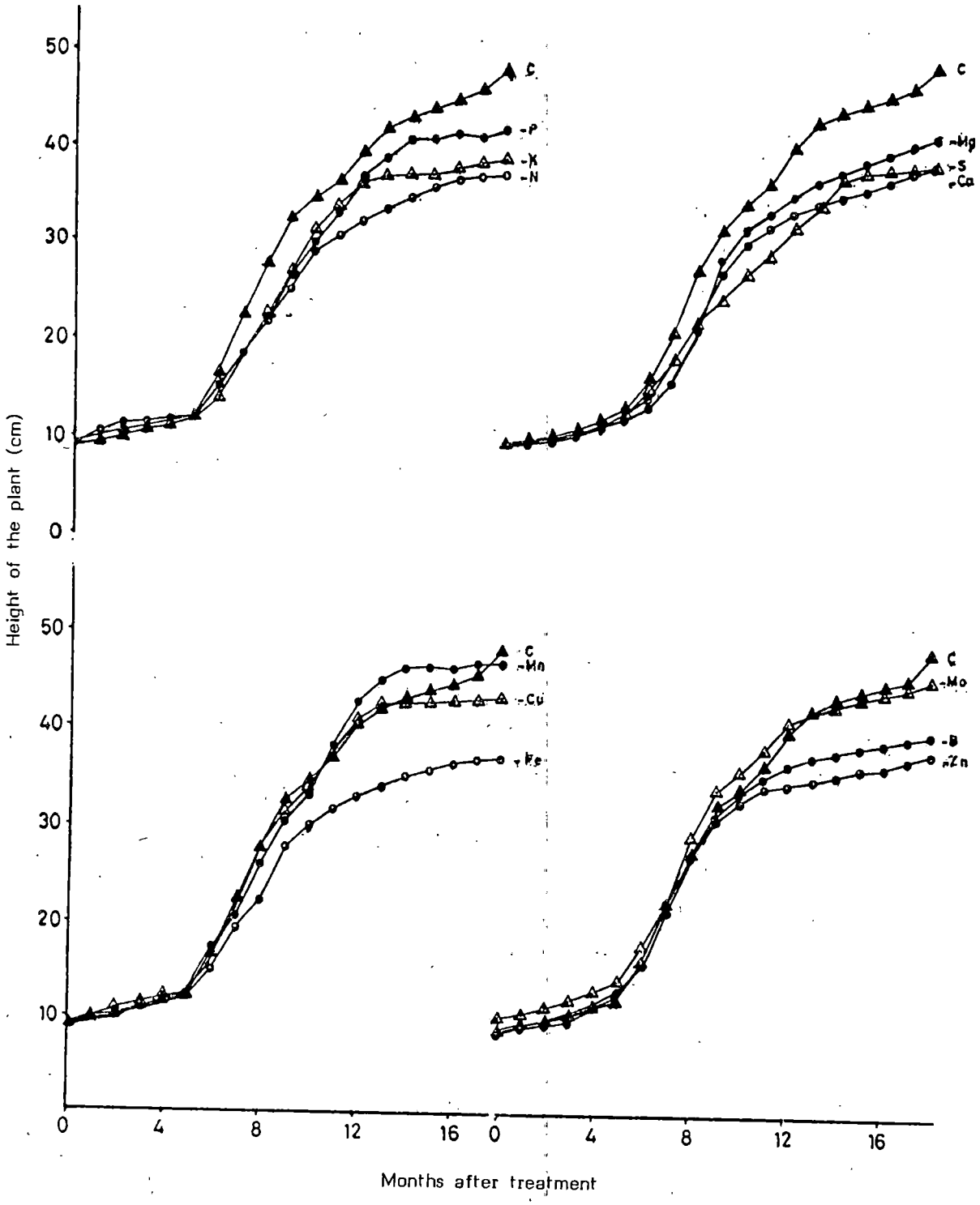



Fig. 2· Effect of nutrient stress on the height of the plant

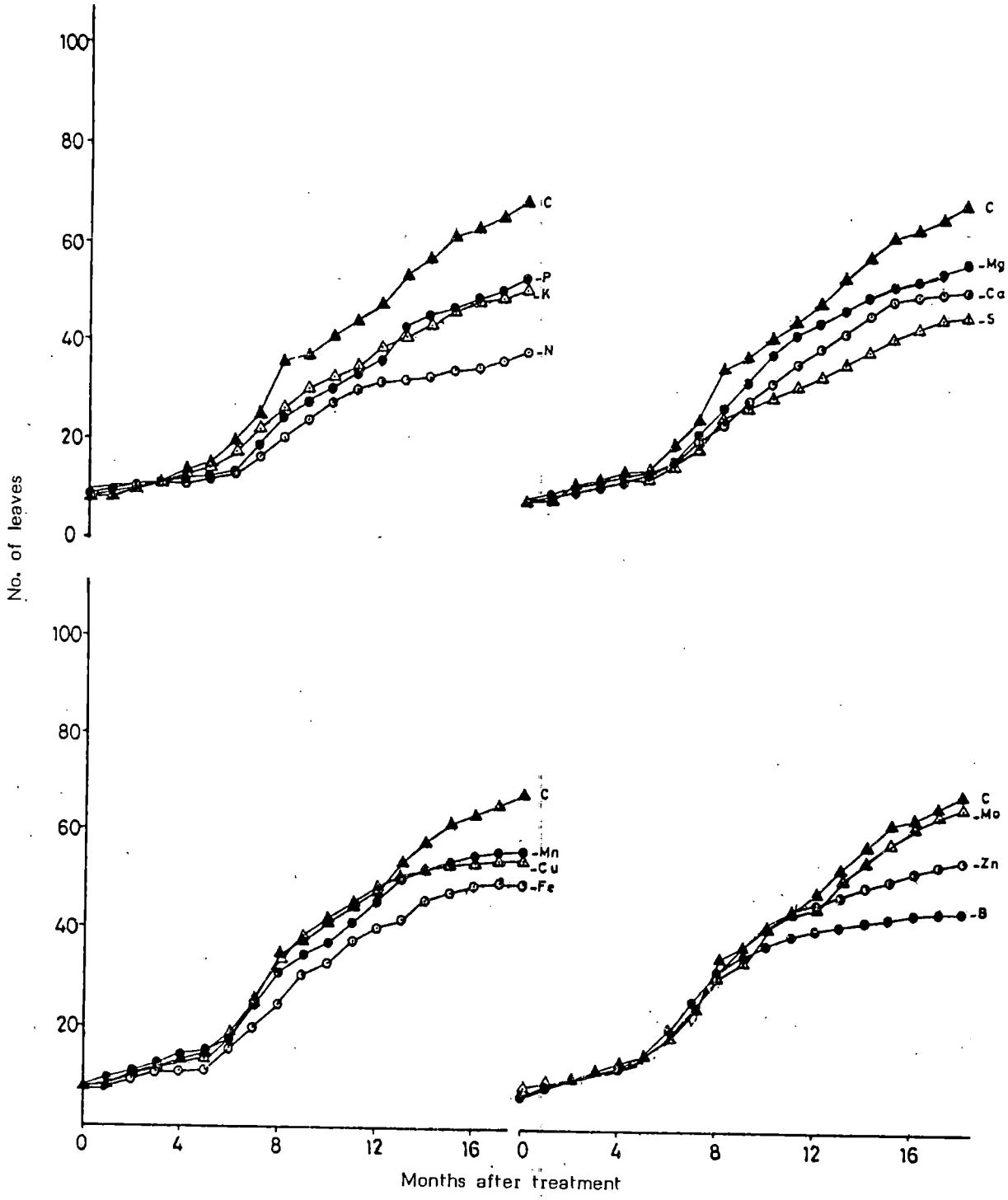



Fig. 3 Effect of nutrient stress on the number of leaves

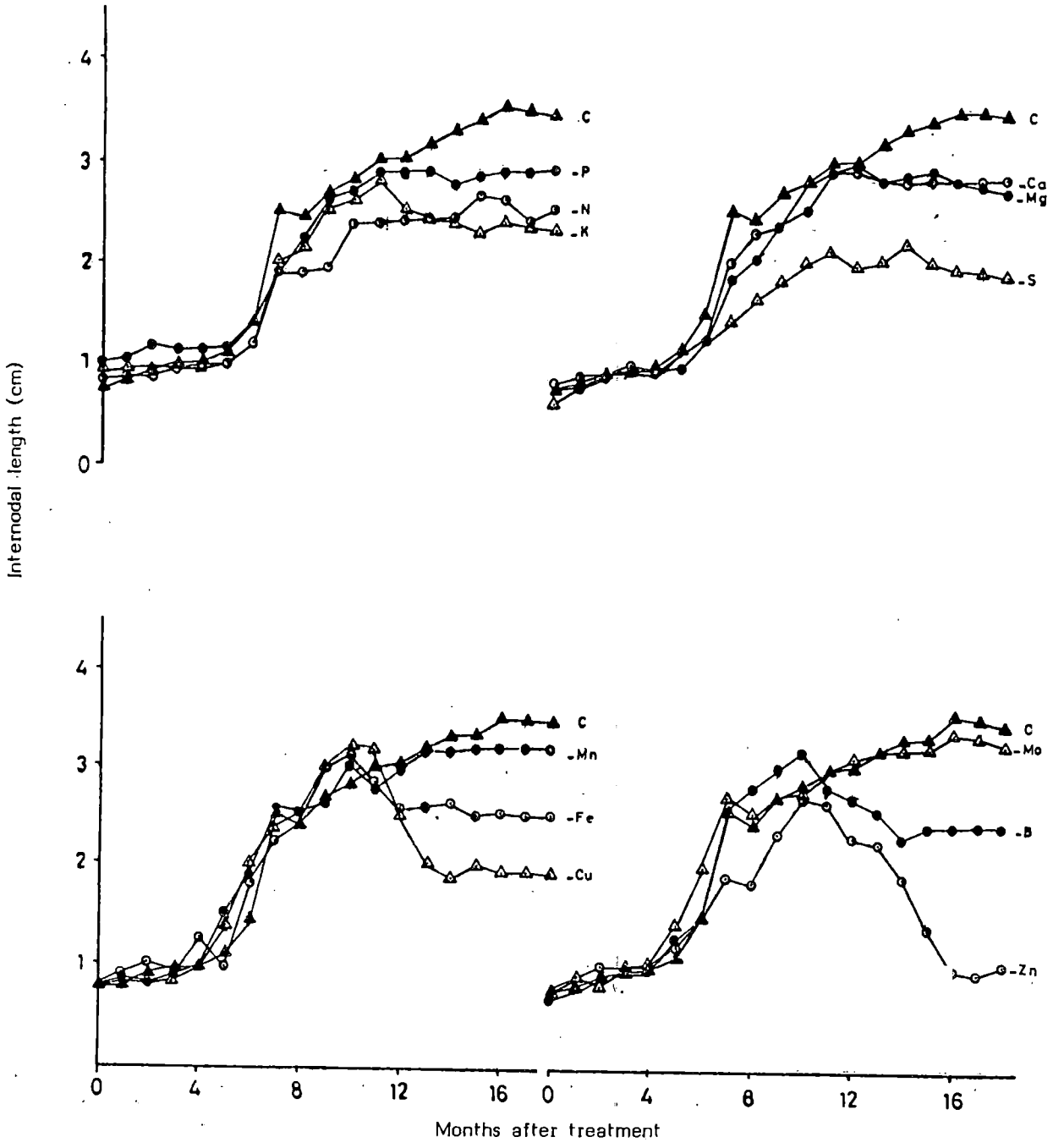



Fig. 4 Effect of nutrient stress on the internodal length

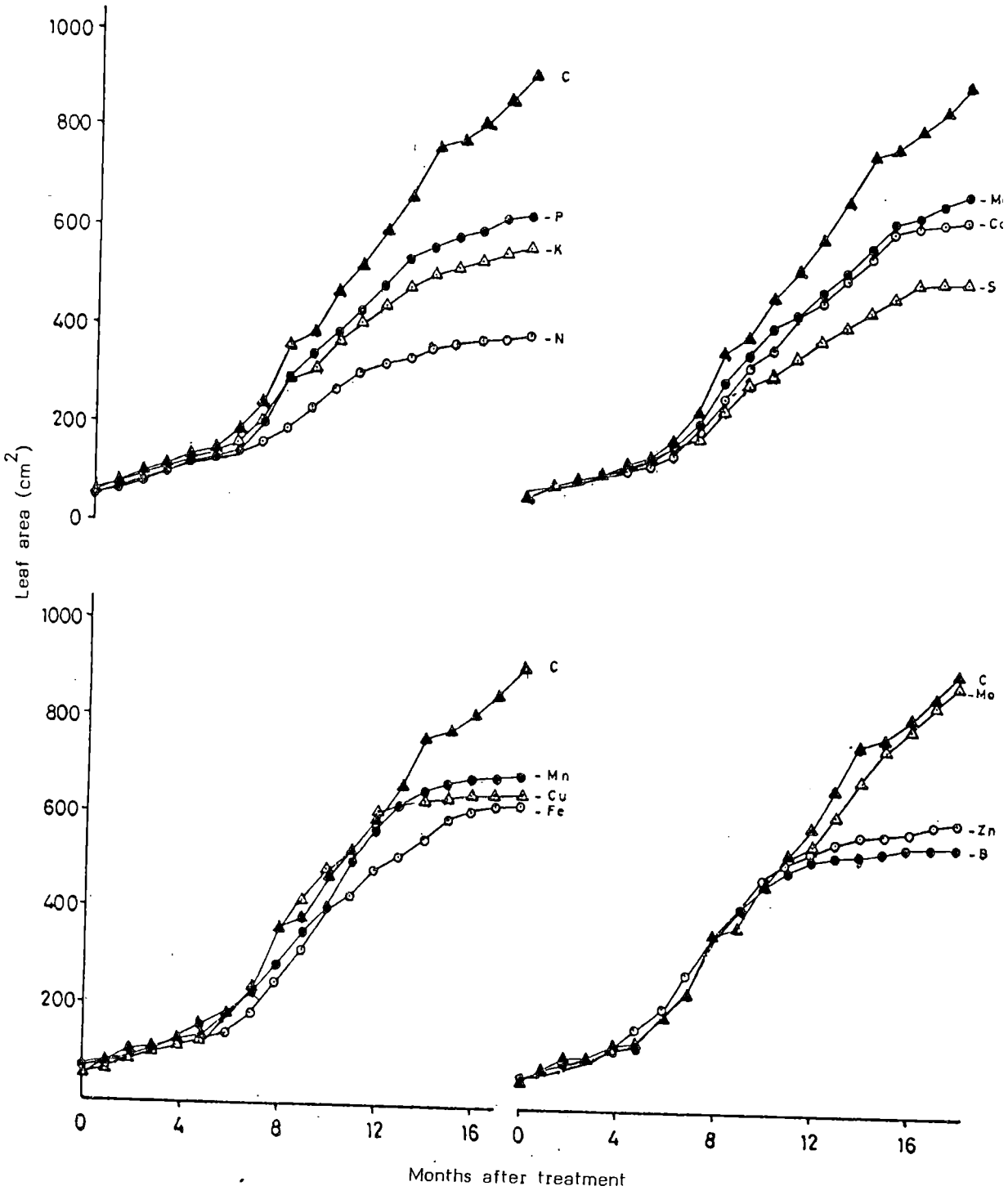



Fig. 5 Effect of nutrient stress on the leaf area

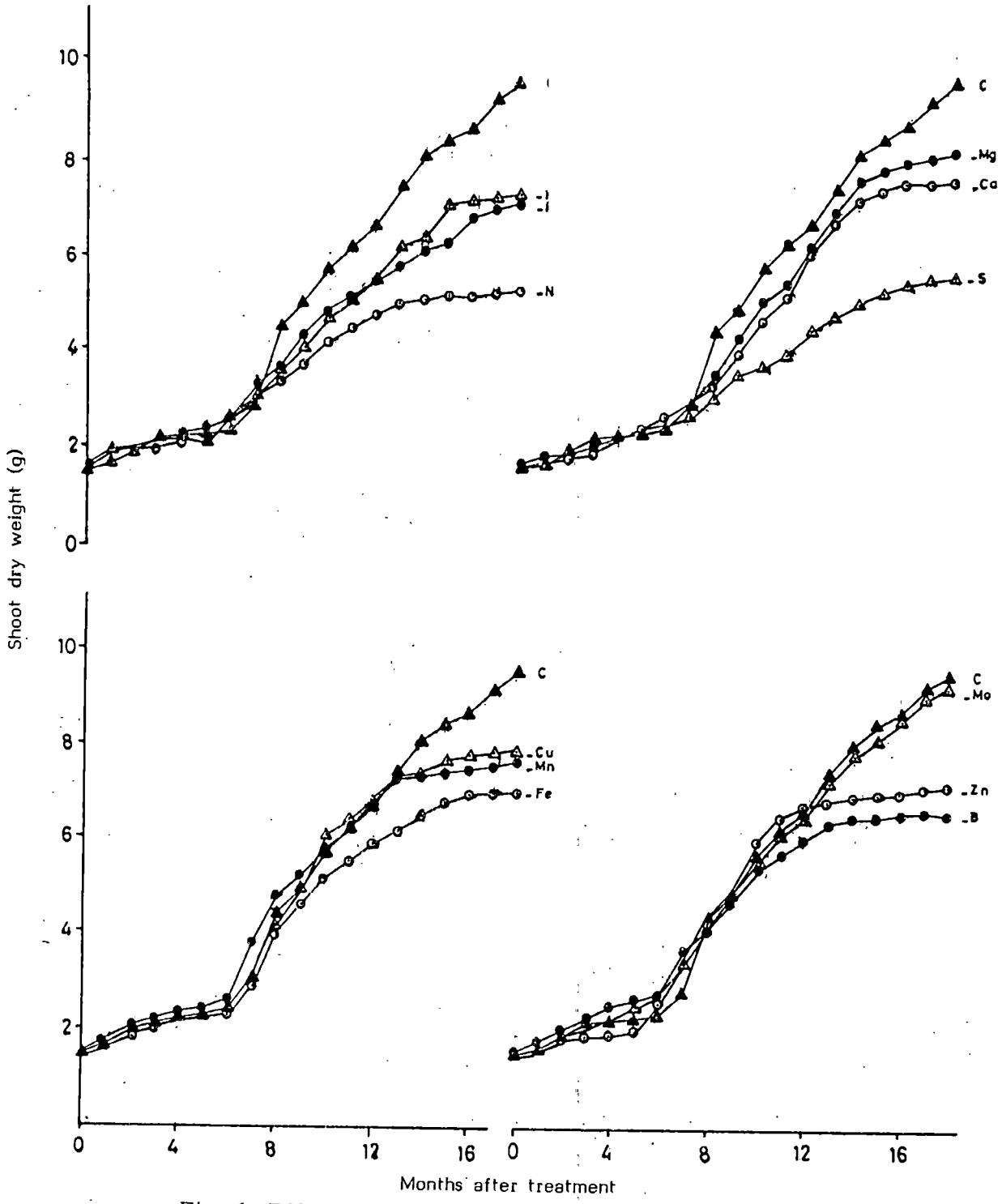



Fig. 6 Effect of nutrient stress on the shoot dry weight

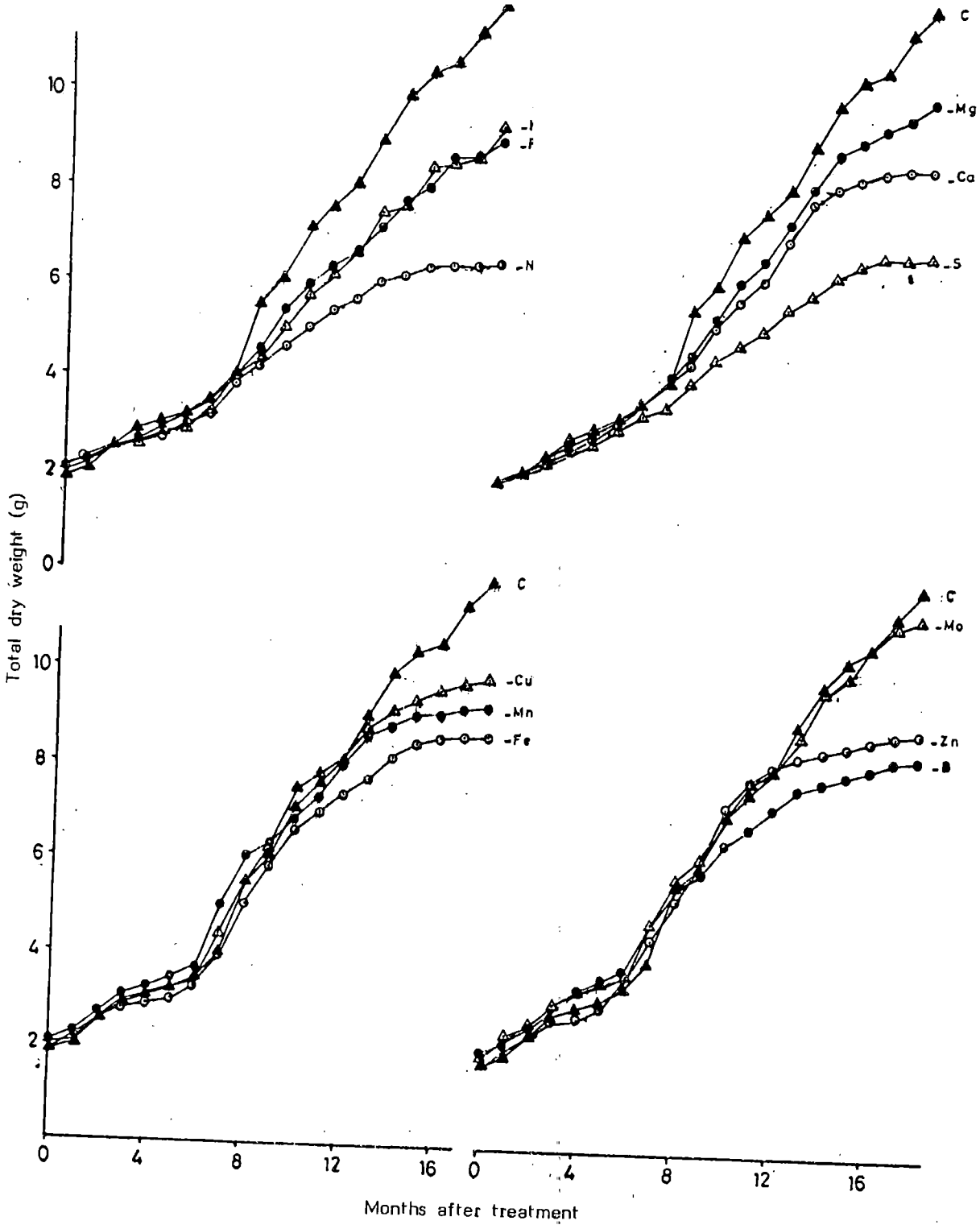



Fig. 7 Effect of nutrient stress on the total dry weight

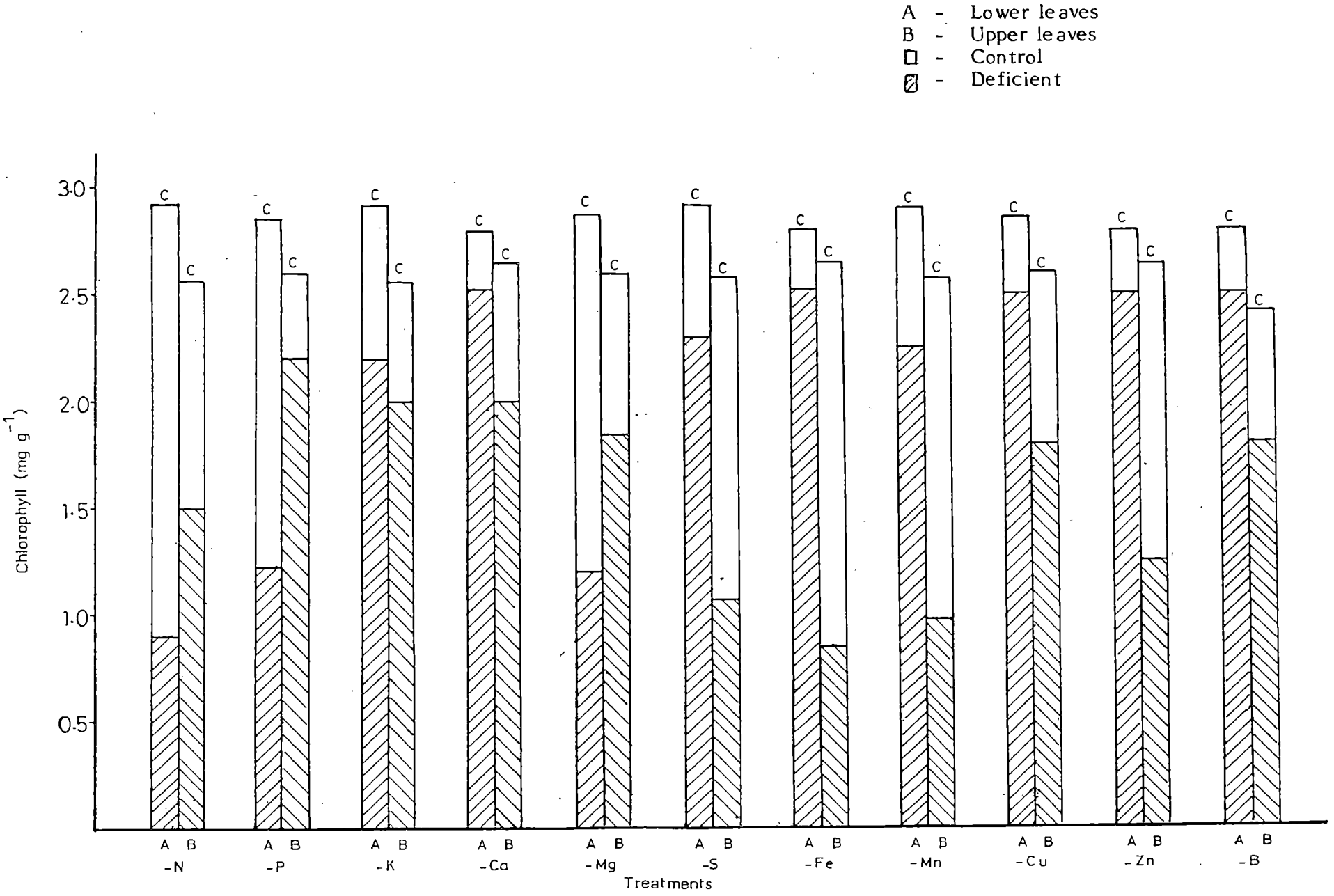



Fig. 8 Effect of nutrient stress on the total chlorophyll content (at the severe stage of deficiency)

deficiency was found to affect the root growth most (Tabie 5, Fig. 9). The effect of stress on the other growth parameters was relatively lesser than this. While root production decreased by 51 per cent, the extent of reduction in other characters was between 13 and 24 per cent (Table 5). Magnesium deficiency was found to affect height of the plant, internodal length, leaf area and total biomass production to the extent of 15 to 25 per cent as compared to healthy plants (Table 5). More or less a similar trend was observed for S deficiency also. The extent of reduction ranged to a higher degree and it ranged between 33 to 41 per cent for number of leaves, internodal length, leaf area, root dry weight and total biomass production, by the time the plants exhibited severe symptoms of nutrient deficiency.

The LAR, NAR, AGR and RGR were found influenced by withdrawing anyone of the secondary nutrient from the nutrient solution (Table 6). The adverse effect was more due to S-stress followed by Ca and Mg.

4.1.2.3 Deficiencies of micronutrients

4.1.2.3.1 Iron, Manganese and Copper

The data pertaining to the influence of Fe, Mn and Cu on growth of clove seedlings are presented in Table 7,8 and Fig. 2 to 8.

Among these three nutrients, the deficiency of Fe had a more marked effect on plant growth (Fig. 2 to 7). Iron deficiency affected growth components like height, number of leaves, internodal length and total leaf area per plant to the extent of 18 to 28 per cent (Table 7). The marked reduction in growth characteristics as well as dry matter production of Fe deficient plants was evident right from 10th month onwards (Fig. 2).

Stress induced by withdrawing Mn from the nutrient solution was reflected on number of leaves, total leaf area and total biomass production. There was a reduction in number of leaves to the extent of 11 per cent and total leaf area by 13 per cent. Manganese stress did not influence the height

Table 5. Effect of secondary nutrient (Ca, Mg, S) stress on growth of clove seedling

| Element under stress | Stage* of deficiency | Months after treatment | Treatment | Growth parameters | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Height (cm) | Number of leaves | Internodal length (cm) | Leaf area ($cm^2$) | Root dry weight(g) | Shoot dry weight(g) | Total dry weight(g) |
| Ca | Initial | 12 | -Ca | 33.63 | 38 | 2.93 | 460 | 1.07 | 5.96 | 7.03 |
| | | | | (17) | (19) | (2) | (22) | (27) | (11) | (13) |
| | | | C | 40.40 | 47 | 3.00 | 5.90 | 1.47 | 6.63 | 8.10 |
| | Severe | 16 | -Ca | 36.67 | 50 | 2.80 | 615 | 0.98 | 7.54 | 8.52 |
| | | | | (18) | (21) | (21) | (24) | (51) | (13) | (20) |
| | | | C | 44.80 | 63 | 3.56 | 807 | 2.00 | 8.63 | 10.63 |
| Mg | Initial | 12 | -Mg | 35.57 | 44 | 2.90 | 478 | 1.26 | 6.18 | 7.44 |
| | | | | (12) | (6) | (3) | (19) | (14) | (7) | (8) |
| | | | C | 40.40 | 47 | 3.00 | 590 | 1.47 | 6.63 | 8.10 |
| | Severe | 18 | -Mg | 41.10 | 56 | 2.70 | 680 | 1.80 | 8.20 | 10.00 |
| | | | | (15) | (16) | (21) | (25) | (22) | (14) | (16) |
| | | | C | 48.10 | 67 | 3.43 | 909 | 2.30 | 9.53 | 11.83 |
| S | Initial | 10 | -S | 26.80 | 29 | 2.03 | 305 | 1.16 | 3.70 | 4.86 |
| | | | | (22) | (28) | (23) | (35) | (19) | (35) | (32) |
| | | | C | 34.30 | 40 | 2.80 | 469 | 1.43 | 5.73 | 7.16 |
| | Severe | 15 | -S | 37.40 | 41 | 2.00 | 467 | 1.30 | 5.29 | 6.59 |
| | | | | (15) | (33) | (41) | (39) | (35) | (37) | (37) |
| | | | C | 44.00 | 61 | 3.36 | 766 | 2.00 | 8.46 | 10.46 |

* Corresponds to the stage when deficient plants started showing foliar symptoms.
Parantheses indicate percentage reduction from healthy plants.

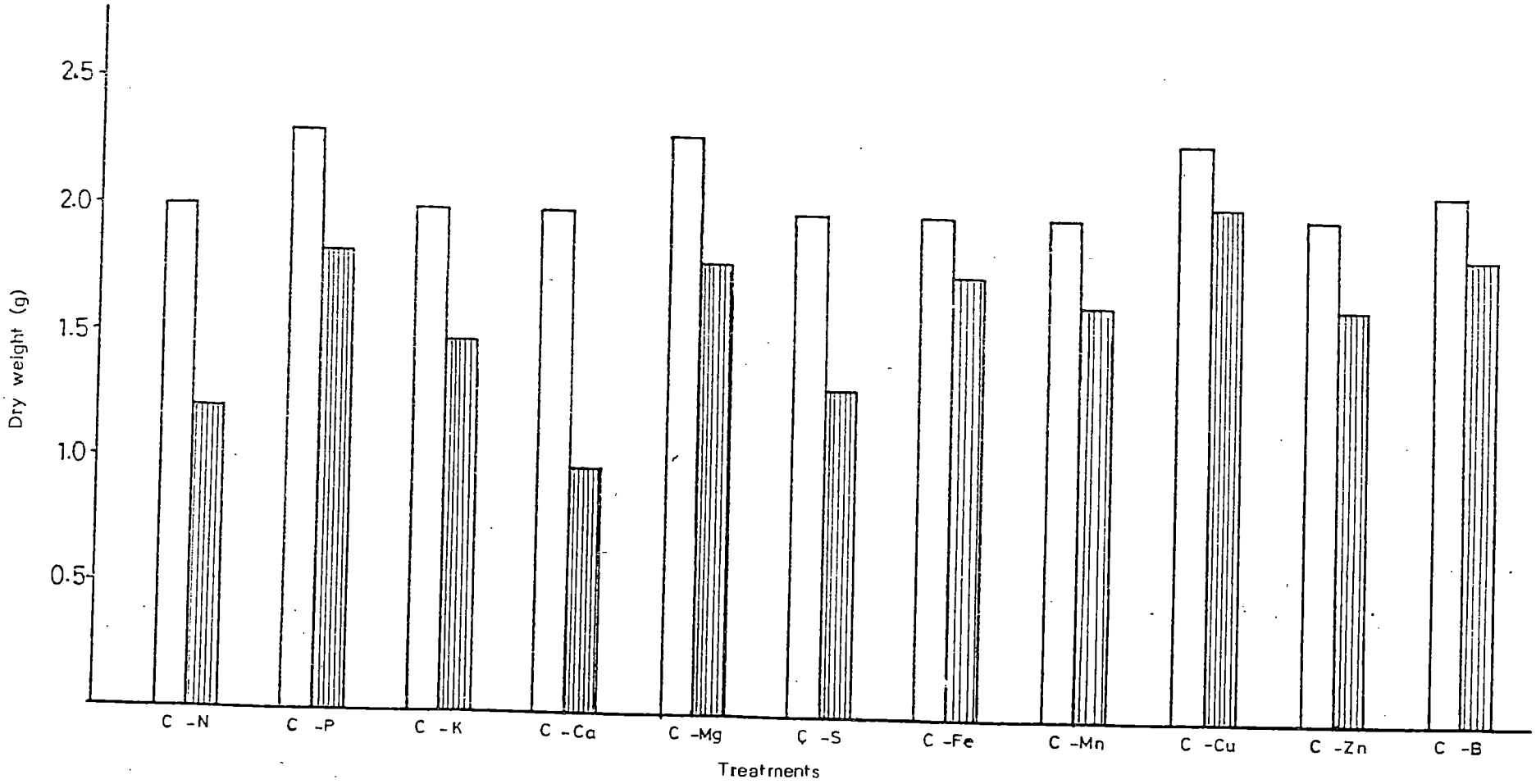



Fig. 9 Effect of nutrient stress on the root dry weight (at the severe stage of deficiency)

Table 6. Effect of secondary nutrient (Ca,Mg, S) Stress on LAR, NAR, AGR and RGR of clove seedling

| Parameter | Treatment | Period (days) 0-180 | 180-360 | 360-540 |
|---|---|---|---|---|
| Leaf area ratio ($cm^2/g$) | C | 45.12 | 66.64 | 75.21 |
| | -Ca | 39.28 | 57.36 | 70.11 |
| | -Mg | 40.84 | 58.76 | 66.40 |
| | -S | 41.73 | 59.01 | 69.89 |
| Net assimilation rate ($g/m^2/day$) | C | 0.7802 | 0.7351 | 0.2800 |
| | -Ca | 0.8479 | 0.6987 | 0.1475 |
| | -Mg | 0.7197 | 0.7234 | 0.2482 |
| | -S | 0.8115 | 0.4991 | 0.1458 |
| Absolute growth rate (g/day) | C | 0.0087 | 0.0255 | 0.0207 |
| | -Ca | 0.0088 | 0.0192 | 0.0079 |
| | -Mg | 0.0078 | 0.0215 | 0.0142 |
| | -S | 0.0083 | 0.0127 | 0.0063 |
| Relative growth rate (g/g/day) | C | 0.0033 | 0.0047 | 0.0021 |
| | -Ca | 0.0033 | 0.0038 | 0.0010 |
| | -Mg | 0.0028 | 0.0041 | 0.0016 |
| | -S | 0.0032 | 0.0028 | 0.0010 |

Table 7. Effect of micronutrient (Fe, Mn, Cu) stress on growth of clove seedling

| Element under stress | Stage of* deficiency | Months after treatment | Treatment | Growth parameters | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Height (cm) | Number of leaves | Internodal length (cm) | Leaf area ($cm^2$) | Root dry weight (g) | Shoot dry weight (g) | Total dry weight (g) |
| Fe | Initial | 12 | -Fe | 32.94 | 41 | 2.60 | 482 | 1.51 | 5.89 | 7.40 |
| | | | | (-18) | (-12) | (-13) | (-18) | (+3) | (-11) | (-9) |
| | | | C | 40.40 | 47 | 3.00 | 590 | 1.47 | 6.63 | 8.10 |
| | Severe | 16 | -Fe | 36.80 | 50 | 2.55 | 602 | 1.78 | 6.82 | 8.60 |
| | | | | (-18) | (-21) | (-28) | (-25) | (-8) | (-22) | (-19) |
| | | | C | 44.80 | 63 | 3.56 | 807 | 1.93 | 8.70 | 10.63 |
| Mn | Initial | 12 | -Mn | 43.24 | 46 | 3.04 | 568 | 1.23 | 6.82 | 8.05 |
| | | | | (+7) | (-2) | (+3) | (-4) | (-16) | (+3) | (-1) |
| | | | C | 40.40 | 47 | 3.00 | 590 | 1.47 | 6.63 | 8.10 |
| | Severe | 15 | -Mn | 46.42 | 54 | 3.20 | 663 | 1.64 | 7.43 | 9.07 |
| | | | | (+6) | (-11) | (-5) | (-13) | (-18) | (-12) | (-13) |
| | | | C | 44.00 | 61 | 3.36 | 766 | 2.00 | 8.46 | 10.46 |
| Cu | Initial | 15 | -Cu | 42.60 | 53 | 2.00 | 630 | 1.78 | 7.70 | 9.48 |
| | | | | (-3) | (-14) | (-41) | (-18) | (-11) | (-9) | (-9) |
| | | | C | 44.00 | 61 | 3.36 | 766 | 2.00 | 8.46 | 10.46 |
| | Severe | 18 | -Cu | 43.07 | 55 | 1.90 | 642 | 2.03 | 7.87 | 9.90 |
| | | | | (-11) | (-18) | (-45) | (-29) | (-12) | (-17) | (-16) |
| | | | C | 48.10 | 67 | 3.43 | 909 | 2.30 | 9.53 | 11.83 |

* Corresponds to the stage when deficient plants started showing foliar symptoms.
Parentheses indicate percentage variation from healthy plants

Table 8. Effect of micronutrient (Fe, Mn, Cu) stress on LAR, NAR, AGR and RGR of clove seeling

| Parameter | Treatment | Period (days) 0-180 | 180-360 | 360-540 |
|---|---|---|---|---|
| Leaf area ratio ($cm^2/g$) | C | 45.12 | 66.64 | 75.21 |
| | -Fe | 40.03 | 58.50 | 68.80 |
| | -Mn | 46.27 | 64.28 | 71.68 |
| | -Cu | 46.31 | 67.96 | 69.31 |
| Net assimilation rate ($g/m^2/day$) | C | 0.7802 | 0.7351 | 0.2800 |
| | -Fe | 0.7864 | 0.8310 | 0.1274 |
| | -Mn | 0.7290 | 0.7016 | 0.1111 |
| | -Cu | 0.7340 | 0.7565 | 0.1553 |
| Absolute growth rate (g/day) | C | 0.0087 | 0.0255 | 0.0207 |
| | -Fe | 0.0076 | 0.0230 | 0.0070 |
| | -Mn | 0.0092 | 0.0241 | 0.0069 |
| | -Cu | 0.0083 | 0.0263 | 0.0097 |
| Relative growth rate (g/g/day) | C | 0.0033 | 0.0047 | 0.0021 |
| | -Fe | 0.0031 | 0.0045 | 0.0008 |
| | -Mn | 0.0033 | 0.0043 | 0.0008 |
| | -Cu | 0.0032 | 0.0049 | 0.0011 |

of the plant and at initial stages of deficiency, there was even a slight increase in height and internodal length compared to that of control plants (Table 7).

The growth of clove plants under Cu stress was similar to that of control plants until about 13 months after inducing the stress (Fig. 2). The influence of Cu stress was more marked on internodal length, leaf area and number of leaves. The decrease was about 45 per cent in internodal length and 29 per cent in leaf area towards the advanced stages of deficiency (Table 7).

Once the deficiency became severe, further increments in height of the plant, number of leaves and leaf area were relatively low for all the three nutrient elements (Fig. 2, 3 and 5).

The LAR, NAR, AGR and RGR for clove plants under Fe, Mn and Cu stress did not vary much from the control plants upto 12 months after inducing the stress. Later, the adverse effect was more for Mn starved plants closely followed by Fe and Cu (Table 8).

4.1.2.3.2 Zinc, Boron and Molybdemum

From the growth measurements and data on biomass production, it was observed that Mo deficiency did not produce any adverse effect on the plant growth (Table 9, Fig. 2 to 9). In contrast, withdrawal of Zn or B from the nutrient solution greatly reduced plant height, leaf production, internodal length, root production and total leaf area. The effects of Zn stress were more pronounced on internodal length (72 per cent) leaf area (28 per cent) and number of leaves (23 per cent). Withdrawal of B from the nutrient solution for 17 months reduced the total dry weight by 26 per cent. The reduction was even more marked in leaf production and internodal length (Table 9). The effects of Zn and B stress were apparent from 10 months after withdrawing the nutrient (Fig. 7). The LAR, NAR, AGR and RGR registered were the lowest for the Zn-starved plants.(Table 10).

Table 9. Effect of micro nutrient (Zn, B, Mo) stress on growth of clove seedling

| Element under stress | Stage* of deficiency | Months after treatment | Treatment | Growth parameters | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Height (cm) | Number of leaves | Internodal length (cm) | Leaf area ($cm^2$) | Root dry weight (g) | Shoot dry weight (g) | Total dry weight (g) |
| Zn | Initial | 13 | -Zn | 35.23 | 47 | 2.24 | 555 | 1.51 | 6.90 | 8.41 |
| | | | | (17) | (13) | (30) | (16) | (3) | (8) | (7) |
| | | | C | 42.30 | 54 | 3.20 | 660 | 1.56 | 7.49 | 9.05 |
| | Severe | 16 | -Zn | 36.30 | 48 | 1.00 | 581 | 1.68 | 7.14 | 8.82 |
| | | | | (19) | (23) | (72) | (28) | (16) | (17) | (17) |
| | | | C | 44.80 | 63 | 3.56 | 807 | 2.00 | 8.63 | 10.63 |
| B | Initial | 14 | -B | 38.20 | 43 | 2.30 | 534 | 1.40 | 6.49 | 7.89 |
| | | | | (12) | (25) | (31) | (30) | (22) | (21) | (21) |
| | | | C | 43.40 | 57 | 3.33 | 762 | 1.80 | 8.16 | 9.96 |
| | Severe | 17 | -B | 39.47 | 44 | 2.40 | 554 | 1.72 | 6.71 | 8.43 |
| | | | | (13) | (32) | (31) | (35) | (18) | (28) | (26) |
| | | | C | 45.40 | 65 | 3.50 | 847 | 2.10 | 9.27 | 11.37 |
| Mo | Symptoms not expressed | 18 | -Mo | 45.43 | 66 | 3.23 | 887 | 2.02 | 9.30 | 11.32 |
| | | | | (6) | (2) | (6) | (2) | (12) | (2) | (4) |
| | | | C | 48.10 | 67 | 3.43 | 909 | 2.30 | 9.53 | 11.83 |

* Corresponds to the stage when deficient plants started showing foliar symptoms.
Parentheses indicate percentage reduction from healthy plants.

Table 10. Effect of micronutrient (Zn, B, Mo) stress on LAR, NAR, AGR and RGR of clove seedling

| Parameter | Treatment | Period (days) 0-180 | 180-360 | 360-540 |
|---|---|---|---|---|
| Leaf area ratio ($cm^2/g$) | C | 45.12 | 66.64 | 75.21 |
| | -Zn | 48.71 | 61.89 | 66.41 |
| | -B | 45.19 | 65.07 | 68.82 |
| | -Mo | 50.53 | 64.34 | 73.74 |
| Net assimilation rate ($g/m^2/day$) | C | 0.7802 | 0.7351 | 0.2800 |
| | -Zn | 0.7947 | 0.7570 | 0.0769 |
| | -B | 0.7582 | 0.5803 | 0.1063 |
| | -Mo | 0.7350 | 0.6948 | 0.2548 |
| Absolute growth rate (g/day) | C | 0.0087 | 0.0255 | 0.0207 |
| | -Zn | 0.0096 | 0.0256 | 0.0044 |
| | -B | 0.0092 | 0.0195 | 0.0057 |
| | -Mo | 0.0096 | 0.0245 | 0.0179 |
| Relative growth rate (g/g/day) | C | 0.0033 | 0.0047 | 0.0021 |
| | -Zn | 0.0037 | 0.0045 | 0.0005 |
| | -B | 0.0032 | 0.0036 | 0.0007 |
| | -Mo | 0.0035 | 0.0044 | 0.0019 |

### 4.1.3 Nutrition of clove seedlings

The clove seedlings fed with complete Hoagland's solution (modified) were found to possess a nutritional status as given in Table 11. Since visual deficiency symptoms were found related with leaf position, the nutrient levels of lower (A) and upper (B) leaves were considered separately. The general trend in the foliar nutrient composition of clove seedlings was that, in the absence of deficiency, the foliar levels of N, Mg, Zn and B were more or less the same on the upper and lower parts of the plant. Phosphorous, Ca, Fe, Mn and Cu showed a tendency to get accumulated more on lower leaves while reverse was the trend for K and S.

#### 4.1.3.1 Foliar nutrient level under nutrient stress

The data on the foliar nutrient composition of clove seedlings which expericenced nutrient stress for a period of 18 months are given in Appendices II to XII.

The omission of an element from the nutrient solution resulted in the reduction of foliar level of that particular element in the plants. The extent of reduction varied for each element.

Though the concentration of nutrient elements were found to decrease at early stages of stress, visual deficiency symptoms were expressed by the plants only at a later stage.

##### 4.1.3.1.1 Nitrogen deficiency

The clove seedlings fed with N-deficient nutrient solution showed a drastic reduction in the foliar nitrogen level. The nutrient level which was 1.29 per cent and 1.53 per cent respectively in the older and younger leaves at the time of starting the treatment were reduced to 0.46 per cent and 0.71 per cent by the end of 18th month. The reduction was more pronounced in older leaves at early stages of stress (Appendix II). The plants showed visible deficiency symptoms when the N level of the older leaves dropped

Table 11. Nutrient status of clove seedlings fed with complete nutrient solution

| Period after treatment (months) | Position of foliage | N % | P % | K % | Ca % | Mg % | S % | Fe ppm | Mn ppm | Cu ppm | Zn ppm | B ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | A | 1.29 | 0.098 | 0.68 | 0.66 | 0.273 | 0.106 | 149 | 207 | 60 | 39 | 31 |
| | B | 1.53 | 0.84 | 1.03 | 0.92 | 0.270 | 0.145 | 140 | 191 | 33 | 40 | 28 |
| 2 | A | 1.36 | 0.099 | 0.88 | 1.44 | 0.289 | 0.122 | 143 | 227 | 50 | 34 | 30 |
| | B | 1.46 | 0.093 | 1.16 | 1.12 | 0.230 | 0.140 | 127 | 217 | 38 | 33 | 28 |
| 4 | A | 1.48 | 0.126 | 1.10 | 1.58 | 0.316 | 0.131 | 146 | 227 | 52 | 39 | 27 |
| | B | 1.54 | 0.106 | 1.50 | 1.04 | 0.250 | 0.146 | 126 | 209 | 38 | 42 | 25 |
| 6 | A | 1.30 | 0.125 | 1.28 | 1.41 | 0.310 | 0.130 | 133 | 251 | 61 | 47 | 34 |
| | B | 1.50 | 0.085 | 1.78 | 0.89 | 0.260 | 0.160 | 125 | 234 | 40 | 50 | 30 |
| 8 | A | 1.31 | 0.128 | 1.43 | 1.24 | 0.288 | 0.125 | 141 | 258 | 64 | 48 | 31 |
| | B | 1.53 | 0.093 | 1.72 | 0.84 | 0.220 | 0.155 | 124 | 244 | 54 | 49 | 28 |
| 10 | A | 1.48 | 0.119 | 1.50 | 1.21 | 0.236 | 0.139 | 165 | 274 | 64 | 50 | 32 |
| | B | 1.55 | 0.093 | 1.63 | 0.80 | 0.254 | 0.172 | 154 | 257 | 55 | 50 | 29 |
| 11 | A | 1.42 | 0.103 | 1.53 | 1.37 | 0.270 | 0.141 | 184 | 281 | 54 | 51 | 27 |
| | B | 1.43 | 0.097 | 1.78 | 0.95 | 0.300 | 0.164 | 161 | 270 | 47 | 52 | 24 |
| 12 | A | 1.33 | 0.121 | 1.61 | 1.36 | 0.260 | 0.130 | 181 | 266 | 64 | 48 | 30 |
| | B | 1.56 | 0.080 | 1.68 | 0.91 | 0.290 | 0.148 | 162 | 254 | 56 | 44 | 29 |
| 13 | A | 1.41 | 0.106 | 1.51 | 1.43 | 0.261 | 0.126 | 171 | 272 | 64 | 58 | 29 |
| | B | 1.50 | 0.080 | 1.67 | 0.90 | 0.290 | 0.156 | 165 | 268 | 54 | 57 | 28 |
| 14 | A | 1.47 | 0.115 | 1.58 | 1.44 | 0.280 | 0.133 | 185 | 289 | 74 | 57 | 31 |
| | B | 1.52 | 0.082 | 1.72 | 0.94 | 0.300 | 0.150 | 175 | 278 | 59 | 56 | 30 |
| 15 | A | 1.54 | 0.124 | 1.48 | 1.40 | 0.270 | 0.146 | 171 | 268 | 64 | 55 | 31 |
| | B | 1.52 | 0.086 | 1.74 | 0.95 | 0.295 | 0.150 | 167 | 261 | 56 | 53 | 28 |
| 16 | A | 1.50 | 0.126 | 1.51 | 1.40 | 0.261 | 0.140 | 164 | 267 | 68 | 55 | 27 |
| | B | 1.51 | 0.103 | 1.70 | 0.90 | 0.262 | 0.161 | 149 | 261 | 49 | 57 | 23 |
| 17 | A | 1.50 | 0.116 | 1.51 | 1.34 | 0.270 | 0.136 | 174 | 283 | 69 | 58 | 28 |
| | B | 1.49 | 0.100 | 1.66 | 0.96 | 0.280 | 0.147 | 145 | 274 | 65 | 60 | 24 |
| 18 | A | 1.50 | 0.126 | 1.56 | 1.37 | 0.290 | 0.144 | 182 | 280 | 60 | 54 | 28 |
| | B | 1.52 | 0.106 | 1.75 | 0.87 | 0.280 | 0.160 | 176 | 260 | 53 | 59 | 27 |

A - Lower leaves B - Upper leaves

to 0.74 per cent and by the time it reached 0.47 per cent, the plants showed severe symptoms of N stress (Table 12). During the corresponding periods, the N level on younger leaves were 1.22 and 1.03 per cent respectively.

Concomittent to the decrease in foliar N level, the P level increased. The increase in P was noted both on lower and upper leaves with more influence on lower leaves. At severe stages of deficiency, the P level in the lower leaves of N-starved plant was 0.15 per cent as against 0.12 per cent in healthy ones. The foliar concentration of K, Fe and Mn was decreased under N stress. The foliar Cu level varied differently in lower and upper leaves. It was reduced in lower leaves but was more on upper leaves. The foliar concentration of Ca, Mg and Zn did not vary much due to N stress.

4.1.3.1.2 Phosphorous deficiency

The foliar nutrient level of clove seedlings as influenced by P-stress are presented in Table 13 and AppendixIII. Withdrawal of P from the nutrient solution reduced the foliar P level in clove seedlings. In control plants, the foliar P level increased from 0.08 to 0.13 per cent as the plants grew. Initial symptoms of P-deficiency were observed when the P content of older leaves was lowered to 0.055 per cent, as against 0.106 per cent P in healthy plants (Table 13). Phosphorous level of older leaves was reduced to 0.045 per cent when plants expressed symptoms of severe deficiency. The younger leaves recorded a P level of 0.06 to 0.07 per cent when the nutrient was in short supply.

As a consequence of reduced P level, foliar Fe and Zn in clove was found to increase. The Fe content increased to the extent of 214 ppm in lower leaves and 198 ppm on upper leaves during severe stages of P-deficiency. Foliar Zn level in P-starved plants were found to be high at initial and severe stages of deficiency. Nitrogen and Ca levels in clove plants under P-stress were found to decrease slightly. Foliar K, Mg, S, Cu and B levels were less influenced by P stress in clove.

Table 12. Effect of nitrogen stress on foliar nutrient level of clove seedling

| Stage* of deficiency | Months after treatment | Position of foliage | Treat-ment | Nutrient level | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N % | P % | K % | Ca % | Mg % | S % | Fe ppm | Mn ppm | Cu ppm | Zn ppm | B ppm |
| Initial | 10 | A | -N | 0.740 | 0.145 | 1.23 | 1.23 | 0.257 | 0.140 | 157 | 244 | 48 | 58 | 35 |
| | | | | (-50) | (+22) | (-18) | (+2) | (+9) | (+1) | (-5) | (-11) | (-25) | (+16) | (+9) |
| | | | C | 1.480 | 0.119 | 1.50 | 1.21 | 0.236 | 0.139 | 165 | 274 | 64 | 50 | 32 |
| | | B | -N | 1.22 | 0.080 | 1.30 | 0.97 | 0.295 | 0.160 | 117 | 209 | 56 | 56 | 32 |
| | | | | (-21) | (-14) | (20) | (+21) | (+16) | (-7) | (-24) | (-19) | (-2) | (+12) | (+10) |
| | | | C | 1.55 | 0.093 | 1.63 | 0.80 | 0.254 | 0.172 | 154 | 257 | 55 | 50 | 29 |
| Severe | 15 | A | -N | 0.47 | 0.148 | 0.90 | 1.37 | 0.275 | 0.156 | 163 | 234 | 44 | 54 | 35 |
| | | | | (-70) | (+19) | (-39) | (-2) | (+2) | (+7) | (-5) | (-13) | (-31) | (-2) | (+13) |
| | | | C | 1.54 | 0.124 | 1.48 | 1.40 | 0.270 | 0.146 | 171 | 268 | 64 | 55 | 31 |
| | | B | -N | 1.03 | 0.100 | 1.30 | 0.95 | 0.286 | 0.173 | 140 | 187 | 63 | 56 | 31 |
| | | | | (-32) | (+16) | (-25) | (0) | (-3) | (+15) | (-16) | (-28) | (+13) | (+6) | (+11) |
| | | | C | 1.52 | 0.086 | 1.74 | 0.95 | 0.295 | 0.150 | 167 | 261 | 56 | 53 | 28 |

* Corresponds to the stage when deficient plants started showing foliar symptoms.

Parentheses indicate percentage variation from healthy plants

A - Lower leaves B - Upper leaves

Table 13. Effect of phosphorus stress on foliar nutrient level of clove seedling

| Stage* of deficiency | Months after treatment | Position of foliage | Treatment | Nutrient level | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N % | P % | K % | Ca % | Mg % | S % | Fe ppm | Mn ppm | Cu ppm | Zn ppm | B ppm |
| Initial | 13 | A | -P | 1.23 (-13) | 0.055 (-48) | 1.58 (+5) | 1.39 (-3) | 0.272 (+4) | 0.130 (+3) | 172 (+1) | 264 (-3) | 67 (+5) | 68 (+17) | 31 (+7) |
| | | | C | 1.41 | 0.106 | 1.51 | 1.43 | 0.261 | 0.126 | 171 | 272 | 64 | 58 | 29 |
| | | B | -P | 1.26 (-16) | 0.070 (-13) | 1.83 (+10) | 0.86 (-4) | 0.300 (+3) | 0.156 (0) | 166 (+1) | 228 (-15) | 56 (+4) | 70 (+23) | 26 (-7) |
| | | | C | 1.50 | 0.080 | 1.67 | 0.90 | 0.290 | 0.156 | 165 | 268 | 54 | 57 | 28 |
| Severe | 18 | A | -P | 1.40 (-7) | 0.045 (-64) | 1.56 (0) | 1.23 (-10) | 0.286 (-1) | 0.120 (-17) | 214 (+18) | 258 (-8) | 63 (+5) | 68 (+26) | 29 (+4) |
| | | | C | 1.50 | 0.126 | 1.56 | 1.37 | 0.290 | 0.144 | 182 | 280 | 60 | 54 | 28 |
| | | B | -P | 1.41 (-7) | 0.060 (-43) | 1.83 (+5) | 0.73 (-16) | 0.280 (0) | 0.160 (0) | 198 (+13) | 223 (-14) | 58 (+9) | 72 (+22) | 28 (+4) |
| | | | C | 1.52 | 0.106 | 1.75 | 0.87 | 0.280 | 0.160 | 176 | 260 | 53 | 59 | 27 |

* Corresponds to the stage when deficient plants started showing foliar symptoms.

Parentheses indicate percentage variation from healthy plants

A - Lower leaves B - Upper leaves

4.1.3.1.3 Potassium deficiency

The influence of K stress on foliar nutrient level of clove is presented in Table 14 and Appendix IV. The influence of K stress on foliar K level of clove was more evident on lower leaves. The foliar K levels were 0.64 and 1.06 per cent respectively for lower and upper leaves of deficient plant at initial stage of deficiency as against 1.61 and 1.68 per cent respectively for lower and upper leaves of healthy plants. The K level was further reduced to 0.56 and 0.99 per cent in deficient plants during severe deficiency.

The K-starved plants were found to have higher leaf Mg. Magnesium was increased both on lower and upper leaves due to K stress. The increase in Mg level was to the extent of 0.369 per cent in lower leaves of K starved ones, as against 0.295 per cent in healthy plants. The influence of K on Ca level was much less as compared to Mg.

4.1.3.1.4 Calcium deficiency

The data pertaining to the influence of Ca stress on foliar nutrient levels of clove are presented in Table 15 and Appendix V. Calcium stress resulted in the reduction of Ca content of the upper leaves. By the time the plants expressed severe deficiency symptoms, the foliar Ca level had declined to 0.76 per cent and 0.35 per cent respectively in the lower and upper leaves as against 1.4 and 0.9 per cent in healthy plants.

The foliar level of K was found affected due to Ca stress. An increasing trend was observed for foliar K levels of plants under Ca stress (Table 15). The concentrations of other nutrients were relatively unaffected by the Ca stress

4.1.3.1.5 Magnesium deficiency

Withdrawal of Mg from the nutrient solution resulted in initial deficiency symptoms to appear by 12th month when the lower and upper leaves registered 0.176 and 0.22 per cent Mg respectively (Table 16). As the symptoms advanced

Table 14. Effect of potassium stress on foliar nutrient level of clove seedling

| Stage* of deficiency | Months after treatment | Position of foliage | Treatment | Nutrient level | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N % | P % | K % | Ca % | Mg % | S % | Fe ppm | Mn ppm | Cu ppm | Zn ppm | B ppm |
| Initial | 12 | A | -K | 1.31 | 0.108 | 0.64 | 1.56 | 0.320 | 0.126 | 164 | 284 | 63 | 52 | 29 |
| | | | | (-2) | (-11) | (-60) | (+15) | (+23) | (-3) | (-9) | (+7) | (-2) | (+8) | (-3) |
| | | | C | 1.33 | 0.121 | 1.61 | 1.36 | 0.260 | 0.130 | 181 | 266 | 64 | 48 | 30 |
| | | B | -K | 1.43 | 0.083 | 1.06 | 0.97 | 0.360 | 0.153 | 137 | 257 | 50 | 50 | 27 |
| | | | | (-8) | (+4) | (-37) | (+7) | (+24) | (+3) | (-15) | (+1) | (-11) | (+14) | (-7) |
| | | | C | 1.56 | 0.080 | 1.68 | 0.91 | 0.290 | 0.148 | 162 | 254 | 56 | 44 | 29 |
| Severe | 15 | A | -K | 1.48 | 0.121 | 0.56 | 1.58 | 0.330 | 0.152 | 163 | 282 | 69 | 56 | 32 |
| | | | | (-4) | (-2) | (-62) | (+13) | (+22) | (+4) | (-5) | (+5) | (+8) | (+2) | (+3) |
| | | | C | 1.54 | 0.124 | 1.48 | 1.40 | 0.270 | 0.146 | 171 | 268 | 64 | 55 | 31 |
| | | B | -K | 1.49 | 0.082 | 0.99 | 1.02 | 0.369 | 0.150 | 135 | 271 | 51 | 60 | 30 |
| | | | | (-2) | (-5) | (-43) | (+7) | (+25) | (0) | (-19) | (+4) | (-9) | (+13) | (+7) |
| | | | C | 1.52 | 0.086 | 1.74 | 0.95 | 0.295 | 0.150 | 167 | 261 | 56 | 53 | 28 |

* Corresponds to the stage when deficient plants started showing foliar symptoms.

Parentheses indicate percentage variation from healthy plants

A - Lower leaves B - Upper leaves

Table 15. Effect of Calcium stress on foliar nutrient level of clove seedling

| Stage* of deficiency | Months after treatment | Position of foliage | Treatment | Nutrient level | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N % | P % | K % | Ca % | Mg % | S % | Fe ppm | Mn ppm | Cu ppm | Zn ppm | B ppm |
| Initial | 12 | A | -Ca | 1.38 (+4) | 0.119 (-2) | 1.57 (-3) | 0.88 (-35) | 0.303 (+17) | 0.133 (+2) | 170 (-6) | 266 (0) | 63 (-2) | 48 (0) | 30 (0) |
| | | | C | 1.33 | 0.121 | 1.61 | 1.36 | 0.260 | 0.130 | 181 | 266 | 64 | 48 | 30 |
| | | B | -Ca | 1.46 (-6) | 0.080 (0) | 1.93 (+15) | 0.47 (-48) | 0.290 (0) | 0.150 (+1) | 164 (+1) | 254 (0) | 53 (-5) | 49 (+11) | 28 (-3) |
| | | | C | 1.56 | 0.080 | 1.68 | 0.91 | 0.290 | 0.148 | 162 | 254 | 56 | 44 | 29 |
| Severe | 16 | A | -Ca | 1.450 (-3) | 0.120 (-5) | 1.66 (+10) | 0.76 (-46) | 0.291 (+12) | 0.130 (-7) | 165 (+1) | 261 (-2) | 63 (-7) | 59 (+7) | 29 (+7) |
| | | | C | 1.50 | 0.126 | 1.51 | 1.40 | 0.261 | 0.140 | 164 | 267 | 68 | 55 | 27 |
| | | B | -Ca | 1.48 (-2) | 0.090 (-13) | 2.07 (+22) | 0.35 (-61) | 0.302 (+15) | 0.156 (-3) | 152 (+2) | 254 (-3) | 51 (+4) | 58 (+2) | 28 (+22) |
| | | | C | 1.51 | 0.103 | 1.70 | 0.90 | 0.262 | 0.161 | 149 | 261 | 49 | 57 | 23 |

* Corresponds to the stage when deficient plants started showing foliar symptoms.

Parentheses indicate percentage variation from healthy plants

A - Lower leaves B - Upper leaves

Table 16. Effect of magnesium stress on foliar nutrient level of clove seedling

| Stage* of deficiency | Months after treatment | Position of foliage | Treatment | Nutrient level | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N % | P % | K % | Ca % | Mg % | S % | Fe ppm | Mn ppm | Cu ppm | Zn ppm | B ppm |
| Initial | 12 | A | -Mg | 1.39 (+5) | 0.103 (-15) | 1.66 (+3) | 1.38 (+2) | 0.176 (-32) | 0.130 (0) | 170 (-6) | 286 (+8) | 61 (-5) | 49 (+2) | 31 (+3) |
| | | | C | 1.33 | 0.121 | 1.61 | 1.36 | 0.260 | 0.130 | 181 | 266 | 64 | 48 | 30 |
| | | B | -Mg | 1.47 (-6) | 0.081 (+1) | 1.82 (+8) | 0.93 (+2) | 0.220 (-24) | 0.150 (+1) | 140 (-14) | 261 (+3) | 49 (-13) | 55 (+2) | 28 (-3) |
| | | | C | 1.56 | 0.080 | 1.68 | 0.91 | 0.290 | 0.148 | 162 | 254 | 56 | 54 | 29 |
| Severe | 18 | A | -Mg | 1.43 (-5) | 0.110 (-13) | 2.00 (+33) | 1.60 (+17) | 0.140 (-52) | 0.120 (-17) | 172 (-6) | 294 (+5) | 66 (+10) | 56 (+4) | 28 (0) |
| | | | C | 1.50 | 0.126 | 1.56 | 1.37 | 0.290 | 0.144 | 182 | 280 | 60 | 54 | 28 |
| | | B | -Mg | 1.42 (-7) | 0.086 (-19) | 2.20 (+26) | 1.06 (+22) | 0.156 (-44) | 0.160 (0) | 160 (-9) | 284 (+9) | 51 (-4) | 57 (-3) | 27 (0) |
| | | | C | 1.52 | 0.106 | 1.75 | 0.87 | 0.280 | 0.160 | 176 | 260 | 53 | 59 | 27 |

* Corresponds to the stage when deficient plants started showing foliar symptoms.

Parentheses indicate percentage variation from healthy plants

A - Lower leaves B - Upper leaves

by 18th month, the Mg levels were further reduced to 0.140 and 0.156 per cent respectively in lower and upper leaves. During the corresponding period, healthy plants had 0.29 and 0.28 per cent Mg in the lower and upper leaves respectively.

In Mg-deficient plants, foliar K and Ca levels were found to increase. A reverse trend was observed for foliar P. At severe stages of Mg-deficiency, the K level of lower and upper leaves increased to 2 to 2.2 per cent as against 1.56 and 1.75 per cent in healthy plants. The influence was much less on Ca and P levels.

4.1.3.1.6 Sulphur deficiency

The foliar S level of clove plants was reduced to 0.10 per cent in the lower and upper leaves when the plants showed initial deficiency symptoms (Table 17). Stress induced for 15 months made the symptoms severe with a further reduction in foliar S level to 0.08 per cent. There appeared no marked difference in S level of lower and upper leaves of S-deficient plants whereas, in healthy plants the S content of upper leaves seemed to be always higher than lower leaves (Table 11). The deficiency of S was not reflected on the foliar concentration of other nutrients (Table 17).

4.1.3.1.7 Iron deficiency

The data on the influence of Fe stress on foliar nutrient levels of clove are presented in Table 18 and Appendix VIII. The iron content of lower and upper leaves was 103 and 46 ppm respectively when the plants exhibited initial symptom of iron deficiency, as against 181 and 162 ppm for healthy plants of the same age group. The levels were further reduced to 94 and 22 ppm within 4 months, when the plants showed severe symptoms of iron deficiency. There was no further reduction in the Fe level on continuing the stress period even for 18 months.

Table 17. Effect of sulphur stress on foliar nutrient level of clove seedling

| Stage* of deficiency | Months after treatment | Position of foliage | Treatment | Nutrient level | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N % | P % | K % | Ca % | Mg % | S % | Fe ppm | Mn ppm | Cu ppm | Zn ppm | B ppm |
| Initial | 10 | A | -S | 1.46 | 0.121 | 1.46 | 1.30 | 0.249 | 0.103 | 153 | 269 | 63 | 45 | 31 |
| | | | | (-1) | (+2) | (-3) | (+7) | (+6) | (-26) | (-7) | (-2) | (-2) | (-10) | (-3) |
| | | | C | 1.48 | 0.119 | 1.50 | 1.21 | 0.236 | 0.139 | 165 | 274 | 64 | 50 | 32 |
| | | B | -S | 1.51 | 0.085 | 1.67 | 0.83 | 0.243 | 0.103 | 149 | 250 | 50 | 51 | 28 |
| | | | | (-3) | (-9) | (+3) | (+4) | (-4) | (-40) | (-3) | (-2) | (-9) | (+2) | (-3) |
| | | | C | 1.55 | 0.093 | 1.63 | 0.80 | 0.254 | 0.172 | 154 | 257 | 55 | 50 | 29 |
| Severe | 15 | A | -S | 1.48 | 0.114 | 1.48 | 1.48 | 0.253 | 0.086 | 175 | 272 | 65 | 61 | 30 |
| | | | | (-4) | (-8) | (0) | (+6) | (-6) | (-41) | (+2) | (+2) | (+2) | (+11) | (-3) |
| | | | C | 1.54 | 0.124 | 1.48 | 1.40 | 0.270 | 0.146 | 171 | 268 | 64 | 55 | 31 |
| | | B | -S | 1.47 | 0.085 | 1.74 | 0.93 | 0.285 | 0.076 | 166 | 254 | 55 | 55 | 26 |
| | | | | (-3) | (-1) | (0) | (-2) | (-3) | (-49) | (-1) | (-3) | (-2) | (+4) | (-7) |
| | | | C | 1.52 | 0.086 | 1.74 | 0.95 | 0.295 | 0.150 | 167 | 261 | 56 | 53 | 28 |

* Corresponds to the stage when deficient plants started showing foliar symptoms.

Parentheses indicate percentage variation from healthy plants

A - Lower leaves B - Upper leaves

Table 18. Effect of iron stress on foliar nutrient level of clove seedling

| Stage* of deficiency | Months after treatment | Position of foliage | Treatment | Nutrient level | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N % | P % | K % | Ca % | Mg % | S % | Fe ppm | Mn ppm | Cu ppm | Zn ppm | B ppm |
| Initial | 12 | A | -Fe | 1.40 (+5) | 0.118 (-3) | 1.50 (-7) | 1.39 (+2) | 0.264 (+2) | 0.144 (+11) | 103 (-43) | 277 (+4) | 66 (+3) | 48 (0) | 30 (0) |
| | | | C | 1.33 | 0.121 | 1.61 | 1.36 | 0.260 | 1.130 | 181 | 266 | 64 | 48 | 30 |
| | | B | -Fe | 1.54 (-1) | 0.088 (+10) | 1.68 (0) | 0.91 (0) | 0.279 (-4) | 0.150 (+1) | 46 (-72) | 262 (+3) | 54 (-4) | 50 (-7) | 28 (-3) |
| | | | C | 1.56 | 0.080 | 1.68 | 0.91 | 0.290 | 0.148 | 162 | 254 | 56 | 54 | 29 |
| Severe | 16 | A | -Fe | 1.46 (-3) | 0.125 (-1) | 1.53 (+1) | 1.44 (+3) | 0.255 (-2) | 0.137 (-2) | 94 (-43) | 298 (+12) | 68 (0) | 56 (+2) | 28 (+3) |
| | | | C | 1.50 | 0.126 | 1.51 | 1.40 | 0.261 | 0.140 | 164 | 267 | 68 | 55 | 27 |
| | | B | -Fe | 1.49 (-1) | 0.090 (-13) | 1.77 (+4) | 0.90 (0) | 0.259 (-1) | 0.156 (-3) | 22 (-85) | 293 (+12) | 49 (0) | 59 (+4) | 26 (+13) |
| | | | C | 1.51 | 0.103 | 1.70 | 0.90 | 0.262 | 0.161 | 149 | 261 | 49 | 57 | 23 |

* Corresponds to the stage when deficient plants started showing foliar symptoms.

Parentheses indicate percentage variation from healthy plants

A - Lower leaves B - Upper leaves

As the foliar iron level was reduced due to Fe stress, the Mn level increased as compared to healthy plants. The Mn level of Fe deficient plants was found to increase to the extent of 298 ppm when the plants exhibited severe symptoms of Fe deficiency (Table 18). All the other elements studied were less affected by Fe-stress.

4.1.3.1.8 Manganese deficiency

Results pertining to the influence of Mn stress on foliar nutrient level of clove are presented in Table 19 and Appendix IX.

Though the foliar Mn level was found to be relatively high in clove, deficiency symptoms were manifested only after a prolonged stress period. Initial symptoms were exhibited 12 months after starting the -Mn treatment, when the foliar Mn level was reduced to 164 and 81 ppm in lower and upper leaves respectively, as against 266 and 254 ppm in healthy plants. The symptoms were severe by 15 months stress period. By the time the Mn level was further reduced to 151 ppm and 55 ppm as against 268 and 261 ppm respectively for lower and upper leaves in healthy plants (Table 19).

The Fe content of Mn deficient plants were relatively high as compared to control. There was an increase in foliar Fe level as the plants expressed severe stages of Mn-deficiency (Table 19, Appendix 9). The influence was more pronounced on upper leaves. Mn-stress was found to have little influence on the other major and minor elements studied.

4.1.3.1.9 Copper deficiency

The results pertaining to the influence of Cu-stress on foliar nutrient level are presented in Table 20 and Appendix X., The foliar Cu level was less affected by the withdrawal of the element from the complete nutrient solution. The reduction in Cu level was evidenced only after a stress period of 10 months. The Cu level was 56 and 14 ppm respectively for lower and upper leaves after a stress period of 15 months (Table 20). When severe deficiency symptoms became evident, the foliar Cu levels were 42 ppm and 11 ppm respectively for the lower and upper leaves. The upper leaves

Table 19. Effect of manganese stress on foliar nutrient level of clove seedling

| Stage* of deficiency | Months after treatment | Position of foliage | Treatment | Nutrient level | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N % | P % | K % | Ca % | Mg % | S % | Fe ppm | Mn ppm | Cu ppm | Zn ppm | B ppm |
| Initial | 12 | A | -Mn | 1.40 (+5) | 0.122 (+1) | 1.54 (-4) | 1.32 (-3) | 0.290 (+12) | 0.126 (-3) | 196 (+8) | 164 (-38) | 68 (+6) | 62 (+15) | 28 (-7) |
| | | | C | 1.32 | 0.121 | 0.61 | 1.36 | 0.260 | 0.130 | 181 | 266 | 64 | 54 | 30 |
| | | B | -Mn | 1.51 (-3) | 0.083 (+4) | 1.76 (+5) | 0.91 (0) | 0.320 (+10) | 0.142 (-4) | 169 (+4) | 81 (-68) | 51 (-10) | 55 (+25) | 27 (-7) |
| | | | C | 1.56 | 0.080 | 1.68 | 0.91 | 0.290 | 0.148 | 162 | 254 | 56 | 44 | 29 |
| Severe | 15 | A | -Mn | 1.47 (-4) | 0.127 (+2) | 1.56 (+5) | 1.37 (-2) | 0.305 (+13) | 0.136 (-9) | 197 (+15) | 151 (-44) | 64 (0) | 60 (+9) | 27 (-13) |
| | | | C | 1.54 | 0.124 | 1.48 | 1.40 | 0.270 | 0.146 | 171 | 268 | 64 | 55 | 31 |
| | | B | -Mn | 1.50 (-1) | 0.080 (-7) | 1.84 (+3) | 0.91 (-4) | 0.280 (-5) | 0.149 (-1) | 200 (+20) | 55 (-79) | 52 (-7) | 56 (+6) | 25 (-11) |
| | | | C | 1.52 | 0.086 | 1.74 | 0.95 | 0.295 | 0.150 | 167 | 261 | 56 | 53 | 28 |

* Corresponds to the stage when deficient plants started showing foliar symptoms.

Parentheses indicate percentage variation from healthy plants

A - Lower leaves B - Upper leaves

Table 20. Effect of copper stress on foliar nutrient level of clove seedling

| Stage* of deficiency | Months after treatment | Position of foliage | Treatment | Nutrient level | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N % | P % | K % | Ca % | Mg % | S % | Fe ppm | Mn ppm | Cu ppm | Zn ppm | B ppm |
| Initial | 15 | A | -Cu | 1.54 (0) | 0.119 (-4) | 1.46 (-1) | 1.46 (+4) | 0.265 (-2) | 0.133 (-9) | 183 (+7) | 270 (+1) | 56 (-13) | 62 (+13) | 29 (-6) |
| | | | C | 1.54 | 0.124 | 1.48 | 1.40 | 0.270 | 0.146 | 171 | 268 | 64 | 55 | 31 |
| | | B | -Cu | 1.55 (+2) | 0.098 (+14) | 1.70 (-2) | 0.89 (-6) | 0.291 (-1) | 0.157 (+5) | 164 (-2) | 248 (-6) | 14 (-75) | 54 (+2) | 27 (-4) |
| | | | C | 1.52 | 0.086 | 1.74 | 0.95 | 0.295 | 0.150 | 167 | 261 | 56 | 53 | 28 |
| Severe | 18 | A | -Cu | 1.57 (+5) | 0.129 (+2) | 1.57 (+1) | 1.38 (+1) | 0.283 (-2) | 0.131 (-9) | 198 (+9) | 282 (+1) | 42 (-30) | 54 (0) | 26 (-7) |
| | | | C | 1.50 | 0.126 | 1.56 | 1.37 | 0.290 | 0.144 | 182 | 280 | 60 | 54 | 28 |
| | | B | -Cu | 1.58 (+4) | 0.107 (+1) | 1.65 (-6) | 0.91 (+4) | 0.273 (-3) | 0.163 (+2) | 173 (-2) | 238 (-9) | 11 (-79) | 60 (+2) | 22 (-19) |
| | | | C | 1.52 | 0.106 | 1.75 | 0.87 | 0.280 | 0.160 | 176 | 260 | 53 | 59 | 27 |

* Corresponds to the stage when deficient plants started showing foliar symptoms.

Parentheses indicate percentage variation from healthy plants

A - Lower leaves B - Upper leaves

were found to be much more affected by the nutrient stress.

Though the Cu stress was found to influence the foliar Cu level of clove plants, it had little influence on the absorption of other elements.

4.1.3.1.10 Zinc deficiency

The results pertaining to the influence of Zn stress on foliar nutrient status are presented in Table 21 and Appendix XI.

At initial stages of Zn deficiency, the Zn level recorded was 27 ppm for leaves on lower half of the stem and 11 ppm for those on the upper half of the stem. The Zn level of upper leaves were found further reduced to 8 ppm by the time the plant expressed severe symptoms of Zn-deficiency. The reduction in Zn level was drastic on upper leaves than on lower leaves.

Zinc-stress was found to influence the foliar level of other nutrients to a lesser extent. Among the 10 other nutrients evaluated, P and Fe were found to respond to Zn-stress. As the foliar Zn level got reduced in plants, the P and Fe levels were slightly increased as compared to healthy plants (Table 21).

4.1.3.1.11 Boron deficiency

The data on folliar nutrient levels in relation to B-stress are presented in Table 22 and Appendix XII. The foliar B level declined to 24 ppm in the lower leaves and to 10 ppm in upper leaves within a stress period of 14 months. Severe symptoms of B deficiency were expressed within a stress period of 17 months and by that time, B level was reduced to 20 ppm in lower leaves and to 9 ppm in upper leaves. The upper leaves were more affected due to starvation.

A decrease in foliar Cu and Zn level was found to be associated with B deficiency. The extent of reduction tuned to 56 ppm for Cu and 51 ppm for Zn as against 65 ppm and 60 ppm for control plants (Table 22).

Table 21. Influence of zinc stress on foliar nutrient level of clove seedling

| Stage* of deficiency | Months after treatment | Position of foliage | Treatment | Nutrient level | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N % | P % | K % | Ca % | Mg % | S % | Fe ppm | Mn ppm | Cu ppm | Zn ppm | B ppm |
| Initial | 13 | A | -Zn | 1.37 | 0.124 | 1.49 | 1.34 | 0.287 | 0.128 | 184 | 280 | 55 | 27 | 30 |
| | | | | (-3) | (+17) | (-1) | (-6) | (+10) | (+2) | (+8) | (+3) | (-14) | (-53) | (+3) |
| | | | C | 1.41 | 0.106 | 1.51 | 1.43 | 0.261 | 0.126 | 171 | 272 | 64 | 58 | 29 |
| | | B | -Zn | 1.56 | 0.090 | 1.76 | 0.90 | 0.302 | 0.158 | 173 | 261 | 48 | 11 | 28 |
| | | | | (+4) | (+13) | (+5) | (0) | (+4) | (+1) | (+5) | (+3) | (-11) | (-81) | (0) |
| | | | C | 1.50 | 0.080 | 1.67 | 0.90 | 0.290 | 0.156 | 165 | 268 | 54 | 57 | 28 |
| Severe | 16 | A | -Zn | 1.41 | 0.136 | 1.54 | 1.42 | 0.278 | 0.128 | 174 | 284 | 54 | 27 | 28 |
| | | | | (-6) | (+8) | (+2) | (+1) | (+7) | (-9) | (+6) | (+6) | (-21) | (-50) | (+4) |
| | | | C | 1.50 | 0.126 | 1.51 | 1.40 | 0.261 | 0.140 | 164 | 267 | 68 | 55 | 27 |
| | | B | -Zn | 1.46 | 0.114 | 1.75 | 0.87 | 0.272 | 0.156 | 164 | 244 | 50 | 8 | 24 |
| | | | | (-3) | (+11) | (+3) | (-3) | (+4) | (-3) | (+10) | (-7) | (+2) | (-86) | (+4) |
| | | | C | 1.51 | 0.103 | 1.70 | 0.90 | 0.262 | 0.161 | 149 | 261 | 49 | 57 | 23 |

* Corresponds to the stage when deficient plants started showing foliar symptoms.

Parentheses indicate percentage variation from healthy plants

A - Lower leaves B - Upper leaves

Table 22. Effect of B stress on foliar nutrient level of clove seedling

| Stage* of deficiency | Months after treatment | Position of foliage | Treat-ment | Nutrient level | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N % | P % | K % | Ca % | Mg % | S % | Fe ppm | Mn ppm | Cu ppm | Zn ppm | B ppm |
| Initial | 14 | A | -B | 1.49 (+1) | 0.112 (-3) | 1.61 (+2) | 1.46 (+1) | 0.285 (+2) | 0.126 (-5) | 184 (-1) | 282 (-2) | 62 (-16) | 57 (0) | 24 (-23) |
| | | | C | 1.47 | 0.115 | 1.58 | 1.44 | 0.280 | 0.133 | 185 | 289 | 74 | 57 | 31 |
| | | B | -B | 1.53 (+1) | 0.083 (+1) | 1.68 (-2) | 0.92 (-2) | 0.293 (-2) | 0.147 (-2) | 169 (-3) | 263 (-5) | 48 (-19) | 49 (-13) | 10 (-67) |
| | | | C | 1.52 | 0.082 | 1.72 | 0.94 | 0.300 | 0.150 | 175 | 278 | 59 | 56 | 30 |
| Severe | 17 | A | -B | 1.48 (-1) | 0.106 (-9) | 1.48 (-2) | 1.31 (-2) | 0.283 (+5) | 0.136 (0) | 166 (-5) | 280 (-1) | 65 (-6) | 56 (-3) | 20 (-29) |
| | | | C | 1.50 | 0.116 | 1.51 | 1.34 | 0.270 | 0.136 | 174 | 283 | 69 | 58 | 28 |
| | | B | -B | 1.49 (0) | 0.087 (13) | 1.56 (-6) | 0.94 (-2) | 0.289 (+3) | 0.152 (+3) | 146 (+1) | 264 (-4) | 56 (-14) | 51 (-15) | 9 (-63) |
| | | | C | 1.49 | 0.100 | 1.66 | 0.96 | 0.280 | 0.147 | 145 | 274 | 65 | 60 | 24 |

* Corresponds to the stage when deficient plants started showing foliar symptoms.

Parentheses indicate percentage variation from healthy plants

A - Lower leaves B - Upper leaves

4.1.4 Recovery of deficient plants

When the deficiency symptoms were visually confirmed, two plants each from the initial and severe stages were fed with complete nutrient solution and observed for recovery. The plants were considered to have recovered of the nutrient deficiency, either when the visual deficiency symptoms had disappeared or when new flushes had emerged without further advancement of the already existing deficiency symptom. The recovered plants were analysed for the foliar nutrient level. The results of the recovery studies are furnished in Table 23.

Plants exhibiting initial stages of visual deficiency symptoms recovered faster when supplied with complete nutrient solution. Quickest recovery was obtained for the N-deficient plants (2 weeks) whereas, calcium and Zn-deficient plants took 5 to 6 weeks to indicate signs of recovery even at initial stages of visual deficiency symptom.

Plants exhibiting severe deficiency symptoms for Ca, S, Mn, Zn or B failed to recover even after supplying the nutrients for two months.

## 4.2 Nutrient distribution and translocation under nutrient stress condition

In this experiment, the patterns of distributin of two anions (P and S) and a cation (Ca) were studied with one year old clove seedlings.

4.2.1 Phosphorus

The data pertaining to the distribution of Pand $^{32}p$ in the stem as well as in the leaf under sufficient and deficient conditions in relation to nodal rank is presented in Tables 24, 25, 30 and Appendix XIII and XIV. When P supply was not limiting, there was a greater accumulation of the nutrient in the plant tissue. Stem was found to accumulate more P than the leaf. A maximum P level of 0.574 per cent on dry matter basis has been recorded on lower stem segment. The foliar P level was maximum at growing tips and has recorded a maximum level of 0.142 per cent. The stem P level of plants receiving Pdecreased from the first node starting from the top to the fifth node. Thereafter, there was a steady increase

Table 23. Recovery of macro and micro nutrient deficiencies in clove seedling

| Deficient nutrient | Stage of deficiency | Time taken for recovery (weeks) | Foliar nutrient status after recovery | |
|---|---|---|---|---|
| | | | A | B |
| N | Initial | 2 | 1.00 % | 1.24 % |
| | Severe | 4 | 0.86 | 1.25 |
| P | Initial | 4 | 0.08 | 0.10 |
| | Severe | 7 | 0.08 | 0.10 |
| K | Initial | 4 | 0.80 | 1.20 |
| | Severe | 6 | 0.80 | 1.20 |
| Ca | Initial | 6 | 1.04 | 0.67 |
| | Severe | - | - | - |
| Mg | Initial | 4 | 0.20 | 0.22 |
| | Severe | 6 | 0.18 | 0.18 |
| S | Initial | 4 | 0.10 | 0.12 |
| | Severe | - | - | - |
| Fe | Initial | 3 | 110 ppm | 50 ppm |
| | Severe | 6 | 100 | 45 |
| Mn | Initial | 3 | 160 | 90 |
| | Severe | - | - | - |
| Cu | Initial | 4 | 55 | 20 |
| | Severe | 5 | 55 | 18 |
| Zn | Initial | 5 | 30 | 20 |
| | Severe | - | - | - |
| B | Initial | 4 | 25 | 15 |
| | Severe | - | - | - |

A - Lower leaves B - Upper leaves - - Not recovered

in the P content of the successive lower nodal positions, with the highest content in the lowest node (Table 24). This pattern of distribution was also found in the leaves in relation to their ranks. Nevertheless, the increase in P content was much less compared to the stem. The only node at which the accumulation of P was more in leaf than in stem, was the youngest node at the tip. In P starved plants also, the stem portion had accumulated more P than did the leaf. However, in the younger portion of the shoot from the first node to the sixth node, the leaves contained more P than the corresponding stem portions. Unlike in the case of control plant, the P concentration did not increase much from the fifth node onwards. Another difference noticed was the maintenance of a steady P level in the stem upto the sixth node. The increase in P content occurred in these P-starved plants only beyond the sixth node.

Emperical equations of linear and quadratic form were tried to examine the goodness of fit of these models in describing the distribution pattern of the nutrient in relation to nodal positions (Table 25). Both linear and quadratic functions yielded low $R^2$ values (the maximum obtained was 0.695) in both sufficient and deficient conditions for the distributions of P in the stem. However, when log P concentration in the stem was used, both linear and quadratic models gave better $R^2$ values ranging from 0.761 to 0.965. Of the two models, the quadratic equation was found to explain the distribution of P in the stem under both sufficient and deficient condition (Fig. 10). In the case of leaf P concentrtion both linear and quadratic models proved unsuitable in describing its distribution as a function of nodal position, but when log P values were used, the quadratic model was superior to linear model for both deficient and sufficient condition (Table 25). The equation explained however, only 61.4 per cent and 69.4 per cent variability in healthy and deficient conditions respectively.

A positive significant relationship between leaf P and stem P was obtained in healthy plants (Table 30). Though the $R^2$ value was less, the relationship was positive and significant in P starved condition also. Both linear and quadratic models yielded more or less similar coefficient of correlation.

Table 24. Distribution pattern of P and $^{32}P$ in clove plants as influenced by P stress

| Parameter | Nodal Rank | Healthy | | Deficient | |
|---|---|---|---|---|---|
| | | Stem | Leaf | Stem | Leaf |
| P (%) | 1 | 0.126 | 0.142 | 0.058 | 0.103 |
| | 2 | 0.110 | 0.102 | 0.058 | 0.090 |
| | 3 | 0.098 | 0.092 | 0.058 | 0.085 |
| | 4 | 0.092 | 0.086 | 0.058 | 0.075 |
| | 5 | 0.093 | 0.088 | 0.058 | 0.068 |
| | 6 | 0.100 | 0.100 | 0.058 | 0.079 |
| | 7 | 0.151 | 0.103 | 0.080 | 0.075 |
| | 8 | 0.161 | 0.113 | 0.089 | 0.076 |
| | 9 | 0.185 | 0.117 | 0.116 | 0.080 |
| | 10 | 0.291 | 0.112 | 0.140 | 0.078 |
| | 11 | 0.344 | 0.127 | 0.165 | 0.076 |
| | 12 | 0.344 | 0.134 | 0.191 | 0.090 |
| | 13 | 0.574 | 0.136 | 0.191 | 0.083 |
| $^{32}P$ (cpm $g^{-1}$) | 1 | 114 | 37 | 380 | 330 |
| | 2 | 104 | 20 | 350 | 75 |
| | 3 | 353 | 24 | 236 | 31 |
| | 4 | 618 | 10 | 401 | 80 |
| | 5 | 552 | 191 | 768 | 268 |
| | 6 | 673 | 174 | 981 | 378 |
| | 7 | 349 | 340 | 1859 | 501 |
| | 8 | 618 | 316 | 2540 | 996 |
| | 9 | 267 | 422 | 2840 | 671 |
| | 10 | 712 | 362 | 2928 | 569 |
| | 11 | 1025 | 412 | 3409 | 501 |
| | 12 | 928 | 321 | 5207 | 920 |
| | 13 | 1970 | 418 | 5207 | 1634 |

Table 25. Goodness of fit ($R^2$) of the mathematical models describing P and $^{32}P$ concentration in clove seedlings as a function of nodal rank

| Variable (y) | Plant part | Condition of the plant | Linear model $y = a \pm bx$ | Quadratic model $y = a \pm bx \pm cx^2$ |
|---|---|---|---|---|
| P concentration (%) | Stem | Healthy | 0.467 | 0.252 |
| | | Deficient | 0.695 | 0.524 |
| | Leaf | Healthy | < 0.001 | < 0.001 |
| | | Deficient | 0.035 | < 0.001 |
| Log P concentration (ppm) | Stem | Healthy | 0.761 | 0.965 |
| | | Deficient | 0.870 | 0.944 |
| | Leaf | Healthy | 0.246 | 0.614 |
| | | Deficient | 0.191 | 0.694 |
| $^{32}P$ activity (cpm $g^{-1}$) | Stem | Healthy | 0.293 | 0.094 |
| | | Deficient | 0.840 | 0.446 |
| | Leaf | Healthy | 0.786 | 0.073 |
| | | Deficient | 0.367 | 0.192 |
| Log $^{32}P$ activity (cpm $g^{-1}$) | Stem | Healthy | 0.546 | 0.581 |
| | | Deficient | 0.859 | 0.860 |
| | Leaf | Healthy | 0.687 | 0.887 |
| | | Deficient | 0.564 | 0.564 |

Note : X is the nodal rank

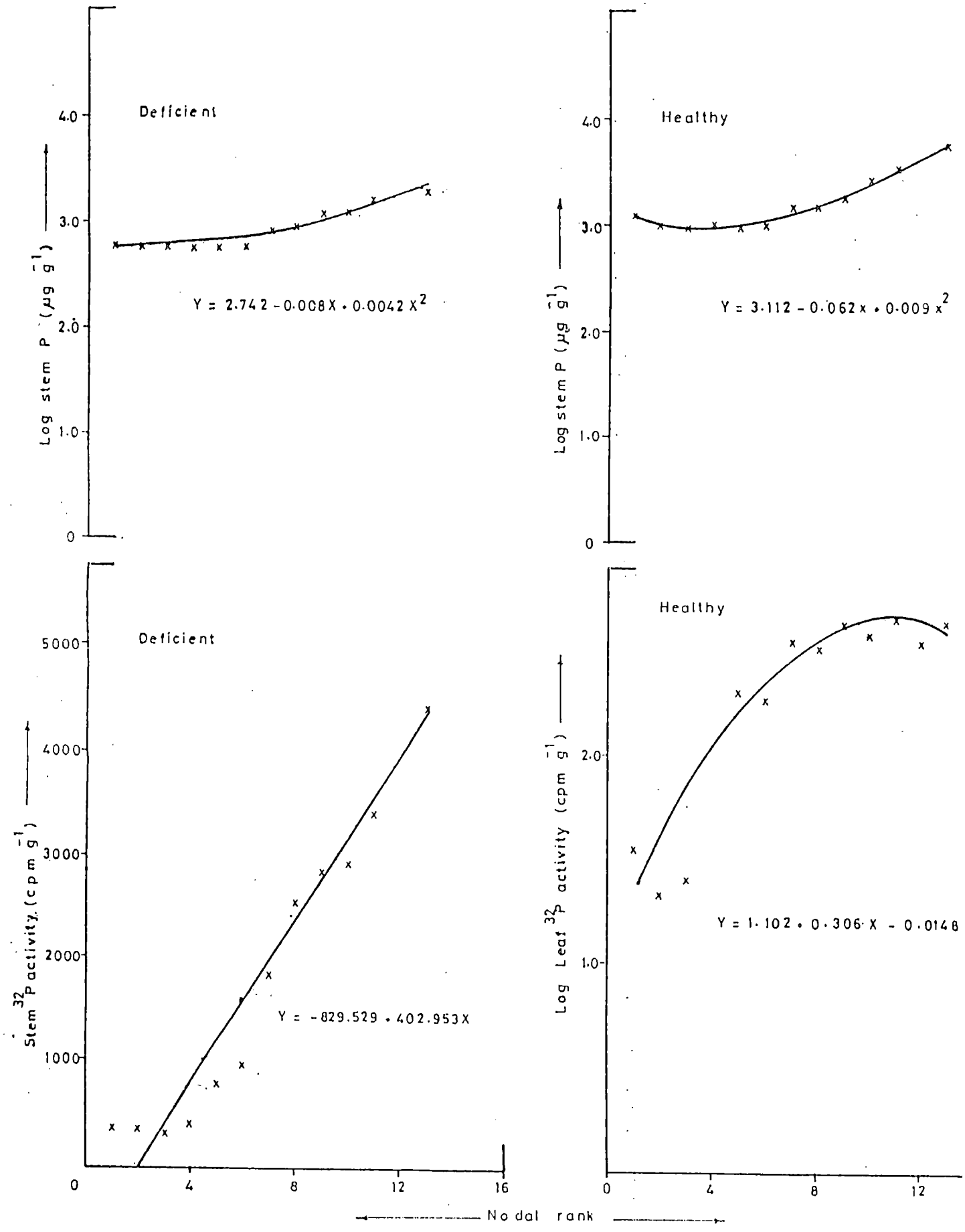



Fig. 10 Distribution of P and $^{32}P$ in healthy and P deficient plants

When labelled P was supplied, the starved plants absorbed more $^{32}p$ than those receiving adequate P. On dry matter basis, the absorption of the radio-label amounted to 1310 and 435 cpm g-1 of dry matter for deficient and sufficient plants respectively. The accumulation of $^{32}p$ in both sufficient and deficient plants was more in the stem than in the leaf (Table 24), the stem portion and leaf at the lowest node accumulating most of the absorbed $^{32}p$ (Plate XXIX).

The distribution of $^{32}p$ in relation to nodal rank in the stem of healthy clove seedlings was not found to be explained by both linear and quadratic models even when logarithmic transformations of $^{32}p$ activity was employed (Table 25). In contrast, the distribution in the stem of P starved plants could be explained by either linear model ($R^2$ = 0.84) using $^{32}p$ activity or by both linear ($R^2$ = 0.859) and quadratic ($R^2$ = 0.86) models when log $^{32}p$ activity was used. Among these, $R^2$ values were slightly better when log transformed data were used. The goodness of fit of the $^{32}p$ data conforming to the linear model is shown in Fig. 10.

The distribution pattern of $^{32}p$ activity in the leaf in relation to nodal rank could be described by the mathematical models only when the plant was not deficient in this nutrient, (Table 25). The quadratic models gave highest $R^2$ values (0.887) when log $^{32}p$ values were used (Fig.10).

The distribution of $^{32}p$ activity in leaf and stem were found related in deficient condition. The linear model explained 64 per cent of the variation in P-staraved plants (Table 30).

4.2.2 Sulphur

Sulphur was more accumulated in the leaf than in the stem of clove plants. The distribution of S in the plant decreased from the uppermost leaf upto the seventh nodal position and tended to increase thereafter in plants receiving S. A more or less similar trend was seen in stem also (Table 26). In S-deficient plants, although the S content was reduced from the upper to lower leaves, the extent of reduction was much less compared to that in S-sufficient plants. The S content of the uppermost leaf in S-deficient plant was 0.146 per cent which decreased to 0.118 per cent

Plate XXIX. Translocation of $^{32}P$ in P starved plant

A. The P-starved plant fed with $^{32}P$

B. The autoradiograph showing the radiolabel accumulated on lower stem and leaf

B

A

Table 26. Distribution pattern of S and $^{35}S$ in clove plants as influenced by S stress

| Parameter | Nodal Rank | Healthy | | Deficient | |
|---|---|---|---|---|---|
| | | Stem | Leaf | Stem | Leaf |
| S (%) | 1 | 0.200 | 0.205 | 0.140 | 0.146 |
| | 2 | 0.166 | 0.182 | 0.130 | 0.137 |
| | 3 | 0.153 | 0.171 | 0.132 | 0.138 |
| | 4 | 0.141 | 0.155 | 0.123 | 0.130 |
| | 5 | 0.135 | 0.143 | 0.114 | 0.128 |
| | 6 | 0.128 | 0.138 | 0.082 | 0.128 |
| | 7 | 0.118 | 0.137 | 0.077 | 0.120 |
| | 8 | 0.124 | 0.150 | 0.088 | 0.118 |
| | 9 | 0.155 | 0.145 | 0.097 | 0.126 |
| | 10 | 0.180 | 0.150 | 0.128 | 0.133 |
| $^{35}S$ (cpm $g^{-1}$) | 1 | 17712 | 54897 | 255486 | 191025 |
| | 2 | 19710 | 10230 | 235406 | 101026 |
| | 3 | 36602 | 12845 | 229625 | 91628 |
| | 4 | 36602 | 7138 | 199612 | 53863 |
| | 5 | 51534 | 4251 | 125697 | 18994 |
| | 6 | 41987 | 4195 | 115444 | 51665 |
| | 7 | 36460 | 4143 | 91873 | 18226 |
| | 8 | 41086 | 4165 | 87874 | 9079 |
| | 9 | 40686 | 4098 | 91172 | 5902 |
| | 10 | 22357 | 4275 | 52402 | 5847 |

in the leaves at the eighth node. Further, the S content increased to 0.133 per cent at the 10th node. On the other hand, in healthy plants, the decrease was from 0.205 per cent in the first leaf to 0.137 per cent in the seventh leaf. The increase in S content beyond the seventh leaf upto 10th leaf was in the range of 0.14 to 0.15 per cent. The accumulation pattern found in the stem was more or less similar to that in the leaf in both sufficient and deficient plants when S was not limiting. The stem portion at the first nodal point had a S level of 0.2 per cent which decreased to 0.118 per cent at the seventh node and rose again to 0.18 per cent at the last node (10th node). In the case of S-deficient plant, the stem portion at first node had a much less concentration of 0.14 per cent which further decreased steadily to about 0.08 to 0.09 per cent between sixth and eighth nodes. The increase in S content beyond this region down to the 10th node was to the extent of 0.128 per cent.

In order to examine whether the distribution of S in the plant part could be described by mathematical expressions, two models namely linear and quadratic were tested. When S concentration was used as the dependent variable, both linear and quadratic models failed to explain the variability. On the other hand, when log S concentration was used as the dependent variable, the distribution pattern in the stem as well as in the leaf as a function of nodal rank could be satisfactorily explained by the quadratic model (Fig. 11). The quadratic equations relating log S concentration in stem and leaf with nodal rank explained 90.2 and 93.7 per cent variability respectively in healthy plants whereas in the deficient condition, the variability explained was 62.4 per cent in the stem and 84.6 per cent in the leaf (Table 27).

In both S-deficient and sufficient condition, significant positive relationship was obtained between S concentration of stem and leaf (Table 30).

S-deficient plants when allowed to absorb $^{35}SO_4^{2-}$ from carrier free $^{35}P$ labelled nutrient solution for one month, took up greater quantity of the nutrient than S sufficient plants. The accumulation of $^{35}S$ in the dry matter of the S-deficient plants was 102596 cpm whereas it was 22668 cpm $g^{-1}$ dry matter in S-sufficient plants. In both sufficient and

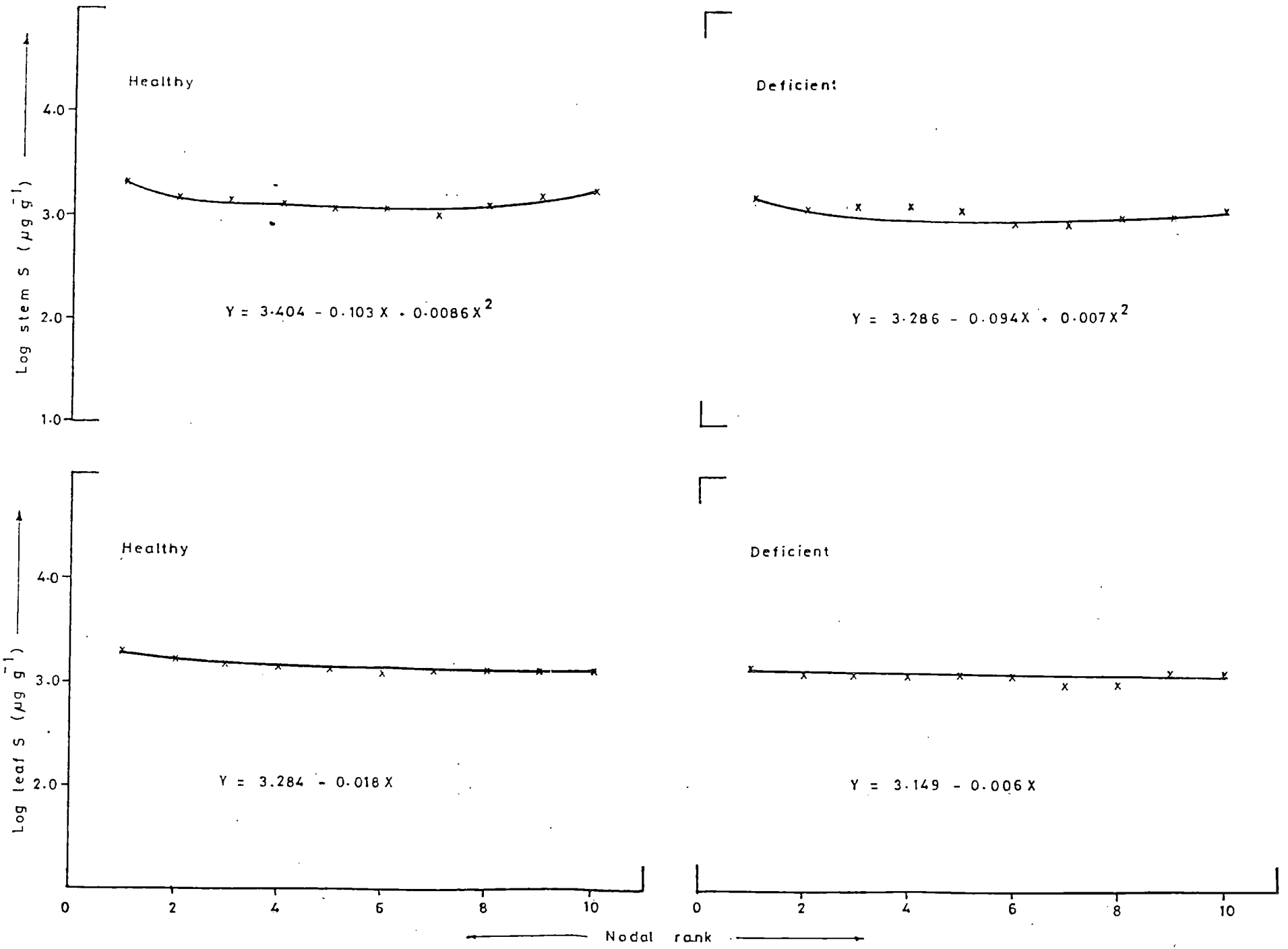



Fig. 11 Distribution of S in health and S-deficient

Table 27. Goodness of fit ($R^2$) of the mathematical models describing S and $^{35}S$ concentration in clove seedlings as a function of nodal rank

| Variable (y) | Plant part | Condition of the plant | Linear model $y = a \pm bx$ | Quadratic model $y = a \pm bx \pm cx^2$ |
|---|---|---|---|---|
| S concentration (%) | Stem | Healthy | 0.013 | < 0.001 |
| | | Deficient | 0.112 | < 0.001 |
| | Leaf | Healthy | 0.478 | < 0.001 |
| | | Deficient | 0.242 | < 0.001 |
| Log S concentration (ppm) | Stem | Healthy | 0.110 | 0.902 |
| | | Deficient | 0.305 | 0.624 |
| | Leaf | Healthy | 0.700 | 0.937 |
| | | Deficient | 0.476 | 0.846 |
| $^{35}S$ activity (cpm $g^{-1}$) | Stem | Healthy | 0.015 | 0.005 |
| | | Deficient | 0.833 | 0.048 |
| | Leaf | Healthy | 0.171 | E |
| | | Deficient | 0.559 | 0.829 |
| Log $^{35}S$ activity (cpm $g^{-1}$) | Stem | Healthy | 0.162 | 0.808 |
| | | Deficient | 0.931 | 0.934 |
| | Leaf | Healthy | 0.636 | 0.890 |
| | | Deficient | 0.960 | 0.962 |

Note : X - is the nodal rank E - Error due to high variation

deficient plants, more radioactivity was recovered from the stem portion than from the leaf. The absorbed radioactivity was accumulated more in the uppermost part of the shoot of both deficient and sufficient plants (Plate XXX).The level of radio-label recorded in the topmost stem portion of S deficient plants was 2,55486 cpm and was 191025 cpm in topmost leaf (Table 26). The radioactivity that could be recovered from the lowest part of the stem was 52402 cpm $g^{-1}$ and was 5847 cpm $g^{1}$ on lowest leaf of S-starved plants.

The distribution of $^{35}S$ in stem and leaves following absorption of this nutrient by healthy and deficient plants also showed a similar trend as in the case of S concentration (Table 27). The distribution followed quadratic model when log $^{35}S$ activity was considered as the dependent variable. It may also be noted that the linear model of the form Log $^{35}S$ activity = a ± bx was equally good as the quadratic model to describe the distribution of the absorbed $^{35}S$ as a function of nodal rank, when the plant was deficient in the nutrient (Fig. 12).

The radio-label recovered from the leaf and stem were found related under S stress. The quadratic model explained 92.7 per cent variability when leaf $^{35}S$ activity was considered as the dependent variable (Table 30).

4.2.3 Calcium

The distribution pattern of Ca in the shoot was not the same under sufficient and deficient conditions. In plants receiving Ca, the upper half of the stem (upto about sixth node) was found to accumulate more Ca than the leaves on this part. On the other hand, lower stem portions were found to contain less Ca than the corresponding leaves. However, the Ca distribution was more on lower part than on upper part, both for stem and leaves (Table 28). In Ca-starved plants there was a steady increase in the concentration of the nutrient in both leaf and stem towards

Plate XXX. Translocation of $^{35}S$ in S-starved plant

A. The S-starved plant fed with $^{35}S$

B. The autoradiograph showing the radiolabel accumulated more on upper leaf and stem

A

B

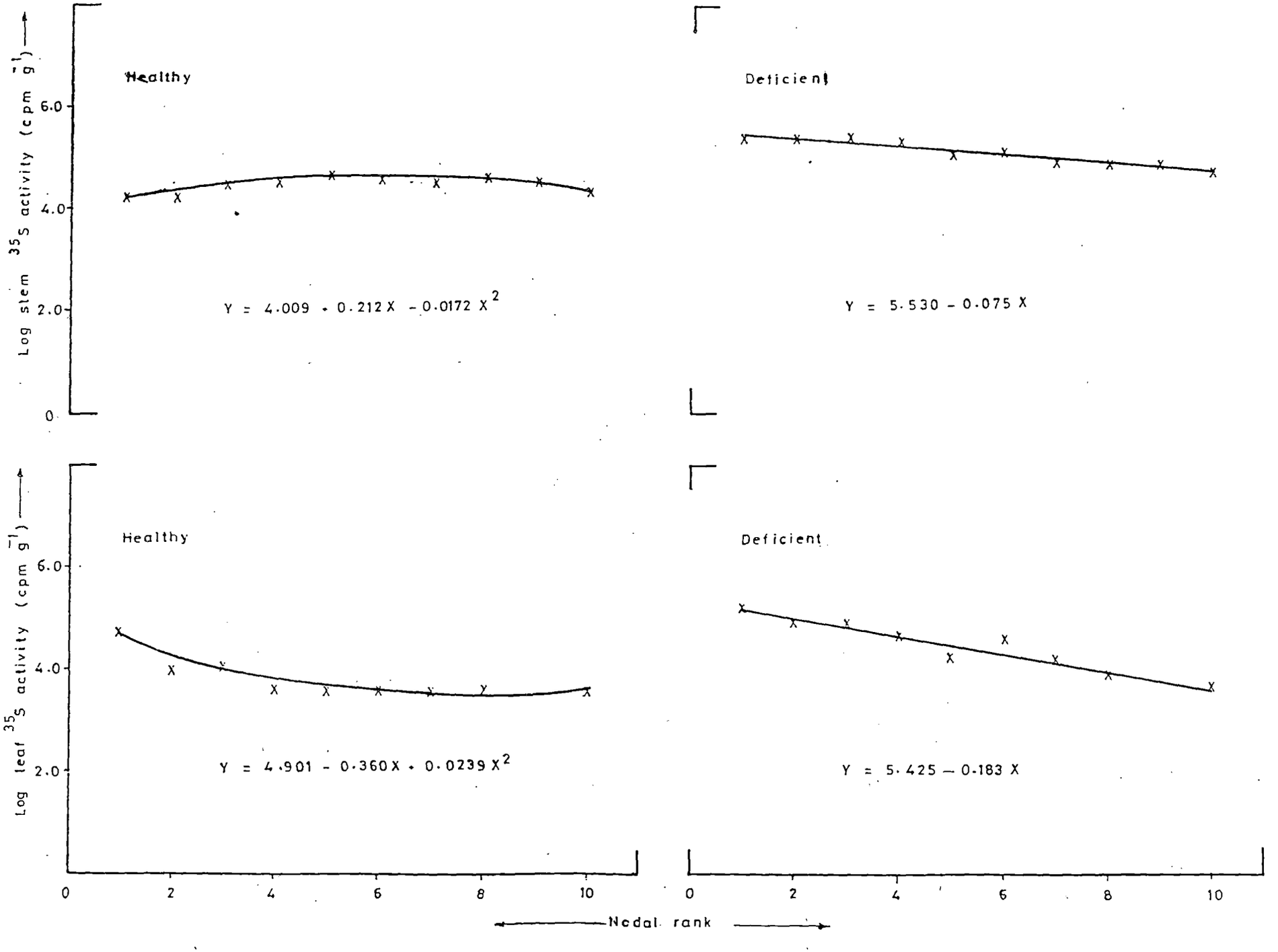

Healthy
Deficient
Log stem $^{35}S$ activity (cpm $g^{-1}$)
Y = 4.009 + 0.212 X - 0.0172 $X^2$
Y = 5.530 - 0.075 X
Healthy
Deficient
Log leaf $^{35}S$ activity (cpm $g^{-1}$)
Y = 4.901 - 0.360 X + 0.0239 $X^2$
Y = 5.425 - 0.183 X
0
2.0
4.0
6.0
0
2
4
6
8
10
Nodal rank

Table 28. Distribution pattern of Ca and $^{45}Ca$ in clove plants as influenced by Ca stress

| Parameter | Nodal Rank | Healthy | | Deficient | |
|---|---|---|---|---|---|
| | | Stem | Leaf | Stem | Leaf |
| Ca (%) | 1 | 0.725 | 0.401 | 0.236 | 0.174 |
| | 2 | 0.773 | 0.624 | 0.253 | 0.398 |
| | 3 | 0.868 | 0.692 | 0.259 | 0.395 |
| | 4 | 0.947 | 0.795 | 0.446 | 0.459 |
| | 5 | 0.938 | 0.937 | 0.462 | 0.586 |
| | 6 | 0.988 | 1.048 | 0.495 | 0.695 |
| | 7 | 1.077 | 1.138 | 0.561 | 0.759 |
| | 8 | 0.757 | 1.209 | 0.565 | 0.846 |
| | 9 | 0.860 | 1.304 | 0.570 | 0.946 |
| | 10 | 1.040 | 1.435 | 0.588 | 1.200 |
| $^{45}Ca$ (cpm $g^{-1}$) | 1 | 625 | 82 | 34688 | 4726 |
| | 2 | 304 | 75 | 65724 | 1777 |
| | 3 | 338 | 108 | 110155 | 1609 |
| | 4 | 861 | 118 | 171188 | 1115 |
| | 5 | 2525 | 86 | 262750 | 2211 |
| | 6 | 6689 | 75 | 327143 | 5092 |
| | 7 | 13079 | 75 | 437829 | 5760 |
| | 8 | 20749 | 170 | 537487 | 14462 |
| | 9 | 32863 | 947 | 790233 | 18071 |
| | 10 | 61067 | 8348 | 950296 | 23186 |

the base. The Ca concentration of the shoot was found to be less in plants grown under Ca stress. The correlation between stem and leaf Ca concentration in control plants was not significant whereas, in deficient plants, the relationship was significant (Table 30).

The distribution of Ca in the stem of healthy plants in relation to nodal rank could not be described by both linear and quadratic models (Table 29). However, when the plant was deficient in Ca, the distribution in the stem could best be explained by the linear and quadratic model using log Ca as the dependent variable. In the case of leaf, simple linear equation was as good as the logarithmicmodels (Table 29, Fig. 13).

When Ca deficient plants were fed with $^{45}Ca$ there was a greater absorption by the plant as could be observerd from the stem and leaf $^{45}Ca$ contents (Table 28). The plants which were well nourished with Ca, absorbed much less quantitites of $^{45}Ca$. On an average, the extent of absorption was 1,88275 and 7459 cpm $g^{-1}$ dry matter respectively for the deficient and sufficient plants. Most of the absorbed radioactivity was found accumulated in the stem in the control and deficient plants. Further, $^{45}Ca$ content of leaf was much less compared to that of stem.(Plate XXXI).

The distribution pattern of absorbed $^{45}Ca$ could be explained by the mathematical models when log $^{45}Ca$ was considered as the dependent variable. There was not much difference in $R^2$ values explaining the variation in the distribution of $^{45}Ca$ in the stem by the two models. Nevertheless, the quadratic equation was found to be better in describing the distribution of $^{45}Ca$ in the leaf in relation to nodal rank (Table 29, Fig. 14).

Table 30. Goodness of fit ($R^2$) of the mathematical models describing the foliar levels of the element in relation to the stem

| Variables y vs. x | Condition of the plant | Linear model $y = a \pm bx$ | Quadratic model $y = a \pm bx \pm cx^2$ |
|---|---|---|---|
| Leaf P vs. stem P | Healthy | 0.760 | 0.827 |
| | Deficient | 0.528 | 0.522 |
| Log leaf P vs. log stem P | Healthy | 0.678 | < 0.001 |
| | Deficient | 0.252 | < 0.001 |
| Leaf $^{32}P$ vs. stem $^{32}P$ | Healthy | 0.088 | 0.023 |
| | Deficient | 0.641 | 0.416 |
| Log leaf $^{32}P$ vs. log stem $^{32}P$ | Healthy | 0.019 | < 0.001 |
| | Deficient | 0.265 | 0.004 |
| Leaf S vs. stem S | Healthy | 0.943 | 0.946 |
| | Deficient | 0.836 | 0.942 |
| Log leaf S vs. log stem S | Healthy | 0.863 | < 0.001 |
| | Deficient | 0.670 | < 0.001 |
| Leaf $^{35}S$ vs. stem $^{35}S$ | Healthy | 0.006 | 0.029 |
| | Deficient | 0.573 | 0.927 |
| Log leaf $^{35}S$ vs. log stem $^{35}S$ | Healthy | 0.185 | < 0.001 |
| | Deficient | 0.756 | < 0.001 |
| Leaf Ca vs. stem Ca | Healthy | 0.302 | 0.306 |
| | Deficient | 0.795 | 0.881 |
| Log leaf Ca vs. log stem Ca | Healthy | 0.130 | < 0.001 |
| | Deficient | 0.640 | < 0.001 |
| Leaf $^{45}Ca$ vs. stem $^{45}Ca$ | Healthy | 0.595 | E |
| | Deficient | 0.781 | 0.722 |
| Log leaf $^{45}Ca$ vs. log stem $^{45}Ca$ | Healthy | 0.204 | 0.004 |
| | Deficient | 0.243 | < 0.001 |

Note : E - Error due to high variation

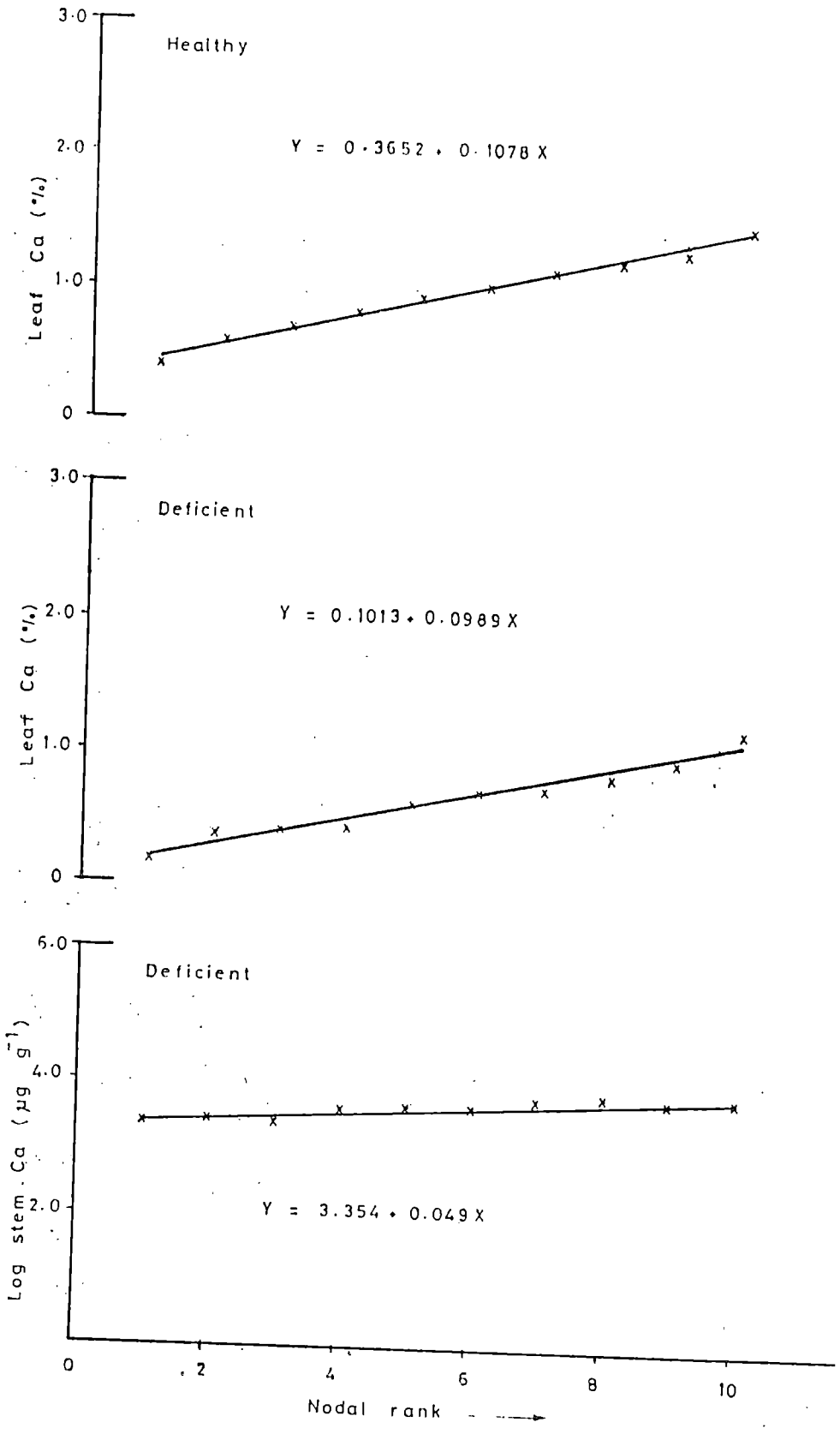



Fig. 13 Distribution of Ca in healthy and Ca deficient plants

Plate XXXI. Translocation of $^{45}Ca$ in Ca-starved plant

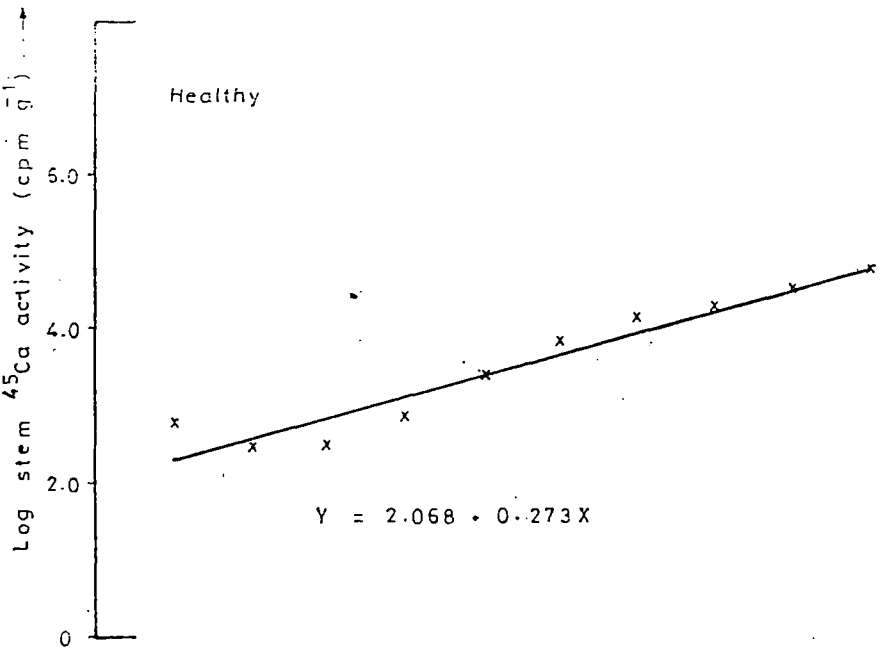
**A.** The Ca-starved plant fed with $^{45}Ca$

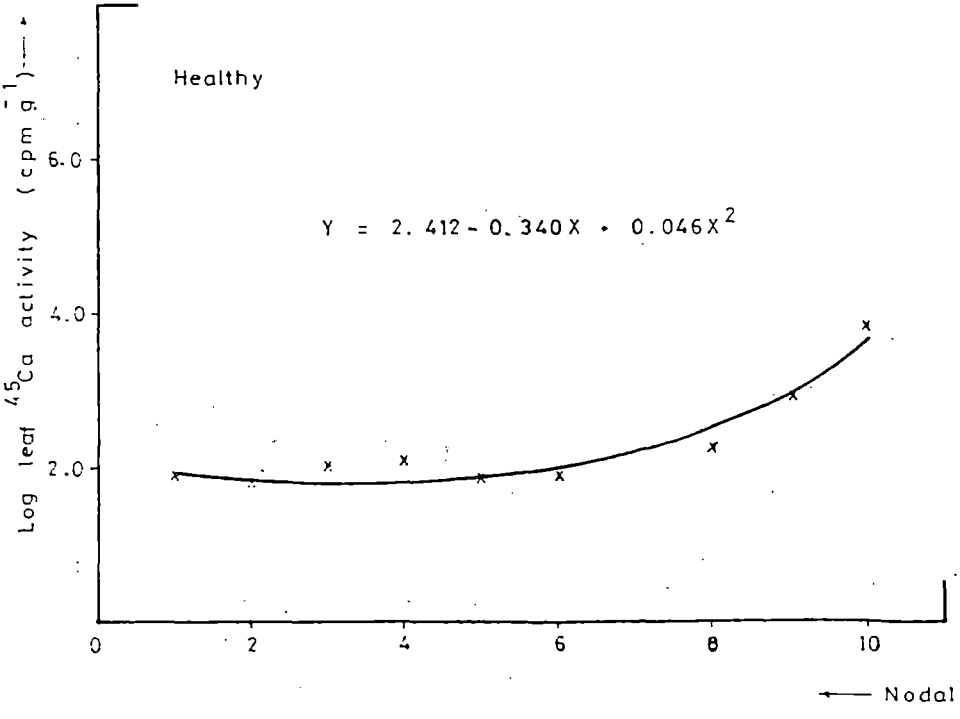
**B.** The autoradiograph showing the radiolabel accumulated more on the stem

B

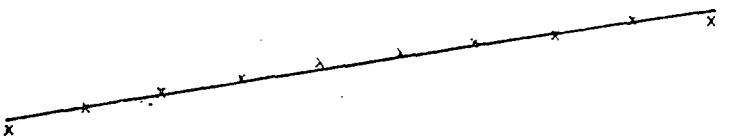


A


Healthy
Log stem $^{45}Ca$ activity (cpm $g^{-1}$)
5.0
4.0
2.0
0
Y = 2.068 + 0.273X


Healthy
Log leaf $^{45}Ca$ activity (cpm $g^{-1}$)
6.0
4.0
2.0
0
2
4
6
8
10
Y = 2.412 - 0.340X + 0.046X$^2$
Nodal

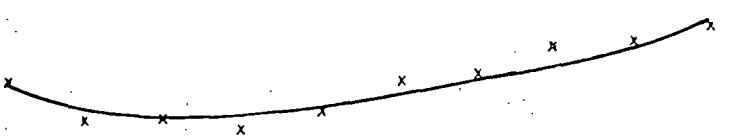
Deficien·

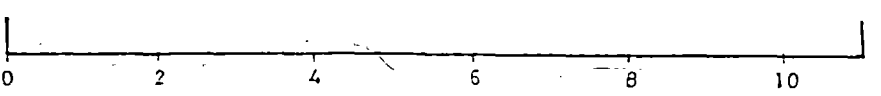


$$Y = 4.540 + 0.153\,X$$

Deficient

$$Y = 3.597 - 0.178\,X + 0.0275\,X^2$$





## 4.3 Annual biomass production and nutrient removal in adult clove trees.

### 4.3.1 Distribution of nutrients

The nutrient concentration in various parts of adult clove tree are given in Table 31. On dry matter basis, the concentration of N in the leaf was the highest followed by flower bud and stem. Leaf contained 1.23 per cent while the other parts had about 0.8 per cent N. Phosphorous was more concentrated in the stem and flower buds than in the leaf. Potassium content on the other hand was more in the harvested produce than the leaf or the stem. In the case of Ca, stem portion and flower bud were better accumulators than the leaf, with a concentration of 1.23 to 1.28 per cent in the former parts and 0.95 per cent in the latter. Highest concentration of Mg was observed in the flower bud (0.295%). It was much less in the stem and leaf (0.20 to 0.21%). Sulphur concentration was the highest in the leaf (0.148%) followed by the flower bud (0.121%) and stem (0.108%). Accumulation of Fe was more in the leaf and stem portions and nearly one half of this concentration (77ppm) was found in the harvested produce. The accumulation of Mn was more in the leaf (1263 ppm) than in flower bud (919 ppm), or stem (794 ppm). Not much difference was observed in the concentration of Cu, Zn and B among the three plant parts. The concentration of Cu was about 18 to 24 ppm much similar to that of B while concentration of Zn in all the three plant parts was slightly less than this (10 to 18 ppm). The Mo level in the plant, was too small to be measured and as such could not be estimated.

### 4.3.2 Partitioning of biomass production and nutrient removal

The annual break up of the biomass produced and the quantities of nutrients removed by the plant are given in Table 32. An 8 year old clove tree was found to add 3.77 kg of dry matter per annum of which, 85 per cent was accounted for the production of leaves. Only 12 per cent and 3 per cent of the total dry matter production were found to be

Table 31. Nutrient distribution in adult clove trees

| Plant part | N % | P % | K % | Ca % | Mg % | S % | Fe ppm | Mn ppm | Cu ppm | Zn ppm | B ppm | Mo ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Leaf | 1.23 | 0.098 | 1.45 | 0.95 | 0.201 | 0.148 | 148 | 1263 | 21 | 15 | 21 | Traces |
| Stem | 0.80 | 0.126 | 1.17 | 1.23 | 0.213 | 0.108 | 138 | 794 | 24 | 18 | 22 | Traces |
| Flower buds (harvested produce) | 0.85 | 0.137 | 1.70 | 1.28 | 0.295 | 0.121 | 77 | 919 | 18 | 10 | 23 | Traces |

Table 32. Partitioning of annual biomass production and nutrient removal in adult clove tree

| Plant part | Dry matter (g/tree) | Moisture (%) | Nutrient removal (g/tree/year) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | N | P | K | Ca | Mg | S | Fe | Mn | Cu | Zn | B |
| Leaf | 3225 (85) | 59 | 39.60 (90) | 3.160 (82) | 46.83 (87) | 30.57 (82) | 6.480 (84) | 4.770 (88) | 0.477 (87) | 4.073 (90) | 0.068 (84) | 0.048 (84) | 0.068 (85) |
| Stem | 435 (12) | 44 | 3.48 (8) | 0.548 (14) | 5.08 (9) | 5.35 (14) | 0.926 (12) | 0.470 (9) | 0.060 (11) | 0.345 (8) | 0.010 (13) | 0.008 (14) | 0.010 (12) |
| Flower buds (Harvested produce | 117 (3) | 68 | 0.99 (2) | 0.160 (4) | 1.98 (4) | 1.50 (4) | 0.345 (4) | 0.142 (3) | 0.009 (2) | 0.108 (2) | 0.002 (3) | 0.001 (2) | 0.003 (3) |
| Total | 3777 | | 44.07 | 3.87 | 53.89 | 37.42 | 7.751 | 5.382 | 0.546 | 4.53 | 0.081 | 0.057 | 0.080 |

Parentheses denote percentage of the total removed

Note : Since Mo concentration in plant parts are below the detection limits, quantities removed were not estimated

due to stem growth and flower buds respectively. The quantities of N, P, K, Ca, Mg, S, Fe, Mn, Cu, Zn and B annually removed by the plant for its added biomass were 44.07, 3.87, 53.89, 37.42, 7.75, 5.38, 0.546, 4.53, 0.081, 0.057 and 0.080 g respectively. The annual nutrient removal by an adult clove tree in the order of preference is given in Fig. 15. Of the total quantities of the nutrient removed, leaf accounted for about 82 to 90 per cent, stem 8 to 14 per cent and harvested produce (flower buds) 2 to 4 per cent.

## 4.4 Seasonal variations in foliar nutrient concentration in bearing clove tree

Statistical analysis of the analytical data for leaf samples representing the four positions indicated significant difference among leaf ranks in the nutrient concentration (Table 33). Nitrogen content was lowest in the first fully matured leaf ($L_1$). A similar trend was also observed for Ca. On the other hand, the concentration of P and K levels were high for the first leaf compared to other leaf ranks. In the case of Mg, the concentration was the same irrespective of the leaf rank and was true for the S level also.

The variation in foliar nutrient level at monthly intervals are presented in Table 34 and depicted in Fig. 16. The data represent the mean values obtained for leaves of rank 1 to 4. During the period of study, there were three flushing times in January - February, May - June and September - October. The fertilizer application was then during July - August. The foliar N concentration was generally low during February - March. Later it increased upto May and then decreased sharply until July. Beyond July, there was an increase upto October.

The P level in the leaves remained more or less steady from November to April. A decrease in the P content of the mature foliage

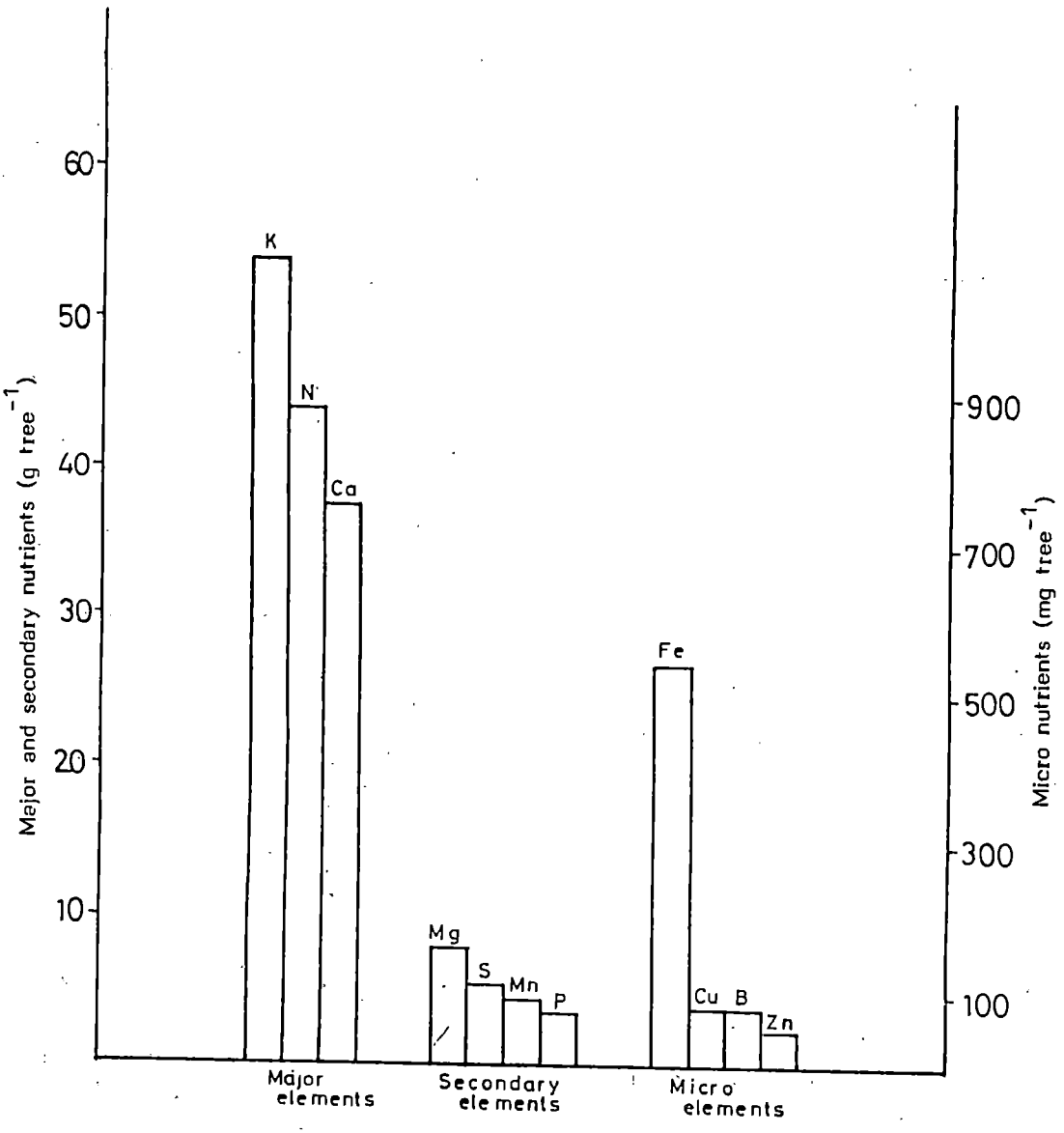



Fig. 15 Annual nutrient removal by the adult clove tree

Table 33. Foliar nutrient level of bearing clove tree as influenced by leaf position

| Leaf rank | N % | P % | K % | Ca % | Mg % | S % |
|---|---|---|---|---|---|---|
| $L_1$ | 1.07 | 0.11 | 1.55 | 0.80 | 0.20 | 0.13 |
| $L_2$ | 1.20 | 0.10 | 1.41 | 0.81 | 0.20 | 0.14 |
| $L_3$ | 1.26 | 0.09 | 1.25 | 0.89 | 0.20 | 0.14 |
| $L_4$ | 1.22 | 0.09 | 1.12 | 0.98 | 0.20 | 0.14 |
| SEm | 0.042 | 0.006 | 0.047 | 0.040 | 0.006 | 0.009 |
| CD (1 %) | 0.046 | 0.007 | 0.051 | 0.044 | 0.006 | 0.010 |

Table 34. Mean monthly variations in foliar nutrient level of bearing clove tree

| Period (months) | Nutrient level | | | | | |
|---|---|---|---|---|---|---|
| | N % | P % | K % | Ca % | Mg % | S % |
| November | 1.20 | 0.08 | 1.66 | 0.76 | 0.22 | 0.12 |
| December | 1.29 | 0.11 | 1.52 | 0.89 | 0.23 | 0.13 |
| January | 1.32 | 0.11 | 1.44 | 0.90 | 0.21 | 0.13 |
| February | 1.25 | 0.10 | 1.44 | 0.93 | 0.20 | 0.14 |
| March | 1.15 | 0.10 | 1.33 | 0.82 | 0.21 | 0.13 |
| April | 1.17 | 0.09 | 0.94 | 0.87 | 0.21 | 0.12 |
| May | 1.32 | 0.08 | 1.40 | 0.93 | 0.21 | 0.12 |
| June | 1.12 | 0.07 | 1.35 | 0.89 | 0.22 | 0.13 |
| July | 0.86 | 0.07 | 1.26 | 0.89 | 0.22 | 0.13 |
| August | 1.04 | 0.10 | 1.36 | 0.82 | 0.16 | 0.15 |
| September | 1.23 | 0.12 | 1.40 | 0.86 | 0.18 | 0.16 |
| October | 1.32 | 0.11 | 1.21 | 0.76 | 0.18 | 0.20 |
| SEm | 0.042 | 0.006 | 0.047 | 0.040 | 0.006 | 0.009 |
| CD (1 %) | 0.077 | 0.011 | 0.085 | 0.074 | 0.010 | 0.017 |

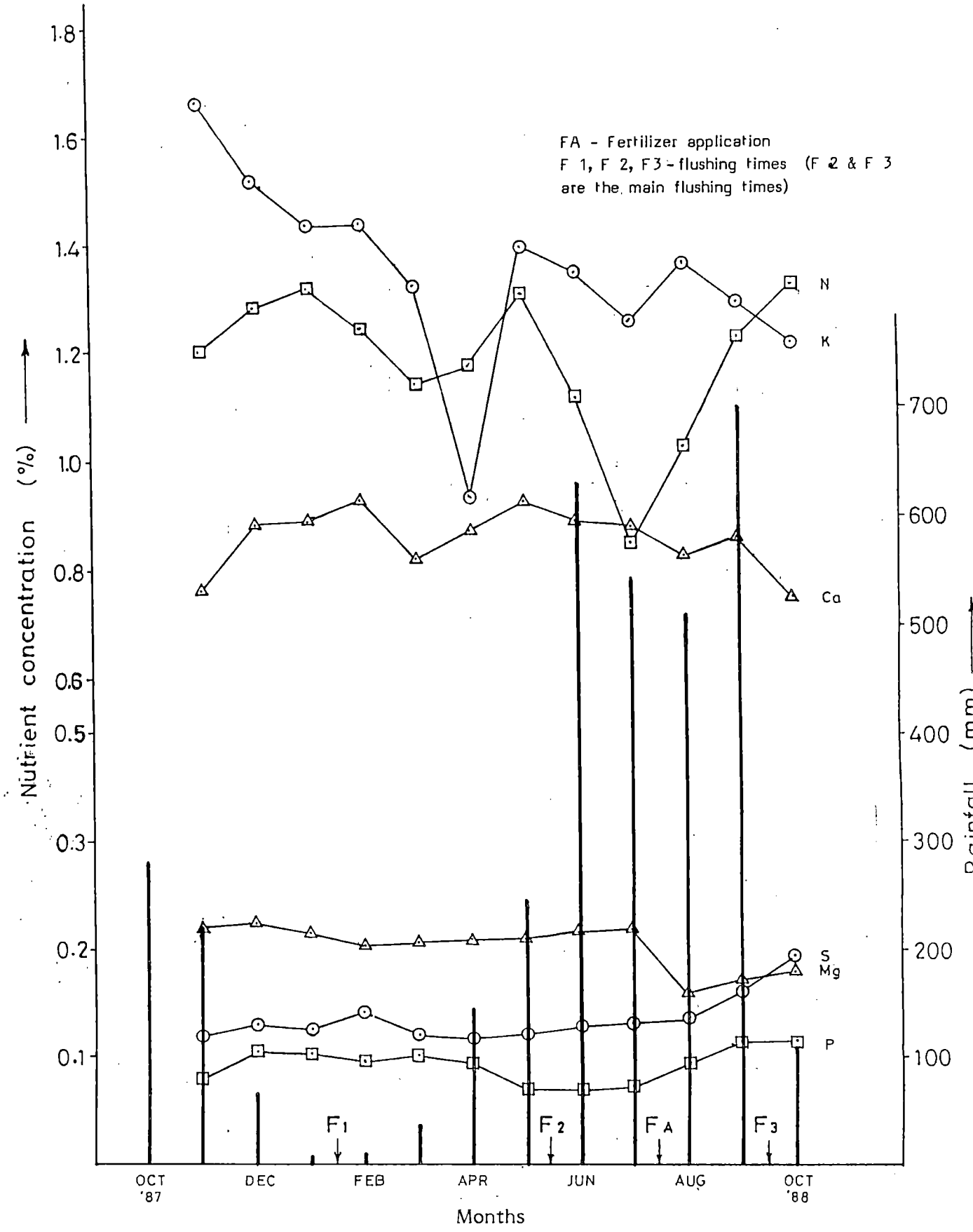



Fig. 16 Seasonal variations in foliar nutrient level of the bearing clove tree

was observed from May to July. The level of P however increased from August onwards upto October.

Potassium level in the foliage decreased steadily from November to April. From May onwards, the trees had a better K level in the leaves, although there was a slight decrease in July. The foliar K level was improved further in August which decreased again until October.

There was a slight increase in foliar Ca level from November to February but in March, the concentration decreased to increase again upto May. Beyond this period, there was a more or less steady decrease in the Ca content of the leaf, except during August - September. The levels of both Mg and S remained relatively unaffected from November to July. In the case of Mg, the foliar level decreased in August, while in the case of S, the level showed an increasing trend after the month of August.

# Discussion

# DISCUSSION

The results obtained from the experiments conducted on the nutrition of clove are discussed in this section.

## 5.1 Nutrient deficiency

### 5.1.1 Nitrogen

Nitrogen deficiency was characterised by a general yellowing of the older leaves. The total chlorophyll content was greatly reduced in N-starved plants. The symptoms spread to younger leaves only during later stages of deficiency. The deficiency resulted in the early defoliation of the affected leaves.

Nitrogen is essential for the synthesis of chloroplast in plants and hence, its deficiency leads to chlorosis of the leaves. About 70 per cent of leaf N exists in chloroplasts (Stocking and Origun, 1962). The appearance of early symptoms on older leaves may be due to the mobile nature of N (Gauch, 1972). In the event of limited supply, the N present in the older leaves get mobilised and translocated to the actively growing points. This would result in the appearance of the deficiency symptoms first on the older leaves. Works reported in cocoa (Maskell et al. 1953), citrus (Jones and Embleton, 1959) and coffee (Muller, 1966) also agree with these findings. The early defoliation is due to the fact that N is essential to maintain the phytohormone balance in plants. Marschner (1982) has reported that the interruption of N would lead to the depression of cytokinin synthesis and enhancement of abscisic acid level favouring leaf abscission.

Nitrogen-stress resulted in substantial growth reduction in clove. Nitrogen-containing compounds constitute about 30 per cent of the dry weight of plants (Kramer and Kozlowski, 1960). Further, the role of N in metabolic processes associated with protoplasm, enzyme reactions and photosynthesis (Greulach, 1973) substantiates the reduced growth rate and biomass production in clove plants under N stress.

Withdrawal of N from the nutrient solution influenced the foliar nutrient levels to varying extent. The foliar N level of clove seedlings ranged between 1.3 and 1.5 per cent. Nitrogen stress reduced the foliar nutrient level, the reduction being more pronounced on lower leaves. This again confirms the mobility of N. Foliar levels of P was found increased under N stress whereas K, Mn and Cu were found reduced. The N-P antagonism has been reported in citrus (Smith 1966) and apple (Stoilov and Lekhova, 1974). The impared protein synthesis and other metabolic activities under the nutrient stress would explain the differential uptake of these vital elements during N deficiency. Variable phloem mobility of Cu has been reported by Loneragan (1982). Copper appeared to be retained on green leaves but rapidly mobilised with N during senescence. This explains the relatively low levels of Cu in lower leaves of N-deficient plants.

The clove plants under N stress recovered from deficiency as the plants were supplied with the element for two to four weeks. The recovered plants recorded the foliar N level, higher than that at initial stage of N-deficiency.

5.1.2 Phosphorus deficiency

Small, brownish spots developed on the older leaves of the P-starved plants which later coalesced to form large necrotic patches. The leaves with burnt areas due to P-deficiency has been reported in citrus (Haas, 1936), avacodo, and strawberry (Childers, 1966). Report made by Bingham (1975) in various tree crops and Philip (1986) in nutmeg are also in agreement with the P-deficiency symptoms obtained for clove in this study. The mobility of the element resulted in the deficiency to occur initially on older leaves.

Reduced plant height, number of leaves and total biomass produced by P-starved plants resulted in a reduced assimilation rate and crop growth rate. Phosphorus being the major controlling factor of energy for all living cells (Epstein, 1978) and the major role played by it as a constituent of nucleoproteins and other metabolically active cell constituents (Gauch, 1972)

justifies the reduced NAR, AGR and RGR values registered by P-starved clove seedlings.

The foliar P level of healthy clove seedlings ranged between 0.098 and 0.13 per cent and symptoms of P stress were expressed when foliar P level was brought down to 0.06 per cent. Phosphorus-starvation markedly reduced the P level of lower leaves, suggesting the remobilisation of absorbed P in the plant and relatively low P-uptake under starved condition.

Phosphorus deficiency was found to increase the foliar Fe and Zn levels. Similar reports have been made by El-Gazzar et al. (1979) in orange, olive and guava. The interaction has also been reported by Gardner et al. (1985). Phosphorus interaction with other elements studied were relatively less in clove. It was found possible to recover P dificient plants by applying the element for seven weeks. The recovered plants putforth new growth and the foliar P level was improved to 0.08 to 0.1 per cent.

5.1.3 Potassium deficiency

Potassium deficiency symptoms in clovewere characterised by the necrosis of the tips and margins of the lamina that progressed inward till about half the leaf blade presented a scorched appearance. Ulrich and Ohki (1975) described the general symptoms of K-deficiency in perennial crops as tip and marginal necrosis. Putrescine (a diamine) produced and accumulated by K-deficient plants is reported to favour foliar necrosis (Richards and Coleman, 1952). Increased partitioning of K to the chloroplast in K-deficient plants as reported by caporn et al.(1982) may be the reason for the relatively less influence of K on chloryphyll content of clove seedlings.

Though K is not a constituent of any cellular compound, its function as a catalyst or an activator in protein synthesis and nitrogen metabolism (Evans and Sorger, 1966; Greulach, 1973) substantiates the reduced growth rate and biomass production of plants under K-stress. Decreased rate of

photosynthesis, lower photochemical efficiency and reduced $CO_2$ conduct... reported for K-deficient plants (caporn et al. 1982) would have reduced the NAR, AGR and RGR of K-starved clove plants.

The foliar K level of healthy clove seedlings ranged between 0.7 and 1.6 per cent. As against N and P levels, the foliar K level was found to be relatively high on upper leaves of clove seedlings. Under conditions of K-stress, the K level of lower leaves were considerably reduced suggesting the remobilisation of K to growing points. Reduced foliar K levels were found associated with a higher Ca and Mg levels, the effect being more on Mg. Antagonistic effects of K with Ca and Mg has been established in different crops (Smith, 1966; Hansen, 1970; Greulach, 1973; Nybe, 1986). Tandon and Sekhon (1988) has reported a strong K - Mg interaction and according to them, K-Ca antagonism occurred commonly under conditions of moisture stress.

Clove plants could be recovered from K deficiency by applying K for four weeks. It was not possible to reverse the already existing symptoms of leaf necrosis, but the further advancement was prevented by applying K.

5.1.4 Calcium deficiency

The younger leaves were the first to be affected by Ca deficiency. Chlorotic and necrotic upper leaves with reduced shoot growth and tip die back in Ca-starved clove plants could be expected considering the relative immobility of Ca reported in plants (Bangerth, 1979). The deficiency symptoms obtained for clove agree with that reported by chapman (1975). The marked reduction in root dry weight (51%) in Ca starved clove plants emphasises the essentiality of Ca ion for root growth. The role of Ca-calmodulin complex in controlling numerous key enzyme system and their involvement in diverse metabolic processes and hormonal regulation of growth (Anderson and Cormier, 1978; Cheung, 1980) would explain the reduced growth rate, assimilation

rate and total biomass production of Ca starved clove plants. The growth of clove was completely arrested by 15 months' stress period.

The foliar Ca level of clove seedlings were relatively high (1 to 1.6%) as compared to other elements. Withdrawal of Ca from the nutrient solution reduced the foliar Ca level more markedly on upper leaves. Calcium accumulated on older leaves were less utilised for new growth. Foliar K levels were found to be high in Ca-starved plants due to their antagonistic relationship. Plants could be recovered of Ca-deficiency only at initial stages of deficiency.

5.1.5 Magnesium deficiency

Chlorotic older and younger leaves with tip and marginal necrosis at later stages were the Mg deficiency symptoms expressed by clove plant. The chlorophyll level was markedly reduced in Mg-starved plants. The necrosis of the laminar tips and margins distinguishes Mg deficiency from the symptoms of N deficiency in clove seedlings. Magnesium being a constituent of chlorophyll, its reduction would naturally induce chlorotic symptoms. The significant role of Mg in photosynthesis, synthesis of ribosomes (Greulach, 1973) and catalytic role as an activator of enzyme concerned with carbohydrate metabolism (Cheung, 1980) explains the reduced growth rate, assimilation rate and total biomass produced by Mg-starved clove plants.

The Mg level of healthy clove seedlings was around 0.28 per cent. Though the element is reported to be mobile inside the plant (Embleton, 1975), the deficiency symptoms were expressed both on lower and upper leaves of clove plants. This may be due to the relatively low foliar levels of Mg in clove plants available for remobilisation. With the lowering of Mg levels in the leaf, the K and Ca levels exhibited an increasing trend. Antagonistic influence of Mg with K and Ca has been reported by Emmert (1961), Hugriet (1979) and Nybe (1986). It was found possible to nullify the effects of Mg stress in clove by supplying the nutrient solution sufficient in Mg. Recovery from initial symptoms occurred in four weeks' time.

5.1.6 Sulphur deficiency

The newly formed leaves were found first affected by S deficiency. The leaves were pale green with low chlorophyll, reduced size and occasionally with marginal necrosis. As reported by Mengel and Kirkby (1978) the S reserves in older leaves may not be contributing to the S supply of younger leaves resulting the deficiency symptoms to occur on younger leaves. Reduced internodal length, tip die back and complete cessation of growth were the marked symptoms at severe stage of S-deficiency. Similar reports have been made in apple, pear, grapes, coffee, pepper etc.(Lott et al., 1960; Childers, 1966; Nybe, 1986). The participation of S in amino acid synthesis and enzymatic activities (Kramer and Kozlowski, 1960, Greulach, 1973) and the direct influence of S on protein level and chlorophyll content (Hewitt, 1963) substantiate the deficiency symptoms, reduced growth rates and assimilation rates of S-starved plants.

The foliar S level of clove seedlings varied between 0.11 and 0.14 per cent. Sulphur starvation reduced this level to nearly half. There was a general tendency for the healthy clove plants to accumulate more S on upper leaves. However, no marked difference in S level was noted for lower and upper leaves of S-deficient plants. It was found possible to recover the plants from initial stages of S-deficiency by supplying sulphate ion through the nutrient solution for 4 weeks. However, once the severe symptoms of leaf necrosis and growth cessation were manifested, it was not possible to recover the deficient plants. The loss of vigour and extremely low levels of the nutrient reserve at severe stages of S-deficiency would have made the plant impossible to restore the S level to the extent needed for the normal cell division and protein synthesis. When a comparison is made among the macro nutrients, N and S were found to manifest foliar deficiency symptoms at the earliest (10th month). Phosphorus took the maximum time (13 months) for the manifestation of deficiency symptoms. All the others (K, Ca & Mg) exhibited the stress influence more or less simultaneously (12 months stress period). The foliar symptoms of N, Mg and S stress in clove were unique

in that chlorotic leaves were noticed in all the three cases. A general yellowing of older leaves which were soon detached from the plant was characteristic of N stress whereas chlorosis of younger leaves that failed to attain normal size was the specific symptom for S stress. Though the Mg stress induced similar symptoms as that of N, the chlorosis soon spread to upper leaves and were necrotic later. Unlike the N-deficient leaves, chlorotic leaves of plants under Mg stress were retained for a longer time (2 months) on the plant. Tip and marginal necrosis of upper chlorotic leaves were common in both Mg and S deficient plants.

Phosphorus, potassium and calcium starved plants exhibited necrotic patches on leaves. Lower leaves were first affected in P and K starved plants. Small reddish brown spots towards the base coalesced to give necrotic patches in P-starved plants whereas K-starved plants were characterised by greyish brown necrotic patches that first appeared in leaf tip and margin and later progressed inward. Ca-starved plants had necrotic upper leaves which later turned chlorotic and defoliated. The stunted growth with bare top and dull green leaves were characteristic for Ca-starved plants.

The vegetative growth of the clove plant was most affected by N stress, followed by S, P, Ca, K and Mg. N-starved plants gave the quickest recovery when supplied with the nutrient and was very slow in the case of Ca-starved ones. It was found difficult to recover plants under severe stages of Ca and S deficiency.

### 5.1.7 Iron deficiency

Interveinal chlorosis on younger leaves were the initial symptoms of Fe-deficiency. As the symptoms advanced, the leaves became increasingly chlorotic and were papery white in many cases. The active participation of Fe in chlorophyll synthesis and the fact that, much of the Fe in the leaves is found in the chloroplasts (Bogorad, 1966) substantiates the foliar symptoms exhibited by Fe-starved clove plants. The relative immobility of the element

inside the plant caused the deficiency to first appear on upper leaves. The role of Fe in photosynthesis and as a catalyst and electron carrier (Nason and Mc Elroy, 1963; Salisbury and Rosc, 1978) in various vital reactions and its participation in mitochondrial enzymes (Burris, 1966) explain the reduced growth and metabolic activity in Fe-starved clove plants. The relatively low level of P and high Mn recorded in Fe-starved plants is in confirmity with that reported by Hewitt (1963) and Carpena et al. (1968).

The Fe status of healthy clove plants ranged between 133 and 185 ppm. The level was comparatively higher on lower leaves. It was possible to recover the deficiency by applying the nutrient continuously for three weeks.

5.1.8 Manganese deficiency

Initial symptoms of Mn deficiency resembled that of Fe. The leaves were pale green, narrow and distorted on later flushes. Variations in number and structure of chloroplasts reported (Hofman, 1967) in Mn-starved plants would have contributed to the reduced chlorophyll content and chlorotic symptoms of Mn-deficient clove plants. The role played by Mn in oxidation reduction reactions and its direct involvement in photosynthesis and respiration (Mehler, 1951; Horiguchi and Fukomoto, 1987) clearly explains the retarded growth rate in Mn-starved plants. The relatively higher level of Mn (207 to 289 ppm) and delayed expression of deficiency symptoms suggest the accumulation of Mn at levels much more than that what is needed for the growth of clove. Wide variation in Mn level of woody plant species have been reported by various workers (Edwards and Asher, 1982; Shkolnik, 1984, (Wang, 1987 and Horiguchi, 1988). Antagonistic effects of Mn with Fe and K has been observed in clove. This has been previously reported in other crops by Somer and Shive (1942) and Hewitt (1963). Application of Mn could correct the deficiency at initial stages of expression.

5.1.9 Copper deficiency

Reduced vigour, leaf size and internodal length, bending of lamina and drying up of leaf tips were found associated with Cu deficiency. The relatively more concentration of Cu reported in chloroplasts (Sorokina, 1967) explain the chlorotic symptom of Cu starved plants. The role of Cu in auxin metabolism (Gamayunova, 1965) explains the reduced internodal length of Cu-starved clove plants.

The involvement of Cu in oxidation reduction reactions including those of respiration, photosynthesis and nitrogen assimilation (Frieden, 1968) substantiates the reduced growth rate and assimilation rate recorded for Cu-starved clove plants.

The foliar Cu level of healthy clove seedlings varied between 50 to 68 ppm. The level of upper leaves were reduced to 11 ppm under severe stages of deficiency. It was found possible to recover the Cu-deficient plants by applying Cu for four to five weeks.

5.1.10 Zinc deficiency

The reduction in internodal length, colour and size of leaves with leaf petiole and lamina showing a tendency to curl down giving a sickle-like appearance was the characteristic symptom associated with Zn deficiency in clove. The symptoms appeared only on new flush. The involvement of Zn in biosynthesis of chlorophyll(fugiwara and Tsutsumi, 1962) would have attributed to the reduced chlorophyll level in Zn-starved clove plants. Being a constituent of many enzymes, it is reported to involve in many of the anabolic and catabolic reactions in the plant system (Nason and Mc Elroy, 1963; Riordan, 1976). Hence, it is quite natural for the clove plants under Zn strss to put forth distorted and impared growth habits. Takaki and Arita (1936) has reported large amounts of tryptamine in Zn-deficient plants

indicating the role of the element in the conversion of tryptamine to IAA in plants. This may be the reason for reduced internodal length giving a rosette appearance to Zn-deficient clove plants. The impared production of protein in meristematic tissues (Kitagishi and Obata, 1986) of Zn-starved plants clearly explain the stunted growth and reduced assimilation rates of clove seedlings towards the later stages of Zn deficiency.

The foliar Zn level of clove seedlings ranged between 34 and 58 ppm. Deficiencies were manifested when the level was brought down to 11 ppm. Reduced Zn level in clove plants was found associated with a higher P and Fe level. Similar interactions have been reported in other crops by Arora et al. (1970), Andrew et al. (1981) and Loneragan (1982). It was found possible to recover Zn deficient clove plants at initial stages of deficiency by supplementing Zn.

5.1.11 Boron

Boron-starved clove plants developed hard and brittle upper leaves which were slightly chlorotic. New growths dried off prematurely leaving a barren top. The degeneration of meristematic tissues, breakdown of parenchyma and poor development of vascular tissues reported in B starved plants (Bradford, 1975) would have contributed to the characteristic B-deficiency symptoms in clove. Marschner (1982) has reported necrosis of apical meristem - the main site of IAA synthesis, synthesis of phenolics, inhibition of xylem and phloem differentiation to act behind the external symptoms exhibited by B-deficient plants.

The B level of healthy clove plants ranged between 27 and 32 ppm. The level was reduced to 10 ppm on upper leaves of deficient plants. It was found possible to recover clove plants at initial stages of B-deficiency by applying B for four weeks.

5.1.12 Molybdenum

Withdrawal of Mo from the nutrient solution for a period of 18 months did not influence the growth of clove seedlings. The chemical analysis showed that the foliar Mo level in healthy plants was too low to be detected.

Among the micronutrients studied, symptoms of nutrient stress were first expressed by Fe and Mn deficiency (12th month) followed by Zn (13th month). Boron and Cu took the maximum time for expression of hunger signs (14 to 15 months). The maximum reduction in biomass production was recorded in B-starved plants (26 per cent) at severe stages of deficiency followed by Fe, Zn, Cu and Mn. Deficiency of all the microelements were expressed on new growth whereas the older shoots remained unaffected. The clove plants starved with Mn, Cu and Zn produced characteristic distorted leaves that could be identified from one another. The leaves were pale and narrow with normal or even larger internodes in Mn-starved plants whereas the internodal length was greatly reduced by Zn and Cu stress. The sickle shape of leaves was characteristic to Zn stress whereas Cu-starved plants produced drooping smaller leaves with reduced turgor. The younger leaves on Cu-deficient plants soon defoliated as against Zn and Mn deficient ones which were retained on the plant.

From the foregoing discussion, characteristic diagnostic symptoms of macro and micronutrient deficiencies in clove may be identified. These are summarised in the following page.

## Diagnostic symptoms of nutrient deficiency in clove

### FOLIAR SYMPTOMS

#### Macro nutrients

| Older leaves | | Younger leaves | |
|---|---|---|---|
| N | General yellowing and early defoliation | Ca | Necrotic spots on leaves which later became chlorotic and a bare top with inactive growing point. |
| P | Dull green leaves with tiny brownish spots that developed to burnt areas. | Mg | Tip and marginal necrosis of chlorotic leaves with downward curling of margin |
| K | Tip and marginal necrosis | S | Newly formed leaves pale yellow and of reduced size, with marginal necrosis |
| Mg | Chlorosis from margin towards midribs | | |

#### Micro nutrients

| Older leaves | | Younger leaves | |
|---|---|---|---|
| Nil | | Fe | Inter veinal chlorosis and papery white younger leaves. |
| | | Mn | Interveinal chlorosis with narrow and distorted pale green younger leaves. |
| | | Cu | Narrow and smaller young leaves with withering, greying, loss of turgor, cupping and curling |
| | | Zn | Rosetting due to reduced internodal length with petiole and lamina curling downwards to form a sickle shape |
| | | B | Hard and brittle leaves of normal size. Abortive new leaves which dried at an early stage |

The threshold level of nutrients in the leaves of two year old clove plants below which visual deficiency symptoms could be expected are as follows :

| Element | Lower leaves | Upper leaves |
|---|---|---|
| N | 1.00 per cent | 1.25 per cent |
| P | 0.08 per cent | 0.10 per cent |
| K | 0.80 per cent | 1.20 per cent |
| Ca | 1.04 per cent | 0.70 per cent |
| Mg | 0.20 per cent | 0.24 per cent |
| S | 0.10 per cent | 0.12 per cent |
| Fe | 105 ppm | 50 ppm |
| Mn | 160 ppm | 85 ppm |
| Cu | 55 ppm | 20 ppm |
| Zn | 30 ppm | 20 ppm |
| B | 25 ppm | 15 ppm |

The level of the element on lower leaves were more sensitive and indicate the nutrient status of the plant in the case of N, P, K and Mg whereas for the other elements the level on upper leaves would give a better indication of the nutrient status of the plant. It is therefore necessary to maintain the threshold level or even a better status of the element in the plant for ensuring adequate nutrition and normal growth.

## 5.2 Nutrient distribution and translocation under nutrient stress condition

The results pertaining to the distribution and translocation of $H_2PO_4^-$, $SO_4^{2-}$ and Ca are discussed hereunder.

5.2.1 Phosphorus

The results obtained revealed that the stem portion serves as a better sink for P compared to leaf in clove. Stem has been described to accumulate more P in different tree crops by Kramer and Kozlowski (1979) and Reddy and Reddy (1987). Both stem and leaf showed a concentration gradient in the accumulation of P, the accumulation increasing from the top to the lower most node, when P was not in short supply. In P starved plants, leaf P level did not increase with increase in nodal rank towards the bottom. In view of the very low concentration of P in deficient plants, such a trend in P accumulation in the leaf can be expected. Further, P would have been remobilised from lower to upper growing parts due to its phloem mobility as explained by Nason and Mc Elroy (1963) and Bouma (1967). The data further indicated that leaf P content on dry matter basis was influenced by P accumulation in the stem, at the corresponding nodal position. When P was not limiting, stem and leaf P concentration were correlated. Between the two models tried, the quadratic function had a slightly better edge over the linear model in the P-sufficient plants (Table 30). However, the relationship was poor in the deficient condition (Table 30). It may be assumed that, P supply to leaf occurs from the corresponding nodal position when P is not limiting.

Phosphorus distribution pattern in the stem was found to be better explained by the quadratic model of the form,

$$\text{Log P (Stem)} = a - bx + cx^2$$

Where,

X is the nodal rank.

This model explained 96.5 and 94.4 per cent variation in sufficient and deficient plants respectively as against 76 and 87 per cent respectively for logarithmic model,

$\log P = a + bx$
(stem)

Where,

X is the nodal rank

Although the leaf P concentration in relation to nodal rank was also better explained by the quadratic model, in view of the low predictability (61 to 69%), the application of this model was found not satisfactory.

When P was supplied to a P-starved plant, there was marked difference in the distribution pattern compared to the healthy plants. The rate of absorption by the starved plant was twice that of healthy one (1310 and 435 cpm $g^{-1}$ dry matter respectively). The absorbed $^{32}P$ was mainly accumulated in the stem portion than in the leaf. A comparison of the distribution pattern of the absorbed label between sufficient and deficient plants indicated that, in the latter, the concentration gradient for $^{32}P$ was more marked along the stem and leaf, compared to the former. The accumulation pattern of absorbed $^{32}P$ was consistent with the normal distribution pattern of the nutrient in the plant. When the plant was under P stress, the major part of the absorbed $^{32}P$ was retained by the lower shoot portion and only a small quantity was translocated to the upper region. These results are in conformity with that obtained in nutrient deficiency studies wherein, lower leaves got depleted first, under P starvation. Hence, better distribution of absorbed P in lower leaves and stem portion is quite reasonable.

The distribution of absorbed $^{32}P$ in the stem was not found to be adequately explained by either linear or quadratic models when P supply was not limiting. However $^{32}P$ distribution in plants deficient in P could be explained by linear equation using $^{32}P$ activity data as well as both linear and quadratic models using log $^{32}P$ data, as the dependent variable (Table 25).

Eventhough the log transformed data yielded slightly better $R^2$ (0.86), linear fit using $^{32}P$ activity data without logarithmic transformation can be considered for describing the distribution pattern of absorbed $^{32}P$ in the stem portion of the deficient plants. In contrast to this, none of the models tested could explain satisfactorily the distribution of $^{32}P$ in the leaf, when the plant was deficient in the nutrient. In healthy plants, both the linear and quadratic function did yield better $R^2$ values.

The correspondence of the distribution pattern of absorbed $^{32}P$ in the leaf to the mathematical models tested when the plant is not deficient in P and the non correspondance of the distribution of $^{32}P$ to either of these models when the plant is deficient in the nutrient may be explained by taking into consideration the impact of the nutrient stress on the plant at the time it received the $^{32}P$ treatment. The plant normally stores more of the absorbed P in the stem. Since there was no active growth for P-starved plants at the time of the treatment, the translocation to the upper leaves was not warranted. The healthy plants were actively growing when it received the $^{32}P$ and hence the translocation was proportionately more to the leaves.

From the foregoing, it is evident that the accumulation of P in the stem as well as in the leaf can be described as a function of nodal position. When the plant is deficient in the nutrient, it absorbs the applied P more but the distribution of absorbed nutrient depend on the physiological condition of the plant.

### 5.2.2 Sulphur

Discontinuation of S from the feeding schedule for about five months had markedly reduced the S concentration in the plant tissue. In clove, leaf was as good as or even a better accumulator of S than the stem. Under both nutrient sufficient and stress condition, the pattern of accumulation of S in the plant was more or less identical, with the greater concentration

in the upper nodal position. This is in conformity with the reports made in other tree crops. Kirkby and Mengel (1978) has reported S to be mainly translocated in an upward direction and the capability of higher plants to move S downward to be poor. Irrespective of the part of the shoot namely stem or leaf, S concentration decreased towards lower nodes.

The stem and leaf S concentration at different nodal points indicated significant relationship between the two concentrations, irrespective of the condition of the plant (sufficient or deficient). This corroborates the view that S supply to the leaves are related to the S content in the corresponding stem portion. Sulphur concentration in the leaf was highly correlated with the concentration in the corresponding stem portion. The distribution pattern of S in leaf and stem with respect to the nodal position was curve linear when log S concentration was considered (Table 27). The model explained more variation in the case of S-sufficient plants (90 - 94%).

The absorption of $^{35}S$ label by deficient plant was considerably more than that receiving S. On dry matter basis the absorption was about four times more than that by the S-sufficient plants. Compared to the higher S content of the leaf, relatively less quantity of $^{35}S$ was translocated to this part. On the other hand, stem portion accumulated more $^{35}S$. The accumulation pattern of $^{35}S$ at different nodal ranks indicated that, the highest accumulation occurs in the newly formed and developing leaves (current flush) while on the mature leaf just below the new flush, the accumulation of the radiolabel was merely half.

The distribution pattern of absorbed $^{35}S$ in both leaf and stem with respect to nodal position in sufficient plants was better described by the quadratic model which explained 80 to 89 per cent of the variability in the observed values when log activity was the dependent variable. On the other hand, when S is limiting, the distribution pattern could be explained either by the exponential model or by the quadratic model to more or less same

extent. In this case, the variability explained was to the order of 93 to 96 per cent. The results indicate that the absorption as well as the pattern of translocation of absorbed S is influenced by the nutrient stress. The greater absorption and preferential translocation of $^{35}S$ towards growing points reflect the important of S to the growing points of the plant.

The results obtained also substantiates the S-deficiency symptoms obtained for clove. The upper leaves were found more sensitive to S-stress than the lower leaves. Eaton (1975) has reported S to have restricted phloem mobility. He has reported no loss in the amount of protein sulphur or organic sulphur in the older leaves of S-starved plants whereas most of the sulphate S moved out of it. The enhanced translocation of absorbed $^{35}S$ to the upper parts of S-starved clove plants is quite reasonable owing to the reduced remobilisation of S.

### 5.2.3 Calcium

When Ca was not in short supply, the accumulation of this element steadily increased more or less in a linear fashion in the leaf towards the lower nodes. Although an increase was noted in Ca content of the stem portion towards the base, it was not much conspicuous towards the lower nodes. A notable difference in the distribution pattern of Ca compared to P and S was the reversal of the trend at lower nodes. In the upper part of the shoot, leaves had a lower concentration than the corresponding stem portion, while in the lower part, leaves had a better concentration than the stem portion. Such a trend was found lacking in deficient plants. However, the Ca level of older stem and leaf were much higher than that of younger parts and is in conformity with the results obtained for Glonti (1970) and Evans (1979). Since Ca, when once deposited in older leaves cannot be mobilised to growing tips (Loneragan and Snowball, 1969) the low Ca level

of older leaves of Ca-starved plants may be due to the low initial accumulation under the stress condition.

Unlike in the case of P and S, under sufficient condition, the concentration of Ca in the leaf was not found to be related with that of the stem. However, when the Ca supply was limiting, there was a linear correspondence between the concentration of these two plant parts. The results indicate that, P and S were distributed directly from the nodal position into the leaves of either side. Such a translocation patten can be observed in the case of Ca only when the plant is under Ca stress.

In healthy plants, none of the models tested could adequately describe the distribution pattern of Ca in the stem in relation to the nodal rank. In plants deficient in this nutrient, the distribution of Ca followed the quadratic and linear equations considering log stem Ca concentration as the dependent variable (Table 29). The distribution pattern of Ca in the leaf could be best explained by simple linear equation irrespective of the condition of the plant.

The stress condition caused by the withdrawal of Ca from the nutrient solution for five months was very severe as could be deduced from $^{45}Ca$ uptake for the starved and well nourished plants. On dry matter basis, the absorption of $^{45}Ca$ by deficient plants was over 25 times than that of control plants. Stem was found to be a better sink for the absorbed label than leaf in both control and deficient plants. Translocation of $^{45}Ca$ to the leaves was not much. The importance of the stem in the accumulation of Ca in the plant was further evident from the high correlation coefficient obtained between stem $^{45}Ca$ and the nodal position.

The distribution of $^{45}Ca$ in the stem and leaf of both healthy and deficient plants in relation to nodal ranks could be described by taking log $^{45}Ca$ as the dependent variable indicating that the relationship is not simple. Further

the exponential model gave a better fit for the data of the stem whereas, the quadratic model proved to be most suitable for determining log $^{45}Ca$ activity in the leaf in relation to nodal position. The difference in the suitability of the models for describing the patterns of accumulation of the absorbed $^{45}Ca$ in the stem and leaf is also indicative of the differential translocation of $^{45}Ca$ to the stem portion and leaves of clove seedlings. The correspondance of the distribution pattern to a mathematical model for a given part irrespective of the nutrient status suggests the absence of stress induced difference in the translocation of this nutrient.

Preferential accumulation of Ca in the older stem tissue and a reduced upward movement has been reported by Tromp (1980). Ferguson (1980) has reported Ca from the wood to get remobilised to developing shoots in Ca-starved plants whereas much of the Ca in the bark are mostly immobilised. High level of xylem Ca (reversible) has been reported in woody plants by Robson and Pitman (1983). Higher partitioning of $^{45}Ca$ to the stem of clove seedlings under Ca-stress may be due to the reduced xylem Ca level in the Ca-starved plants.

## 5.3 Annual biomass production and nutrient removal in adult clove trees

In an adult bearing clove tree, leaf was found to be the major accumulator of N, S and Mn on dry matter basis. Flower buds served as the best sink for P, K and Mg. Both stem and flower buds were equally efficient in accumulating Ca. Generally leaf was a poor accumulator of P and relatively so for Ca also. Leaf and stem were better accumulators of Fe than flower buds. In the case of other nutrients namely Cu, Zn and B the concentration in different plant parts were more or less similar. The concentration of Mo was found to be the least in the plant and was below the detection level of the analytical method used. Low P and higher Ca, K and Mn requirements of clove plants has been reported by Finck (1973). Comparable results has

also been reported in other tree crops by Wenot (1971), Reddy and Reddy (1987) and Stassen (1987).

The three clove trees used in the study for estimating the annual biomass production and its nutrient removal had an average yield of 117 g of dried flower buds. The low yield of the plants under the study may be primarily due to the fact that, these plants were grown under rainfed condition and were only in the early years of flowering (8 years old). Nevertheless, the data generated from the study are indicative of the relative importance of different nutrients to the crop. The requirements of different materials by the crop is in the decreasing order of K>N>Ca>Mg>S>Mn>P>Fe>Cu>B>Zn. It is important to note that the P requirement of the crop is much less than the conventional secondary nutrients like Ca, Mg and S and the micronutrient, Mn. On the other hand, the requirement of the conventional secondary nutrient Ca is found to be relatively high. Though it is not possible to distinguish the exact role of Mn in this crop, substantial quantity accumulated in the plant suggests a high requirement of Mn for the crop. Levanidov (1957) has reported Mn rich plants or 'manganophiles' among woody plants and has related the increased Mn level to their biochemical composition. Manganese as one of the strongest oxidising agent was found to counterbalance the large amount of tannides in such crops (Levanidov, 1961). The role of Mn in the synthesis of eugenol-a phenol which is the main constituent of essential oil of clove is to be looked into on assessing the essentiality of the element to the crop.

The annual biomass added up (excluding roots) was found to be 3.78 kg. on dry matter basis. Of these, about 85 per cent was by way of leaf production while stem and flower buds contributed 12 and 3 per cent respectively. Eventhough the accumulation pattern of different nutrients in the different parts of the plant varied considerably, total accumulation of a nutrient was

found to be the highest in leaf, followed by stem and flower buds. This is expected because of the greater, contribution of leaf than the other two parts in the total biomass production of the plant. In other words, the differences in the distribution pattern get nullified as most of the dry matter produced by the plant comes from the leaf.

## 5.4 Seasonal variation in foliar nutrient concentration in bearing clove tree

The foliar nutrient level varied with leaf ranks but was not identical for the different major and minor elements. Varying trends in foliar nutrient level at different positions has also been observed in clove seedlings in the previous experiments.

The foliar N level of mature clove tree was found influenced by the rainfall as well as fertilizer applications. The lower levels of N in the foliage during February and March could be attributed to insignificant amounts of rainfall received during this period. When the moisture regeme of the soil was improved due to the receipt of rains, N uptake was found enhanced as reflected on the N concentration in the leaf upto May. However, despite the continuance of rain in the following months upto July, the foliar N level was found to decline. Significant leaching of $NO_3^-$ in the soil coupled with a larger demand of this nutrient for the new growth would have been responsible for the decrease in the N status of the foliage. This view was further supported by the increase of N content following fertilizer application.

As far as P level in the leaf is concerned, it was not much influenced by the rainfall as was evident from the foliar P levels, during low rainfall period from December to March. It may be noted that, with the onset of monsoon in April, the absorption of P decreased and when the tree put forth new flushes, it more or less maintained a steady P level in the leaf.

Nevertheless, subsequent to fertilizer application in the rainy season, there was a perceptible increase in leaf P content. The decrease in foliar K content from November to April may be ascribed to the decreased soil moisture supply. The K uptake increased with the receipt of rain in April but decreased in June due to flushing and consequent nutrient demand. The decrease was made good however, following fertilizer application in the middle of July. A further decrease observed after fertilizer application could be mainly due to the increased nutrient demand for the new growth as well as due to the probable leaching of K in the laterite soil. The decrease was further aggrevated when the tree putforth another flush in middle of September. This would also indicate a further dilution of absorbed nutrient in the biomass produced.

The decrease in foliar N and K level in the leaf during summer months may be due to the fact that, the plant will be preparing for the new flush with greater accumulation of dry matter. The first flush which occurred in January was rather insignificant and cannot account for the decrease in the level of these nutrients. Hirobe and Ogaki (1968) has reported reduced foliar level due to the translocation of major part of the nutrient to the roots of the citrus plants in winter when there was practically no growth.

The fluctuation in the foliar Ca level during the period of one year was not much compared to that of N or K. However, the Ca concentration in the leaf decreased steadily following the second flush, indicating inadequate supply of this nutrient to meet the greater demand for the newly produced biomass. However, the Ca nutrition was found to improve immediately after fertilizer application. This may be due to the contribution of this element from super phosphate as the fertilizer contains 20 per cent of Ca. Absorption of more Ca by coconut palm when fertilised with super phosphate was reported by Anilkumar and Wahid (1989). The increased absorption of S following fertilizer application as revealed from the foliar analysis may also be due

to the contribution from superphosphate, as this fertilizer also contain S (11%). On the other hand, the decrease in foliar Mg level following fertilizer application could be due to the increased uptake of K and consequent antagonism. K-Mg antagonism was also observed in clove seedlings in previous experiments of this study.

Seasonal influence on foliar nutrient level has been reported in various other crops like rubber (Shorrocks, 1962) citrus (Hirobe and Ogaki, 1968, and Alcaraz et al., 1979) and apple (Mason and Whitefield, 1960, Ludders and Buneman, 1973 and GuManru et al., 1981).

# Summary

## SUMMARY

The investigations pertaining to the nutritional aspects of clove (Syzygium aromaticum (L.) Merr. and Perry) were carried out in the College of Horticulture with a view to induce nutrient deficiency symptoms in clove seedlings and to understand the pattern of nutrient distribution and translocation under stress condition. The annual nutrient removal by bearing clove trees and the seasonal variations in foliar nutrient concentrations were also assessed. The results of the study are summarised below.

The N-deficiency symptoms in clove first appeared as a general yellowing of older leaves. The symptoms gradually spread to the upper leaves and the chlorotic older leaves were soon defoliated. By the severe stage of deficiency, the plant growth was retarded to the extent of 20 to 53 per cent in plant height, number of leaves, leaf area, root dry weight and total biomass produced. The N level of lower leaves of deficient plant was 0.74 and 0.47 per cent respectively at initial and severe stages of deficiency. The upper leaves of N-deficient plants registered a relatively higher level of foliar N (1.03 to 1.22 %). It was possible to rescue the N-deficient plants by applying the nutrient for two to four weeks.

The P-deficiency symptoms in clove appeared as small brownish spots on dull green older leaves. The spots coalesced together to give a burnt appearance. Phosphorus stress reduced the growth parameters to the extent of 13 to 37 per cent by the time the plants expressed severe deficiency symptoms. The foliar level of the element was reduced to 0.05 to 0.06 per cent at advanced stages of deficiency. It was possible to recover P-deficient plants by applying P for four to seven weeks.

The K-stress resulted in K-deficiency symptoms that appeared first on older leaves. Leaf tip and margins turned brown and gradually progressed inward, presenting a scorched appearance for the leaf blade. Potassium-stress for a period of 18 months reduced the various growth parameters to the extent of 15 to 32 per cent. By that time, the K level of lower leaves was reduced to 0.56 to 0.99 per cent. Foliar Mg level was found to be relatively high under K-stress. The K-starved plants when supplied with complete nutrient solution for four to six weeks put forth new flushes without the advancement of already existing symptoms.

Calcium deficiency in clove was characterised with reduced shoot growth and tip die back. The younger growth was affected first. Leaves developed necrotic areas near tip and margin which became chlorotic and was defoliated later. By severe Ca deficiency, the growth parameters were reduced to the extent of 13 to 51 per cent, the effect being more severe on root growth. The Ca level of starved plants were reduced to the extent of 0.3 to 0.5 per cent on upper leaves whereas the impact was less severe on lower leaves. Potassium level was found to be relatively high in Ca-starved plants. It was possible to recover the deficiency by applying the element continuously for six weeks.

Though the Mg deficiency symptoms in clove were first expressed on older leaves, it soon spread to upper foliage giving a pale appearance to the whole plant. In later stages, the young developing leaves failed to develop normal size and colour and were occasionally necrotic at tip and margins. The total chlorophyll was greatly reduced (1.2 mg as against 2.9 mg for control) on older leaves. The deficient plants recorded 15 to 25 per cent reduction in various growth parameters. The foliar Mg level in starved plants was reduced to 0.14 to 0.16 per cent. The K and Ca levels of Mg-starved plants were found to be relatively high. It was found

possible to recover Mg-deficient plants by applying the element continuously for four to six weeks.

Sulphur-starved clove plants developed foliar symptoms when the foliar S level was reduced to 0.08 to 0.1 per cent. The newly produced leaves were the most affected by S stress. They were pale in colour with reduced internodal length and failed to attain normal size. The young leaves had a tendency to shed prematurely. The growth parameters were reduced to the extent of 15 to 41 per cent by the time the plants expressed severe symptoms of S deficiency. It was possible to recover the S-deficiency symptoms by applying the element for four weeks. However, it was rather difficult to requip the plants exhibiting severe S-deficiency symptoms.

Interveinal chlorosis and production of pale and papery white leaves at later stages marked the severe symptoms of Fe deficiency in clove. The total chlorophyll of deficient leaf was reduced to 0.85 mg as against 2.65 mg in healthy plants. There was a reduction to the extent of 19 to 28 per cent in various growth parameters by the time the clove plants exhibited severe symptoms of Fe-deficiency. The nutrient level was reduced to 22 ppm in upper leaves of deficient plant. The Fe-starved plants recovered from the deficiency symptoms on applying the element for three to six weeks.

Manganese deficiency symptoms resembled that of iron at early stages. Later, the leaves were pale, smaller and distorted. Though there was not much reduction in plant height, the leaf area and the total biomass produced were reduced to the extent of 13 per cent by the time the plant expressed severe deficiency symptoms. The foliar Mn level of deficient plants were reduced to 55 ppm and was found recovered of the initial symptoms on applying the element continuously for three weeks.

The older leaves of the Cu-starved clove plant did not exhibit any marked deficiency symptom. The new leaves produced were small, narrow and chlorotic. Loss of turgor, bending of lamina and tip drying were associated with later stages of Cu-deficiency. The internodal length and leaf area were greatly reduced (29 to 45 per cent) in Cu-starved plants. The Cu level recorded in upper leaves of Cu-deficient plant was between 11 and 14 ppm. Application of the element for four to five weeks nullified the effects of Cu-starvation on newly produced flush.

Reduced internodal length, rosetting and sickle shape of newly produced leaves characterised the Zn ceficiency symptoms in clove. The total chlorophyll content of upper leaves were reduced to 1.25 mg as against 2.65 mg in healthy plants. The Zn level of deficient leaves were reduced to 8 to 11 ppm. It was found possible to recover Zn-starved plants by applying complete nutrient solution for five weeks at initial stages of deficiency.

Boron-deficiency in clove was characterised by hard and brittle upper leaves and aborted new gorwth which dried off prematurely. There was a complete sessation of growth due to death of meristematic area. The gorwth parameters were reduced to the extent of 12 to 30 per cent. The level of B in upper leaves of deficient clove plants was found reduced to 9 ppm.

Molybdemum-starvation was found to have little effect on clove seedlings. The Mo level in the foliage was found to be very low to be detected by normal methods.

The pattern of distribution and translocation of the elements studied (P, S and Ca) were found to vary in clove plants. Stem was found to be a better accumulator of P with the highest P level on lowest node. The significant correlation existed between stem P and leaf P indicate the

supply to the leaf to occur from the corresponding nodal position. Phosphorus from lower plant parts were found remobilised in P-starved plants. The stem and leaf at lower nodes accumulated most of the absorbed $^{32}P$. P-starved clove plants absorbed and translocated P at a much faster rate than those which were adequately supplied with P.

Sulphur was found more accumulated in clove leaves than in the stem and was maximum on the upper most leaf. The S level of stem was found related to the nodal rank with the maximum level at upper most node. In both deficient and sufficient conditions, significant positive relationship was obtained between S concentration of stem and leaf. Sulphur was found not translocated from lower leaves and more radiolabel was recovered from upper most part of the shoot.

The Ca distribution was more on lower part of the clove plants both in the stem and leaf. The Ca concentration of stem was found to be less in plants grown under Ca stress. Stem and leaf Ca concentration were found related only in deficient plants. The rate of absorption of $^{45}Ca$ was much less by plants well nourished with Ca. Most of the absorbed radioactivity was found accumulated in the stem both in control and deficient plants.

In adult clove trees, leaf was found to be a better accumulator of N, S, Fe and Mn whereas K and Mg were maximum in flower buds. Both stem and flower buds were more or less equally good for accumulating P and Ca. There was not much variation among the plant parts in the distribution of micro elements, Cu, Zn and B.

Phosphorus requirement by the crop was found to be much less than the other primary and secondary nutrients. Whereas, the Ca and Mn levels were relatively high. The order of preference of nutrient removal by an adult clove tree was K> N > Ca > Mg > S > Mn > P > Fe > Cu > B > Zn.

Leaf contributed about 85 per cent of the total biomass produced by a tree in an year. Though the accumulation pattern of different nutrients in different parts of the plant varied considerably, total accumulation was found to be highest in the leaf.

The levels of N, P, K and Ca varied significantly among the different leaf ranks. The seasonal fluctuations were more marked for the foliar N and K levels of the bearing clove plants.

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# *Appendices*

APPENDIX I

Coefficients of determination ($R^2$) yielded by different models for leaf area estimation

| Sl. No. | Model | $R^2$ |
|---|---|---|
| 1. | y = -17.3948 + 1.82012 L + 5.62925 B | 0.977 |
| 2. | y = 0.55548 + 0.56001 L B | 0.982 |
| 3. | y = 0.58 L B | 0.980 |

L = Maximum length of the leaf

B = Maximum breadth of the leaf

Effect of nitrogen stress on foliar nutrient composition of clove seedlings

| Months after treatment | N % | P % | K % | Ca % | Mg % | S % | Fe ppm | Mn ppm | Cu ppm | Zn ppm | B ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | A - Lower leaves | | | | | | |
| 0 | 1.29 | 0.098 | 0.67 | 1.06 | 0.273 | 0.106 | 149 | 207 | 60 | 39 | 31 |
| 2 | 1.35 | 0.098 | 0.90 | 1.41 | 0.284 | 0.120 | 139 | 211 | 52 | 46 | 30 |
| 4 | 1.40 | 0.115 | 1.10 | 1.34 | 0.300 | 0.125 | 150 | 223 | 52 | 48 | 28 |
| 6 | 1.17 | 0.120 | 1.16 | 1.43 | 0.300 | 0.126 | 151 | 234 | 50 | 53 | 31 |
| 8 | 0.99 | 0.110 | 1.40 | 1.43 | 0.290 | 0.128 | 161 | 243 | 53 | 60 | 33 |
| 10 | 0.74 | 0.145 | 1.23 | 1.23 | 0.257 | 0.140 | 157 | 244 | 48 | 58 | 35 |
| 11 | 0.63 | 0.123 | 1.20 | 1.44 | 0.250 | 0.150 | 160 | 250 | 50 | 53 | 32 |
| 12 | 0.59 | 0.128 | 1.30 | 1.43 | 0.246 | 0.150 | 169 | 255 | 52 | 56 | 31 |
| 13 | 0.54 | 0.136 | 1.10 | 1.45 | 0.270 | 0.140 | 172 | 248 | 48 | 57 | 30 |
| 14 | 0.55 | 0.148 | 1.00 | 1.32 | 0.280 | 0.150 | 164 | 252 | 48 | 62 | 36 |
| 15 | 0.47 | 0.148 | 0.90 | 1.37 | 0.275 | 0.156 | 163 | 234 | 44 | 54 | 35 |
| 16 | 0.47 | 0.155 | 0.75 | 1.40 | 0.278 | 0.130 | 154 | 240 | 49 | 48 | 36 |
| 17 | 0.46 | 0.168 | 0.83 | 1.35 | 0.282 | 0.140 | 120 | 245 | 48 | 48 | 27 |
| 18 | 0.46 | 0.173 | 0.81 | 1.40 | 0.285 | 0.140 | 141 | 237 | 50 | 49 | 27 |
| | | | | | B - Upper leaves | | | | | | |
| 0 | 1.53 | 0.084 | 1.03 | 0.92 | 0.268 | 0.145 | 140 | 191 | 33 | 40 | 28 |
| 2 | 1.48 | 0.081 | 1.09 | 1.12 | 0.250 | 0.150 | 122 | 187 | 47 | 50 | 29 |
| 4 | 1.45 | 0.080 | 1.40 | 1.02 | 0.330 | 0.150 | 124 | 198 | 45 | 52 | 30 |
| 6 | 1.36 | 0.092 | 1.56 | 1.07 | 0.330 | 0.140 | 124 | 206 | 48 | 55 | 29 |
| 8 | 1.24 | 0.094 | 1.70 | 1.05 | 0.314 | 0.150 | 125 | 222 | 59 | 63 | 29 |
| 10 | 1.22 | 0.080 | 1.30 | 0.97 | 0.295 | 0.160 | 117 | 209 | 56 | 56 | 32 |
| 11 | 1.22 | 0.088 | 1.56 | 1.07 | 0.280 | 0.180 | 129 | 201 | 59 | 55 | 39 |
| 12 | 1.17 | 0.086 | 1.34 | 0.82 | 0.270 | 0.186 | 140 | 210 | 58 | 60 | 37 |
| 13 | 1.07 | 0.093 | 1.33 | 0.88 | 0.260 | 0.170 | 152 | 213 | 60 | 59 | 38 |
| 14 | 1.16 | 0.101 | 1.30 | 0.90 | 0.270 | 0.180 | 137 | 199 | 64 | 62 | 35 |
| 15 | 1.03 | 0.100 | 1.30 | 0.95 | 0.286 | 0.173 | 140 | 187 | 63 | 56 | 31 |
| 16 | 0.92 | 0.102 | 1.43 | 0.87 | 0.280 | 0.165 | 111 | 189 | 68 | 49 | 34 |
| 17 | 0.74 | 0.100 | 1.40 | 0.99 | 0.332 | 0.165 | 103 | 205 | 66 | 49 | 25 |
| 18 | 0.70 | 0.107 | 1.43 | 0.82 | 0.306 | 0.168 | 112 | 189 | 68 | 51 | 28 |

Effect of phosphorus stress on foliar nutrient composition of clove seedlings

| Months after treatment | N % | P % | K % | Ca % | Mg % | S % | Fe ppm | Mn ppm | Cu ppm | Zn ppm | B ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | A - Lower leaves | | | | | | |
| 0 | 1.29 | 0.098 | 0.67 | 1.06 | 0.273 | 0.106 | 149 | 207 | 60 | 39 | 31 |
| 2 | 1.37 | 0.097 | 0.83 | 1.20 | 0.297 | 0.113 | 126 | 214 | 51 | 45 | 28 |
| 4 | 1.50 | 0.090 | 1.21 | 1.26 | 0.290 | 0.126 | 144 | 244 | 53 | 49 | 28 |
| 6 | 1.47 | 0.095 | 1.31 | 1.41 | 0.300 | 0.157 | 133 | 257 | 64 | 61 | 27 |
| 8 | 1.33 | 0.080 | 1.40 | 1.34 | 0.215 | 0.146 | 144 | 243 | 62 | 59 | 27 |
| 10 | 1.45 | 0.065 | 1.50 | 1.33 | 0.256 | 0.140 | 154 | 269 | 65 | 66 | 32 |
| 11 | 1.43 | 0.058 | 1.52 | 1.43 | 0.266 | 0.123 | 184 | 249 | 68 | 63 | 27 |
| 12 | 1.29 | 0.056 | 1.64 | 1.38 | 0.267 | 0.123 | 185 | 259 | 66 | 65 | 26 |
| 13 | 1.23 | 0.055 | 1.58 | 1.39 | 0.273 | 0.130 | 172 | 264 | 67 | 68 | 31 |
| 14 | 1.25 | 0.048 | 1.60 | 1.29 | 0.276 | 0.113 | 193 | 254 | 62 | 62 | 29 |
| 15 | 1.31 | 0.050 | 1.61 | 1.37 | 0.286 | 0.116 | 183 | 258 | 64 | 58 | 29 |
| 16 | 1.34 | 0.046 | 1.63 | 1.37 | 0.296 | 0.116 | 187 | 279 | 65 | 64 | 30 |
| 17 | 1.36 | 0.047 | 1.60 | 1.36 | 0.270 | 0.153 | 210 | 262 | 65 | 66 | 30 |
| 18 | 1.40 | 0.045 | 1.56 | 1.23 | 0.286 | 0.120 | 214 | 258 | 63 | 68 | 29 |
| | | | | | B - Upper leaves | | | | | | |
| 0 | 1.53 | 0.08 | 1.03 | 0.92 | 0.268 | 0.145 | 140 | 191 | 33 | 40 | 28 |
| 2 | 1.50 | 0.083 | 1.17 | 0.93 | 0.254 | 0.147 | 131 | 187 | 38 | 51 | 29 |
| 4 | 1.55 | 0.080 | 1.67 | 0.99 | 0.260 | 0.153 | 140 | 215 | 37 | 51 | 32 |
| 6 | 1.56 | 0.080 | 1.80 | 0.83 | 0.260 | 0.170 | 125 | 220 | 41 | 64 | 29 |
| 8 | 1.46 | 0.080 | 1.86 | 0.88 | 0.210 | 0.163 | 115 | 228 | 50 | 63 | 28 |
| 10 | 1.51 | 0.080 | 1.81 | 0.90 | 0.296 | 0.163 | 127 | 230 | 53 | 71 | 29 |
| 11 | 1.43 | 0.073 | 1.77 | 0.88 | 0.286 | 0.160 | 161 | 220 | 55 | 67 | 30 |
| 12 | 1.29 | 0.066 | 1.84 | 0.90 | 0.286 | 0.152 | 162 | 219 | 54 | 71 | 25 |
| 13 | 1.26 | 0.070 | 1.83 | 0.86 | 0.300 | 0.156 | 166 | 228 | 56 | 70 | 26 |
| 14 | 1.37 | 0.070 | 1.78 | 0.84 | 0.296 | 0.166 | 178 | 221 | 56 | 67 | 31 |
| 15 | 1.37 | 0.073 | 1.77 | 0.84 | 0.286 | 0.173 | 168 | 224 | 52 | 66 | 26 |
| 16 | 1.35 | 0.063 | 1.88 | 0.80 | 0.276 | 0.163 | 201 | 243 | 56 | 68 | 29 |
| 17 | 1.35 | 0.070 | 1.80 | 0.82 | 0.276 | 0.150 | 195 | 225 | 54 | 68 | 28 |
| 18 | 1.41 | 0.060 | 1.83 | 0.73 | 0.280 | 0.160 | 198 | 223 | 58 | 72 | 28 |

APPENDIX IV

Effect of potassium stress on foliar nutrient composition of clove seedlings

| Months after treatment | N % | P % | K % | Ca % | Mg % | S % | Fe ppm | Mn ppm | Cu ppm | Zn ppm | B ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | A - Lower leaves | | | | | | |
| 0 | 1.29 | 0.098 | 0.67 | 1.06 | 0.273 | 0.106 | 149 | 207 | 60 | 39 | 31 |
| 2 | 1.35 | 0.097 | 0.89 | 1.33 | 0.297 | 0.113 | 141 | 209 | 59 | 39 | 30 |
| 4 | 1.36 | 0.112 | 0.94 | 1.47 | 0.313 | 0.120 | 145 | 235 | 51 | 40 | 29 |
| 6 | 1.32 | 0.123 | 1.00 | 1.40 | 0.310 | 0.129 | 134 | 253 | 61 | 52 | 34 |
| 8 | 1.34 | 0.123 | 0.89 | 1.46 | 0.310 | 0.123 | 141 | 260 | 63 | 56 | 30 |
| 10 | 1.39 | 0.120 | 0.80 | 1.37 | 0.303 | 0.137 | 150 | 256 | 60 | 49 | 33 |
| 11 | 1.43 | 0.116 | 0.72 | 1.52 | 0.320 | 0.150 | 168 | 281 | 61 | 52 | 30 |
| 12 | 1.31 | 0.108 | 0.64 | 1.56 | 0.320 | 0.126 | 164 | 284 | 63 | 52 | 29 |
| 13 | 1.30 | 0.108 | 0.60 | 1.56 | 0.320 | 0.126 | 164 | 284 | 60 | 52 | 29 |
| 14 | 1.44 | 0.118 | 0.64 | 1.56 | 0.330 | 0.123 | 169 | 285 | 60 | 58 | 30 |
| 15 | 1.48 | 0.121 | 0.56 | 1.58 | 0.330 | 0.152 | 163 | 282 | 69 | 56 | 32 |
| 16 | 1.50 | 0.120 | 0.58 | 1.63 | 0.330 | 0.136 | 160 | 286 | 67 | 61 | 31 |
| 17 | 1.48 | 0.115 | 0.57 | 1.66 | 0.340 | 0.133 | 162 | 298 | 62 | 62 | 32 |
| 18 | 1.50 | 0.123 | 0.58 | 1.62 | 0.330 | 0.130 | 161 | 300 | 69 | 64 | 32 |
| | | | | | B - Upper leaves | | | | | | |
| 0 | 1.53 | 0.084 | 1.03 | 0.92 | 0.268 | 0.145 | 140 | 191 | 33 | 40 | 28 |
| 2 | 1.50 | 0.080 | 1.30 | 1.17 | 0.268 | 0.140 | 127 | 197 | 34 | 44 | 27 |
| 4 | 1.46 | 0.097 | 1.10 | 0.89 | 0.270 | 0.157 | 127 | 210 | 38 | 44 | 26 |
| 6 | 1.52 | 0.097 | 1.17 | 0.87 | 0.280 | 0.153 | 120 | 236 | 40 | 48 | 30 |
| 8 | 1.54 | 0.090 | 1.09 | 0.88 | 0.300 | 0.147 | 123 | 244 | 47 | 49 | 27 |
| 10 | 1.57 | 0.096 | 1.05 | 0.85 | 0.330 | 0.160 | 133 | 239 | 54 | 52 | 29 |
| 11 | 1.49 | 0.093 | 1.06 | 0.92 | 0.370 | 0.163 | 150 | 242 | 53 | 58 | 27 |
| 12 | 1.43 | 0.083 | 1.06 | 0.97 | 0.360 | 0.153 | 137 | 257 | 50 | 50 | 27 |
| 13 | 1.49 | 0.083 | 1.03 | 1.00 | 0.340 | 0.133 | 137 | 272 | 55 | 59 | 27 |
| 14 | 1.52 | 0.080 | 1.00 | 1.00 | 0.360 | 0.153 | 144 | 252 | 54 | 66 | 28 |
| 15 | 1.49 | 0.082 | 0.99 | 1.02 | 0.369 | 0.150 | 135 | 271 | 51 | 60 | 30 |
| 16 | 1.51 | 0.083 | 0.90 | 1.06 | 0.356 | 0.170 | 134 | 268 | 58 | 60 | 28 |
| 17 | 1.49 | 0.083 | 0.86 | 1.00 | 0.350 | 0.153 | 138 | 264 | 57 | 63 | 29 |
| 18 | 1.48 | 0.083 | 0.73 | 1.06 | 0.360 | 0.160 | 136 | 247 | 65 | 60 | 29 |

Effect of calcium stress on foliar nutrient composition of clove seedlings

| Months after treatment | N % | P % | K % | Ca % | Mg % | S % | Fe ppm | Mn ppm | Cu ppm | Zn ppm | B ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | A - Lower leaves | | | | | | |
| 0 | 1.29 | 0.098 | 0.676 | 1.06 | 0.273 | 0.106 | 149 | 207 | 60 | 39 | 31 |
| 2 | 1.37 | 0.088 | 0.890 | 1.06 | 0.280 | 0.110 | 144 | 222 | 52 | 38 | 35 |
| 4 | 1.43 | 0.125 | 1.07 | 1.05 | 0.300 | 0.126 | 146 | 230 | 53 | 40 | 36 |
| 6 | 1.34 | 0.177 | 1.23 | 1.05 | 0.310 | 0.136 | 134 | 255 | 57 | 50 | 27 |
| 8 | 1.31 | 0.116 | 1.45 | 1.04 | 0.290 | 0.127 | 144 | 252 | 64 | 49 | 30 |
| 10 | 1.46 | 0.097 | 1.57 | 1.02 | 0.290 | 0.127 | 163 | 273 | 63 | 50 | 29 |
| 11 | 1.42 | 0.104 | 1.63 | 0.09 | 0.290 | 0.150 | 170 | 282 | 59 | 49 | 31 |
| 12 | 1.38 | 0.119 | 1.57 | 0.88 | 0.303 | 0.133 | 170 | 266 | 63 | 48 | 30 |
| 13 | 1.39 | 0.109 | 1.55 | 0.78 | 0.290 | 0.137 | 171 | 276 | 63 | 52 | 28 |
| 14 | 1.43 | 0.107 | 1.77 | 0.78 | 0.300 | 0.130 | 179 | 285 | 72 | 63 | 29 |
| 15 | 1.49 | 0.110 | 1.61 | 0.76 | 0.300 | 0.132 | 176 | 258 | 63 | 58 | 31 |
| 16 | 1.45 | 0.120 | 1.66 | 0.76 | 0.291 | 0.130 | 165 | 261 | 63 | 59 | 29 |
| 17 | 1.46 | 0.116 | 1.67 | 0.76 | 0.290 | 0.126 | 172 | 284 | 66 | 55 | 30 |
| 18 | 1.44 | 0.120 | 1.67 | 0.76 | 0.290 | 0.126 | 178 | 284 | 66 | 58 | 29 |
| | | | | | B - Upper leaves | | | | | | |
| 0 | 1.53 | 0.084 | 1.03 | 0.92 | 0.268 | 0.145 | 140 | 191 | 33 | 40 | 28 |
| 2 | 1.44 | 0.083 | 1.11 | 1.11 | 0.243 | 0.133 | 130 | 206 | 35 | 42 | 35 |
| 4 | 1.55 | 0.110 | 1.53 | 0.99 | 0.254 | 0.138 | 129 | 212 | 36 | 48 | 33 |
| 6 | 1.54 | 0.080 | 1.69 | 0.90 | 0.280 | 0.159 | 125 | 233 | 41 | 52 | 27 |
| 8 | 1.56 | 0.097 | 1.88 | 0.74 | 0.250 | 0.142 | 128 | 236 | 52 | 51 | 29 |
| 10 | 1.56 | 0.070 | 1.70 | 0.70 | 0.290 | 0.153 | 148 | 258 | 53 | 52 | 27 |
| 11 | 1.51 | 0.080 | 1.93 | 0.67 | 0.280 | 0.160 | 155 | 265 | 46 | 52 | 28 |
| 12 | 1.46 | 0.080 | 1.93 | 0.47 | 0.290 | 0.150 | 164 | 254 | 53 | 49 | 28 |
| 13 | 1.37 | 0.080 | 1.89 | 0.43 | 0.310 | 0.155 | 160 | 261 | 53 | 50 | 26 |
| 14 | 1.43 | 0.070 | 2.06 | 0.44 | 0.320 | 0.160 | 170 | 272 | 57 | 64 | 28 |
| 15 | 1.48 | 0.070 | 1.96 | 0.37 | 0.320 | 0.160 | 167 | 251 | 57 | 55 | 29 |
| 16 | 1.48 | 0.090 | 2.07 | 0.35 | 0.302 | 0.156 | 152 | 254 | 51 | 58 | 28 |
| 17 | 1.57 | 0.080 | 2.17 | 0.34 | 0.310 | 0.150 | 150 | 272 | 53 | 59 | 29 |
| 18 | 1.38 | 0.100 | 2.13 | 0.34 | 0.310 | 0.143 | 160 | 262 | 53 | 60 | 28 |

Effect of magnesium stress on foliar nutrient composition of clove seedlings

| Months after treatment | N % | P % | K % | Ca % | Mg % | S % | Fe ppm | Mn ppm | Cu ppm | Zn ppm | B ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | A - Lower leaves | | | | | | |
| 0 | 1.29 | 0.098 | 0.67 | 1.06 | 0.273 | 0.106 | 149 | 207 | 60 | 39 | 31 |
| 2 | 1.33 | 0.079 | 0.80 | 1.20 | 0.280 | 0.117 | 140 | 216 | 54 | 40 | 31 |
| 4 | 1.42 | 0.112 | 1.10 | 1.50 | 0.280 | 0.128 | 137 | 210 | 54 | 41 | 28 |
| 6 | 1.34 | 0.123 | 1.20 | 1.44 | 0.290 | 0.137 | 132 | 219 | 59 | 41 | 31 |
| 8 | 1.41 | 0.123 | 1.40 | 1.44 | 0.270 | 0.128 | 140 | 256 | 60 | 52 | 30 |
| 10 | 1.47 | 0.120 | 1.47 | 1.46 | 0.236 | 0.134 | 149 | 268 | 63 | 55 | 33 |
| 11 | 1.43 | 0.103 | 1.45 | 1.45 | 0.207 | 0.130 | 166 | 283 | 55 | 55 | 30 |
| 12 | 1.39 | 0.103 | 1.66 | 1.38 | 0.176 | 0.130 | 170 | 286 | 61 | 49 | 31 |
| 13 | 1.38 | 0.103 | 1.82 | 1.66 | 0.168 | 0.126 | 169 | 282 | 62 | 51 | 31 |
| 14 | 1.42 | 0.112 | 1.85 | 1.60 | 0.171 | 0.126 | 180 | 286 | 70 | 50 | 32 |
| 15 | 1.44 | 0.103 | 1.88 | 1.65 | 0.170 | 0.130 | 182 | 293 | 66 | 59 | 32 |
| 16 | 1.42 | 0.113 | 2.00 | 1.64 | 0.160 | 0.133 | 177 | 290 | 68 | 57 | 32 |
| 17 | 1.45 | 0.110 | 2.00 | 1.58 | 0.146 | 0.123 | 168 | 294 | 61 | 54 | 29 |
| 18 | 1.43 | 0.110 | 2.00 | 1.60 | 0.140 | 0.120 | 172 | 294 | 66 | 56 | 28 |
| | | | | | B - Upper leaves | | | | | | |
| 0 | 1.53 | 0.084 | 1.03 | 0.92 | 0.268 | 0.145 | 140 | 191 | 33 | 40 | 28 |
| 2 | 1.43 | 0.097 | 1.30 | 0.96 | 0.240 | 0.147 | 121 | 193 | 32 | 38 | 27 |
| 4 | 1.53 | 0.097 | 1.40 | 1.03 | 0.257 | 0.144 | 116 | 189 | 35 | 38 | 24 |
| 6 | 1.54 | 0.093 | 1.72 | 0.88 | 0.250 | 0.153 | 119 | 198 | 37 | 50 | 27 |
| 8 | 1.49 | 0.090 | 1.66 | 0.89 | 0.260 | 0.167 | 122 | 218 | 37 | 53 | 27 |
| 10 | 1.54 | 0.080 | 1.73 | 0.87 | 0.253 | 0.155 | 130 | 246 | 42 | 49 | 28 |
| 11 | 1.45 | 0.080 | 1.76 | 1.00 | 0.236 | 0.165 | 140 | 264 | 45 | 52 | 28 |
| 12 | 1.47 | 0.081 | 1.82 | 0.93 | 0.220 | 0.150 | 140 | 261 | 49 | 55 | 28 |
| 13 | 1.42 | 0.083 | 2.06 | 0.96 | 0.216 | 0.151 | 153 | 272 | 49 | 50 | 29 |
| 14 | 1.43 | 0.070 | 2.16 | 1.01 | 0.210 | 0.156 | 167 | 262 | 56 | 54 | 27 |
| 15 | 1.46 | 0.073 | 2.16 | 1.03 | 0.203 | 0.155 | 163 | 279 | 51 | 55 | 28 |
| 16 | 1.40 | 0.083 | 2.33 | 1.03 | 0.180 | 0.160 | 167 | 270 | 46 | 56 | 27 |
| 17 | 1.44 | 0.073 | 2.27 | 1.03 | 0.166 | 0.167 | 162 | 285 | 54 | 53 | 26 |
| 18 | 1.42 | 0.086 | 2.20 | 1.06 | 0.156 | 0.160 | 160 | 284 | 57 | 57 | 27 |

APPENDIX VII

Effect of sulphur stress on foliar nutrient composition of clove seedlings

| Months after treatment | N % | P % | K % | Ca % | Mg % | S % | Fe ppm | Mn ppm | Cu ppm | Zn ppm | B ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | A - Lower leaves | | | | | | |
| 0 | 1.29 | 0.098 | 0.67 | 1.06 | 0.273 | 0.106 | 149 | 207 | 60 | 39 | 31 |
| 2 | 1.36 | 0.086 | 0.80 | 1.23 | 0.280 | 0.120 | 149 | 216 | 55 | 35 | 28 |
| 4 | 1.47 | 0.125 | 1.03 | 1.36 | 0.280 | 0.107 | 142 | 210 | 56 | 35 | 27 |
| 6 | 1.42 | 0.123 | 1.22 | 1.42 | 0.290 | 0.113 | 135 | 219 | 56 | 39 | 30 |
| 8 | 1.37 | 0.121 | 1.31 | 1.35 | 0.270 | 0.117 | 141 | 256 | 59 | 43 | 28 |
| 10 | 1.46 | 0.121 | 1.46 | 1.30 | 0.240 | 0.103 | 153 | 269 | 63 | 45 | 31 |
| 11 | 1.39 | 0.118 | 1.46 | 1.33 | 0.270 | 0.093 | 176 | 284 | 61 | 49 | 25 |
| 12 | 1.37 | 0.113 | 1.50 | 1.36 | 0.273 | 0.093 | 164 | 281 | 65 | 49 | 29 |
| 13 | 1.46 | 0.104 | 1.46 | 1.39 | 0.266 | 0.090 | 178 | 269 | 66 | 54 | 29 |
| 14 | 1.55 | 0.106 | 1.54 | 1.39 | 0.283 | 0.086 | 178 | 276 | 66 | 59 | 31 |
| 15 | 1.48 | 0.114 | 1.48 | 1.48 | 0.253 | 0.086 | 175 | 272 | 65 | 61 | 30 |
| 16 | 1.46 | 0.115 | 1.48 | 1.45 | 0.263 | 0.080 | 178 | 271 | 61 | 62 | 27 |
| 17 | 1.42 | 0.106 | 1.51 | 1.36 | 0.276 | 0.086 | 180 | 271 | 64 | 61 | 26 |
| 18 | 1.44 | 0.103 | 1.47 | 1.36 | 0.266 | 0.080 | 188 | 282 | 60 | 61 | 26 |
| | | | | | B - Upper leaves | | | | | | |
| 0 | 1.53 | 0.084 | 1.03 | 0.92 | 0.268 | 0.145 | 140 | 191 | 33 | 40 | 28 |
| 2 | 1.44 | 0.093 | 1.50 | 0.96 | 0.270 | 0.140 | 128 | 193 | 37 | 33 | 25 |
| 4 | 1.50 | 0.106 | 1.46 | 0.96 | 0.260 | 0.133 | 123 | 210 | 36 | 37 | 25 |
| 6 | 1.50 | 0.103 | 1.68 | 0.89 | 0.272 | 0.127 | 125 | 223 | 40 | 44 | 26 |
| 8 | 1.54 | 0.090 | 1.71 | 0.85 | 0.240 | 0.130 | 123 | 236 | 46 | 46 | 24 |
| 10 | 1.51 | 0.085 | 1.67 | 0.83 | 0.244 | 0.103 | 149 | 250 | 50 | 51 | 28 |
| 11 | 1.43 | 0.086 | 1.70 | 0.90 | 0.280 | 0.093 | 165 | 268 | 51 | 51 | 22 |
| 12 | 1.39 | 0.086 | 1.70 | 0.91 | 0.280 | 0.076 | 160 | 253 | 54 | 51 | 26 |
| 13 | 1.47 | 0.066 | 1.66 | 0.91 | 0.290 | 0.076 | 170 | 251 | 53 | 55 | 28 |
| 14 | 1.47 | 0.085 | 1.74 | 0.87 | 0.290 | 0.086 | 169 | 264 | 55 | 52 | 28 |
| 15 | 1.47 | 0.085 | 1.74 | 0.93 | 0.285 | 0.076 | 166 | 254 | 55 | 55 | 26 |
| 16 | 1.47 | 0.080 | 1.71 | 0.92 | 0.260 | 0.075 | 163 | 257 | 50 | 53 | 22 |
| 17 | 1.43 | 0.083 | 1.74 | 0.93 | 0.270 | 0.060 | 169 | 256 | 52 | 52 | 23 |
| 18 | 1.43 | 0.086 | 1.74 | 0.88 | 0.280 | 0.056 | 172 | 264 | 52 | 58 | 23 |

Effect of iron stress foliar nutrient composition of clove seedlings

| Months after treatment | N % | P % | K % | Ca % | Mg % | S % | Fe ppm | Mn ppm | Cu ppm | Zn ppm | B ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | A - Lower leaves | | | | | | |
| 0 | 1.29 | 0.098 | 0.67 | 1.06 | 0.273 | 0.106 | 149 | 207 | 60 | 39 | 31 |
| 2 | 1.29 | 0.099 | 0.89 | 1.15 | 0.272 | 0.110 | 138 | 218 | 52 | 40 | 31 |
| 4 | 1.40 | 0.097 | 1.00 | 1.36 | 0.295 | 0.123 | 125 | 227 | 52 | 40 | 28 |
| 6 | 1.26 | 0.115 | 1.05 | 1.41 | 0.305 | 0.129 | 120 | 258 | 56 | 43 | 32 |
| 8 | 1.30 | 0.126 | 1.37 | 1.31 | 0.289 | 0.136 | 118 | 266 | 65 | 45 | 31 |
| 10 | 1.46 | 0.118 | 1.48 | 1.30 | 0.242 | 0.138 | 109 | 280 | 63 | 48 | 31 |
| 11 | 1.43 | 0.105 | 1.46 | 1.36 | 0.255 | 0.147 | 106 | 287 | 65 | 47 | 28 |
| 12 | 1.40 | 0.118 | 1.50 | 1.39 | 0.264 | 0.144 | 103 | 277 | 66 | 48 | 30 |
| 13 | 1.45 | 0.105 | 1.49 | 1.40 | 0.259 | 0.138 | 105 | 286 | 65 | 52 | 32 |
| 14 | 1.39 | 0.112 | 1.54 | 1.40 | 0.269 | 0.123 | 100 | 284 | 69 | 55 | 29 |
| 15 | 1.48 | 0.121 | 1.51 | 1.47 | 0.258 | 0.136 | 100 | 284 | 69 | 58 | 31 |
| 16 | 1.46 | 0.125 | 1.53 | 1.44 | 0.255 | 0.137 | 94 | 298 | 68 | 56 | 28 |
| 17 | 1.49 | 0.117 | 1.50 | 1.44 | 0.268 | 0.143 | 92 | 328 | 72 | 56 | 28 |
| 18 | 1.50 | 0.121 | 1.52 | 1.30 | 0.273 | 0.137 | 90 | 352 | 72 | 57 | 27 |
| | | | | | B - Upper leaves | | | | | | |
| 0 | 1.53 | 0.084 | 1.03 | 0.92 | 0.268 | 0.145 | 140 | 191 | 33 | 40 | 28 |
| 2 | 1.50 | 0.083 | 1.12 | 0.97 | 0.237 | 0.130 | 133 | 199 | 35 | 43 | 28 |
| 4 | 1.52 | 0.098 | 1.60 | 1.04 | 0.251 | 0.145 | 109 | 214 | 38 | 45 | 25 |
| 6 | 1.51 | 0.085 | 1.48 | 0.93 | 0.250 | 0.149 | 100 | 236 | 37 | 49 | 28 |
| 8 | 1.54 | 0.093 | 1.73 | 0.92 | 0.235 | 0.155 | 81 | 232 | 36 | 49 | 27 |
| 10 | 1.55 | 0.083 | 1.74 | 0.84 | 0.243 | 0.160 | 65 | 263 | 43 | 50 | 28 |
| 11 | 1.49 | 0.080 | 1.68 | 0.91 | 0.288 | 0.157 | 52 | 268 | 41 | 51 | 24 |
| 12 | 1.54 | 0.088 | 1.68 | 0.91 | 0.279 | 0.150 | 46 | 262 | 54 | 50 | 28 |
| 13 | 1.50 | 0.085 | 1.68 | 0.92 | 0.288 | 0.153 | 38 | 267 | 40 | 52 | 28 |
| 14 | 1.52 | 0.088 | 1.74 | 0.89 | 0.278 | 0.153 | 37 | 286 | 44 | 60 | 27 |
| 15 | 1.52 | 0.084 | 1.78 | 0.91 | 0.271 | 0.156 | 30 | 290 | 53 | 62 | 29 |
| 16 | 1.49 | 0.090 | 1.77 | 0.90 | 0.259 | 0.156 | 22 | 293 | 49 | 59 | 26 |
| 17 | 1.49 | 0.086 | 1.71 | 0.91 | 0.261 | 0.157 | 24 | 292 | 54 | 60 | 25 |
| 18 | 1.51 | 0.099 | 1.76 | 0.87 | 0.265 | 0.153 | 24 | 294 | 50 | 59 | 24 |

APPENDIX IX

Effect of manganese stress on foliar nutrient composition of clove seedlings

| Months after treatment | N % | P % | K % | Ca % | Mg % | S % | Fe ppm | Mn ppm | Cu ppm | Zn ppm | B ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | A - Lower leaves | | | | | | |
| 0 | 1.29 | 0.098 | 0.67 | 1.06 | 0.273 | 0.106 | 149 | 207 | 60 | 39 | 31 |
| 2 | 1.30 | 0.096 | 0.89 | 1.27 | 0.270 | 0.110 | 142 | 202 | 47 | 33 | 30 |
| 4 | 1.40 | 0.118 | 1.24 | 1.41 | 0.300 | 0.110 | 142 | 190 | 52 | 33 | 29 |
| 6 | 1.35 | 0.125 | 1.42 | 1.38 | 0.310 | 0.126 | 139 | 198 | 59 | 45 | 31 |
| 8 | 1.30 | 0.120 | 1.44 | 1.30 | 0.290 | 0.138 | 144 | 196 | 65 | 47 | 30 |
| 10 | 1.47 | 0.122 | 1.48 | 1.33 | 0.260 | 0.123 | 164 | 168 | 65 | 53 | 33 |
| 11 | 1.44 | 0.123 | 1.52 | 1.32 | 0.310 | 0.127 | 182 | 162 | 61 | 57 | 26 |
| 12 | 1.40 | 0.122 | 1.54 | 1.32 | 0.290 | 0.126 | 196 | 164 | 68 | 62 | 28 |
| 13 | 1.47 | 0.117 | 1.54 | 1.29 | 0.290 | 0.136 | 203 | 165 | 67 | 59 | 31 |
| 14 | 1.47 | 0.116 | 1.52 | 1.32 | 0.302 | 0.137 | 198 | 149 | 69 | 62 | 30 |
| 15 | 1.47 | 0.127 | 1.56 | 1.37 | 0.305 | 0.136 | 197 | 151 | 64 | 60 | 27 |
| 16 | 1.49 | 0.128 | 1.60 | 1.32 | 0.325 | 0.133 | 198 | 150 | 62 | 63 | 27 |
| 17 | 1.48 | 0.126 | 1.61 | 1.33 | 0.323 | 0.134 | 204 | 150 | 67 | 65 | 31 |
| 18 | 1.49 | 0.126 | 1.68 | 1.36 | 0.307 | 0.131 | 201 | 150 | 55 | 62 | 27 |
| | | | | | B - Upper leaves | | | | | | |
| 0 | 1.53 | 0.084 | 1.03 | 0.92 | 0.270 | 0.145 | 140 | 193 | 33 | 40 | 28 |
| 2 | 1.48 | 0.086 | 1.21 | 1.22 | 0.250 | 0.148 | 123 | 195 | 36 | 38 | 27 |
| 4 | 1.50 | 0.084 | 1.59 | 1.03 | 0.250 | 0.143 | 126 | 191 | 39 | 44 | 26 |
| 6 | 1.49 | 0.096 | 1.68 | 0.97 | 0.260 | 0.153 | 123 | 189 | 38 | 51 | 28 |
| 8 | 1.50 | 0.090 | 1.68 | 0.93 | 0.220 | 0.153 | 122 | 140 | 44 | 50 | 26 |
| 10 | 1.51 | 0.090 | 1.66 | 0.86 | 0.270 | 0.147 | 138 | 112 | 50 | 49 | 28 |
| 11 | 1.48 | 0.083 | 1.70 | 0.95 | 0.320 | 0.153 | 150 | 98 | 45 | 53 | 23 |
| 12 | 1.51 | 0.083 | 1.76 | 0.91 | 0.320 | 0.142 | 169 | 81 | 51 | 55 | 27 |
| 13 | 1.50 | 0.087 | 1.80 | 0.92 | 0.320 | 0.157 | 184 | 70 | 51 | 58 | 29 |
| 14 | 1.50 | 0.087 | 1.80 | 0.92 | 0.290 | 0.157 | 194 | 59 | 56 | 60 | 28 |
| 15 | 1.50 | 0.080 | 1.84 | 0.91 | 0.280 | 0.149 | 200 | 55 | 52 | 56 | 25 |
| 16 | 1.49 | 0.087 | 1.87 | 0.88 | 0.290 | 0.157 | 200 | 48 | 53 | 67 | 25 |
| 17 | 1.49 | 0.093 | 1.92 | 0.82 | 0.300 | 0.155 | 200 | 48 | 53 | 62 | 30 |
| 18 | 1.51 | 0.097 | 1.99 | 0.81 | 0.290 | 0.157 | 200 | 43 | 50 | 64 | 25 |

APPENDIX X

Effect of copper stress on foliar nutrient concentration of clove seedlings

| Months after treatment | N % | P % | K % | Ca % | Mg % | S % | Fe ppm | Mn ppm | Cu ppm | Zn ppm | B ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | A - Lower leaves | | | | | | |
| 0 | 1.29 | 0.098 | 0.67 | 1.06 | 0.273 | 0.106 | 149 | 207 | 60 | 39 | 31 |
| 2 | 1.32 | 0.097 | 0.83 | 1.39 | 0.275 | 0.127 | 136 | 226 | 59 | 39 | 29 |
| 4 | 1.44 | 0.103 | 1.20 | 1.47 | 0.380 | 0.129 | 143 | 228 | 58 | 39 | 28 |
| 6 | 1.26 | 0.128 | 1.30 | 1.45 | 0.320 | 0.128 | 134 | 252 | 64 | 49 | 36 |
| 8 | 1.32 | 0.128 | 1.46 | 1.37 | 0.260 | 0.120 | 138 | 280 | 61 | 48 | 32 |
| 10 | 1.46 | 0.118 | 1.55 | 1.28 | 0.233 | 0.130 | 164 | 281 | 60 | 50 | 31 |
| 11 | 1.45 | 0.115 | 1.46 | 1.34 | 0.267 | 0.139 | 181 | 285 | 59 | 56 | 27 |
| 12 | 1.30 | 0.118 | 1.57 | 1.37 | 0.240 | 0.127 | 177 | 277 | 61 | 59 | 31 |
| 13 | 1.42 | 0.119 | 1.53 | 1.38 | 0.253 | 0.124 | 179 | 279 | 60 | 62 | 28 |
| 14 | 1.46 | 0.119 | 1.50 | 1.42 | 0.256 | 0.135 | 183 | 285 | 58 | 63 | 30 |
| 15 | 1.54 | 0.119 | 1.46 | 1.46 | 0.265 | 0.133 | 183 | 270 | 56 | 62 | 29 |
| 16 | 1.55 | 0.123 | 1.47 | 1.45 | 0.267 | 0.130 | 195 | 268 | 43 | 54 | 27 |
| 17 | 1.58 | 0.127 | 1.53 | 1.38 | 0.267 | 0.132 | 184 | 287 | 40 | 54 | 25 |
| 18 | 1.57 | 0.129 | 1.57 | 1.38 | 0.283 | 0.131 | 198 | 282 | 42 | 54 | 26 |
| | | | | | B - Upper leaves | | | | | | |
| 0 | 1.53 | 0.084 | 1.03 | 0.92 | 0.270 | 0.145 | 140 | 193 | 33 | 40 | 28 |
| 2 | 1.48 | 0.095 | 1.67 | 1.13 | 0.234 | 0.140 | 116 | 216 | 35 | 37 | 28 |
| 4 | 1.54 | 0.110 | 1.53 | 1.10 | 0.270 | 0.140 | 120 | 215 | 35 | 39 | 25 |
| 6 | 1.50 | 0.078 | 1.79 | 0.97 | 0.243 | 0.146 | 120 | 234 | 32 | 50 | 32 |
| 8 | 1.52 | 0.077 | 1.72 | 0.89 | 0.247 | 0.154 | 128 | 254 | 33 | 53 | 29 |
| 10 | 1.51 | 0.090 | 1.73 | 0.89 | 0.270 | 0.161 | 144 | 250 | 34 | 50 | 27 |
| 11 | 1.51 | 0.094 | 1.76 | 0.94 | 0.293 | 0.160 | 163 | 256 | 24 | 54 | 24 |
| 12 | 1.55 | 0.087 | 1.68 | 0.94 | 0.267 | 0.147 | 168 | 259 | 18 | 57 | 29 |
| 13 | 1.46 | 0.087 | 1.76 | 0.96 | 0.283 | 0.147 | 167 | 255 | 17 | 60 | 27 |
| 14 | 1.56 | 0.095 | 1.66 | 0.98 | 0.267 | 0.146 | 165 | 263 | 14 | 63 | 27 |
| 15 | 1.55 | 0.098 | 1.70 | 0.89 | 0.291 | 0.157 | 164 | 248 | 14 | 54 | 27 |
| 16 | 1.56 | 0.102 | 1.71 | 0.94 | 0.256 | 0.146 | 170 | 245 | 14 | 59 | 24 |
| 17 | 1.58 | 0.107 | 1.67 | 0.95 | 0.267 | 0.149 | 167 | 240 | 12 | 60 | 24 |
| 18 | 1.58 | 0.107 | 1.65 | 0.91 | 0.273 | 0.163 | 173 | 238 | 11 | 60 | 22 |

Effect of zinc stress on foliar nutrient composition of clove seedlings

| Months after treatment | N % | P % | K % | Ca % | Mg % | S % | Fe ppm | Mn ppm | Cu ppm | Zn ppm | B ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | A - Lower leaves | | | | | | |
| 0 | 1.29 | 0.098 | 0.67 | 1.06 | 0.273 | 0.106 | 149 | 207 | 60 | 39 | 31 |
| 2 | 1.33 | 0.098 | 0.79 | 1.37 | 0.277 | 0.110 | 146 | 222 | 54 | 39 | 30 |
| 4 | 1.37 | 0.120 | 1.00 | 1.48 | 0.286 | 0.126 | 144 | 224 | 54 | 40 | 28 |
| 6 | 1.37 | 0.128 | 1.23 | 1.41 | 0.291 | 0.124 | 137 | 249 | 59 | 38 | 30 |
| 8 | 1.31 | 0.128 | 1.33 | 1.32 | 0.285 | 0.124 | 146 | 263 | 64 | 39 | 28 |
| 10 | 1.37 | 0.116 | 1.47 | 1.27 | 0.267 | 0.122 | 161 | 264 | 60 | 36 | 30 |
| 11 | 1.38 | 0.106 | 1.45 | 1.34 | 0.278 | 0.140 | 172 | 285 | 57 | 31 | 26 |
| 12 | 1.33 | 0.119 | 1.45 | 1.43 | 0.276 | 0.129 | 165 | 282 | 59 | 29 | 29 |
| 13 | 1.37 | 0.124 | 1.49 | 1.34 | 0.287 | 0.128 | 184 | 280 | 55 | 27 | 30 |
| 14 | 1.45 | 0.127 | 1.57 | 1.32 | 0.290 | 0.128 | 165 | 285 | 59 | 24 | 31 |
| 15 | 1.49 | 0.128 | 1.56 | 1.36 | 0.286 | 0.134 | 171 | 282 | 57 | 26 | 29 |
| 16 | 1.41 | 0.136 | 1.54 | 1.42 | 0.278 | 0.128 | 174 | 284 | 54 | 27 | 28 |
| 17 | 1.42 | 0.130 | 1.49 | 1.36 | 0.279 | 0.128 | 168 | 285 | 55 | 22 | 30 |
| 18 | 1.39 | 0.134 | 1.57 | 1.35 | 0.283 | 0.190 | 184 | 283 | 57 | 24 | 27 |
| | | | | | B - Upper leaves | | | | | | |
| 0 | 1.53 | 0.084 | 1.02 | 0.92 | 0.270 | 0.145 | 140 | 193 | 33 | 40 | 28 |
| 2 | 1.48 | 0.090 | 1.25 | 1.03 | 0.232 | 0.128 | 141 | 211 | 35 | 36 | 28 |
| 4 | 1.55 | 0.098 | 1.53 | 1.10 | 0.238 | 0.143 | 129 | 211 | 38 | 36 | 25 |
| 6 | 1.48 | 0.084 | 1.61 | 1.13 | 0.267 | 0.147 | 128 | 231 | 39 | 30 | 27 |
| 8 | 1.57 | 0.095 | 1.62 | 0.94 | 0.224 | 0.151 | 132 | 245 | 37 | 22 | 26 |
| 10 | 1.53 | 0.093 | 1.70 | 0.85 | 0.253 | 0.159 | 145 | 243 | 48 | 17 | 27 |
| 11 | 1.46 | 0.092 | 1.68 | 0.89 | 0.286 | 0.152 | 169 | 260 | 45 | 15 | 25 |
| 12 | 1.55 | 0.090 | 1.66 | 0.89 | 0.290 | 0.156 | 146 | 265 | 46 | 13 | 28 |
| 13 | 1.56 | 0.090 | 1.76 | 0.90 | 0.302 | 0.158 | 173 | 261 | 48 | 11 | 28 |
| 14 | 1.51 | 0.110 | 1.75 | 0.91 | 0.296 | 0.143 | 176 | 269 | 48 | 11 | 27 |
| 15 | 1.51 | 0.113 | 1.79 | 0.87 | 0.300 | 0.146 | 162 | 254 | 49 | 10 | 26 |
| 16 | 1.46 | 0.114 | 1.75 | 0.87 | 0.272 | 0.156 | 164 | 244 | 50 | 8 | 24 |
| 17 | 1.48 | 0.117 | 1.68 | 0.89 | 0.265 | 0.134 | 156 | 257 | 47 | 8 | 24 |
| 18 | 1.49 | 0.115 | 1.67 | 0.90 | 0.258 | 0.134 | 174 | 239 | 48 | 8 | 26 |

APPENDIX XII

Effect of boron stress on foliar nutrient composition of clove seedlings

| Months after treatment | N % | P % | K % | Ca % | Mg % | S % | Fe ppm | Mn ppm | Cu ppm | Zn ppm | B ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | A - Lower leaves | | | | | | |
| 0 | 1.29 | 0.098 | 0.67 | 1.06 | 0.273 | 0.107 | 149 | 207 | 60 | 39 | 31 |
| 2 | 1.37 | 0.097 | 0.78 | 1.31 | 0.287 | 0.110 | 149 | 236 | 54 | 39 | 29 |
| 4 | 1.46 | 0.104 | 0.97 | 1.46 | 0.312 | 0.124 | 147 | 232 | 52 | 38 | 30 |
| 6 | 1.41 | 0.118 | 1.12 | 1.41 | 0.303 | 0.132 | 140 | 255 | 62 | 39 | 31 |
| 8 | 1.38 | 0.117 | 1.40 | 1.38 | 0.292 | 0.130 | 144 | 273 | 59 | 49 | 30 |
| 10 | 1.40 | 0.110 | 1.47 | 1.41 | 0.269 | 0.122 | 157 | 281 | 60 | 52 | 29 |
| 11 | 1.40 | 0.101 | 1.43 | 1.42 | 0.289 | 0.137 | 163 | 279 | 59 | 48 | 28 |
| 12 | 1.46 | 0.110 | 1.61 | 1.45 | 0.283 | 0.129 | 171 | 275 | 61 | 44 | 25 |
| 13 | 1.43 | 0.108 | 1.59 | 1.38 | 0.275 | 0.121 | 172 | 283 | 58 | 47 | 23 |
| 14 | 1.49 | 0.112 | 1.61 | 1.46 | 0.285 | 0.126 | 184 | 282 | 62 | 57 | 24 |
| 15 | 1.49 | 0.122 | 1.55 | 1.48 | 0.290 | 0.140 | 177 | 267 | 65 | 52 | 21 |
| 16 | 1.50 | 0.119 | 1.50 | 1.41 | 0.290 | 0.138 | 168 | 268 | 56 | 53 | 24 |
| 17 | 1.48 | 0.106 | 1.48 | 1.31 | 0.283 | 0.136 | 166 | 280 | 65 | 56 | 20 |
| 18 | 1.45 | 0.116 | 1.45 | 1.32 | 0.288 | 0.125 | 172 | 283 | 63 | 56 | 20 |
| | | | | | B - Upper leaves | | | | | | |
| 0 | 1.53 | 0.084 | 1.02 | 0.92 | 0.270 | 0.145 | 140 | 193 | 33 | 39 | 28 |
| 2 | 1.46 | 0.090 | 1.18 | 1.08 | 0.236 | 0.140 | 129 | 213 | 39 | 37 | 28 |
| 4 | 1.53 | 0.093 | 1.41 | 1.05 | 0.255 | 0.146 | 127 | 209 | 40 | 38 | 29 |
| 6 | 1.50 | 0.085 | 1.74 | 1.00 | 0.267 | 0.153 | 117 | 234 | 43 | 43 | 28 |
| 8 | 1.51 | 0.088 | 1.79 | 1.00 | 0.225 | 0.158 | 121 | 243 | 39 | 47 | 26 |
| 10 | 1.53 | 0.095 | 1.71 | 0.82 | 0.249 | 0.160 | 149 | 261 | 46 | 46 | 18 |
| 11 | 1.52 | 0.085 | 1.73 | 0.95 | 0.309 | 0.167 | 158 | 261 | 42 | 52 | 13 |
| 12 | 1.51 | 0.087 | 1.79 | 0.93 | 0.296 | 0.155 | 155 | 256 | 47 | 38 | 14 |
| 13 | 1.50 | 0.076 | 1.66 | 0.93 | 0.288 | 0.165 | 163 | 257 | 46 | 46 | 11 |
| 14 | 1.53 | 0.083 | 1.68 | 0.92 | 0.293 | 0.147 | 169 | 263 | 48 | 49 | 10 |
| 15 | 1.50 | 0.080 | 1.62 | 0.90 | 0.288 | 0.157 | 159 | 247 | 47 | 46 | 10 |
| 16 | 1.52 | 0.098 | 1.60 | 0.92 | 0.270 | 0.159 | 148 | 254 | 42 | 49 | 9 |
| 17 | 1.49 | 0.087 | 1.56 | 0.94 | 0.289 | 0.152 | 146 | 264 | 56 | 51 | 9 |
| 18 | 1.46 | 0.097 | 1.60 | 0.92 | 0.281 | 0.166 | 157 | 267 | 50 | 54 | 9 |

Correlation coefficients and regression equation for various parameters of P absorption in healthy and deficient plants

| Variables y vs. x | Condition of the plant | Regression equation | $R^2$ |
|---|---|---|---|
| Leaf P vs. Stem P (%) | Healthy | $y = 0.089 + 0.092\ x$ | 0.760 |
| | | $y = 0.077 + 0.210\ x - 0.188\ x^2$ | 0.827 |
| | Deficient | $y = 0.072 + 0.043\ x$ | 0.528 |
| | | $y = 0.075 + 0.003\ x + 0.160\ x^2$ | 0.522 |
| Log leaf P vs. Log stem P | Healthy | $y = 2.335 + 0.215\ x$ | 0.677 |
| | | $y = -0.169 + 1.343\ x + 0.475\ x^2$ | 0.001 |
| | Deficient | $y = 2.705 + 0.060\ x$ | 0.252 |
| | | $y = 0.078 - 0.411\ x + 3.417\ x^2$ | 0.001 |
| Stem P vs. Nodal rank (ppm) | Healthy | $y = -158.720 + 318.410\ x$ | 0.467 |
| | | $y = 61.258 - 515.639\ x + 1886\ x^2$ | 0.252 |
| | Deficient | $y = 176.153 + 116.153\ x$ | 0.695 |
| | | $y = 13.679 - 70.100\ x + 632.845\ x^2$ | 0.524 |
| Log stem P vs. Nodal rank | Healthy | $y = 2.812 + 0.060\ x$ | 0.761 |
| | | $y = 3.112 - 0.062\ x + 0.009\ x^2$ | 0.965 |
| | Deficient | $y = 2.602 + 0.050\ x$ | 0.870 |
| | | $y = 2.742 - 0.008\ x + 0.004\ x^2$ | 0.944 |
| Leaf P vs. Nodal rank (ppm) | Healthy | $y = 1124.230 + 5.989\ x$ | 0.001 |
| | | $y = 12.922 - 169.335\ x + 1562.517\ x^2$ | 0.001 |
| | Deficient | $y = 875.525 - 10.839\ x$ | 0.035 |
| | | $y = 5.108 - 80.390\ x + 1046.06\ x^2$ | 0.001 |
| Log leaf P vs. Nodal rank | Healthy | $y = 2.979 + 0.009\ x$ | 0.246 |
| | | $y = 3.098 - 0.038\ x + 0.003\ x^2$ | 0.614 |
| | Deficient | $y = 2.940 - 0.005\ x$ | 0.191 |
| | | $y = 3.024 - 0.040\ x + 0.003\ x^2$ | 0.694 |

Correlation coefficients and regression equation for various parameters of $^{32}P$ absorption in healthy and deficient plants

| Variables y vs. x | Condition of the plant | Regression equation | $R^2$ |
|---|---|---|---|
| Leaf $^{32}P$ vs. stem $^{32}P$ ($cpm\ g^{-1}$) | Healthy | $y = 116.489 + 0.184\ x$ | 0.088 |
| | | $y = 0.00008 + 0.362\ x + 58.858\ x^2$ | 0.023 |
| | Deficient | $y = 21.187 + 0.260\ x$ | 0.641 |
| | | $y = 0.00002 + 0.126\ x + 108.142\ x^2$ | 0.416 |
| Log leaf $^{32}P$ vs. Log stem $^{32}P$ | Healthy | $y = -0.165 + 0.826\ x$ | 0.019 |
| | | $y = 0.157 + 0.004\ x + 0.888\ x^2$ | 0.001 |
| | Deficient | $y = -1.818 + 1.355\ x$ | 0.265 |
| | | $y = -0.456 + 4.124\ x - 5.927\ x^2$ | 0.004 |
| Stem $^{32}P$ vs. Nodal rank ($cpm\ g^{-1}$) | Healthy | $y = -22.809 + 94.974\ x$ | 0.293 |
| | | $y = 13.064 - 92.941 + 483.658\ x^2$ | 0.094 |
| | Deficient | $y = 829.529 + 402.953\ x$ | 0.840 |
| | | $y = 28.764 + 11.326\ x + 130.732\ x^2$ | 0.446 |
| Log stem $^{32}P$ vs. Nodal rank | Healthy | $y = 2.317 + 0.065\ x$ | 0.546 |
| | | $y = 2.245 + 0.070\ x - 0.0004\ x^2$ | 0.581 |
| | Deficient | $y = 2.236 + 0.123\ x$ | 0.859 |
| | | $y = 2.198 + 0.138\ x - 0.0011\ x^2$ | 0.860 |
| Leaf $^{32}P$ vs. Nodal rank ($cpm\ g^{-1}$) | Healthy | $y = -3.568 + 37.884\ x$ | 0.786 |
| | | $y = -1.966 + 64.508\ x - 67.458\ x^2$ | 0.073 |
| | Deficient | $y = -83.872 + 91.621\ x$ | 0.367 |
| | | $y = 9.771 - 40.473\ x + 231.376\ x^2$ | 0.192 |
| Log leaf $^{32}P$ vs. Nodal rank | Healthy | $y = 1.594 + 0.106\ x$ | 0.687 |
| | | $y = 1.102 + 0.306\ x - 0.015\ x^2$ | 0.887 |
| | Deficient | $y = 1.897 + 0.095\ x$ | 0.564 |
| | | $y = 1.914 + 0.088\ x + 0.0005\ x^2$ | 0.564 |

Correlation coefficients and regression equation for various parameters of S absorption in healthy and deficient plants

| Variables y vs. x | Condition of the plant | Regression equation | $R^2$ |
|---|---|---|---|
| Leaf S vs. Stem S (%) | Healthy | $y = 0.034 + 0.866\ x$ | 0.943 |
| | | $y = 0.011 + 1.166\ x - 0.959\ x^2$ | 0.946 |
| | Deficient | $y = 0.091 + 0.352\ x$ | 0.836 |
| | | $y = 0.168 - 1.148\ x + 6.960\ x^2$ | 0.942 |
| Log leaf S vs. Log stem S | Healthy | $y = 0.669 + 0.802\ x$ | 0.863 |
| | | $y = 0.203 - 0.492\ x + 2.728\ x^2$ | 0.001 |
| | Deficient | $y = 2.275 + 0.276\ x$ | 0.670 |
| | | $y = 1.244 - 7.727\ x + 13.578\ x^2$ | 0.001 |
| Stem S vs. Nodal rank (ppm) | Healthy | $y = 1659.33 - 28.97\ x$ | 0.013 |
| | | $y = 30.909 - 368.969\ x + 2339.33\ x^2$ | 0.001 |
| | Deficient | $y = 1354.0 - 44.181\ x$ | 0.112 |
| | | $y = 17.348 - 235.015\ x + 1735.666\ x^2$ | 0.001 |
| Log stem S vs. Nodal rank | Healthy | $y = 3.215 - 0.008\ x$ | 0.110 |
| | | $y = 3.404 - 0.103\ x + 0.009\ x^2$ | 0.902 |
| | Deficient | $y = 3.132 - 0.017\ x$ | 0.305 |
| | | $y = 3.286 - 0.094\ x + 0.007\ x^2$ | 0.624 |
| Leaf S vs. Nodal rank (ppm) | Healthy | $y = 1919.354 - 66.612\ x$ | 0.478 |
| | | $y = 14.879 - 226.923\ x + 2236.135\ x^2$ | 0.001 |
| | Deficient | $y = 1413.054 - 19.541\ x$ | 0.242 |
| | | $y = 7.169 - 98.782\ x + 1566.500\ x^2$ | 0.001 |
| Log leaf S vs. Nodal rank | Healthy | $y = 3.28 - 0.018\ x$ | 0.700 |
| | | $y = 3.364 - 0.58\ x + 0.004\ x^2$ | 0.937 |
| | Deficient | $y = 3.149 - 0.006\ x$ | 0.476 |
| | | $y = 3.200 - 0.032\ x + 0.002\ x^2$ | 0.846 |

Correlation coefficients and regression equation for various parameters of $^{35}S$ absorption in healthy and deficient plants

| Variables y vs. x | Condition of the plant | Regression equation | $R^2$ |
|---|---|---|---|
| Leaf $^{35}S$ vs. Stem $^{35}S$ ($cpm\ mg^{-1}$) | Healthy | $y = 40.455 - 0.654\ x$ | 0.006 |
| | | $y = 0.025 + 0.993\ x + 16.914\ x^2$ | 0.029 |
| | Deficient | $y = -50.858 + 0.731\ x$ | 0.573 |
| | | $y = 0.005 - 0.998\ x + 58.284\ x^2$ | 0.927 |
| Log leaf $^{35}S$ vs. Log stem $^{35}S$ | Healthy | $y = 10.341 - 1.440\ x$ | 0.185 |
| | | $y = 1.425 - 14.129\ x + 38.554\ x^2$ | 0.001 |
| | Deficient | $y = -5.880 + 2.031\ x$ | 0.756 |
| | | $y = 0.805 - 6.157\ x + 14.912\ x^2$ | 0.001 |
| Stem $^{35}S$ vs. Nodal rank ($cpm\ mg^{-1}$) | Healthy | $y = 27.051 + 1.320\ x$ | 0.015 |
| | | $y = -1.185 + 14.360\ x + 0.972\ x^2$ | 0.005 |
| | Deficient | $y = 275.716 - 23.250\ x$ | 0.833 |
| | | $y = 1.309 - 37.942\ x + 306.832\ x^2$ | 0.048 |
| Log stem $^{35}S$ vs. Nodal rank | Healthy | $y = 4.389 + 0.022\ x$ | 0.162 |
| | | $y = 4.009 + 0.212\ x - 0.017\ x^2$ | 0.808 |
| | Deficient | $y = 5.530 - 0.075\ x$ | 0.931 |
| | | $y = 5.500 - 0.061\ x - 0.001\ x^2$ | 0.934 |
| Leaf $^{35}S$ vs. Nodal rank ($cpm\ mg^{-1}$) | Healthy | $y = 30.269 - 3.611\ x$ | 0.171 |
| | | $y = 1.128 - 15.767 + 54.290\ x^2$ | E |
| | Deficient | $y = 150.28 - 17.814\ x$ | 0.559 |
| | | $y = 3.580 - 56.773\ x + 225.146\ x^2$ | 0.829 |
| Log leaf $^{35}S$ vs. Nodal rank | Healthy | $y = 4.393 - 0.102\ x$ | 0.636 |
| | | $y = 4.901 - 0.360\ x + 0.024\ x^2$ | 0.890 |
| | Deficient | $y = 5.425 - 0.183\ x$ | 0.960 |
| | | $y = 5.487 - 0.218\ x + 0.003\ x^2$ | 0.962 |

Correlation coefficients and regression equation for various parameters of Ca in sufficient and deficient plants

| Variables y vs. x | Condition of the plant | Regression equation | $R^2$ |
|---|---|---|---|
| Leaf Ca vs. Stem Ca (%) | Healthy | $y = -0.379 + 1.490\ x$ | 0.302 |
| | | $y = -0.626 + 2.031\ x - 0.291\ x^2$ | 0.306 |
| | Deficient | $y = -0.203 + 1.914\ x$ | 0.795 |
| | | $y = 0.968 - 4.624\ x + 8.044\ x^2$ | 0.881 |
| Log leaf Ca vs. Log stem Ca | Healthy | $y = -2.881 + 1.731\ x$ | 0.130 |
| | | $y = 0.599 - 2.998\ x + 6.452\ x^2$ | 0.001 |
| | Deficient | $y = -1.117 + 1.346\ x$ | 0.640 |
| | | $y = 3.717 - 25.189\ x + 46.137\ x^2$ | 0.001 |
| Stem Ca vs. Nodal rank (ppm) | Healthy | $y = 7863.333 + 201.758\ x$ | 0.065 |
| | | $y = 58.523 + 845.50\ x + 6575\ x^2$ | 0.001 |
| | Deficient | $y = 2003.33 + 442.121\ x$ | 0.786 |
| | | $y = -41.022 + 893.371\ x + 1100.835\ x^2$ | 0.007 |
| Log stem Ca vs. Nodal rank | Healthy | $y = 3.895 + 0.010$ | 0.052 |
| | | $y = 3.828 + 0.043\ x - 0.003\ x^2$ | 0.412 |
| | Deficient | $y = 3.354 + 0.049\ x$ | 0.840 |
| | | $y = 3.218 + 0.117\ x - 0.006\ x^2$ | 0.926 |
| Leaf Ca vs. Nodal rank (ppm) | Healthy | $y = 3652.666 + 1078.242\ x$ | 0.976 |
| | | $y = 29.090 + 1398.242\ x + 3012.666\ x^2$ | 0.010 |
| | Deficient | $y = 1013.333 + 989.939\ x$ | 0.929 |
| | | $y = 34.583 + 609.522\ x + 1774.166\ x^2$ | 0.038 |
| Log leaf Ca vs. Nodal rank | Healthy | $y = 3.655 + 0.054\ x$ | 0.924 |
| | | $y = 3.541 + 0.112\ x - 0.005\ x^2$ | 0.977 |
| | Deficient | $y = 3.325 + 0.078\ x$ | 0.919 |
| | | $y = 3.191 + 0.145\ x - 0.006\ x^2$ | 0.945 |

Correlation coefficients and regression equation for various parameters of $^{45}Ca$ in healthy and deficient plants

| Variables y vs. x | Condition of the plant | Regression equation | $R^2$ |
|---|---|---|---|
| Leaf $^{45}Ca$ vs. Stem $^{45}Ca$ ($cpm\ g^{-1}$) | Healthy | $y = -592.525 + 0.115\ x$ | 0.595 |
| | | $y = 0.001 - .0.080\ x + 230.303\ x^2$ | E |
| | Deficient | $y = -0.975 + 0.024\ x$ | 0.781 |
| | | $y = 0.0198 + 4.96\ x + 1547\ x^2$ | 0.722 |
| Log leaf $^{45}Ca$ vs. Log stem $^{45}Ca$ | Healthy | $y = 0.392 + 0.526\ x$ | 0.204 |
| | | $y = 0.854 - 5.585\ x + 10.761\ x^2$ | 0.004 |
| | Deficient | $y = -0.070 + 0.696\ x$ | 0.243 |
| | | $y = 1.540 - 15.572\ x + 42.555\ x^2$ | 0.001 |
| Stem $^{45}Ca$ vs. Nodal rank ($cpm\ mg^{-1}$) | Healthy | $y = 16.582 + 5.544\ x$ | 0.515 |
| | | $y = 1.275 - 8.486\ x + 11.478\ x^2$ | E |
| | Deficient | $y = -175.017 + 98.866\ x$ | 0.855 |
| | | $y = 10.558 - 17.281\ x + 57.278\ x^2$ | 0.405 |
| Log stem $^{45}Ca$ vs. Nodal rank | Healthy | $y = 2.068 + 0.273\ x$ | 0.933 |
| | | $y = 2.283 + 0.166\ x + 0.0098\ x^2$ | 0.941 |
| | Deficient | $y = 4.540 + 0.153\ x$ | 0.969 |
| | | $y = 4.349 + 0.245\ x - 0.008\ x^2$ | 0.989 |
| Leaf $^{45}Ca$ vs. Nodal rank ($cpm\ g^{-1}$) | Healthy | $y = -1680.533 - 488.896\ x$ | 0.105 |
| | | $y = 193.647 - 1641.228\ x + 2579.716\ x^2$ | E |
| | Deficient | $y = -4.242 + 2.189\ x$ | 0.501 |
| | | $y = -0.5350 - 3.696\ x + 7.529\ x^2$ | 0.820 |
| Log leaf $^{45}Ca$ vs. Nodal rank | Healthy | $y = 1.400 + 0.171\ x$ | 0.610 |
| | | $y = 2.412 - 0.340\ x + 0.046\ x^2$ | 0.877 |
| | Deficient | $y = 2.993 + 0.124\ x$ | 0.651 |
| | | $y = 3.597 - 0.178\ x + 0.027\ x^2$ | 0.855 |

# DEFICIENCY SYMPTOMS OF MINERAL NUTRIENTS IN CLOVE (*Syzygium aromaticum* (L.) Merr. and Perry).

By

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**ABSTRACT OF THE THESIS**

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## ABSTRACT

Experiments were conducted at the College of Horticulture on nutritional aspects of clove, to study the nutrient deficiency symptoms as well as the distribution pattern of nutrients in starved clove plants. The deficiency symptoms were induced in clove seedlings in sand culture. The distribution patterns of P, S (anions) and Ca (cation) were studied in the nutrient-starved seedlings employing radio isotopes. Besides, the annual nutrient removal and the seasonal fluctuations in the foliar nutrient concentration were studied in bearing clove trees.

Older leaves were the first to exhibit 'hunger signs' due to the stress induced by N, P, K and Mg starvation whereas the symptoms were manifested on the younger growth due to deficiency of Ca, S, Fe, Mn, Cu, Zn and B. General yellowing of the older leaves and early defoliation were the symptoms expressed by N-starved plants. Phosphorus stress resulted in small brownish spots to appear on older leaves of clove seedlings which later coalesced to form necrotic patches. Tip and marginal necrosis that gradually progressed inward marked the K-deficiency symptoms. Reduced shoot growth and tip die back associated with necrotic patches on upper leaves were the characteristics of Ca deficiency. Though the chlorotic symptoms were visualised on the older leaves of Mg starved plant, it soon spread to younger leaves which failed to develop full size and colour and became necrotic later. Newly formed foliage of S-starved plants were chlorotic and reduced in size with a tendency to drop prematurely. Interveinal chlorosis with the later growth paler and papery white were the characteristics of Fe deficiency. The new growth putforth by Mn, Cu and Zn starved plants had abnormal leaves, characteristic to each element. Zinc deficiency was unique with the sickle shaped leaves and rosette appearance. Boron deficiency was

characterised by brittle leaves, occasionally with tip and marginal necrosis. New growth was small and aborted in case of B starved plants. Molybdenum stress did not produce any symptoms during the period of 24 months.

There was reduction in the growth attributes due to induced nutrient stress. The adverse effects were more marked in the case of N and S starvation, wherein the plant height, leaf area and total biomass produced were reduced to the extent of 20 to 53 per cent. Calcium was found to inlfuence root growth the most. Among the minor elements, Zn and B stress had more pronounced reduction in growth (17 to 25%). The nutrient stress reduced the foliar levels of that particular element in the plant and was occasionally interfered with the other elements. N-P, P-Zn, K-Mg, Fe-Mn interactions were observed.

The patterns of distribution and translocation of P, S and Ca were found to vary in clove plants. Stem was a better accumulator of P whereas S level was more in leaves. Lower plant parts registered high P and Ca levels whereas reverse was true for S in plants sufficiently supplied with the nutrient. Lower shoot portion accumulated most of the radio label in P and Ca-starved plants. Major part of the radiolabel was recovered from upper parts of the S-starved plants. Phosphorus from lower plant parts were remobilised under the stress condition whereas, S was found not translocated. The levels of the element in the stem and leaf were found correlated, indicating the supply of P and S to the leaf from the corresponding stem portion. In the case of Ca, such a relation was observed only in the starved plants. Stem was found to be a better sink for the absorbed $^{45}$Ca-label both in the case of deficient and sufficient plants.

In an adult clove tree which had just started bearing, leaf was found to be the major accumulator of N, S, Fe and Mn on drymatter basis. Flower buds served as the best sink for K and Mg. Both the stem

and flower buds were equally efficient in accumulating P and Ca. The requirement of different nutrients by the crop was in the order of K > N > Ca > Mg > S > Mn > P > Fe > Cu > B > Zn. Though the accumulation pattern of different nutrients in various plant parts varied considerably, leaf accounted for the major part (80 to 90%) of the nutrient removed.

Seasonal variation in foliar nutrient levels was observed in bearing clove plants. The foliar N and K levels were found influenced by rainfall, flushing periods and fertiliser application. Seasonal influence on P, Ca, Mg and S levels were relatively low.