INVESTIGATIONS ON THE NUTRITION OF BLACK PEPPER [Piper nigrum L.]

By

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THESIS

Submitted in partial fulfilment of the

requirements for the degree of

Doctor of Philosophy in Horticulture

Faculty of Agriculture

Kerala Agricultural University

Department of
Plantation Crops and Spices
COLLEGE OF HORTICULTURE
Vellanikkara, Trichur
1986

DECLARATION

I hereby declare that this thesis entitled "Investigations on the nutrition of black pepper (*Piper nigrum* L.)" 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.

Vellanikkara,
25th February, 1986.

(E.V. NYBE)

T O

M Y W I F E

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I hereby declare that this thesis entitled "Investigations on the nutrition of black pepper (*Piper nigrum* L.)" 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.

Vellanikkara,
25th February, 1986.

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CERTIFICATE

Certified that this thesis entitled "Investigations on the nutrition of black pepper (Piper nigrum L.)" is a record of research work done independently by Sri. E.V.Nybe, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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CERTIFICATE

We, the undersigned members of the Advisory Committee of Sri. E.V. Nybe, a candidate for the degree of Doctor of Philosophy in Horticulture, agree that the thesis entitled "Investigations on the nutrition of black pepper (Piper nigrum L.)" may be submitted by Sri.E.V. Nybe in partial fulfilment of the requirements for the degree.

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INTRODUCTION

Black pepper (*Piper nigrum* L.), the king of spices still retains the crown enjoying a vital role in the national economy. The Indian pepper enjoyed monopoly in the world market till the turn of the 19th century when other countries like Indonesia and Brazil entered the pepper trade. In India, pepper ranks first among the spices export, amounting to 28.5 per cent of the total quantity of spices exported (89165 tonnes) which accounted for 29 per cent of the total earnings (Rs.208.63 crores) during the year 1984-'85.

In India, pepper is cultivated in an area of 1.07 lakh hectares which forms about 50 per cent of the area under this crop in the world. Inspite of this, India's contribution to the total pepper production in the world is only 20,640 tonnes and India stands only fourth among the major producers. The trend in the production of pepper in India, although showed gradual increase from 1977-'78 to 1980-'81 (21,000 to 29,400 tonnes), declined thereafter reaching as low as 20,640 tonnes in 1984-'85. The demand growth rate of pepper in the world market has been estimated at four per cent per annum by the World Pepper Community. The National Commission on Agriculture has also recently projected the requirement of pepper in India as 51,000 tonnes by 1990 and 58,000 tonnes by 2000 A.D.,

against the present production of 20,640 tonnes. Hence, there is need to increase the production to cope up with the increasing demand for export as well as for internal consumption.

About 98 per cent of the area in the country is located in Kerala and about 80 per cent of the total production of pepper comes from the State. This reflects the importance of the crop in the State's economy. Though, Kerala is the native home of pepper and its cultivation is in existance from time immemorial, it is paradoxical to note that the average yield of this valuable spice in the State is very low (0.2 kg/standard), as compared to that in the other pepper producing countries like Malaysia (4.0 kg/standard) and Brazil (3.0 kg/standard) which started the cultivation only by the end of 18th century.

The low productivity and production of pepper in Kerala is mainly attributed to large number of senile vines, uneconomic varieties, undermanuring, imbalanced manuring and lack of sufficient soil conservation measures. Field trials on nutrition have given only an indication of the requirements of nutrients. However, in a perennial crop like pepper, identification of the 'hunger signs' and standardization of the foliar diagnosis technique will help to correct the deficiencies quickly and to maintain the required balanced nutritional status in the plants. The studies conducted by De Waard (1969) and Sushama et al.(1982)

provide information on the choice of the leaf to be sampled in pepper for foliar diagnosis. But no work has been carried out in India for fixing up the critical levels in aiding the diagnosis of latent nutrient deficiencies.

Development of deficiency symptoms will be useful to identify the deficiencies in the field and to take appropriate corrective measures in time. But the work on these lines is confined to Malaysia only and that too on macronutrients namely N, P, K, Ca and Mg (De Waard, 1969). This necessitated the present investigations which were undertaken with the following objectives:

i) To induce macro and micronutrient deficiency symptoms

ii) To estimate the vegetative growth and foliar nutrient levels at different stages of deficiency

iii) To determine the dynamics of nutrient concentrations in the leaf as influenced by the seasons

iv) To find out the nature and magnitude of the relationships of foliar nutrient levels with yield

REVIEW OF LITERATURE

Though black pepper is the most important export-oriented spice crop of India, very little research has been done on the mineral nutrition of this crop. What little work had been done on this aspect is mainly in Indonesia and Malaysia.

1. Role of mineral nutrient elements in plant growth and development

1.1 Nitrogen

Nitrogen is commonly the fourth most abundant element in plants, following carbon and the elements of water. As a constituent of protein, enzymes and chlorophyll, N is involved in all processes associated with protoplasm, enzymic reactions and photosynthesis. As much as 70 per cent of the leaf N may be in chloroplasts (Stocking and Ongun, 1962). As first shown by Hewitt *et al.* (1956), N as nitrate ion is involved in the initiation of the activity of nitrate reductase, an inducible enzyme (Ferrari and Varner, 1969) and NH_4^+ ions may repress induction of nitrate reductase (Morton, 1956).

1.2 Phosphorus

Phosphorus is one of the three quantitatively prominent nutrient elements which are absorbed as complex ions, the

other two being N and S. Phosphate plays a key role in energy metabolism. Incorporated into adenosine triphosphate (ATP), it is the part and parcel of the universal "energy currency" of all living cells. As a constituent of nucleoproteins, is involved in the unique portion of protoplasm, concerned with cell division and the transfer of hereditory characteristics by the chromosomes. It is a constituent of phospholipids and one of these, lecithin, is believed to be present in cell membrane of all living cells. Phosphorus is concerned with H^+ transfers in the Krebs' cycle, glycolysis and the pentose cycle (McElroy and Glass, 1951, 1952). A considerable portion of the energy liberated by respiration is stored within cells as high-energy phosphate bonds (ADP and ATP) and as reduced coenzymes, NADH and NADPH. High energy phosphate bonds provide energy for synthesis of compounds such as sucrose, starch and proteins.

Phosphrous has long been known to be involved in photosynthesis in connection with phosphorylation of various intermediates in CO_2 assimilation. In the two photochemical reactions occurring during photosynthesis, P is involved in the conversion of light into physiologically useful chemical energy by the formation of NADPH and ATP. Phosphate participates more directly in the true photochemical events of photosynthesis than does CO_2, infact, CO_2 assimilation is dependent on a preceding phosphate

assimilation resulting in ATP formation at the expense of light energy (Arnon, 1959).

Phosphorus is a constituent of pyridoxal phosphate - a co-enzyme for transamination systems (Green et al., 1945; Lichstein et al., 1945) and for glutamic acid decarboxylase (Baddiley and Gale, 1945; Schales et al., 1946). Phosphorus is also a component of sugar phosphates, phytic acid, and other compounds in plants (Evans and Sorger, 1966).

Low external concentrations of P increased the concentrations of Zn, Cu, Fe and Mn in leaves (Wallace et al., 1969). High external concentration of P may induce Zn deficiency. The greater portion of inorganic phosphate in cells appears to be stored in the vacuole and to take no part in steadystate metabolism (Loughman, 1960). Stout et al. (1951) suggested the effect of phosphorus in promoting the absorption of molybdate by plants.

1.3 Potassium

Potassium is the only monovalent cation essential for all higher plants, the essentiality of which was recognised more than 100 years ago (Reed, 1942). Although the relatively high requirement of K by most plants has been reported by a number of scientists (Evans and Sorger, 1966; Kilmer et al. 1968), no one has isolated a K-containing compound from plants. Potassium appears to be completely

water soluble in plants. The principal role of K is that of an activator of numerous enzymes. Evans and Sorger (1966) have listed no less than 46 enzymes from animals and plants which require monovalent cations for maximal activity. Potassium is an activator of pyruvate kinase (Evans, 1963) and succinyl CoA synthetase (Bush, 1969). Investigations have established the involvement of K in starch synthesis. (Preiss and Greenberg, 1967; Murata and Akazawa, 1968; Nitsos and Evans, 1969). During K deficiency, lack of starch synthesis could be the result of reduced energy supply since K is necessary for glycolysis, oxidative phosphorylation, photophosphorylation and for adenine synthesis (Evans and Sorger, 1966).

Potassium appears to play a role in translocation, since a deficiency of K decreased translocation of labeled photosynthate from leaves to other portions of sugarcane plants (Hartt, 1969). The K dependence of light stimulated opening of stomata has been reported by a number of scientists (Fischer and Hsiao, 1968; Humble and Hsiao, 1969; Thomas, 1970).

1.4 Calcium

Calcium is the major cation of the middle lamella of cell walls, of which calcium pectate is a principal constituent. Calcium has, therefore, an important bearing on the mechanical strength of tissues (Tagawa and Bonner,

1957; Cleland, 1960; Rasmussen, 1967). Marinos (1962) concluded that Ca is essential for the formation of cell membrane systems on which functional integrity and cellular metabolism are dependent. Uhrstrom (1969) after studying the effects of auxin and Ca on growth and elasticity of sunflower hypocotyls concluded that Ca imparts rigidity to cell wall and that it is necessary for growth. However, at superoptimal concentrations of Ca the cell wall becomes too rigid and cell elongation is inhibited.

A definite role of Ca in N metabolism was indicated by Paulsen and Harper (1968). Synthesis of nitrate reductase was reduced by Ca deficiency and nitrate accumulation but the activity of nitrate reductase was unaffected by this deficiency. Therefore, it was concluded that Ca is involved in intracellular transport of nitrate and not in the induction or activity of enzymes. Calcium is essential for the growth and development of roots (Rios and Pearson, 1964). Brewbaker and Kwack (1963) found Ca to be indispensable for the germination of pollen and growth of pollen tube. Calcium functions as an activator or phosphatases (Krishnan, 1949).

1.5 Magnesium

Magnesium is involved in the most important synthetic reaction on earth, namely, photosynthesis. Each

chlorophyll molecule contains an atom of Mg, that is 2.7 per cent of the weight of chlorophyll molecule. It is an activator of more number of enzymes than any other element. Magnesium is an activator for enolase (Utter and Werkman, 1942) pyrophosphatase (Bailey and Webb, 1944) hexokinase (Bailey and Webb, 1948) and carboxylase (Mee, 1949). All phosphokinases depend on - SH groups and are activated by Mg (Dixon, 1949). According to Wallace and Mueller (1962), there was a higher Mg requirement at higher temperature than at lower temperature for a reaction sequence in CO_2 fixation during photosynthesis.

Antagonistic effects between Mg and Ca and Mg and K have also been reported by Emmert (1961). Ulrich and Ohki (1975) reported Mg induced K deficiency in crop plants.

1.6 Sulphur

All plant proteins have S containing amino acids like cysteine, cystine and methionine. It is also a component of lipoic acid, coenzyme A, thiamine pyrophosphate, biotin, adenosine 5 phosphosulphate and other compounds (Evans and Sorger, 1966).

Thompson (1967) in his review of S metabolism stated that from a quantitative point of view the most important function of S metabolism in plants is to produce cysteine and methionine.

Volatile compounds containing S contribute to the characteristic odours given off by onions, mustard etc.

1.7 Iron

Iron is a constituent of Fe porphyrin (hemes), enzymes such as catalase, peroxidase and cytochrome oxidase. There are also non-heme Fe proteins including ferredoxins and mitochondrial Fe enzymes which play roles in electron transport (Burris, 1966). Iron also appears to be essential for chlorophyll synthesis (Bogorad, 1966) but it is not a part of chlorophyll. It is not known whether it is directly or indirectly concerned - possibly as a constituent of or activator of some enzyme system. Iron functions in photosynthesis, nitrate and nitrite reductions (Betts and Hewitt, 1966 and Joy and Hageman, 1966) and in N fixation.

1.8 Manganese

Manganese acts as an activator of many enzymes including certain dehydrogenases and carboxylases. It plays an important role in glycolysis and Krebs' cycle and hence in its absence glucose accumulates. Manganese is also essential for chlorophyll synthesis.

Manganese when present at high concentrations in the medium may induce Fe deficiency in plants (Hewitt, 1963).

Manganese is the activator of B carboxylases which

catalyze the assimilation of CO_2 and lead to the formation of di-and tricarboxylic acids.

1.9 Zinc

A relationship between Zn and auxin was first suggested by Skoog (1940). He concluded that Zn is required for maintenance of auxin in an active state and not for its synthesis. However, Tsui (1948) from the experiments with tomato found Zn essential for the synthesis of tryptophan a precursor of IAA, the principal hormone of higher plants. Tsui's conclusion has been supported by Salami and Kenefick (1970). Zinc is a constituent of carbonic anhydrase, lactic dehydrogenase and many respiratory enzymes (Vallee, 1959 and Price, 1962). It is an essential constituent of alcohol dehydrogenase, glutamic dehydrogenase, alkaline phosphatase and carboxypeptidase B (Evans and Sorger, 1966).

In the absence of Zn more glucose get accumulated and the synthesis of cellulose get reduced. The osmotic pressure of the cell will be high in the absence of Zn and there may be no cell elongation in the absence of IAA.

In tomato, apical cell duplication and reduction of chromosomes were observed in the absence of Zn. It was also found that in the absence of Zn, the equilibrium of RNA and DNA gets disturbed. RNA concentration gets reduced by the activation of oxidative enzyme under Zn deficiency which in turn lowers the protein synthesis.

1.10 Copper

Like Zn, Cu is a constituent of several enzymes including polyphenol oxidase, ascorbic acid oxidase and lactase. Polyphenol oxidase was reported to occur in beet chloroplasts (Arnon, 1949). Oxidation of phenols will not take place in the absence of Cu which results in the accumulation of gum on the twigs and fruits. Ascorbic acid oxidase might serve in the terminal step of aerobic respiration. Copper is also found necessary for the formation of the precursor of chlorophyll. It is also a constituent of cytochrome oxidase. Some of the anthocyanins and carotene are also governed by copper.

1.11 Boron

Boron is not a part of any enzyme, but a specific regulatory step in carbohydrate metabolism has been identified. Lee and Aronoff (1967) have shown that B combines with 6 phosphogluconate, the first intermediate in this pathway to form a 6 phosphogluconate borate complex. This cannot be further metabolized and the pentose shunt pathway is thereby inhibited.

Growing points of both root and shoot stop elongating when B is deficient and under severe deficiency, become discoloured, disorganized and die. This is related to an effect of B on RNA metabolism. In B deficiency, flowering

is inhibited, water relations become abnormal and leaves and stems appear desiccated and may have a stiff woody feel. The germination of pollen grains and growth of pollen tube are severely inhibited by lack of B (Stanley and Lichtenberg, 1963). Boron is also involved in translocation of sugars from leaves. Necrosis of phloem is reported in clover and tomato in the absence of B.

2. Characteristic symptoms of deficiency and toxicity of mutrient elements

2.1 Nitrogen

Nitrogen being a mobile element within the plant, deficiency results in movement of N from older leaves to active younger leaves with the result that the older leaves turn yellow (Gauch, 1972). Jones (1975) listed the symptoms of N deficiency and its excess in various crop plants. Working with avacado, he observed a slight fading of the normal dark green colour of the leaves and retardation of shoot elongation during early stages of N deficiency followed by uniform yellowing of foliage. The new leaves produced were small in size. Cooli et al. (1958) described the visual symptoms of N deficiency in coffee as pale green leaves, yellowing of primary veins and older leaves leading to the ultimate shedding. Shaulis and Kimball (1956) and Christ and Ulrich (1954) reported uniformly light green leaves, weak vine growth and early cessation of shoot

elongation as symptoms of nitrogen deficiency in grapes. The N deficiency symptoms in citrus had been studied by a number of scientists (Pratt, 1958; Reuther et al., 1958 and Jones and Embleton, 1959). These workers reported yellowing of leaves, stunted growth of trees and die back of twigs in the event of N deficiency.

Excessive N generally enhances vegetative growth of plants with a concomitant reduction in yield or fruit quality (Embleton et al., 1959; Jones and Embleton, 1959). According to Jones (1975), there are no sharp boundaries demarcating deficiency, optimum and excess levels of N. Chapman (1949) reported that in citrus under conditions of N deficiency, the foliar concentration reduced to less than two per cent and the toxic symptoms appeared when the N concentration exceeded 3.5 per cent. The corresponding values in the case of grapes were 0.01 per cent and 0.5 per cent respectively (Cook and Kishaba, 1956).

2.2 Phosphorus

According to Gauch (1972), P deficiency induces the formation of anthocyanin pigments and the leaves acquire a purple colour. In certain plants, the only symptom which can be seen is the intensely deep bluish green colour of the leaves. In P deficient plants, the older leaves become chlorotic, but newly formed leaves remain dark green.

Bingham (1975) explained the P deficiency symptoms in tree crops and bushes as slow growth, sparse foliage which was dull bronze to purple tinged and early dropping of leaves. Haas (1936) observed dull bronze green leaves with burned areas on older leaves followed by shedding as the symptoms associated with P deficiency in lemon and orange. In apple, P deficiency symptom was expressed as small dark green leaves with bronze to purple tinge (Wallace, 1953). Cook and Millar (1949) reported that in alfalfa P deficiency resulted in yellowing and early dropping of older leaves. Since excess P is associated with impeded uptake of Cu (Bingham and Garber, 1960) and Zn (Loneragan, 1950) P toxicity is expressed as Cu and Zn deficiency symptoms.

Foliar concentrations indicating P nutrition of various crops were reported by a number of workers. In lemon, mandarin orange and grapes, plants showing P deficiency contained less than 0.1 per cnet P (Bingham and Martin, 1956; Sato et al., 1958 and Bergman et al., 1958) and in coffee it was 0.08 per cent (Loue, 1954).

2.3 Potassium

The most characteristic symptom of K deficiency in several crop plants is the scorching of the tips and margins of recently matured leaves (Ulrich and Ohki, 1975). The tips and margins turn yellow first, then to brown

giving a scorched appearance and finally they become brittle and dry up. Once scorching of the leaves has taken place, the process is irreversible. Evans and Murray (1953) described the K deficiency symptoms in cacao as paling of interveinal region near leaf margin which become necrotic. Marginal necrosis progresses more rapidly between veins, yellow zone appearing on inner surface of invading necrotic zone. According to Chapman et al (1947) K deficiency symptom in orange could be designated as "Fluting" or "Tucking" of leaves with a variety of chlorotic spotting patterns. In coffee, K deficiency symptoms are expressed as crowding together of young leaves, darkening of leaf area between veins and irregular development of leaves (Eckstein et al., 1937). Purseglove (1977) described K deficiency in coffee as brown scorching of entire leaf margins, affecting older leaves first followed by shedding of leaves. In grapes, K deficiency leads to yellowing of leaves with brown spots and necrosis. The spots fall out forming holes and leaves then become brittle (Eckstein et al., 1937).

Leaf analysis of K deficient cacao plants revealed that it contained 1.67 per cent K in leaves (Hardy, 1937) whereas it was less than 0.3 per cent in orange; 0.42 to 0.55 per cent in concord grapes (Shaulis and Kimball, 1956); 0.4 to 0.5 per cent in rubber (Bolle Jones, 1954); 0.61 per cent in tea (Portsmouth, 1953) and 0.79 per cent in vanilla (McCollam, 1953).

2.4 Calcium

Calcium deficiency symptoms generally appear first in roots. Root tips become slimy and turn black (Gauch, 1940). Chapman (1975a) described Ca deficiency symptoms in various crops and listed methods for correcting them. Calcium being immobile within the plant deficiency symptoms are first manifested in young leaves. They are often distorted and small, the margins are irregular and the leaves frequently show spotted and/or necrotic areas. There may be dieback of terminal buds. In grapes, Ca deficiency results in interveinal and marginal chlorosis of young leaves followed by necrotic pinhead spots near margins and vine tips dieback (Hagler and Scott, 1949). Franco and Mendes (1949) described Ca deficiency symptoms in coffee as death of terminal buds and yellowing of leaf margins followed by browning and necrosis of margins of older leaves. According to Chapman (1963), the symptoms of Ca deficiency in citrus are dieback of twig tips with the development of weak shoots from lateral buds which soon die, preceded by yellowing at leaf margins and between the veins with more or less necrosis and shedding. Excess calcium produces ill effects such as decreased availability of P, K, B, Mn, Fe and Zn.

2.5 Magnesium

Unlike Ca, Mg is mobile within the plant system and

hence deficiency symptoms first appear on older leaves. Characteristically, there is a loss of green colour between the veins followed by chlorosis and/or development of brilliant colours. The chlorosis may start at the leaf margins or tip and progress inward interveinally (Embleton, 1975). In more severe cases, the whole leaf may turn yellow or other brilliant colours, necrosis may develop interveinally or along margins or tips of leaves and in some plants the leaves curl. Premature defoliation usually occurs. In cacao, Boynton and Erickson (1954) observed interveinal chlorosis and necrosis followed by immature defoliation as Mg deficiency symptoms. Chlorosis of older leaves which begins at leaf tip and premature shedding of affected leaves are the Mg deficiency symptoms described by Reitz (1958) and Tanaka (1960) in citrus. In grapes, the deficiency symptoms are interveinal yellow spots on older leaves which develop into continuous yellow areas at margins and between veins with the area adjacent to veins remaining green. Veins and margins of leaves may remain green, necrotic spots eventually develop and leaves drop off prematurely (Jacob, 1958 and Tanaka, 1960). According to Hewitt and Bull (1956), Mg deficiency symptoms in rubber are olive or yellowish green chlorotic interveinal patches which turn bright yellow or orange, eventually large dark brown regularly spaced necrotic patches occur between the lateral veins. These brown areas coalesce to form a

brown strip within the green marginal zone. Very little information is available on visual symptoms of Mg excess. A definite deformation of leaves in wheat was observed as a result of Mg toxicity (Trelease and Trelease, 1931).

The leaf tissue analysis indicating Mg deficiency condition reported in some crops are given below:

Banana - 0.04 to 0.09 per cent (Murray, 1960)

Cacao - 0.16 to 0.30 per cent (Boynton and Erickson, 1954)

Grapes - 0.07 to 0.22 per cent (Scott & Scott, 1951)

2.6 Sulphur

A general, overall yellowing of leaves occur during a deficiency of S but unlike in N deficiency, here the youngest leaves are chlorotic (Gauch, 1972). Storey and Leach (1933) observed leaves of S deficient tea plants turning yellow with stiff texture.

Haas and Thomas (1928) noted that pronounced interveinal yellowing was associated with excess of S in lemon which was later confirmed by Aldrich et al. (1955).

Foliar analysis of S deficient citrus plants showed concentration of 0.08 to 0.10 per cent S (Chapman and Brown, 1941).

2.7 Iron

Being relatively immobile, Fe deficiency appears first on the younger leaves on the plant. Deficiency manifests as interveinal chlorosis which in severe cases make the entire leaf blades yellow to whitish yellow (Gauch, 1972). According to Wallihan (1975), Fe deficiency produces a specific type of leaf chlorosis that is usually fairly easy to diagnose. There is a sharp distinction between green veins and the less green or yellow tissue between veins. This is in contrast with the chlorosis resulting from Zn or Mn deficiencies in which there is gradation of green colour within the interveinal tissues, with the darker colour occurring adjacent to the veins. Jacobson and Oertli (1956) developed a confirmity test for Fe deficiency in which a dilute solution (0.5 to 1.0%) of ferrous sulphate when applied to the chlorotic foliage as spray, will make it green in two weeks.

2.8 Manganese

Manganese deficiency symptoms ressemble that of Mg deficiency except that in the case of Mn deficiency, interveinal chlorosis appears on the younger leaves rather than on the older leaves. Homann (1967) reported that in Mn deficient higher plants, either a reduction in the number of chloroplasts or a disorganization of the chloroplast takes place resulting in a low concentration of chlorophyll.

In the case of Mn deficiency in citrus, young leaves show a network of green veins on a lighter green background, the stage which closely ressembles Fe deficiency (Labanauskas, 1975). But it differs from Fe deficiency in that it produces an irregular green band along the mid-rib and the main lateral veins.

When Mn is present in toxic levels, pineapple leaves develop severe chlorosis (Sherman, 1957). In citrus, Mn toxicity symptoms are expressed as marginal yellowing and necrotic spots on leaves (Parker and Southwick, 1941).

2.9 Zinc

Zinc deficiency is very common in many crops under field condition. Typical interveinal chlorosis termed as 'mottle leaf', reduced internodal length and 'little leaf' are the common symptoms of Zn deficiency (Chapman, 1975b). Chlorosis is characterized by irregular green band along the mid-rib and lateral veins with light green, greenish yellow or pale yellow interveinal tissues. Chapman discussed the nature of Zn deficiency symptoms on various kinds of plants giving the Zn concentrations associated with deficiency, normal growth and toxicity.

Nair et al. (1968) while investigating the Zn deficiency associated with citrus dieback in India described the visual symptoms of the same as leaf mottling and

reduction in size with narrow and pointed shape. They also observed reduced terminal growth and dieback symptoms in case of severe deficiency. Nair and Mukherjee (1970) observed that appearance of leaf chlorotic symptoms associated with Zn deficiency in citrus was seasonal, the spring and summer growth flushes producing chlorosis and ' dieback symptoms from April to June whereas July flush developed no chlorotic symptoms and September-October flush light symptoms. Excess Zn usually produces Fe chlorosis in plants (Chapman et al., 1940; Hewitt, 1948 and Smith and Specht, 1953).

2.10 Copper

Deficiency symptoms are not so specific as with Fe, Zn or Mn deficiencies. In most plants the terminal growth is the first to be affected with dieback of twigs or growing points. Terminal leaves may show chlorosis, necrotic spotting or other abnormalities (Reuther and Labanauskas, 1975). In citrus the first symptom is the production of large dark green leaves which is accompanied by gumming and dieback of the shoots. The leaves slowly become yellowish and drop. Leaves are commonly irregular with a "bowing up" of the midrib (Camp et al., 1949).

Excess Cu induces Fe chlorosis symptoms (Chapman et al., 1940; Smith and Reuther, 1953). It may also cause

stunting, reduced branching, thickening and abnormally dark colouration of rootlets of many plants.

2.11 Boron

Boron is quite immobile in most plant species and deficiency symptoms appear at the top. In general B deficiency leads to degeneration of the meristematic tissues (including the cambium), breakdown of the walls of paranchyma cells and feeble development of the vascular tissues. Phloem and xylem are imperfectly developed (Bradford, 1975). Terminal growth shows rosetting, dieback, discolouration and failure to grow, leaves show various abnormalities such as thickening, brittleness, curling, wrinkling and chlorosis. Eaton (1944) studied the B deficiency symptoms in grapes and reported that terminal bud remained dormant, young leaves distorted, chlorotic and necrotic areas formed at margins and between veins and shortened internodes.

Excess B produces a progressive necrosis of the leaf beginning at the tip and/or margins as chlorotic yellowing. The leaf tip and margins soon show a burned or scorched appearance which later involves the entire leaf before it drops prematurely.

3. Nutrition of black pepper

3.1 Manures and manuring

The work on nutrition of black pepper is rather limited.

Chancy (1951) established the essentiality of phosphatic sources of nutrients for black pepper growth on red soils of Vietnam. Results of the investigation conducted in India by Marinet(1953) revealed the necessity of liming acid soils for proper pepper cultivation, however, no definite pH limits have been recommended. Significant responses to lime also has been reported from Sarawak by Purseglove et al., (1981). They also opined that organic manures were extensively used in Sarawak for growing pepper. The usual form of compound fertilizer used was a mixture of urea, double superphosphate, muriate of potash and kieserite (as a Mg source) along with trace elements such as Fe, Cu, Mn, Zn, B and Mo. De Waard (1978) found that addition of alkaline compounds to mounds prior to planting resulted in an increase in growth and earlier establishment.

De Waard (1964) worked out the nutrient removal by the variety Kuching (1729 vines/ha) as 252.04 kg N, 31.75 kg P_2O_5 and 224.04 kg K_2O per hectare. According to Sim (1971) the nutrient removal by 17 year old vines was 233 kg N, 39 kg P_2O_5, 207 kg K_2O, 30 kg MgO and 105 kg CaO per hectare. Pillai and Sasikumaran (1976) computed the nutrient removal by black pepper giving an average yield of 1 kg dry pepper/ vine from one hectare of land as 34.0 kg N, 3.5 kg P_2O_5 and 32.0 kg K_2O. Based on the above results, a manurial

schedule of 100 g N, 40 g P_2O_5 and 140 g K_2O per vine per year was recommended by them. Later on Pillai et al. (1979) concluded that higher levels of N adversely affected the yield in Panniyur 1 variety of pepper and accordingly they fixed 60 g N per vine per year as the maximum limit. Studies conducted at the Kerala Agricultural University by Jayasree Sankar (1985) showed that annual nutrient removal by a five year-old vine through harvest of 1.284 kg dry pepper per plant was 38.5 g N, 36.7 g K, 14.9 g Ca, 13.7 g Mg, 2.2 g P, 1.37 g S, 218 mg Fe, 155 mg Mn, 28 mg Zn and 47 mg Cu. The study also revealed that an annual recycling of about 0.7 kg dry matter containing 25.7 g N, 0.94 g P, 6.5 g K, 20 g each of Ca and Mg, 0.8 g S, 131.4 mg Fe, 1008 mg Mn, 13 mg Zn and 14.2 mg Cu could be expected from the defoliation of erythrina standard during summer months. From the study employing the radiotracter technique, she suggested that fertilizer application should be restricted to a semicircle of radius 30 cm facing the vine irrespective of the type of standard for maximum utilization. In view of the prepond-erance of feeder roots of vine within 10 cm from the soil surface, broadcast application of fertilizer and raking in was recommended.

De Waard (1969) reported the critical levels of N, P, K, Ca and Mg as 2.70, 0.10, 2.00, 1.00 and 0.20 per cent

respectively on dry weight basis, below which deficiencies of the concerned elements are expected to occur.

From an experiment to study the effect of organic and inorganic fertilizers on the yield of pepper, Raj (1972) observed that there was significant difference between NPK mixture with trace elements and organic manure. Later, Raj (1978) suggested a sound fertilizer policy, based on the nutrient removal by crop, crop size, yield per unit area and nutrient status of leaf as indicated by foliage analysis.

Geetha (1981) observed that the NPK content was higher during flowering and spike development (from June to November) but the same was found to decrease from November to December in flowering laterals. The Ca content was more in non-flowering shoots from July to December. She attributed low N and K content of flowering shoots during November - December as one of the reasons for spike shedding in pepper. Sushama et al. (1984) found significant positive correlation of yield with P and K of leaf whereas N content failed to establish significant positive correlation with yield. Kurian (1982) stated that there was no significant difference in levels of N, P, Ca and Mg in pepper leaves from July to September. Concentration of K was highest during the above period. The N and P content gradually decreased from July as berries mature in November whereas

the K content slightly increased in September followed by a decrease in November.

De Waard and Sutton (1960) attributed the drooping and yellowing of pepper, grown in highly acid soils of Sarawak to Al toxicity. De Waard (1979) refers to the key role played by nutrients, especially K, in the development of yellow leaf disease of pepper and recommends a fertilizer mixture of 400 kg N + 180 kg P + 480 kg K + 426 kg Ca + 112 kg Mg per hectare along with proper mulching to control the disease. Wahid et al. (1982) after studying the mineral nutrition of slow wilt affected black pepper reported that the K content of leaves from healthy plants was considerably higher than that of diseased vines. Foliar yellowing and tip necrosis of laminae were noted in diseased vines which were attributed to N and K deficiencies respectively. The pot culture studies confirmed the N deficiency as the cause for foliar yellowing. They also observed no difference in micronutrient levels between the healthy and diseased vines.

Very little information is available regarding the micronutrient nutrition of black pepper. The results of the studies so far conducted are reviewed. Sim (1973) estimated the quantity of total micronutrients to range between 0.21 and 12.91 g per plant in vines coming under the age group of less than one year to 17 years in Sarawak.

The annual micronutrient removal per vine was calculated as 365 mg Fe, 281 mg Mn, 104 mg Zn, 89 mg Cu and 60 mg B. Severe Mg deficiency and Al and Mn toxicity were reported by Sim (1974) in Sarawak pepper gardens. In Sarawak, the necessity for micronutrient application to black pepper has been recognised and 28 g trace elements per vine per year has been recommended (Purseglove et al., 1981).

3.2. Nutritional deficiencies in pepper

Employing pot culture experiment De Waard (1969) could induce visual deficiency symptoms associated with five major elements such as N, P, K, Ca and Mg in pepper. The symptoms described by De Waard are summarized below:

3.2.1 Nitrogen

A clear uniform yellowing of the leaves developed varying via. an initial light green to yellow, deep yellow or orange yellow. There was not much difference in age or in position of the leaves with respect to colour intensity. In more advanced stages the extreme end of the leaf tip became black and necrotic, occasionally abscission of leaf took place. Concurrent with the development of the symptoms, growth retardation and reduction in leaf size were observed. Persisting deficiency led to a condition where the entire plant was bare except for tufts of immature leaves on the extreme ends of the branches.

3.2.2 Phosphorus

Mature leaves exhibited a very dark bluish green to purple discolouration on the upper surface which was consistent as in other crops.

3.2.3 Potassium

Potassium deficiency symptom appeared to be black necrosis beginning at the extreme distal end of the otherwise healthy, green mature leaf blade. The necrosis progressed along the leaf margins. In advanced stages the mesophyll in between the affected marginal areas turned progressively more necrotic until approximately 1/3 to 1/4 of the distal portion of the leaf blade became dead and brittle exhibiting a coal black colour. The proximal portion remained healthy and dark green and the leaves showed no tendency for immediate abscission.

3.2.4 Calcium

In the early stages, tiny brown necrotic spots surrounded by yellow halo developed on the upper surface of mature and immature leaves. Later on, the appearance became a general light yellow with chlorotic areas. Those chlorotic areas tend towards the distal end of the leaf, usually involving at least half of the leaf surface. In more advanced stages acute black necrotic strips developed on the leaf margins, particularly of the distal half or

occasionally at the tip. The marginal necrotic areas did not expand towards the centre of the blade. The proximal portion exhibited pale green colour with occasional scattered necrotic pin head spotting. The under surface of leaf displayed brown necrotic spots between the main veins. The affected leaves dropped at the gentle touch.

3.2.5 Magnesium

Oval shaped interveinal yellow discolouration was observed in the older leaves. Those ovals expanded towards the leaf margin and after reaching the edge, the yellow areas eventually coalesced around the extreme ends of the five major veins. Narrow bands of green tissue alongside of the veinal bundles contrasted sharply against the yellow areas. The major veins remained green while the higher order veins turned yellow.

De Waard (1969) also studied the deficiency symptoms of the aforesaid nutrients under field condition and reported that the symptoms resembled to that observed in pot culture studies. However, no patterns of symptoms associated with P deficiency have been observed under field condition. So also, Ca deficiency symptoms were not common under field condition.

4. Foliar diagnosis

Foliar diagnosis through chemical analysis of leaf

tissue is regarded as a tool for assessing the nutrient status of the plants and in detecting the "hidden hunger" or "visual deficiency" of one or more elements.

Lagatu and Maume (1926) in France were among the first to develop foliar diagnostic techniques for a perennial crop. Since then a great variety of crops have been tested nutritionally by foliar diagnosis. For plantation crops, it was Loue (1953) who first used this method for robusta coffee.

Prevot and Ollagnier (1957) after comparing the efficiency of foliar and soil analysis for determining nutrient requirements of groundnut, stated that foliar diagnosis could be a good tool for assessing nutrient requirement on the spot. De Waard (1969) was the first to introduce foliar diagnosis in black pepper. Sim (1974) reported that leaf nutrients gave better correlation with yield than soil nutrients.

4.1 Plant organ to be sampled

For the interpretation of analytical value, selection of index tissue is very important. According to Smith (1962), for all practical purposes, the leaf or a selected portion of the leaf is the most suitable part for representing the overall nutrient status of the plant. The leaf composition depends upon the age and physiological stage of the plant, the position on the plant, the age of

leaf, the season and condition of leaf sampled (Emert, 1959 and Embleton and Jones, 1964).

Pillai and Sasikumaran (1976) studying the N, P, K, Ca and Mg levels in root, stem, leaf and spike of four year old Panniyur 1 pepper vines reported that N and K were highest and P lowest in leaves.

4.2 Effect of age and position of leaf

Loue (1953) preferred the fourth pair of leaves in coffee to represent the nutritional status, whereas Meueller (1959) reported that the fifth or sixth pair was more sensitive when the plants suffered with incipient deficiencies.

De Waard (1969) concluded that the first mature leaf with petiole, from fruit bearing high order branches could be designated as the best reflect of nutrients. However, N was significantly high in the second mature leaf. He also observed that concentrations of N and K were high in leaves of average size, compared to small ones. The N and K contents were decreased with increasing thickness of leaves. The nutrient content of leaves varied from 2.7 to 3.1 per cent for N, 0.10 to 0.16 per cent for P and 2.62 to 3.40 per cent for K.

Results of the study conducted by Sushama et al. (1982) in Kerala revealed that the first mature leaf counting from

the tip of the lateral shoot could be considered as the best for the foliar diagnosis of N, P and K in pepper.

4.3 Seasonal effects

The influence of climatic factors on nutrient concentration was studied in detail by a number of scientists in various crop plants. A significant negative correlation between light intensity and nutrient concentration in general was observed in banana (Murray, 1961), rubber (Shorrocks, 1962) and apricot (Malik, 1966). De Waard (1969) reported significant reduction in leaf K of pepper leaves collected from dense shade.

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

In pepper, concentration of K remained unchanged in leaves from 7 a.m. to 1 p.m. whereas the N content decreased from early morning to late afternoon which was not significant from 7 a.m. to 10 a.m. (De Waard, 1969).

According to De Waard (1969) the physiologically important months in Sarawak, for pepper were January, April and July, which coincided with the periods of fruit initiation, berry enlargement and harvest. Over the period

from January to May, N concentration fell by 17 per cent, whereas it remained constant during May followed by a small rise in June - July. Significant increase in P content from January to July was also recorded. Potassium concentration was found to decrease with time after the initial rise in January.

Bataglia et al. (1976) reported a rise in N content of leaves of pepper in autumn and a decrease in winter. Phosphorus concentration was highest in summer and declined thereafter. Potassium was high in summer, reached a peak in autumn and declined in winter.

Sushama et al. (1984) reported that the period just prior to flushing (i.e., last week of May) of pepper was the best suited period for collection of leaf samples for foliar diagnosis.

4.4 Sampling procedure for pepper

Based on the study on foliar diagnosis, De Waard (1969) recommended that : (i) apparently homogeneous blocks should be selected with respect to environment and physiological condition of vines (ii) each sample should be subdivided into compact sub-blocks equivalent to 70 sample vines in order to ensure even contribution of each portion of the area (iii) within each sub-block the sample unit should be selected at random (iv) vines should be first sampled in

January and subsequently as frequently as necessary (v) from each plant four leaves should be collected forming a sampling population, meeting the following standards. (a) the first older mature leaf from fruit-bearing laterals exposed to sunlight and located on the lower 2/3rd of the canopy; (b) leaves of average size and thickness with the petioles retained; (c) leaves representing north, east, south and west quarter aspects of the vine equally. (vi) sampling should be done between 7 a.m. and 1 p.m. (vii) the leaves collected should be mixed to form a single composite sample.

MATERIALS AND METHODS

The investigations reported herein consist of two parts, the first part aims at inducing nutrient deficiency symptoms in sand culture and the second part is concerned with the nature and magnitude of relationships of foliar nutrient levels with yield.

1. Development of nutrient deficiency symptoms

To induce deficiency symptoms in black pepper, sand culture experiment was undertaken in the green house of the Radiotracer Laboratory, College of Horticulture, Kerala Agricultural University, Vellanikkara from December, 1983 to August, 1985.

1.1 Preparation of sand

Pure quartz silica sand of 250 mesh obtained from M/s. Usha Minichem Industries, Bangalore was used for sand culture studies. The sand was first washed with tap water and then kept soaked in dilute hydrochloric acid for 24 hours. Subsequently, the sand was washed with tap water and then with deionized water until it became chloride free.

1.2 Pots, planting material and planting

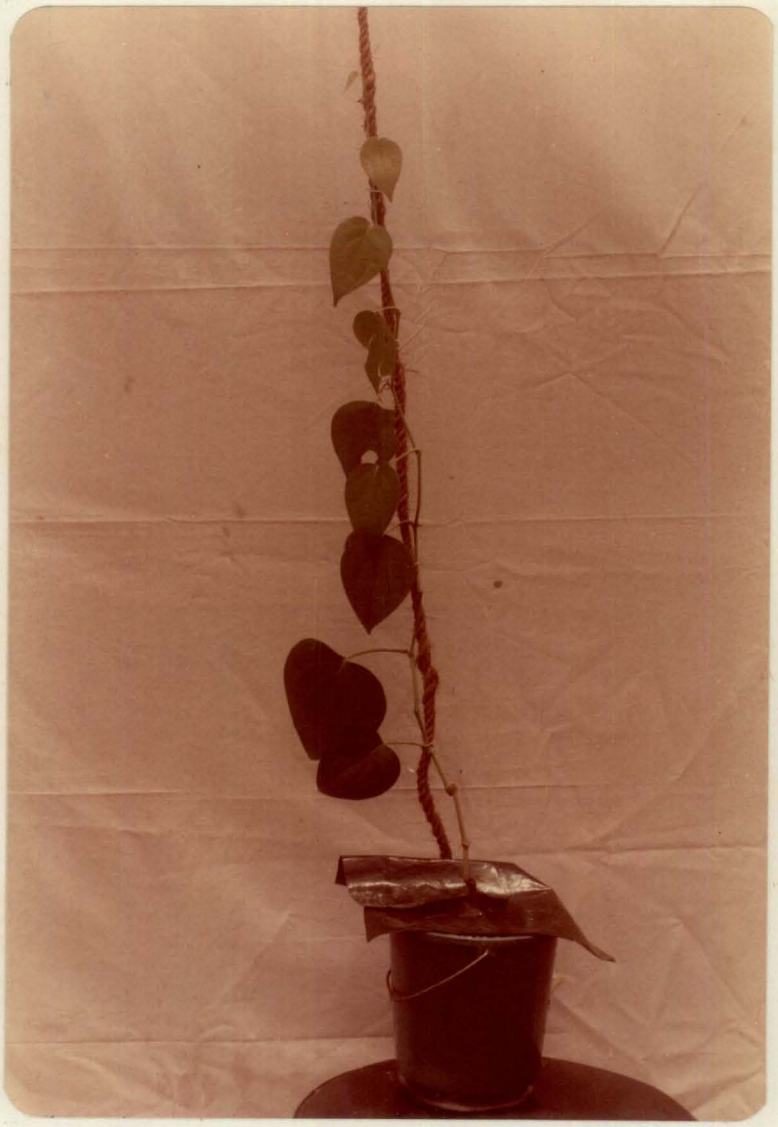
Polythene buckets of 20 cm height and with a diameter of 18 cm at the top, tapering to 12 cm at the bottom were

used for raising pepper plants for the studies (Plate I). The buckets were rinsed with dilute hydrocholoric acid and then washed with deionized water to avoid contamination. The bottom of the bucket was provided with a small drainage hole which was covered with watch glass duly supported with a thin pad of lead free glass wool.

Six month old rooted cuttings of the hybrid variety, Panniyur 1 were used for the experiment (Plate II). The buckets were filled with acid washed sand (@ 4 kg/bucket) after providing a thin polythene sheet lining to the inner walls in order to avoid any possible contamination. The rooted cuttings obtained in polybags were carefully pulled out from the container and washed thoroughly in tap water to remove the adhering potting mixture. Due precautions were taken to see that the roots were not damaged during washing. Finally, the roots were washed in deionized water. The rooted cuttings were then planted in polythene buckets containing acid washed sand at the rate of one plant per pot and watered with deionized water. The pots were arranged on the concrete benches with a spacing of 30 cm from one another inside the greenhouse wherein the sunlight was allowed to enter at about 60 per cent of its natural intensity and air temperature and humidity were non-limiting. The vines were trailed on coir ropes suspended from the ceiling of the greenhouse.

PLATE I - The container and the sand used for the sand culture studies

PLATE II - Six month old rooted cutting immediately after transplanting to the sand medium



The sand surface in the pot was covered with finely perforated black polythene sheet to prevent the growth of algae and to reduce excessive evaporation. For the initial 15 days the plants were watered with deionized water and thereafter the treatments were imposed.

1.3 Treatments

i) Complete nutrient solution

ii) Complete nutrient solution minus nitrogen

iii) Complete nutrient solution minus phosphorus

iv) Complete nutrient solution minus potassium

v) Complete nutrient solution minus calcium

vi) Complete nutrient solution minus magnesium

vii) Complete nutrient solution minus sulphur

viii) Complete nutrient solution minus iron

ix) Complete nutrient solution minus manganese

x) Complete nutrient solution minus zinc

xi) Complete nutrient solution minus copper

xii) Complete nutrient solution minus boron

Thirty plants were provided under each treatment and there was a total of 360 plants in the experiment.

1.3.1 Preparation of nutrient solutions

Original Hewitt's solution with minor modifications suggested by De Waard (1969) was used.

Composition of complete nutrient solution

Elements	meq/l	mg pure element/l
N	12	168.00
P	3	31.00
S	6	96.00
Ca	8	160.00
Mg	3.5	42.60
K	2.0	78.00
Fe (trivalent)	1.3	24.21
Mn (bivalent)	0.02	0.55
Cu	0.002	0.06
Zn	0.003	0.10
B	2 ppm	2.00
Mo	0.03 ppm	0.03

In each treatment where a cation was omitted, Na was introduced as a substitute, in the case of anions SO_4 was used as the replacing ion. Analytically pure chemicals (AR grade) were used for the preparation of the solutions.

Every tenth day fresh nutrient solutions were prepared by diluting aliquots of appropriate stock solutions to the desired concentrations. The pH of the final solutions was adjusted to 5.0 by the addition of concentrated NaOH or HCl.

When the solutions were given at the concentrations suggested by De Waard, salt injury symptoms such as yellowing and drying up of the leaves were noted in all the treatments. But it could be prevented by reducing the concentration of the feeding solution to 50 per cent of the recommended strength. Therefore, this concentration was adopted.

Plants were watered every alternate day with 300 ml of respective nutrient solution. The sand in each pot was flushed with deionized water at intervals of ten days to prevent salt accumulation which was followed by the application of fresh nutrient solution.

1.4 Stages of deficiency symptoms

The aerial portion of plants under each treatment were carefully watched every day for the appearance of any symptoms and the dates of appearance of symptoms suspected to be due to deficiency were recorded. Colour photographs were also taken even in the suspected cases. The symptoms were confirmed when at least three plants developed similar symptoms under a particular treatment. Based on the intensity of deficiency, four stages were identified for convenience during the development of symptoms. They are (i) 'initial' (ii) 'medium' (iii) 'severe' and (iv) 'very severe'.

1.5 Observations on growth parameters

Two plants were removed at random from each treatment at an interval of one month starting from two months after the commencement of treatments. From the tenth month onwards the sample size was reduced to one because of the limited availability of experimental plants. These plants were used to find out the dry matter and macro and micronutrient contents.

Individual plant observations on the following growth parameters were recorded at monthly intervals starting from the second month after the application of the treatments.

1.5.1 Length of vine

The length of individual vines in a treatment was measured from the soil surface upto the growing point using a flexible measuring tape. The length of the branches was also measured and added with the length of the main vine to work out the average length of the vine.

1.5.2 Internodal length

The total number of nodes (including the nodes of the branches, if any) per vine was counted first. Then the length of the vine was divided by the number of nodes of that vine to get the internodal length.

1.5.3 Number of leaves

The total number of leaves on a vine including those on branches was counted and recorded separately. The number of leaves per vine was then determined by calculating their mean.

1.5.4 Leaf area index

The first four fully matured leaves from each of the plant were selected for the purpose. The length of the lamina from the base to the tip and the breadth at the centre were measured. The leaf area index calculated was the product of length and breadth obtained as detailed above.

1.6 Dry matter content

The plants under each treatment were uprooted, at random and separated into root, shoot and leaf portions. Their dry weights were recorded separately after drying in a cross flow air oven at 70°C ± 2° till constant weights were obtained.

1.7 Chemical analyses

The dry weight of root, stem and leaves were recorded separately. The dried leaves were ground in a Wiley-mill to particles of 40 mesh size and chemically analysed for the macro and micronutrients as detailed below:

For the determination of N, the extract prepared by digesting 0.1 g of the sample in 5 ml concentrated sulphuric acid (using hydrogen peroxide) after appropriate dilution was used. The colorimetric method suggested by Snell and Snell (1967) was employed for the estimation. The intensity of colour developed by Nessler's reagent was read in a spectrophotometer (Spectronic-20) at 410 nm.

Diacid extracts were prepared by digesting 1 g of the sample using 15 ml of 1:1 concentrated nitric acid perchloric acid mixture (Johnson and Ulrich, 1959) which was made up to 100 ml. Aliquots from this solution 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) after appropriate dilution. The yellow colour was read in a spectrophotometer (Spectronic-20) at a wave length of 470 nm. Potassium was estimated using flame photometer (EEL make). Sulphur in the diacid digest was determined turbidimetrically following barium chloride method (Hart, 1961) employing a spectrophotometer (Spectronic-20).

An atomic absorption spectrophotometer (IL-257-USA) was made use of for determining the Ca, Mg, Fe, Mn, Zn and Cu content. For the determination of Ca and Mg, $SrCl_2$ (1000 ppm Sr in the final solution) was used as the releasing agent.

Boron was estimated colorimetrically by using curcumin oxalic acid reagent (Jackson, 1958). The colour developed as a result of the formation of rosecyanine was read in a spectrophotometer at a wavelength of 540 nm.

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

2. Investigations on the seasonal variation and relationships of foliar nutrients with yield

The plants of an existing NPK fertilizer experiment started in 1971 at the Pepper Research Station, Panniyur, Cannanore District, Kerala were made use of for this investigation. The details of the experimental area are as follows:

The field is located at an altitude of 95 m above MSL on a moderately sloping terrain which enjoys a typical humid tropical climate. The meteorological data of the experimental site for 1981 and 1982 are presented in Appendices I and II respectively. The soil of the experimental area is acid laterite (pH5.0) of clay loam texture (coarse sand 20%, fine sand 14.4%, silt 17.6% and clay 48.0%). The available nutrient status of the soil is given in Appendix III.

2.1 Experimental details

Variety	- Panniyur 1
Year of planting	- 1971
Spacing	- 3.5 m x 2.0 m
Year of starting the experiment	- 1975
Design	- 3^3 NPK factorial, totally confounding NP^2K^2 in RBD
Number of replications	- 2
Number of treatments	- 27
Number of blocks	- 6
Total number of plots	- 54
Number of plants per plot	- 5

Treatment levels

n_0	50 g N/vine/year
n_1	100 g N/vine/year
n_2	150 g N/vine/year
p_0	50 g P_2O_5/vine/year
p_1	100 g P_2O_5/vine/year
p_2	150 g P_2O_5/vine/year
k_0	50 g K_2O /vine/year
k_1	100 g K_2O / vine/year
k_2	150 g K_2O / vine/year

The plants were trailed on Erythrina indica standards. The sources of nutrients were urea, superphosphate and muriate of potash. All the plants were supplied with 10 kg green leaves and 500 g lime per year. Fertilizers were given as a single dose during August in each year and green leaves and lime during July.

2.2 Selection of plants for sampling

Out of the 270 experimental plants, 200 plants were selected based on the previous two years yield data and physical condition of the plant. Leaf samples were collected separately from each plant and analysed for macro and micronutrients.

2.3 Collection of leaf samples

The leaf samples were collected following the procedure standardized by De Waard (1969). Sampling commenced from April prior to flowering and continued upto harvest at bimonthly intervals as given below:

1st - April
(pre flowering)

2nd - June

3rd - August

4th - October

5th - December
(just after harvest)

The samples were collected consecutively for two years in 1981 and 1982. The first mature older leaf from the fruit bearing side branches, exposed to sunlight and located on the lower two third of the canopy was selected as the sample leaf (De Waard, 1969).

From each plant, eight leaves with petiole intact were collected at the rate of two each from the north, east, south and west quarter aspects of the vine. The sample leaves were of average size and thickness. The time of sampling was between 8 a.m. and 12 noon.

2.4 Preparation of leaves for analysis

The collected leaves were wiped with a clean cloth moistened in distilled water, packed loosely in paper bag and dried in a cross flow air oven at 70°C $\pm$ 2° for 48 hours. The dried leaves were ground in a Wiley-mill to a finess of 40 mesh and stored in polythene bottles until analysis.

2.5 Chemical analyses

The leaf samples were analysed separately for all the macro and micronutrients following the methods outlined in section 1.7.

2.6 Yield

Individual plant yield of the selected 200 plants for the year 1981 and 1982 were recorded and expressed as green yield per plant (kg of green berries).

2.7 Statistical analysis

The plants of the field experiment were grouped into 25 yield classes separately for each year. The mean nutrient values of these 25 classes were used for further statistical analysis.

To find out the nature and magnitude of relationship between yield and foliar nutrient levels at different intervals of sampling and to arrive at their critical levels, the data were subjected to linear and quadratic regression analyses by applying the methods suggested by Panse and Sukhatme (1978). Path coefficient analysis was carried out as per the method suggested by Dewey and Lu (1959) considering yield as the dependent variable and foliar nutrient levels as the independent variables to estimate the direct and indirect effects of each nutrient on yield.

RESULTS

Nutrient deficiency symptoms

A detailed sand culture experiment using six month old rooted cuttings of Panniyur 1 variety of black pepper was conducted to induce macro and micronutrient deficiency symptoms. The visual symptoms manifested were confirmed by subsequent foliar analysis and recovery studies. The results of the investigations are presented below under four major heads such as foliar symptoms, effect of deficiencies on vegetative growth, foliar nutrient compositions and recovery of the deficient plants.

1. Foliar symptoms of nutrient deficiencies

The first symptoms were developed on the leaves. Based on the intensity, the symptoms were classified into four stages ('initial', 'medium', 'severe' and 'very severe'). The symptoms are described based on the intensity ratings for all the elements tested.

1.1 Complete nutrient solution

The plants which received complete nutrient treatment exhibited a vigorous vegetative growth with dark green leaves throughout the period of investigations. There were no deficiency symptoms.

1.2 Nitrogen deficiency

The initial symptom of N deficiency appeared during the fourth month after treatment on the older leaves as pale green colouration of the entire laminae. The growth and general health of the plant, however, was not affected at this stage (initial stage).

One month after the occurrence of the initial symptom, the older leaves became uniformily yellow (medium stage). The yellowing gradually spread over to the younger leaves and by the sixth month, the symptoms attained a severe nature (severe stage). During this stage, the leaf including the petiole turned deep yellow or orange yellow (Plate III). All the leaves on the plant exhibited discolouration, but the intensity was low towards the growing point. Concurrent with the development of the symptoms, growth retardation and reduction in leaf size were also observed (Plate V). The leaf tips and margins at the lower end became necrotic and brown in colour which gradually spread towards inside and proximal end.

By eight months after treatment, the whole lamina became necrotic and brown (Plate IV). The completely necrotic leaves were held attached to the vine for about five to ten days and then dropped (very severe stage). The growth was completely stunted and ultimately the entire vine was stripped off except a few immature leaves at the growing point.

PLATE III - Leaves showing different stages of N deficiency symptoms
1. Healthy 2. Initial 3. Medium 4. Severe

PLATE IV - Leaves showing very severe stage of N deficiency

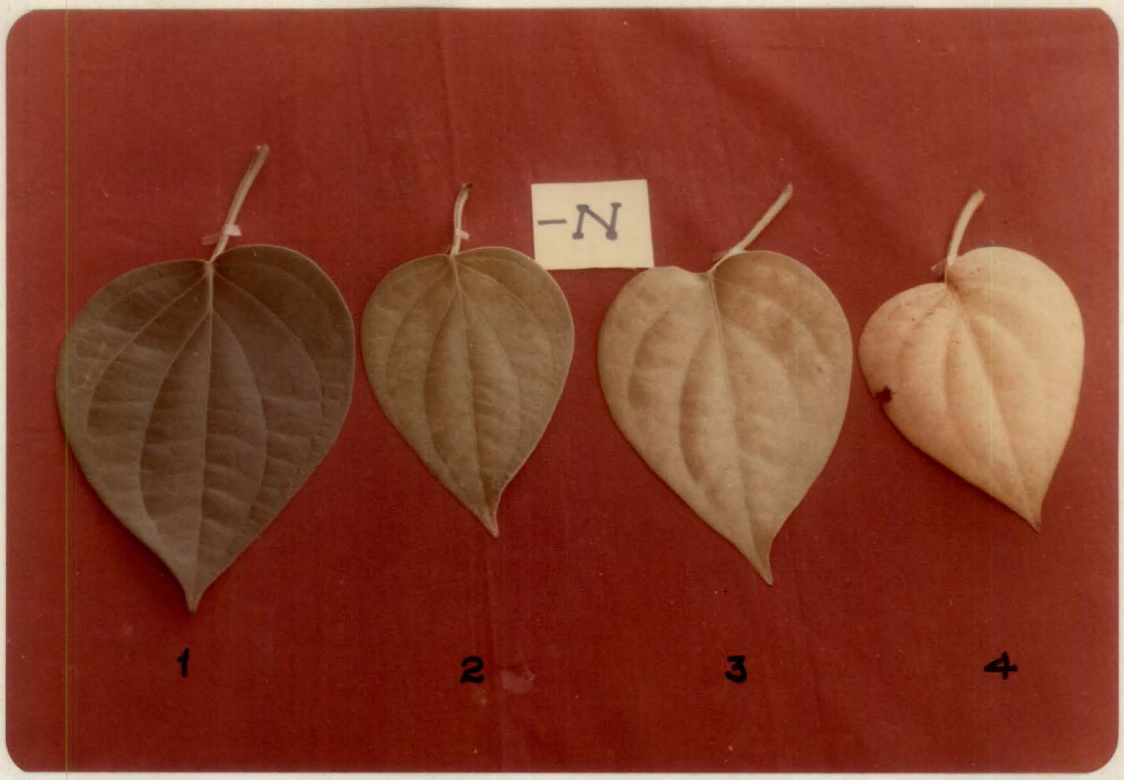

-N
1
2
3
4

PLATE V - The N deficient plant to show the reduction in size of leaves as compared with healthy plant


C
-N

1.3 Phosphorus deficiency

The initial symptom of P deficiency was developed only ten months after the treatment. Bright green to bluish green colour of the older leaves was the first symptom. However, at this stage (initial stage) the symptom was not conspicuous to use as a tool for diagnosis of P deficiency.

There was practically no change in the initial symptoms for the next two months. Thereafter, the older leaves turned bronze green without any other prominent changes (medium stage). After one month, the leaf tips and margins developed necrosis (severe stage). Stunted growth was also observed during this stage.

The necrosis spread to the inner portion of the laminae and the necrotic areas on the older leaves showed burnt appearance (Plate VI, very severe stage). This stage was closely preceded (15 days after) by the severe stage. The laminae of the older leaves exhibited a downward curving at the margins where necrosis has occurred and later dropped off. No new growth was produced and the vines presented a wilted appearance with drooping of the very few leaves that remained on the vine (Plate VII).

1.4 Potassium deficiency

Visual symptoms of K deficiency was first manifested

PLATE VI - Leaves showing very severe stage of P deficiency

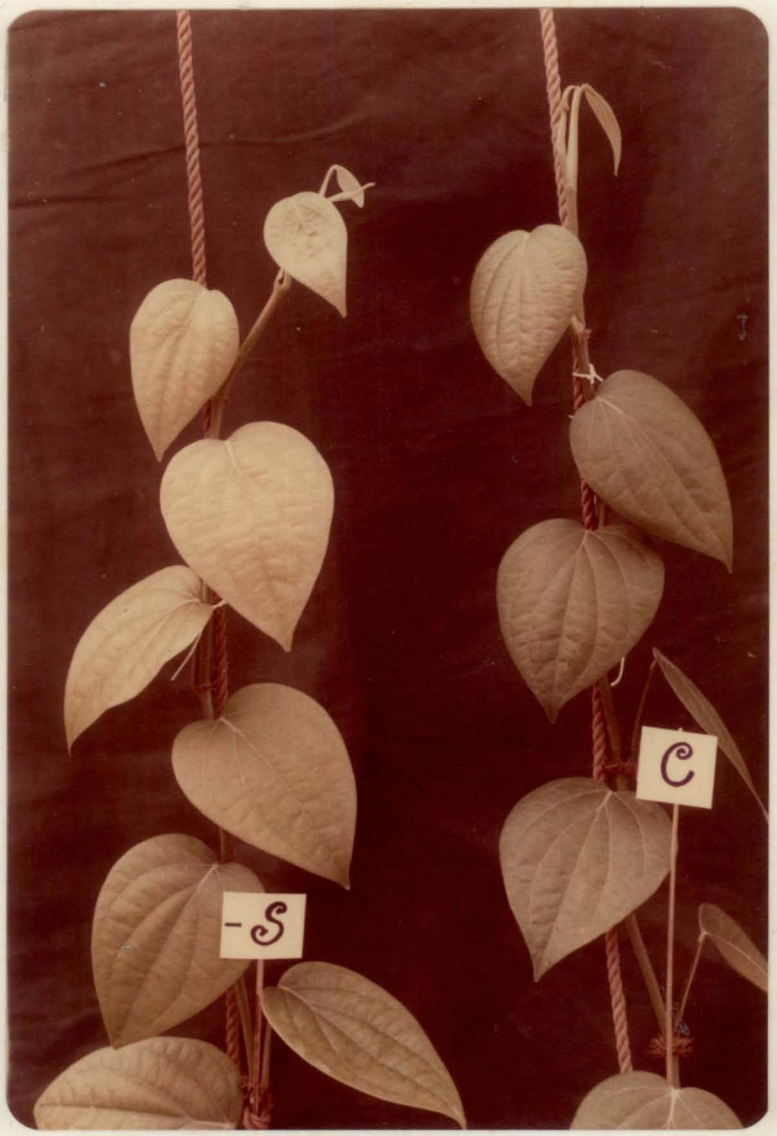

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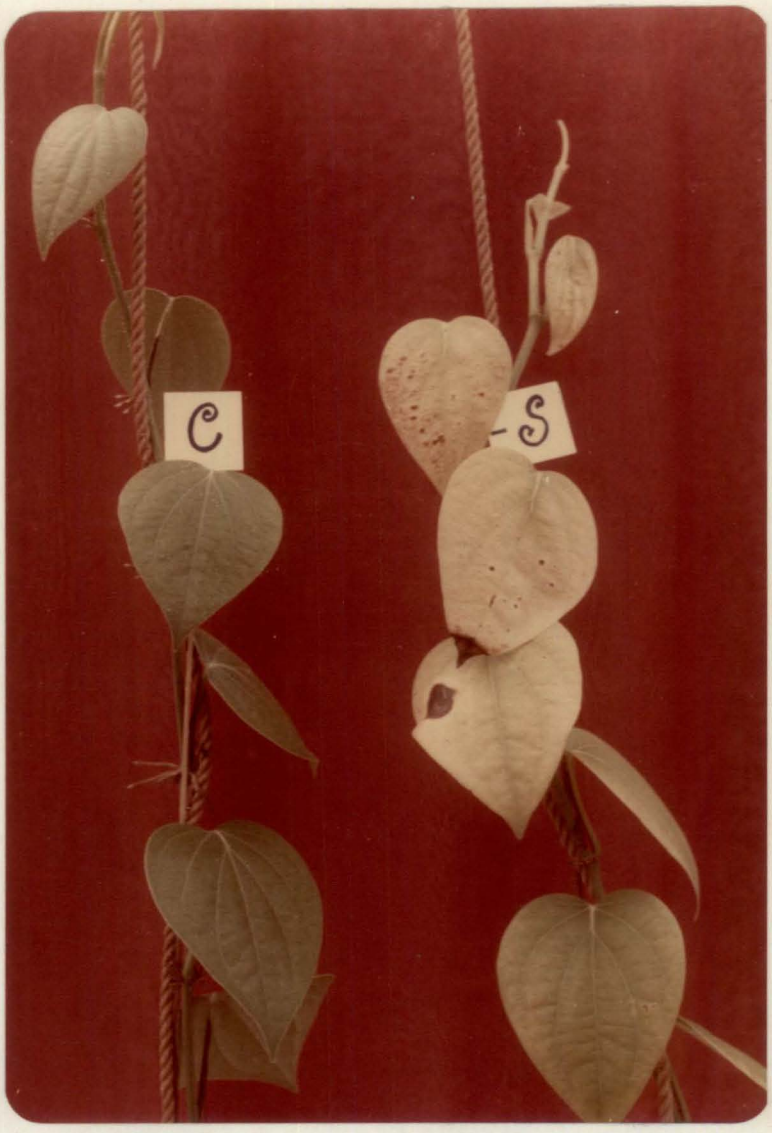
PLATE VII - The plant showing very severe stage of P deficiency


C
-S

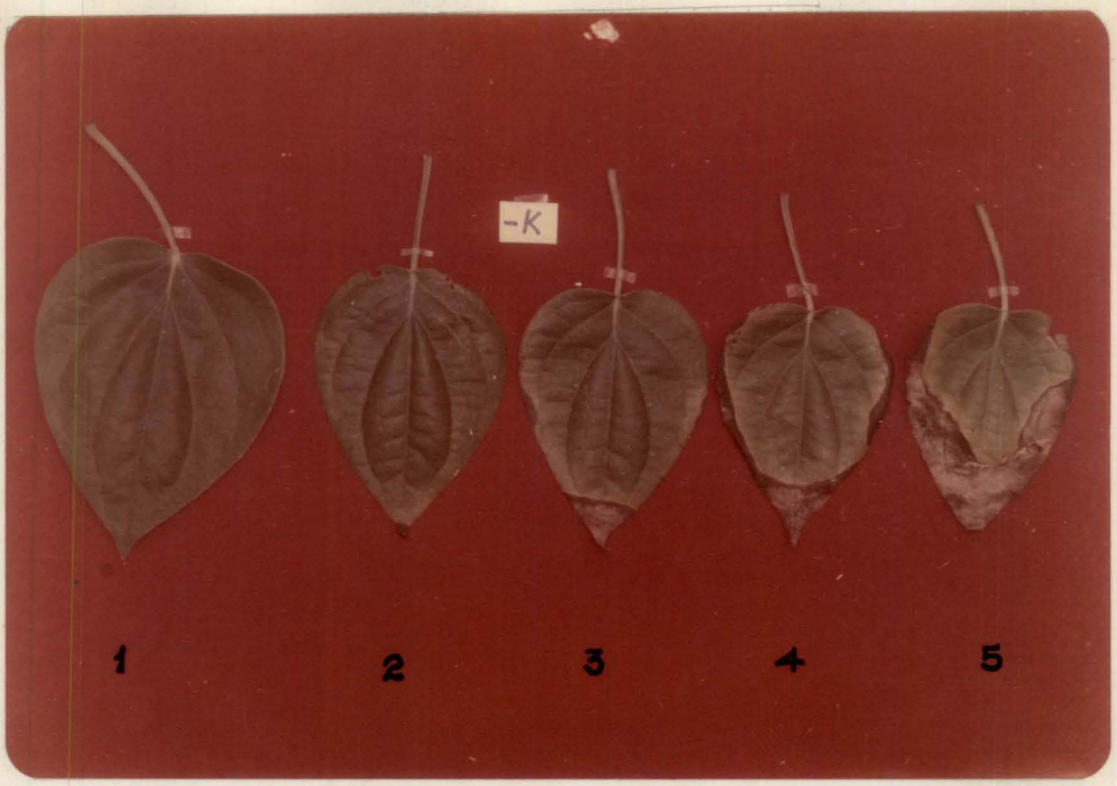
during the fifth month after treatment. The symptom was characterized by the necrosis of the older leaf tips. Unlike in the case of N deficiency, the necrotic area was black in colour (initial stage). The necrotic spot which appeared at the tip of the lamina gradually progressed towards proximal end and covered about one tenth of the leaf (Plate VIII). The necrosis appeared at the leaf margins. The symptom gradually, spread to the upper leaves also (medium stage).

The symptoms attained severity when the necrotic area occupied about one third portion of the leaf lamina (severe stage). The marginal necrosis which appeared during the medium stage developed inward to the centre of the lamina. During this stage, the leaves in the lower half of the vine were affected. The affected leaves were otherwise healthy but for the necrotic area.

Within one month after the beginning of the preceding stage, about two-thirds of the laminae of the older leaves became necrotic (very severe stage). The symptoms progressed upward and covered approximately lower two-thirds of the leaves on the vine. The proximal portion of the lamina remained green in colour. The border which demarcates the healthy and necrotic areas was charcoal black in colour which faded to ash coloured necrotic area and green coloured healthy area via. pale yellow or orange (Plate VIII). The affected leaves even with the very severe

PLATE VIII - Leaves showing different stages of K deficiency
1. Healthy 2. Initial 3. Medium 4. Severe
5. Very severe

PLATE IX - The K deficient plant at very severe stage as compared with healthy plant


-K
1
2
3
4
5


C
-K

symptoms showed no tendency for abscission (Plate IX).

1.5 Calcium deficiency

Calcium deficiency symptom was manifested only after one year of growth of the vine. The initial symptom appeared as tiny brown necrotic pinhead spots over chlorotic area near the leaf margins (initial stage). The symptom was first observed on immature leaves followed by mature ones. One and a half months after the occurrence of the initial symptom, the necrotic spots enlarged and were surrounded by yellow halo (Plate X). The chlorotic area spread towards the distal end of the leaf (medium stage).

Fifteen days after, the affected leaves developed interveinal chlorosis and die back of vine tips (severe stage). Thereafter, black necrotic areas near the leaf margins were developed. This did not spread towards the centre of the leaf blade (Plate X). The proximal portion of the lamina remained pale green in colour with occasional scattered brown necrotic spots. The affected leaves were shed and finally, only the immature leaves remained attached to the plant (Plate XI, very severe stage).

1.6 Magnesium deficiency

Magnesium deficiency symptom first appeared on the older leaves (Plate XII) eleven months after starting the treatment. The symptom observed was pale yellow discolouration of the leaf margins and tips (initial

PLATE X - Leaves showing different stages of Ca deficiency
1. Healthy 2. Initial 3. Medium 4. Very severe

PLATE XI - The plant showing very severe stage of Ca deficiency


Cā
1
2
3
4

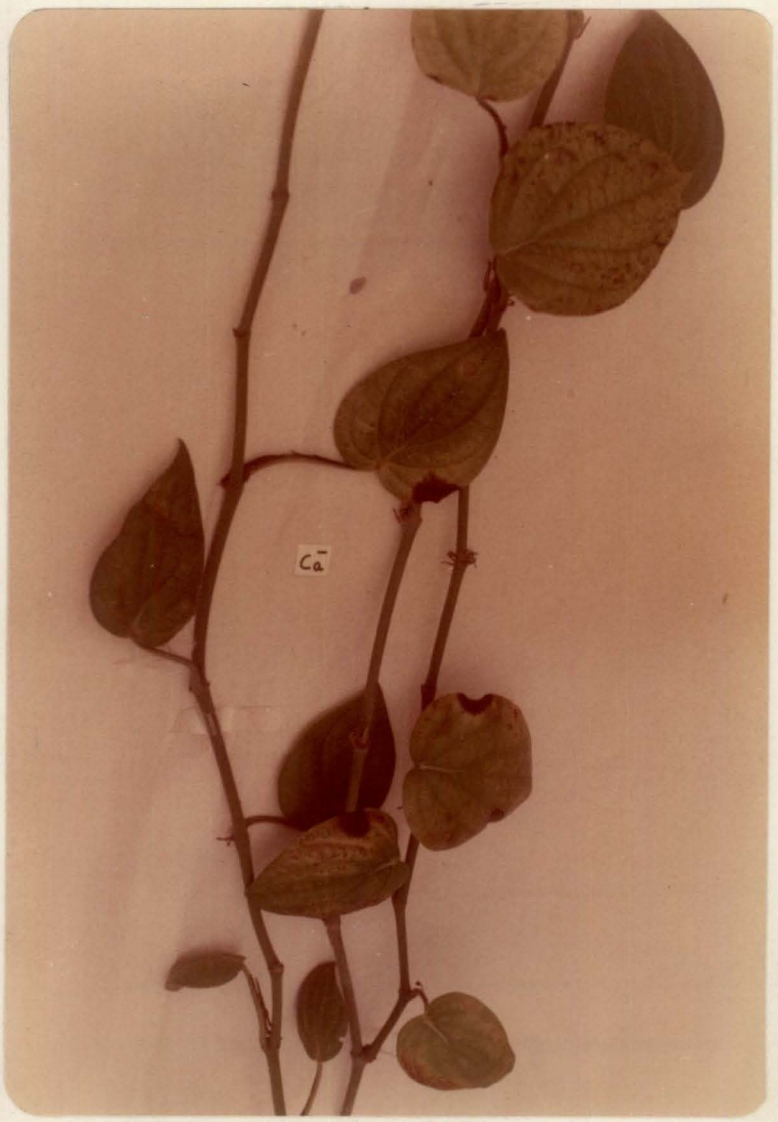
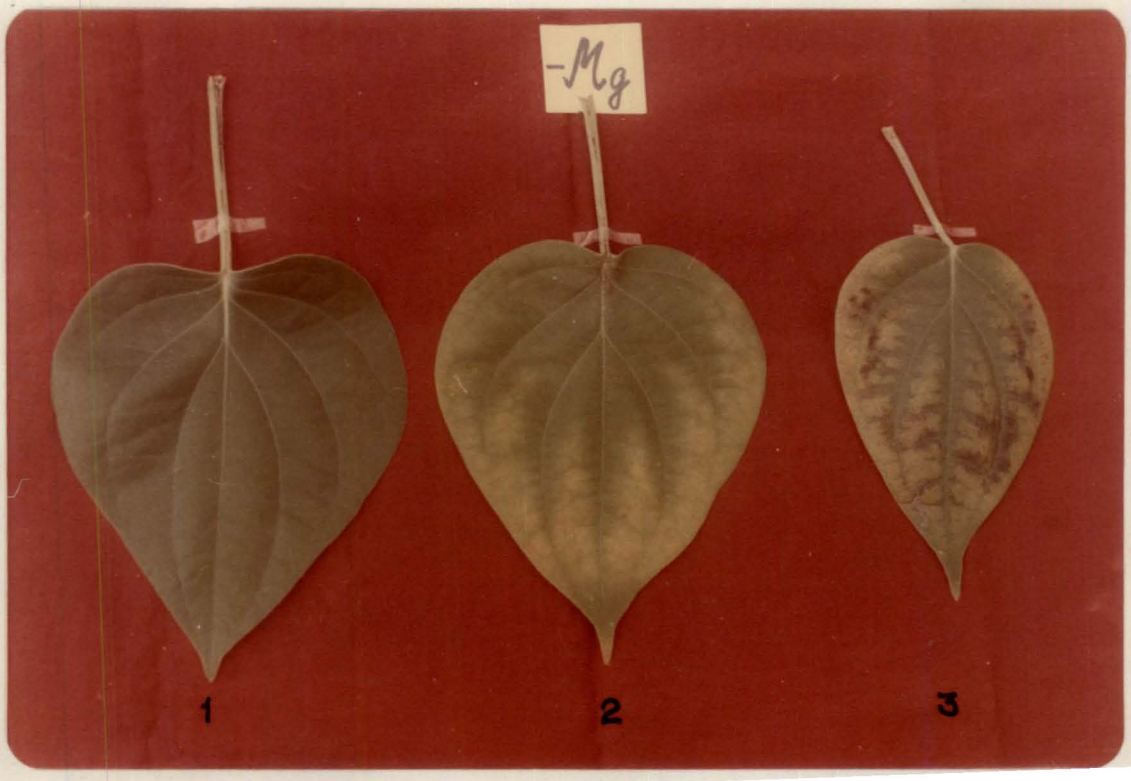

Cā

PLATE XII - The Mg deficient plant with the older leaves exhibiting the deficiency symptoms

PLATE XIII - Leaves showing different stages of Mg deficiency
1. Healthy 2. Severe 3. Very severe


-Mg
C


-Mg
1
2
3

One month after the expression of the initial symptom, oval shaped interveinal chlorotic areas started developing from the leaf tip (medium stage). Gradually, the oval chlorotic area expanded towards the leaf margins. Bands of green tissue along the major veins were seen which taper gradually towards a sharp junction at the distal end. The major veins remained green whereas the laterals turned yellow (severe stage). Small interveinal necrotic spots appeared on the lamina (Plate XIII).

By the third month after the expression of the initial symptom, the intensity of deficiency reached a very severe stage. The chlorotic area developed towards the base of the laminae. But the proximal end where the major veins join together to form the midrib and the major veins alongwith a narrow band remained green. The necrotic spots enlarged and coalesced to form necrotic patches followed by defoliation (very severe stage).

1.7 Sulphur deficiency

Among the macro and micronutrients selected for the present investigation, the earliest visual deficiency symptom was expressed by the element S. The initial symptom appeared during the third month of treatment as pale green to silvery white discolouration of the younger three to four leaves (Plate XIV). There was a specific gradation with regard to the intensity of discolouration, the youngest

PLATE XIV - The plant showing initial stage of S deficiency


-S

leaf being the most intensely coloured (initial stage). A month after the initial symptom was manifested, the colour of the affected leaves turned uniform yellow (Plate XV). By this time, the discolouration spread to few more lower leaves also. The growth gradually retarded (medium stage).

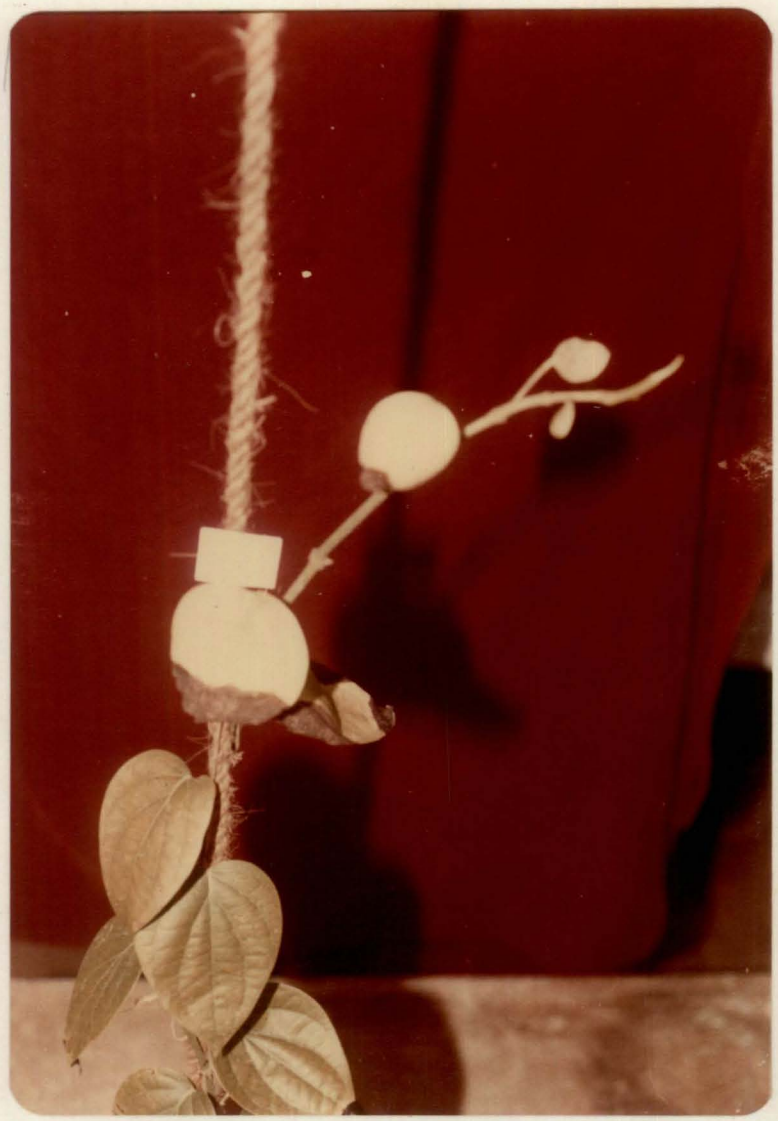
The next stage was characterized by the appearance of multitude of tiny necrotic spots on the laminae of the affected leaves. The terminal bud failed to develop and complete stunting of growth was observed. The leaf tip turned black and necrotic (Plate XVI). Black round necrotic areas were also seen on the lamina (severe stage).

The necrotic area progressed from the distal end to the proximal end involving about one-third to two-third portion of the lamina (Plate XVII). The affected leaves were shed prematurily. Die back of the vine tip was also noticed. The symptoms progressed from the tip to the base of the vine and ultimately only the basal fully matured four or five leaves remained, attached to the plant (very severe stage).

1.8 Iron deficiency

The effect of Fe deficiency was first noticed on the top two to three immature leaves during the fourth month

PLATE XV - The plant showing medium stage of S deficiency



of treatment (Plate XVIII). Interveinal chlorosis with green band along the veins, the symptom typical to Fe deficiency in many other crops was observed in pepper also (initial stage). This interveinal chlorosis gradually intensified (medium stage).

Three months after the initial symptom was expressed, chlorosis spread to another eight to ten lower leaves also. During this stage, green colour was absent in the finest veins of the chlorotic leaves. But the green bands along the major veins were present (Plate XIX, severe stage). However, growth retardation and premature leaf fall could be observed. The symptoms remained as such without further progress even after five months (very severe stage).

1.9 Manganese deficiency

Interveinal chlorosis of the younger leaves was the first visual symptom of Mn deficiency. The symptom was observed six months after treatment (initial stage). The vein clearing progressed much and the symptom spread to the middle whorl leaves also. This condition was observed about one month after the beginning of the initial symptoms (medium stage).

The chlorotic area covered almost complete of the interveinal portion making the major veins and laterals more prominent (Plate XX). The pale yellow colour of the

PLATE XVI - The plant showing severe stage of S deficiency

PLATE XVII - The plant showing very severe stage of S deficiency

PLATE XVIII - The Fe deficient plant with the younger leaves exhibiting the deficiency symptoms

PLATE XIX - Leaves showing different stages of Fe deficiency
1. Healthy 2. Initial 3. Severe


-Fe

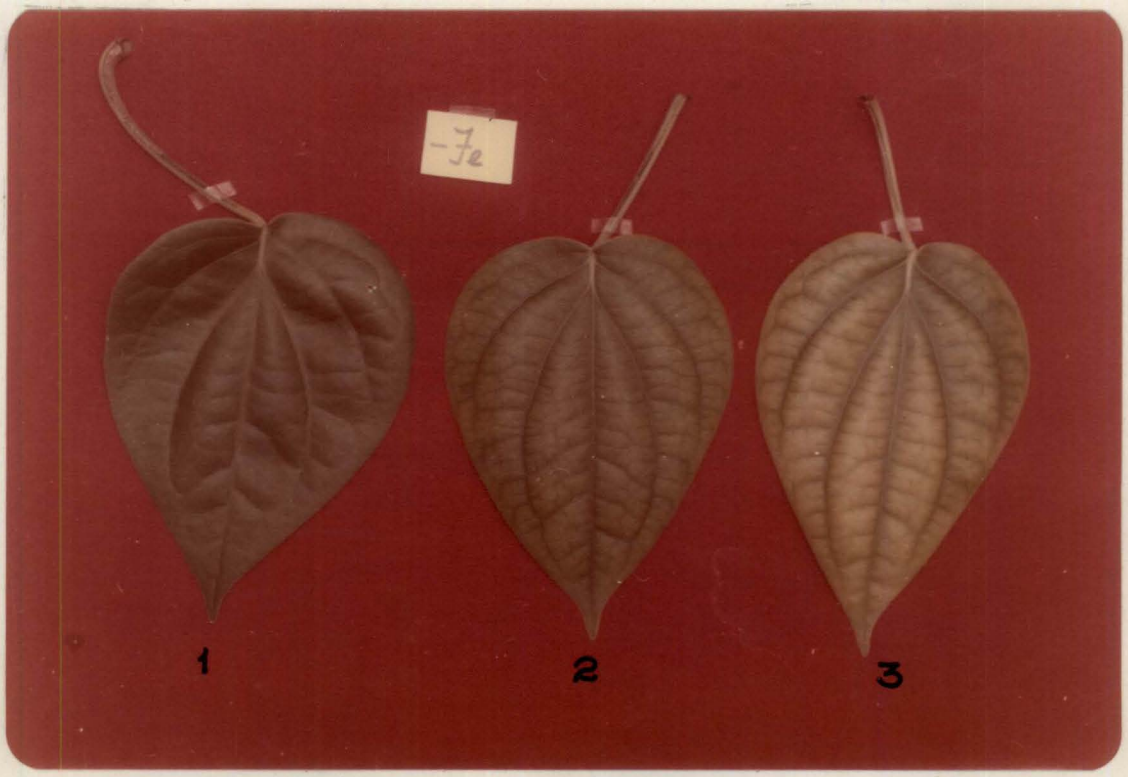
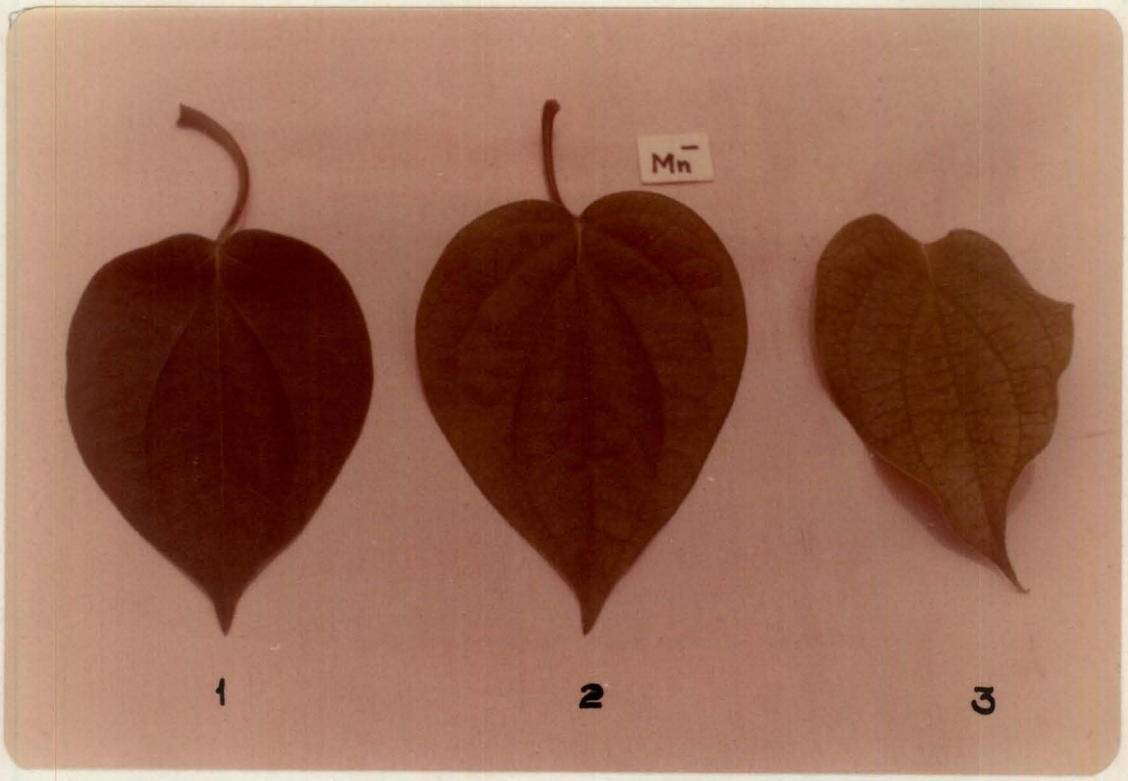

-Fe
1
2
3

PLATE XX - Leaves showing different stages of Mn deficiency
1. Healthy 2. Initial 3. Severe


Mn⁻
1
2
3

chlorotic area changed to bronze yellow (severe stage). Within a period of four months, very severe symptoms such as abscission of the affected leaves and growth retardation were exhibited by the plant (very severe stage). The major difference from Fe deficiency was that the green bands along the major veins were absent in this case.

1.10 Copper deficiency

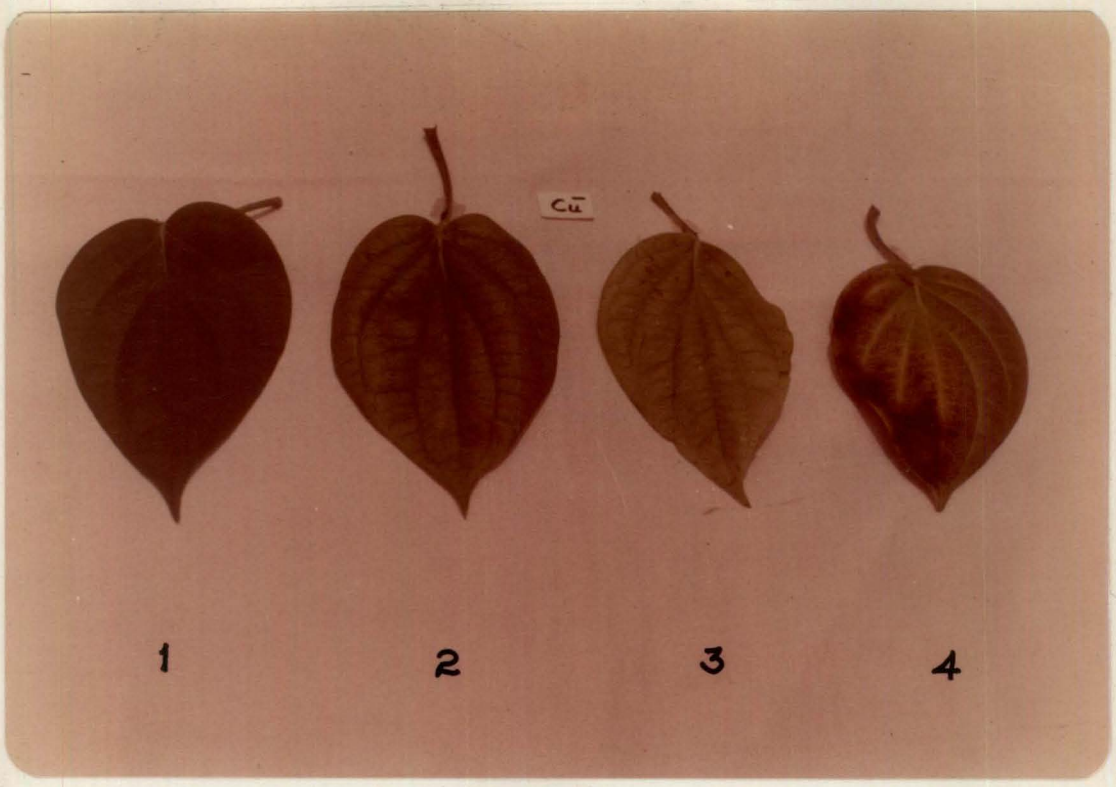
As in the case of Fe and Mn deficiencies, the first symptom manifested was interveinal chlorosis of young leaves. The symptom was expressed at the later stage of growth i.e., about one year after treatment (initial stage).

Gradually, yellow chlorotic area spread to the entire interveinal portion. The fine veins turned chlorotic and the green colour of the major veins and laterals faded to pale green which could be observed from Plate XXI (medium stage).

Within a period of fifteen days the entire lamina including veins became chlorotic. Dark brown necrotic spots developed towards the tip and margin of the leaf. The terminal growth was arrested and new growth from the basal portion of the vine was initiated (severe stage). During the next stage the laminae became deep bronze and

PLATE XXI - Leaves showing different stages of Cu deficiency
1. Healthy 2. Medium 3. Severe
4. Very severe

PLATE XXII - The plant showing very severe stage of Cu deficiency


Cu̅
1
2
3
4


C
Cu̅

necrotic spots coalesced to form large black necrotic areas near the tips and margins (very severe stage). The major veins were conspicuous with the interveinal area by deep orange yellow colour (Plate XXI). Inward curling of the necrotic margins was also observed. Shedding of the very severely affected leaves was also observed which led to sparse foliage (XXII). The new growth produced also showed the characteristic symptoms.

1.11 Zinc deficiency

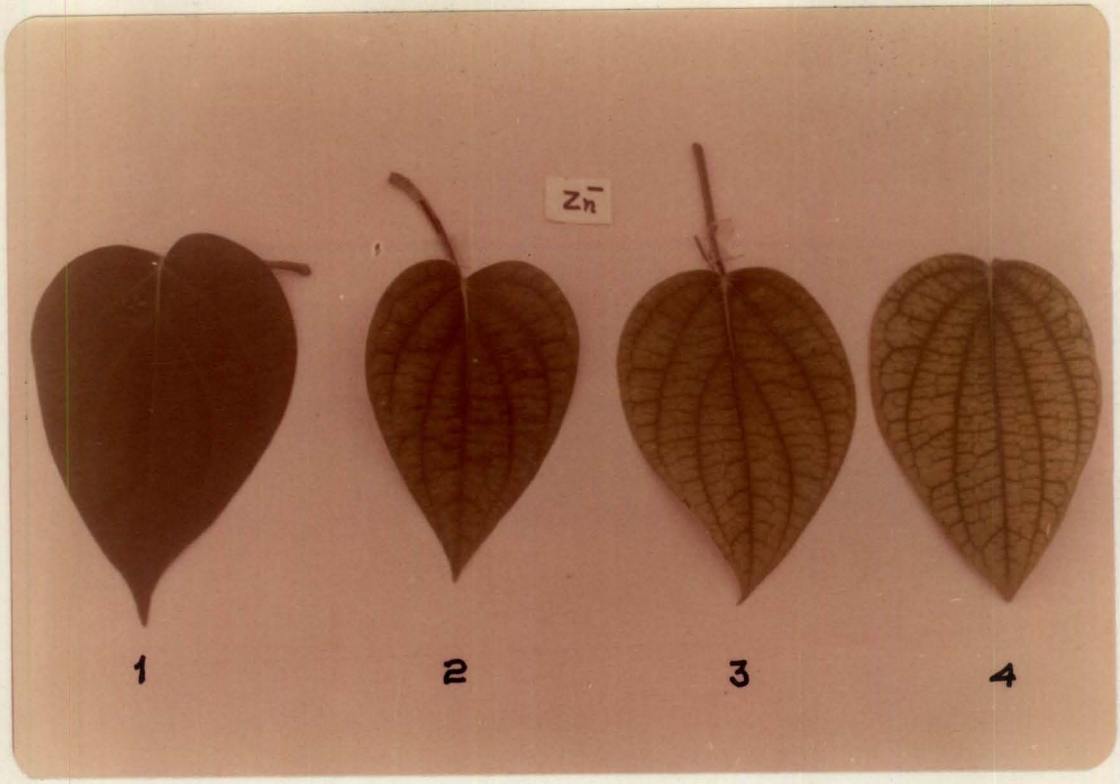
The first visible symptom of Zn deficiency was manifested during the twelfth month after treatment. The characteristic symptom was the interveinal chlorosis of the laminae of the younger leaves (initial stage). Within a period of one month, the chlorosis developed further so that a network of green veins could be clearly seen in pale yellow background (medium stage). Chlorosis spread to the lower immature leaves also.

By about two months, the colour of the interveinal chlorotic area became more deep with dark green veins (Plate XXIII). The new leaves produced were smaller in size (severe stage).

The young flush produced also showed the deficiency symptoms. The terminal growth was retarded and the internodal length reduced. A number of lateral branches

PLATE XXIII - Leaves showing different stages of Zn deficiency
1. Healthy 2.Initial 3. Medium
4. Severe

PLATE XXIV - The plant showing leaf rosetting due to Zn deficiency


Zn⁻
1
2
3
4


Zn⁻

with shortened internodes and small leaves were produced from the terminal portion of the vine which resulted in bunching or rosetting (Plate XXIV). Abscission of leaf was seldom noticed (very severe stage).

1.12 Boron deficiency

Boron deficiency was first noticed nine months after treatment. The initial symptom was observed as the failure of development of terminal bud. Small branches appeared below the terminals, young leaves were distorted (initial stage). The plants exhibited stunted growth. The terminal leaves became abnormal in size and when mature, interveinal chlorotic patches were visible on the laminae. This condition was noticed two months after the appearance of the initial symptoms (medium stage).

One month after the occurrence of the chlorotic patches, the affected leaves became thick, brittle and presented a mottled appearance with bright orange coloured mottles (Plate XXV). No symptom was expressed by the basal leaves (severe stage).

Within a period of four months after the expression of the initial symptom, the mottling became very severe. The area on the lower side of the lamina corresponding to the mottles on the upper surface became grey brown (very severe stage). The major as well as lateral veins became

PLATE XXV - The terminal leaves showing severe stage of B deficiency

PLATE XXVI - The lower surface of the leaf showing very severe stage of B deficiency


-B


-B

very prominent with pale green colour in grey brown inter-veinal background (Plate XXVI). Very severely affected leaves showed black necrotic areas with charred appearance which started from the lower leaf margins and progressed upward marginally and towards the centre of the laminae. Later on, cracks appeared on the necrotic area and small pieces of the same got detached from the lamina. The affected leaves were retained on the plant for a long period and only during extreme deficiency condition abscission occurred.

The characteristic diagnostic symptoms of macro and micronutrient deficiencies observed in black pepper are presented in a tabular form in the following page.

2. Effect of nutrient deficiencies on vegetative growth and development

2.1 Nitrogen deficiency

The data on the effect of N deficiency on vegetative growth are furnished in Table 1 and Fig. 1, 2 and 3.

It could be observed from the table that there was reduction in shoot growth of N deficient plants which ranged between 5.7 cm and 133.0 cm from initial to very severe stage as compared to healthy ones. The extent of reduction was 8 per cent during the initial stage which increased upto 56 per cent within four months (very severe stage). The reduction in number of leaves varied from

Diagnostic symptoms of nutrient deficiency in black pepper

FOLIAR SYMPTOMS

MACRONUTRIENTS		MICRONUTRIENTS	
Older leaves	Younger leaves	Older leaves	Younger leaves
N uniform yellowing	Ca brown necrotic spots on chlorotic area	Nil	Fe interveinal chlorosis with green band along major veins
P purple to bronze yellow lamina with ash coloured necrotic areas	S uniform yellowing with necrotic spots		Mn bronze yellow colour of interveinal area
K tip and marginal necrosis			Cu bronze colour of entire lamina with necrotic tips and margins
Mg oval interveinal chlorotic area			Zn interveinal chlorosis with prominent green network of veins, little leaf and rosetting
			B large, brittle and mottle leaves with grey brown interveinal patches on lower side

Table 1. Effect of deficiency of nitrogen on vegetative characters

Stages of nitrogen deficiency	Months after treatment	Length of vine (cm)	No. of leaves	Inter-nodal length (cm)	Leaf area index (cm^2)	Dry matter production (g)			
						Root	Shoot	Leaves	Total
Initial	4	68.7 (8)	12.5 (10)	5.3 (2)	53.8 (29)	1.2 (8)	21.8 (8)	15.4 (21)	38.4 (14)
Complete*	4	74.4	13.9	5.4	76.2	1.3	23.8	19.6	44.7
Medium	5	95.9 (9)	21.2 (13)	4.2 (21)	44.3 (47)	1.6 (11)	30.6 (6)	25.1 (8)	57.3 (7)
Complete*	5	105.4	24.5	5.3	83.0	1.8	32.6	27.3	61.7
Severe	6	101.5 (35)	23.0 (34)	3.9 (13)	32.2 (63)	1.6 (36)	32.1 (29)	25.5 (36)	59.2 (32)
Complete*	6	156.2	34.8	4.5	86.8	2.5	45.1	40.0	87.6
Very severe	8	103.0 (56)	23.0 (53)	3.9 (20)	32.2 (63)	1.9 (39)	32.0 (49)	25.2 (56)	59.1 (51)
Complete*	8	236.0	48.6	4.9	85.9	3.1	62.9	56.8	122.8

* Plants receiving complete nutrients

Figures given in parenthesis indicate percentage reduction from healthy vines

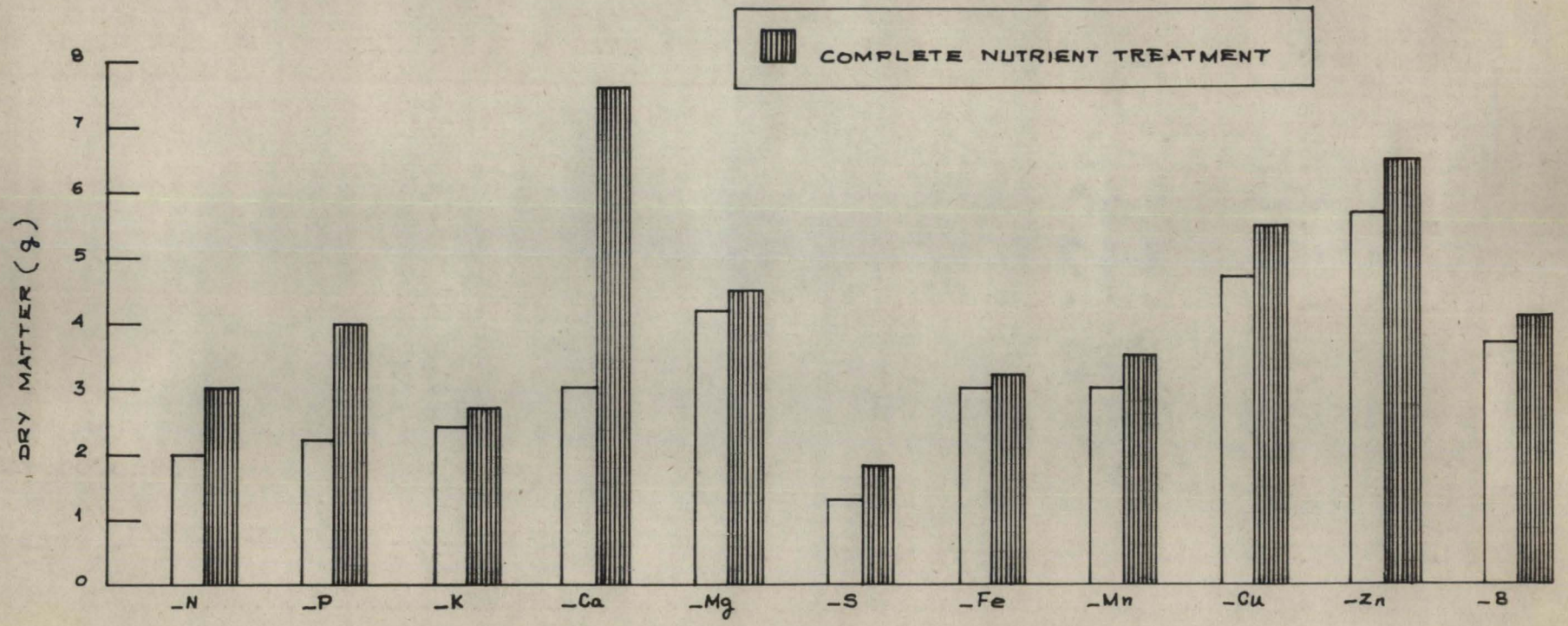


FIG: 1. EFFECT OF DEFICIENCY OF MACRO AND MICRONUTRIENTS ON ROOT GROWTH (AT VERY SEVERE STAGE)

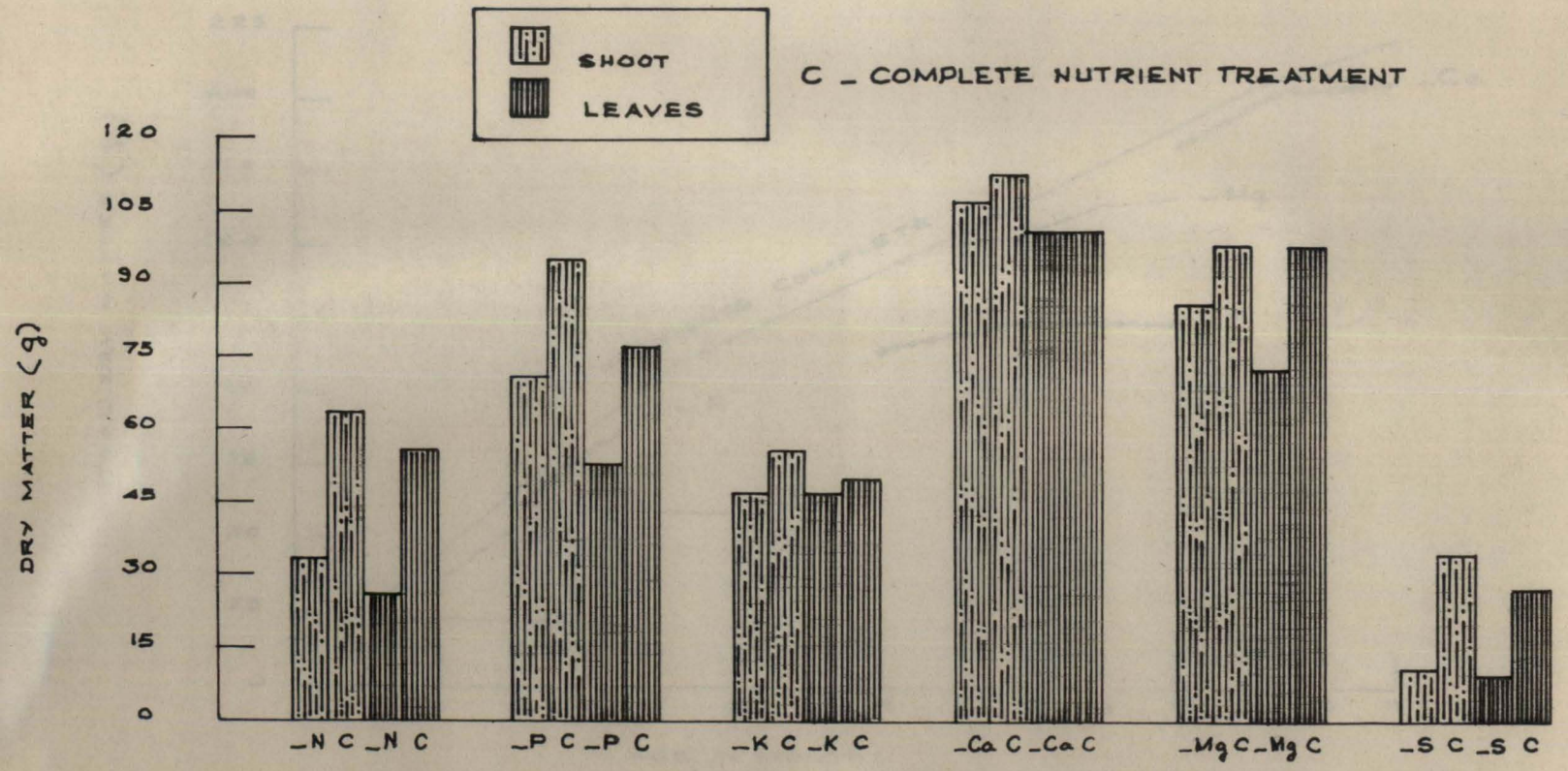


FIG: 2. EFFECT OF DEFICIENCY OF MACRONUTRIENTS ON SHOOT AND LEAF GROWTH(AT VERY SEVERE STAGE)

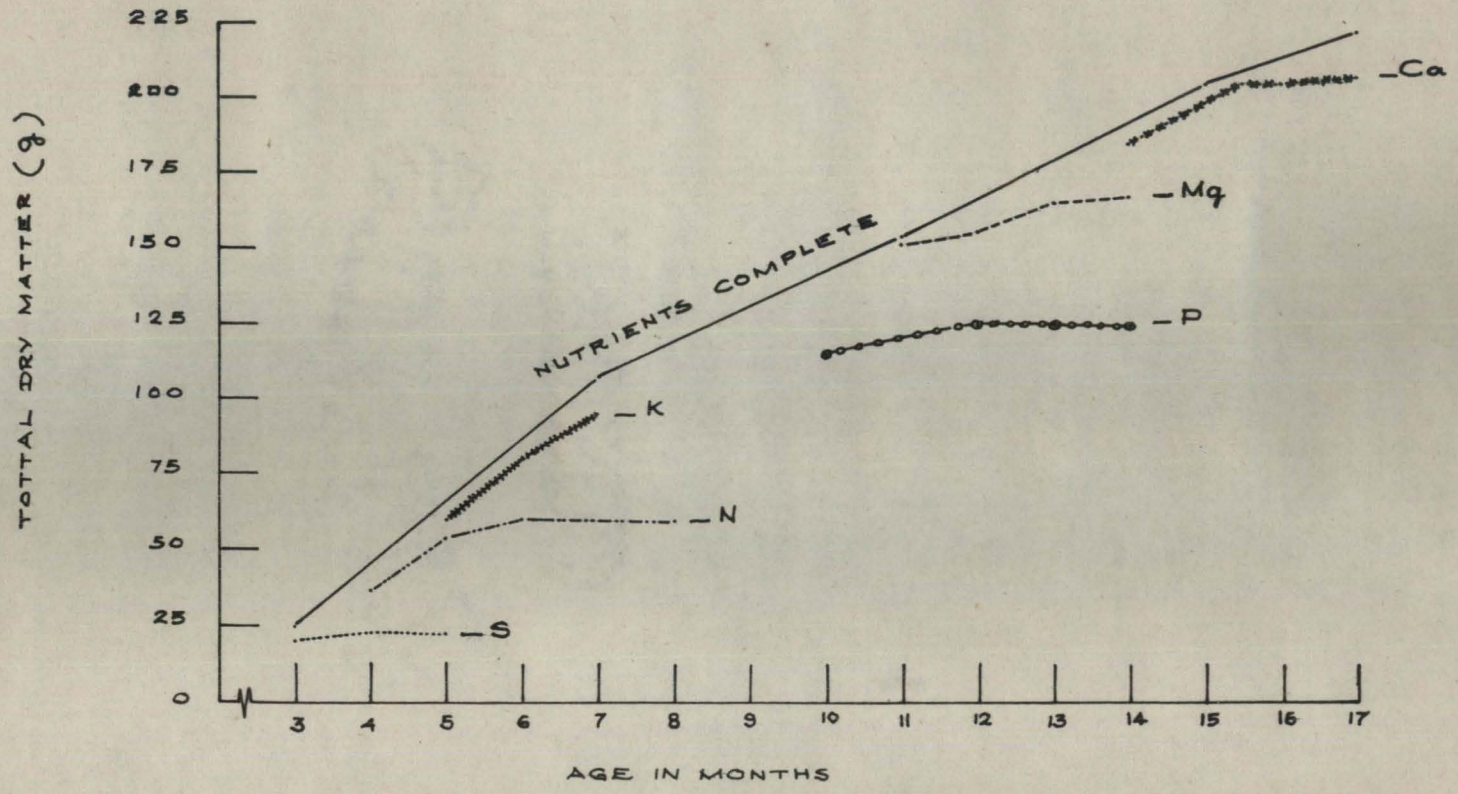


FIG: 3. DRY MATTER CONTENT AS INFLUENCED BY MACRONUTRIENTS AT DIFFERENT STAGES OF DEFICIENCY

1.4 to 25.6 from initial to very severe stage which corresponded to 10 per cent and 53 per cent respectively. The omission of N resulted in decreased internodal length which ranged between 0.1 cm and 1.1 cm from initial to very severe stage as compared to plants which received complete nutrient treatment. During the initial stage, the magnitude of reduction from the healthy vine was 2 per cent and that during very severe stage was 20 per cent. The leaf area index showed a decreasing trend with the advancement of deficiency. The reduction ranged from 22.4 to 53.7 cm^2 within eight months period (from initial to very severe stage) During the severe and very severe stage it registered a reduction by 63 per cent which was only 29 per cent in the initial stage.

The data presented in Table 1 revealed that the dry matter production was adversely affected by N deficiency. The range of reduction in dry weight of roots from initial to very severe stage as compared to healthy plants was 0.1 to 1.2 g (Fig.1). The extent of reduction was 8 per cent and 39 per cent respectively, during the initial and very severe stages (Plate XXVII). The dry weight of shoot also registered a reduction by 8 to 49 per cent during a period of four months (Fig.2). The quantity reduced was 2.0 to 30.9 g within eight months period (from initial to very severe stage). With regard to the dry matter of leaves, the reduction from healthy plants ranged from 4.2 to 31.6 g

PLATE XXVII - The root system of plants showing deficiencies of N, P and K as compared to that of healthy plant

PLATE XXVIII - The root system of plants showing deficiencies of Ca, Mg and S as compared to that of healthy plant


C
-N
-P
-K


C
-Ca
-Mg
-S

during a period of eight months. The magnitude of reduction was 21 per cent during the initial stage which increased upto 56 per cent within four months (Fig.2). There was increase in growth, ofcourse at lower rate, upto sixth month even though visual deficiency symptoms were manifested by the fourth month (Fig.3). The reduction in total dry matter content ranged between 14 per cent (initial) and 51 per cent (very severe) within a period of four months. The growth was completely arrested after six months as evidenced by the total dry matter production.

Due to N deficiency there was a decrease of 56 per cent in shoot growth, 53 per cent in number of leaves, 20 per cent in internodal length, 63 per cent in leaf area index and 51 per cent in total dry matter production during a period of eight months. The growth was completely arrested by the sixth month.

2.2 Phosphorus deficiency

The results pertaining to the effect of P deficiency on vegetative growth are presented in Table 2 and Fig. 1, 2 and 3.

Absence of P adversely affected all the growth parameters except internodal length and leaf area index. The growth of shoot was reduced by 61.9 to 118.8 cm during a period of 13.5 months. The amount of reduction was

Table 2. Effect of deficiency of phosphorus on vegetative characters

Stages of phosphorus deficiency	Months after treatment	Length of vine (cm)	No. of leaves	Inter-nodal length (cm)	Leaf area index (cm^2)	Dry matter production (g)			
						Root	Shoot	Leaves	Total
Initial	10	270.0 (-19)	50.0 (-18)	5.3 (-2)	80.3 (-3)	3.0 (-14)	60.0 (-20)	52.0 (-24)	115.0 (-22)
Complete*	10	331.9	61.2	5.4	82.4	3.5	75.1	68.0	146.6
Medium	12	312.5 (-20)	54.2 (-23)	5.6 (+2)	81.5 (+5)	2.5 (-36)	69.2 (-21)	55.0 (-24)	126.7 (-23)
Complete*	12	388.7	70.1	5.5	78.0	3.9	87.8	72.5	164.2
Severe	13	316.5 (-24)	55.0 (-29)	5.6 (+4)	80.6 (+4)	2.4 (-41)	70.0 (-24)	53.0 (-29)	125.4 (-27)
Complete*	13	416.7	77.5	5.4	77.6	4.1	92.3	74.3	170.7
Vere severe	13.5	318.2 (-27)	55.0 (-32)	5.7 (+4)	78.2 (-2)	2.2 (-45)	70.6 (-26)	53.0 (-30)	125.8 (-28)
Complete*	13.5	437.0	81.0	5.5	79.8	4.0	95.0	75.8	174.8

* Plants receiving complete nutrients

Figures given in parenthesis indicate percentage variation from healthy vines

19 per cent in the initial stage which increased upto 27 per cent within a period of three and a half months. The number of leaves also showed a decreasing trend and the reduction as compared to healthy plants ranged from 11.2 to 26.0 leaves from initial to very severe stage. The extent of reduction was 18 per cent during initial stage which increased upto 32 per cent by three and a half months. No marked variation from healthy vines was observed in the case of internodal length and leaf area index. However, there was a slight increase in internodal length which registered 4 per cent within a period of one and a half months after medium stage. During medium and severe stages leaf area index showed an increase by 5 per cent and 4 per cent, respectively whereas a slight reduction by 3 per cent and 2 per cent were observed during initial and very severe stages.

With respect to the dry matter content of roots, a steady decrease was observed from initial to very severe stage (Plate XXVII). The quantum of reduction ranged from 0.5 (14%) to 3.8 g (45%) within a period of three and a half months after initial stage (Fig.1). The dry matter of shoot showed a reduction which ranged from 15.1 to 25.6 g during a period of 13.5 months. The reduction was 20 per cent during the initial stage which increased upto 26 per cent in the very severe stage (Fig.2). The leaves also recorded 30 per cent reduction in dry weight during very severe stage

(Fig.2). The deficiency of P affected the crop growth at comparatively later stage (12 months after treatment) as could be seen from Fig.3. The decrease in total dry matter production was as much as 28 per cent during the very severe stage as compared with the normal vines.

Phosphorus deficiency resulted in a reduction by 27 per cent in shoot growth, 32 per cent in number of leaves, 45 per cent in dry weight of roots and 28 per cent in total dry matter content. The growth and development were practically nil from the twelfth month onwards.

2.3 Potassium deficiency

Table 3 and Fig. 1, 2 and 3 present the results of the effect of K on vegetative growth of pepper vines.

A decreasing trend in shoot growth was observed in all the stages of deficiency. But the reduction was only 11 per cent in a period of seven months (very severe stage). The amount of reduction ranged from 3.4 to 21.2 cm from initial to very severe stage, respectively. The reduction in number of leaves, internodal length and leaf area index was only marginal as compared to healthy vines. The amount of reduction was to the tune of 7, 4 and 1 per cent respectively, in the case of number of leaves, internodal length and leaf area index during the very severe stage (7th month).

Table 3. Effect of deficiency of potassium on vegetative characters

Stages of potassium deficiency	Months after treatment	Length of vine (cm)	No. of leaves	Inter-nodal length (cm)	Leaf area index (cm^2)	Dry matter production (g)			
						Root	Shoot	Leaves	Total
Initial	5	102.0 (3)	24.0 (2)	5.1 (4)	80.0 (4)	1.5 (17)	31.8 (2)	28.0 (3)	61.3 (1)
Complete*	5	105.4	24.5	5.3	83.0	1.8	32.6	27.3	61.7
Medium	5.5	125.3 (4)	27.8 (4)	4.5 (0)	84.1 (1)	1.7 (15)	35.1 (6)	30.1 (6)	66.9 (6)
Complete*	5.5	130.1	29.0	4.5	85.0	2.0	37.5	32.0	71.5
Severe	6	138.8 (11)	30.5 (12)	4.5 (0)	85.2 (2)	2.2 (12)	42.0 (7)	35.3 (12)	79.5 (9)
Complete*	6	156.2	34.8	4.5	86.8	2.5	45.1	40.0	87.6
Very severe	7	175.6 (11)	38.0 (7)	4.6 (4)	85.0 (1)	2.4 (11)	46.8 (15)	45.5 (7)	94.7 (11)
Complete*	7	196.8	40.7	4.8	85.9	2.7	54.8	49.1	106.6

* Plants receiving complete nutrients

Figures given in parenthesis indicate percentage reduction from healthy vines

The degree of reduction in respect of dry matter content was also very low (Fig. 1 and 2). The quantum of reduction in dry weight of roots was 0.3 g in all the four stages of deficiency (Plate XXVII). The rate of reduction has actually decreased from initial to very severe stage (17 to 11%). The magnitude of reduction in the case of dry weight of shoot ranged from 2 to 15 per cent within a period of two months (from initial to very severe stage) Maximum reduction in dry matter content of leaves was noticed during severe stage (6th month) and thereafter, the rate of reduction has decreased to 7 per cent. The total dry matter content also showed a steady decrease from 1 to 11 per cent within a period of two months of deficiency. In terms of quantity, the reduction ranged between 0.4 g and 11.9 g during a period of seven months (Fig.3). It is of interest to note that even at very severe stage of deficiency, growth progressed uninhibited, though the rate was reduced.

Omission of K from the growing medium resulted in a decrease in shoot growth by 11 per cent, number of leaves by 12 per cent, internodal length by 4 per cent and dry matter content by 11 per cent. There was no cessation of growth at any stage of K deficiency, although the rate of growth was below the normal.

Among the primary nutrients, the deficiency of N was found to affect vegetative growth very seriously. The

reduction in length of vine due to N deficiency was 56 per cent whereas it was 27 per cent and 11 per cent respectively, in the case of P and K deficiencies. The internodal length showed 20 per cent and 4 per cent decrease in the case of N and K deficiencies. However, P deficiency resulted in 4 per cent increase. The number of leaves and leaf area index were highly reduced as a result of N deficiency. The extent of reduction was 53 per cent and 63 per cent respectively. The reduction in number of leaves was 32 per cent due to P deficiency while it was only 7 per cent in the case of K deficiency. No pronounced reduction was noticed in the case of leaf area index due to P (2%) and K (1%) deficiencies.

The root growth was very much reduced as a result of P deficiency (45%) as compared to N (39%) or K (11%) deficiency. However, the reduction in total dry matter content was highest with regard to N deficiency (51%) followed by P (28%) and K (11%) deficiencies. In the case of N deficiency, growth was completely arrested by the sixth month after treatment whereas 13 months were taken in the case of P deficient plants. However, growth was not completely arrested upto the seventh month (very severe stage) after treatment due to K deficiency.

2.4 Calcium deficiency

The data on the effect of Ca deficiency on vegetative characters are furnished in Table 4 and Fig. 1, 2 and 3.

From the table it could be observed that as far as the vegetative growth was concerned, the influence of Ca was comparatively less. There was reduction in shoot growth which ranged between 7.1 cm (initial) and 32 cm (very severe) as compared to healthy plants. The degree of reduction was only 2 per cent during initial stage which gradually reached 6 per cent within three months. The reduction in number of leaves was only 1 to 2 per cent as compared to healthy vines. The reduction in internodal length ranged from 0.1 to 0.4 cm during a period of 17 months (from initial to very severe stage). This corresponds to 2 per cent and 8 per cent respectively. There was no pronounced reduction in leaf area index. However, a reduction by 4 per cent was observed during the very severe stage of deficiency.

The results revealed that Ca has got a very pronounced effect on root growth in pepper (Fig.1). The reduction in root growth ranged between 0.3 g and 4.6 g from initial to very severe stage as compared to healthy plants. The magnitude of reduction reached 61 per cent at very severe stage (Plate XXVIII) which was only 7 per cent during the initial stage. The dry matter content of shoot and leaves

Table 4. Effect of deficiency of calcium on vegetative characters

Stages of calcium deficiency	Months after treatment	Length of vine (cm)	No. of leaves	Inter-nodal length (cm)	Leaf area index (cm^2)	Dry matter production (g)			
						Root	Shoot	Leaves	Total
Initial	14	438.9 (2)	81.5 (1)	5.2 (2)	85.0 (1)	4.2 (7)	95.3 (3)	90.3 (7)	189.8 (5)
Complete*	14	446.0	82.1	5.3	85.6	4.5	98.1	96.6	199.2
Medium	15.5	460.3 (3)	91.3 (2)	5.0 (0)	84.2 (1)	4.5 (24)	100.2 (5)	98.8 (1)	203.5 (4)
Complete*	15.5	475.5	93.0	5.0	85.0	5.9	105.6	99.6	211.1
Severe	16	471.6 (4)	93.8 (1)	4.8 (4)	83.1 (1)	3.9 (40)	103.7 (5)	99.1 (2)	206.7 (4)
Complete*	16	490.8	95.0	5.0	83.8	6.5	108.9	101.0	216.4
Very severe	17	480.4 (6)	94.3 (1)	4.8 (8)	82.4 (4)	3.0 (61)	105.6 (7)	100.1 (1)	208.7 (6)
Complete*	17	512.4	95.6	5.2	85.4	7.6	113.7	101.4	222.7

* Plants receiving complete nutrients

Figures given in parenthesis indicate percentage reduction from healthy vines

recorded a reduction by 7 per cent and 1 per cent respectively, during very severe stage (Fig.2). However, the reduction in dry matter content of leaves was much higher (7%) during the initial stage. The decrease in total dry matter content varied from 9.4 to 14.0 g which corresponds to 5 per cent and 6 per cent respectively. The deficiency of Ca affected the crop growth only at a later stage i.e., 15.5 months after treatment (Fig.3).

Deficiency of Ca resulted in a reduction by 6 per cent in shoot growth, 8 per cent in internodal length, 61 per cent in dry matter of roots and 6 per cent in total dry matter. The growth was completely arrested at 15.5 months after treatment.

2.5 Magnesium deficiency

The data on the influence of Mg on vegetative growth are presented in Table 5 and depicted in Fig.1, 2 and 3.

Reduction in growth of shoot was observed which ranged between 5.4 cm and 59.1 cm from initial to very severe stage as compared to healthy vines. The reduction was only 1 per cent during the initial stage which reached 13 per cent within a period of three months (very severe stage). The number of leaves and leaf area index showed a reduction by 7 per cent at very severe stage (14 months after treatment). The reduction in number of leaves ranged from 1.6 to 5.9 and that of leaf area index from 1.1 to 6.4 cm^2 from

Table 5. Effect of deficiency of magnesium on vegetative characters

Stages of magnesium deficiency	Months after treatment	Length of vine (cm)	No. of leaves	Internodal length (cm)	Leaf area index (cm^2)	Dry matter production (g)			
						Root	Shoot	Leaves	Total
Initial	11	360.2 (1)	65.2 (2)	5.2 (2)	76.1 (1)	3.2 (9)	80.0 (1)	68.8 (2)	152.0 (2)
Complete*	11	365.6	66.8	5.3	77.2	3.5	81.1	70.0	154.6
Medium	12	372.6 (4)	67.1 (4)	5.5 (0)	75.7 (3)	3.6 (8)	82.6 (6)	69.3 (4)	155.5 (5)
Complete*	12	388.7	70.1	5.5	78.0	3.9	87.8	72.5	164.2
Severe	13	380.3 (9)	74.7 (4)	5.3 (2)	76.3 (2)	4.0 (2)	84.4 (9)	70.5 (5)	164.9 (3)
Complete*	13	416.7	77.5	5.4	77.6	4.1	92.3	74.3	170.7
Very severe	14	386.9 (13)	76.2 (7)	5.4 (4)	79.2 (7)	4.2 (7)	85.7 (13)	72.8 (25)	168.7 (15)
Complete*	14	446.0	82.1	5.6	85.6	4.5	98.1	96.6	199.2

* Plants receiving complete nutrients

Figures given in parenthesis indicate percentage reduction from healthy vines

initial to very severe stage as compared to healthy vines. The internodal length was not much affected by Mg deficiency. However, a decrease by 4 per cent was recorded during the very severe stage.

With respect to the dry matter of roots, the rate of reduction has higher (9%) during the initial stage as compared with severe or very severe stages (2% and 7%, Plate XXVIII). The dry matter of shoot and leaves recorded a reduction by 1 per cent (1.1 g) and 2 per cent (1.2 g) respectively, during the initial stage which increased to 13 per cent (12.4 g) and 25 per cent (13.8 g) respectively, within a period of three months (very severe stage, Fig.2). The total dry matter content showed a reduction which amounted to 2 per cent at the initial stage and 15 per cent at the very severe stage. As evidenced by the total dry matter content depicted in Fig. 3, stunted growth was observed from the thirteenth month onwards. However, complete arrest of growth was not observed.

The results on the effect of Mg deficiency showed that there was a decrease of 13 per cent in shoot growth, 7 per cent each in number of leaves, leaf area index and dry weight of roots, 13 per cent in dry weight of shoot, 25 per cent in dry weight of leaves and 15 per cent in total dry matter content. Magnesium deficiency resulted in stunted growth from the thirteenth month after treatment.

2.6 Sulphur deficiency

The results of S deficiency on growth parameters are presented in Table 6 and Fig. 1, 2 and 3.

The reduction in shoot growth varied between 6.6 cm (initial) and 50.4 cm (very severe) during a period of five months as compared to plants under complete nutrient treatment. The degree of reduction was as much as 13 per cent during the initial stage which increased to 48 per cent in about two months. The number of leaves also showed a great reduction amounting to 12 per cent and 63 per cent respectively, during the initial and very severe stages. The number reduced ranged from 1.2 to 15.5 within a period of five months (very severe stage). There was not much variation in the case of internodal length except a slight reduction by 5 per cent at severe stage of deficiency. The leaf area index also showed a notable decrease by 6 per cent during the initial stage which gradually increased to 17 per cent within two months.

The total dry matter as well as the dry matter of root, shoot and leaves recorded a considerable decrease as compared to healthy vines. The dry weight of roots was reduced by 9 per cent during the initial stage and 28 per cent during the very severe stage (Fig.1 and Plate XXVIII). The reduction in dry weight of shoot ranged between 2.0 g (initial) and 20.4 g(very severe) during a period of five

Table 6. Effect of deficiency of sulphur on vegetative characters

Stages of sulphur deficiency	Months after treatment	Length of vine (cm)	No. of leaves	Inter-nodal length (cm)	Leaf area index (cm^2)	Dry matter production (g)			
						Root	Shoot	Leaves	Total
Initial	3	45.2 (13)	8.5 (12)	5.3 (0)	71.3 (6)	1.0 (9)	10.1 (17)	9.3 (21)	20.4 (18)
Complete*	3	51.8	9.7	5.3	75.9	1.1	12.1	11.8	25.0
Medium	4	51.0 (31)	9.0 (35)	5.3 (2)	68.5 (10)	1.1 (15)	11.3 (53)	9.5 (52)	21.9 (51)
Complete*	4	74.4	13.9	5.4	76.2	1.3	23.8	19.6	44.7
Severe	4.5	55.0 (40)	9.0 (54)	5.3 (5)	68.5 (14)	1.1 (27)	12.2 (56)	9.6 (57)	22.9 (55)
Complete*	4.5	90.6	19.7	5.6	79.4	1.5	27.5	22.2	51.2
Very severe	5	55.0 (48)	9.0 (63)	5.3 (0)	68.5 (17)	1.3 (28)	12.2 (63)	9.6 (65)	23.1 (63)
Complete*	5	105.4	24.5	5.3	83.0	1.8	32.6	27.3	61.7

* Plants receiving complete nutrients

Figures given in parenthesis indicate percentage reduction from healthy vines

months as compared to plants under complete nutrient treatment. The reduction was 17 per cent during the initial stage and 63 per cent at the very severe stage (Fig.2). The dry matter content of leaves recorded 21 per cent reduction during the initial stage which increased upto 65 per cent in about two months (Fig.2). The quantum of reduction varied from 2.5 to 17.7 g during a period of five months (from initial to very severe stage). The total dry matter content was reduced by 63 per cent within a period of five months (very severe stage, Fig: 3). The absence of S affected the crop growth within a short period of three months after treatment. As compared to other macro and micronutrients, the element S manifested the earliest deficiency symptoms. The growth was completely arrested by the fourth month due to S deficiency.

There was a decrease of 48 per cent in shoot growth, 63 per cent in number of leaves, 17 per cent in leaf area index, 28 per cent in dry matter of roots, 63 per cent in dry matter of shoot, 65 per cent in dry matter of leaves and 63 per cent in total dry matter content. The growth was completely arrested by the fourth month after treatment.

With regard to the secondary nutrients, S deficiency symptoms were manifested at an early stage (3rd month) followed by Mg (11th month) and Ca (14th month). The reduction in shoot and leaf growth was maximum in the case

of S deficiency whereas Ca deficiency recorded the highest reduction in root growth by 61 per cent as compared to 7 per cent in Mg and 17 per cent in S deficient plants. The extent of reduction in shoot growth was 6, 13 and 48 per cent in the case of Ca, Mg and S deficiencies respectively. There was not much variation with respect to internodal length due to deficiency of secondary elements. The reduction in number of leaves was maximum in the case of S deficiency (63%) followed by Mg (7%) and Ca (1%) deficiencies. Leaf area index also showed 17 per cent reduction in the case of S deficiency as against 4 and 7 per cent respectively, in Ca and Mg deficiencies. The total dry matter production was not much affected by Ca (6%) and Mg (15%) deficiencies whereas a considerable reduction amounting to 63 per cent was observed in the case of S deficiency. The growth was completely arrested by 4.5 months after treatment due to S deficiency whereas no complete arrest of growth was observed even at very severe stage due to Ca and Mg deficiencies.

2.7 Iron deficiency

The results pertaining to the effect of Fe deficiency on vegetative growth are presented in Table 7 and Fig. 1, 4 and 5.

Table 7. Effect of deficiency of iron on vegetative characters

Stages of iron deficiency	Months after treatment	Length of vine (cm)	No. of leaves	Inter-nodal length (cm)	Leaf area index (cm^2)	Dry matter production (g)			
						Root	Shoot	Leaves	Total
Initial	4	70.1 (6)	11.5 (17)	5.5 (2)	75.5 (1)	1.2 (8)	21.5 (10)	18.2 (7)	40.9 (9)
Complete*	4	74.4	13.9	5.4	76.2	1.3	23.8	19.6	44.7
Medium	5	96.3 (9)	17.8 (27)	5.4 (26)	77.3 (7)	1.5 (17)	22.3 (32)	20.1 (26)	43.9 (29)
Complete*	5	105.4	24.5	4.3	83.0	1.8	32.6	27.3	61.7
Severe	7	162.3 (18)	35.3 (13)	4.6 (4)	81.4 (5)	2.6 (4)	36.5 (33)	39.9 (19)	79.0 (26)
Complete*	7	196.8	40.7	4.8	85.9	2.7	54.8	49.1	106.6
Very severe	9	175.2 (37)	37.0 (33)	4.7 (10)	80.2 (5)	3.0 (6)	39.6 (39)	40.2 (31)	82.8 (35)
Complete*	9	276.2	55.3	5.2	84.6	3.2	64.9	58.4	126.5

* Plants receiving complete nutrients

Figures given in parenthesis indicate percentage reduction from healthy vines

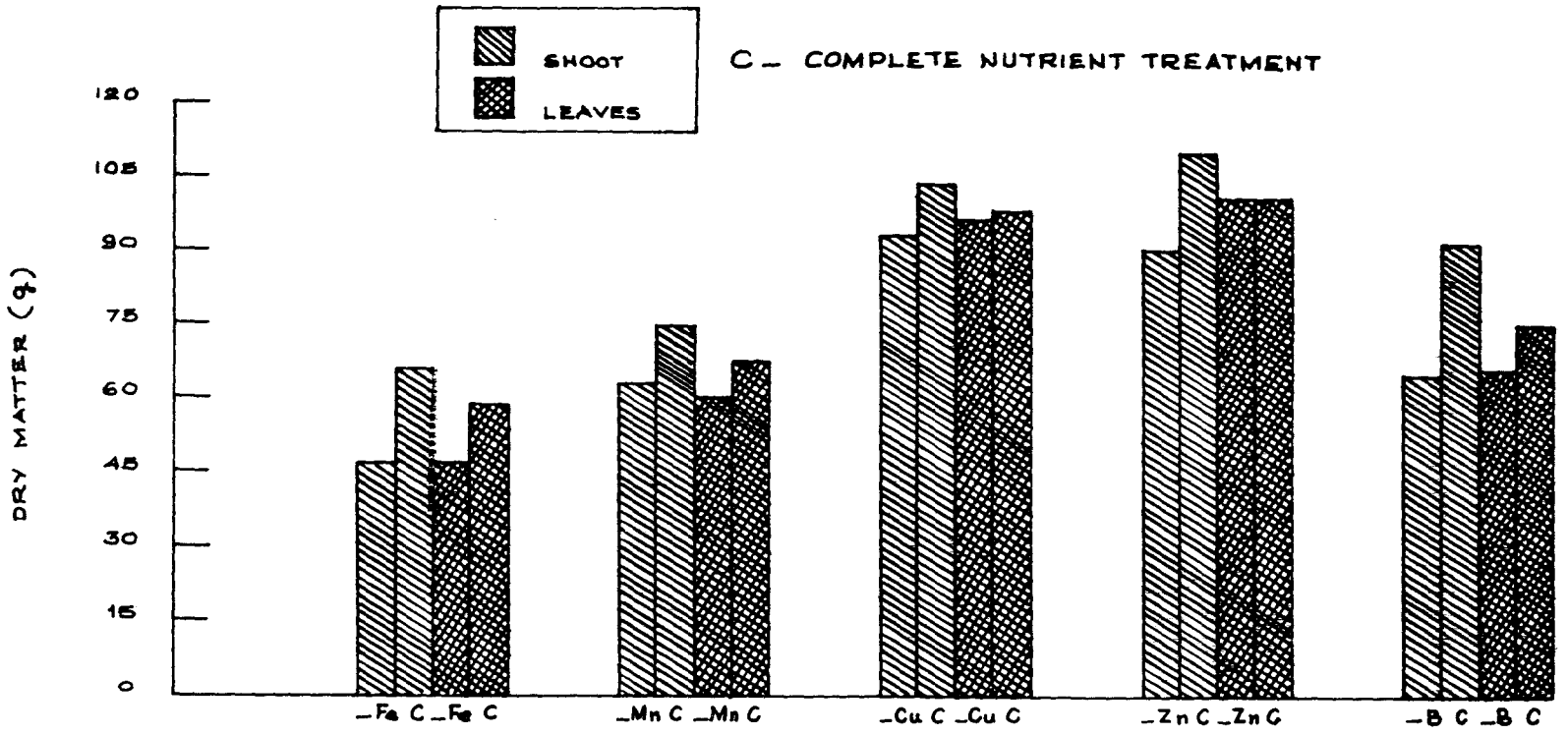


FIG: 4. EFFECT OF DEFICIENCY OF MICRONUTRIENTS ON SHOOT AND LEAF GROWTH(AT VERY SEVERE STAGE)

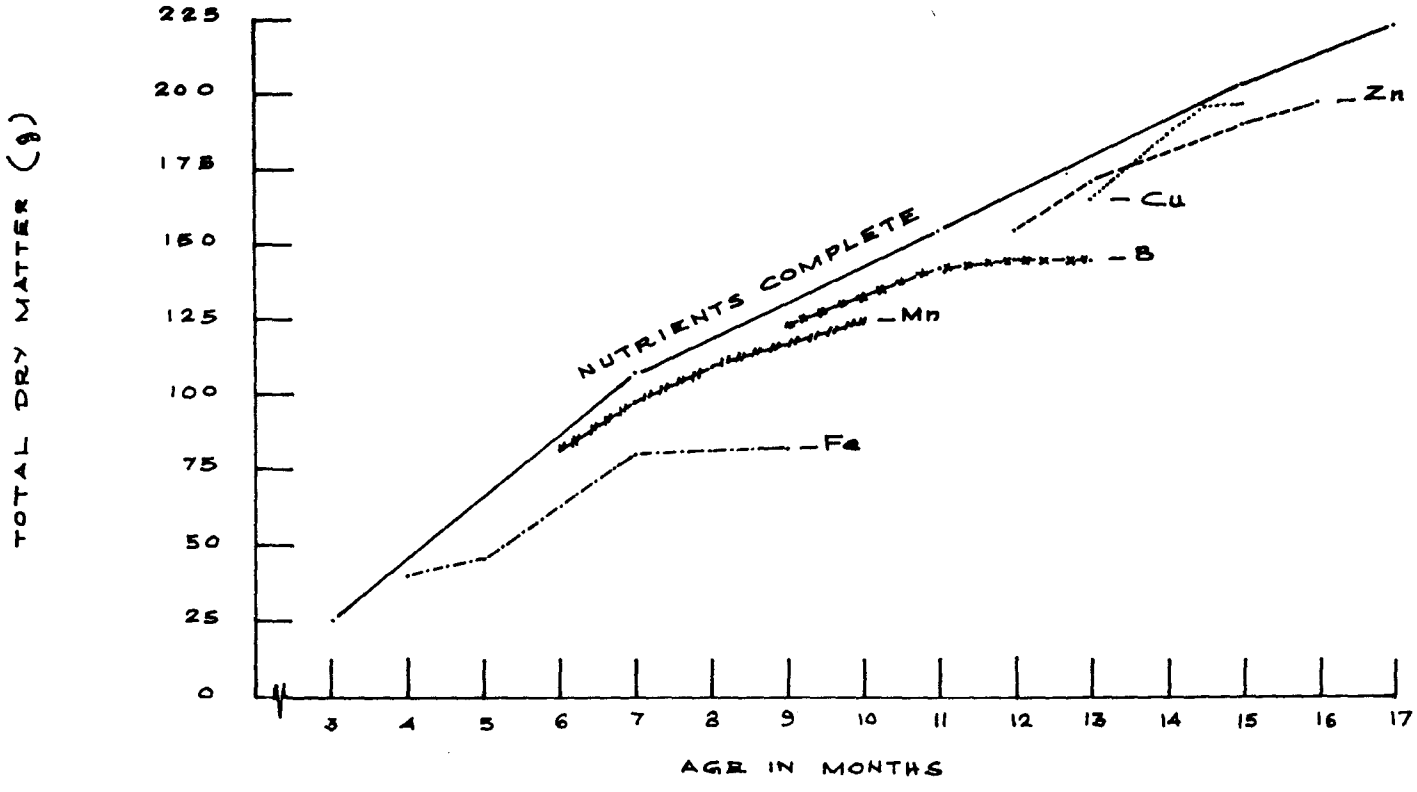


FIG: 5. DRY MATTER CONTENT AS INFLUENCED BY MICRONUTRIENTS AT DIFFERENT STAGES OF DEFICIENCY

It could be seen from the table that the reduction in growth of shoot varied from 4.3 to 101 cm (from initial to very severe stage) as compared to healthy plants. The extent of reduction was 6 per cent at initial stage which increased to 37 per cent in about five months time. The number of leaves recorded a decrease which was to the tune of 17 per cent during initial stage and 33 per cent during very severe stage. The actual number of leaves reduced ranged between 2.4 and 18.3 during a period of nine months (from initial to very severe stage). The reduction in internodal length varied from 0.1 to 0.5 cm within a period from four (initial) to nine (very severe) months which amounted 2 per cent and 10 per cent, respectively. The leaf area index also showed a slight reduction by 5 per cent at very severe stage.

The rate of reduction with respect to the dry weight of roots did not follow a specific pattern. The percentage reduction was 8 per cent during initial stage which increased to 17 per cent during the next stage. Thereafter, the rate of reduction was decreased to 4 per cent and again increased to 6 per cent during very severe stage (Fig.1). The shoot growth recorded a decrease by 10 per cent during the initial stage and by 39 per cent during very severe stage. The amount of reduction ranged between 2.3 g and 25.3 g. The dry matter of leaves got reduced by 1.4 g at the initial stage and showed 18.2 g reduction during very

severe stage (Fig.4). The percentage of reduction was 7 and 31 respectively, during the initial and very severe stages. The total dry matter content was reduced by 9 per cent during the initial stage and the rate of reduction went on increasing and reached 35 per cent in about five months (very severe stage). The growth was almost static from the seventh month onwards as proved by the data on total dry matter content (Fig.5).

Among the micronutrients, deficiency of Fe was found to affect vegetative growth at comparatively early stage (4 months after treatment). The shoot growth was reduced by 37 per cent, number of leaves by 33 per cent, internodal length by 10 per cent, dry matter of roots by 6 per cent, dry matter of shoot by 39 per cent, dry matter of leaves by 31 per cent and total dry matter by 35 per cent. The growth was practically nil from the seventh month onwards due to Fe deficiency.

2.8 Manganese deficiency

The extent of reduction of vegetative growth as a result of omission of Mn from the growing medium is presented in Table 8 and Fig. 1, 4 and 5.

No pronounced influence on vegetative growth could be observed by Mn deficiency. However, the length of vine showed a decrease by 4 to 10 per cent in a period of ten

Table 8. Effect of deficiency of manganese on vegetative characters

Stages of manganese deficiency	Months after treatment	Length of vine (cm)	No. of leaves	Inter-nodal length (cm)	Leaf area index (cm^2)	Dry matter production (g)			
						Root	Shoot	Leaves	Total
Initial	6	150.1 (4)	33.1 (5)	4.5 (0)	82.4 (5)	2.5 (0)	40.5 (10)	39.1 (2)	82.1 (6)
Complete*	6	156.2	34.8	4.5	86.8	2.5	45.1	40.0	87.6
Medium	7	185.6 (6)	38.4 (6)	4.7 (2)	81.6 (5)	2.5 (7)	51.6 (6)	44.2 (10)	98.3 (8)
Complete*	7	196.8	40.7	4.8	85.9	2.7	54.8	49.1	106.6
Severe	8	208.6 (12)	43.0 (12)	4.8 (2)	80.2 (7)	2.8 (10)	56.2 (11)	51.8 (9)	110.8 (10)
Complete*	8	236.0	48.6	4.9	85.9	3.1	62.9	56.8	122.8
Very severe	10	300.2 (10)	55.4 (9)	5.0 (7)	77.5 (6)	3.0 (14)	62.8 (16)	60.2 (11)	126.0 (14)
Complete*	10	331.9	61.2	5.4	82.4	3.5	75.1	68.0	146.6

* Plants receiving complete nutrients

Figures given parenthesis indicate percentage reduction from health vines

months (from initial to very severe stage). The reduction in length was 6.1 cm during the initial stage which was increased to 31.7 cm in about four months (very severe stage). The number of leaves and leaf area index were reduced by 5 per cent during the initial stage. However, the maximum reduction observed was during the severe stage in both cases (12% and 7% respectively). The internodal length also registered 7 per cent reduction in a period of ten months as compared to healthy vines.

The dry matter of root, shoot and leaves recorded a reduction by 14, 16 and 11 per cent respectively, during the very severe stage (Fig. 1 and 4). During the initial stage there was no reduction in root growth whereas the dry matter of shoot and leaves registered a decrease by 10 per cent and 2 per cent respectively. The total dry matter content also showed a reduction by 14 per cent during the very severe stage. The quantum of reduction was as much as 5.5 to 20.6 g during a period of ten months (initial to very severe stage). Eventhough the rate of growth was much reduced, complete arrest of growth could not be observed upto ten months after treatment (Fig.5).

There was reduction in shoot growth by 10 per cent, number of leaves by 12 per cent, internodal length by 7 per cent, leaf area index by 7 per cent, dry matter of root by 14 per cent, dry matter of shoot by 16 per cent, dry

matter of leaves by 11 per cent and total dry matter by 14 per cent. There was no complete arrest of growth as a result of Mn deficiency.

2.9 Copper deficiency

The results of the study on the effect of Cu deficiency on vegetative growth are furnished in Table 9 and Fig. 1, 4 and 5.

During the initial stage of Cu deficiency there was no marked reduction in vegetative growth. A reduction amounting to 10 per cent was observed in the case of shoot growth as compared to healthy vines during the very severe stage. The reduction in length of vine ranged between 15.8 cm and 46.0 cm within a period of 15 months (from initial to very severe stage). The reduction in number of leaves was only 0.5 per cent during the initial stage which increased to 7 per cent in about two months. The reduction in the case of internodal length and leaf area index was not so pronounced. However, a reduction by 4 per cent during the initial stage was observed in the case of internodal length. The reduction in leaf area index was maximum during medium stage (5%).

The dry matter of roots was reduced by 10 per cent during the initial stage which increased to 15 per cent within two months. The reduction ranged between 0.4g (intial) and 0.8 g (very severe) during a period of 15 months (Fig.1). The dry

Table 9. Effect of deficiency of copper on vegetative characters

Stages of copper deficiency	Months after treatment	Length of vine (cm)	No. of leaves	Inter-nodal length (cm)	Leaf area index (cm^2)	Dry matter production (g)			
						Root	Shoot	Leaves	Total
Initial	13	400.9	77.1	5.2	77.0	3.7	88.8	74.2	167.7
		(4)	(0.5)	(4)	(0.8)	(10)	(4)	(0.1)	(2)
Complete*	13	416.7	77.5	5.4	77.6	4.1	92.3	74.3	170.7
Medium	14	417.2	80.2	5.2	81.1	4.0	92.6	91.8	188.4
		(7)	(2)	(2)	(5)	(11)	(6)	(5)	(5)
Complete*	14	446.0	82.1	5.3	85.6	4.5	98.1	96.6	199.2
Severe	14.5	420.0	82.4	5.1	80.5	4.4	93.3	95.8	193.4
		(8)	(4)	(2)	(2)	(14)	(8)	(1)	(5)
Complete*	14.5	455.2	85.4	5.2	82.3	5.1	101.0	97.0	203.1
Very severe	15	420.0	82.4	5.1	81.0	4.7	93.3	95.8	193.8
		(10)	(7)	(0)	(0.7)	(15)	(10)	(2)	(6)
Complete*	15	466.0	89.0	5.1	81.6	5.5	103.2	98.0	206.7

* Plants receiving complete nutrients

Figures given in parenthesis indicate percentage reduction from health vines

matter content of shoot and leaves also got reduced by 10 per cent and 2 per cent respectively, during the very severe stage. The results suggested that Cu deficiency could affect the crop growth only at a later stage of 14.5 months after treatment (Fig.5).

Copper deficiency resulted in a reduction of shoot growth by 10 per cent, number of leaves by 7 per cent, dry matter of root by 15 per cent, dry matter of shoot by 10 per cent and total dry matter content by 6 per cent. Growth of vine in terms of total dry matter content was completely arrested by 14.5 months after treatment due to Cu deficiency.

2.10 Zinc deficiency

The results on the effect of Zn deficiency on vegetative growth are presented in Table 10 and Fig. 1, 4 and 5.

The decrease in length of vine ranged between 23.5 cm (initial) and 80.2 cm (very severe) within a period of 16 months after treatment as compared to healthy vines. The magnitude of reduction was 6 per cent during the initial stage which increased upto 16 per cent in about four months. In contrast to other vegetative characters, the number of leaves which was 2 per cent less than the normal vines during the initial stage recorded an increase by 6 per cent during the very severe stage. The internodal length was

Table 10. Effect of deficiency of zinc on vegetative characters

Stages of zinc deficiency	Months after treatment	Length of vine (cm)	No. of leaves	Inter-nodal length (cm)	Leaf area index (cm^2)	Dry matter production (g)			
						Root	Shoot	Leaves	Total
Initial	12	365.2 (-6)	67.7 (-3)	5.3 (-4)	65.2 (-16)	3.5 (-10)	81.3 (-7)	70.6 (-3)	155.4 (-6)
Complete*	12	388.7	70.1	5.5	78.0	3.9	87.8	72.5	164.2
Medium	13	394.8 (-5)	78.9 (+2)	5.0 (-7)	61.3 (-21)	3.8 (-7)	87.6 (-5)	76.2 (-3)	167.6 (-2)
Complete*	13	416.7	77.5	5.4	77.6	4.1	92.3	74.3	170.7
Severe	15	405.0 (-13)	94.1 (+6)	4.3 (-16)	55.4 (-32)	5.0 (-9)	90.0 (-13)	95.1 (-3)	190.1 (-8)
Complete*	15	466.0	89.0	5.1	81.6	5.5	103.2	98.0	206.7
Very severe	16	410.6 (-16)	101.1 (+6)	4.0 (-20)	50.0 (-40)	5.6 (-14)	91.2 (-16)	100.4 (-1)	197.2 (-9)
Complete*	16	490.8	95.0	5.0	83.8	6.5	108.9	101.0	216.4

* Plants receiving complete nutrients

Figures given in parenthesis indicate percentage variation from health vines

reduced by 4 per cent during the initial stage and by 20 per cent in about four months after the occurrence of initial symptoms. The reduction ranged between 0.2 cm and 1.0 cm in a period of 16 months. The quantum of reduction in leaf area index ranged between 12.8 cm^2 and 33.8 cm^2 within a period of four months after the initiation of deficiency. The magnitude of reduction was 16 per cent during the initial stage which increased upto 40 per cent at the very severe stage.

The dry matter content of root, shoot and leaves recorded a reduction by 14, 16 and 1 per cent respectively, during the very severe stage of deficiency (Fig.1 and 4). The reduction in total dry matter content varied between 8.8 g (initial) and 19.2 g (very severe) in 16 months. The extent of reduction was 9 per cent during the very severe stage which was 6 per cent at the initial stage. However, complete cessation of growth was not observed (Fig.5).

The extent of reduction in shoot growth was 16 per cent, internodal length 20 per cent, leaf area index 40 per cent, dry matter of root 14 per cent, dry matter of shoot 16 per cent and total dry matter 9 per cent. There was no complete arrest of growth due to Zn deficiency as evidenced by the total dry matter production.

2.11 Boron deficiency

The data related with the effect of B deficiency on vegetative growth are presented in Table 11 and depicted in Fig. 1, 4 and 5.

The results revealed that the deficiency of B could inhibit growth at comparatively early period. There was reduction in length of vine which ranged between 10.7 cm and 130.3 cm from initial to very severe stage as compared to healthy vines. The extent of decrease was 4 per cent at the initial stage which was increased upto 31 per cent in about four months (very severe stage). The number of leaves showed a reduction by 30 per cent during the very severe stage whereas the leaf area recorded an increase by 18 per cent during the same stage. The reduction in leaf number during the initial stage was 8 per cent and the increase in leaf area was 1 per cent. There was practically no variation in internodal length as compared to that of the healthy vines. However, a slight reduction by 4 per cent was observed during the severe stage.

The dry matter of roots showed a reduction by 6 per cent (0.2 g) during the initial stage and 10 per cent (0.4 g) at very severe stage (Fig.1). The dry matter of shoot and leaves recorded a reduction by 31 per cent and 13 per cent respectively, during the very severe stage (Fig.4). The quantum

Table 11. Effect of deficiency of boron on vegetative characters

Stages of boron deficiency	Months after treatment	Length of vine (cm)	No. of leaves	Inter-nodal length (cm)	Leaf area index (cm^2)	Dry matter production (g)			
						Root	Shoot	Leaves	Total
Initial	9	265.5 (-4)	50.9 (-8)	5.2 (0)	85.8 (+1)	3.0 (-6)	58.8 (-9)	58.2 (-0.3)	121.0 (-4)
Complete*	9	276.2	55.3	5.2	84.6	3.2	64.9	58.4	126.5
Medium	11	280.2 (-23)	53.8 (-19)	5.2 (-2)	89.7 (+16)	3.1 (-11)	62.2 (-23)	63.5 (-9)	128.8 (-17)
Complete*	11	365.6	66.8	5.3	77.2	3.5	81.1	70.0	154.6
Severe	12	286.4 (-26)	54.5 (-22)	5.3 (-4)	91.9 (+18)	3.5 (-10)	63.6 (-28)	65.0 (-10)	132.1 (-20)
Complete*	12	388.7	70.1	5.5	78.0	3.9	87.8	72.5	164.2
Very severe	13	286.4 (-31)	54.5 (-30)	5.3 (-2)	91.9 (+18)	3.7 (-10)	63.6 (-31)	65.0 (-13)	132.3 (-22)
Complete*	13	416.7	77.5	5.4	77.6	4.1	92.3	74.3	170.7

* Plants receiving complete nutrients

Figures given in parenthesis indicate percentage variation from healthy vines

of reduction ranged between 6.1 g and 20.7 g in respect of shoot and from 0.2 to 9.3 g in the case of leaves from initial to very severe stage. The total dry matter content showed a reduction by 4 per cent during the initial stage and 22 per cent during the very severe stage. The growth was practically arrested by the twelfth month after treatment as could be seen from Fig. 5.

There was a decrease of 31 per cent in length of vine, 30 per cent in number of leaves, 10 per cent in dry matter of roots, 31 per cent in dry matter of shoots, 13 per cent in dry matter of leaves and 22 per cent in total dry matter content. The leaf area recorded an increase by 18 per cent. The vegetative growth was completely arrested by twelfth month after treatment.

The deficiency symptom of Fe was found to occur at an early stage (4th month) as compared to other micronutrients whereas deficiency of Cu manifested only at a later stage i.e., 13 months after treatment. The length of vine and number of leaves recorded a reduction by 37 per cent and 33 per cent respectively, due to Fe deficiency. Boron deficiency resulted in a reduction in length of vine and number of leaves by 31 per cent and 30 per cent respectively. In contrast to other micronutrients, the deficiency of B resulted in an increase in leaf area index by 18 per cent. The reduction in leaf area index and internodal length due to Zn deficiency was 40 and 20 per cent respectively.

There was not much variation from the healthy vines with respect to vegetative characters as a result of deficiency of Mn and Cu. Growth was completely arrested by 7, 14.5 and 12 months after treatment due to deficiency of Fe, Cu and B respectively. But in the case of Mn and Zn, complete inhibition of growth was not observed even at the very severe stage of deficiency though the rate of reduction of growth has increased with the advancement of deficiency.

3. Effect of nutrient deficiencies on the foliar composition

Appearance of visual symptoms on the plant is an indication of probable nutrient deficiency. Foliar nutrient concentrations could provide often confirmatory evidence regarding the nutrient(s) which may be deficient.

3.1 Nitrogen deficiency

The data on the foliar nutrient concentration at different stages of N deficiency are presented in Table 12.

There was a gradual decrease in foliar N level with increasing severity of the deficiency. Nitrogen level in the leaves of healthy plants was found to be 3.01 to 3.30 per cent while it decreased in deficient plants. During the initial stage of deficiency, the actual foliar content of N was 2.45 per cent (-19%). Further drop to 1.56 per cent (-53%) in foliar level occurred within a period of four months.

Table 12. Foliar composition of nutrients at different stages of nitrogen deficiency

Stages of nitrogen deficiency	Months after treatment	Macronutrients (%)						Micronutrients (ppm)				
		N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B
Initial	4	2.45 (-19)	0.285 (+2)	2.95 (-0.3)	1.57 (-7)	1.030 (-21)	0.163 (-16)	121 (-2)	72 (-4)	95 (-9)	55 (-10)	46 (-4)
Complete*	4	3.01	0.280	2.96	1.68	1.301	0.195	123	75	104	61	48
Medium	5	2.20 (-29)	0.302 (+4)	2.95 (0)	2.04 (-1)	1.303 (-7)	0.188 (-10)	125 (-2)	75 (-4)	122 (-2)	65 (-4)	50 (0)
Complete*	5	3.12	0.291	2.95	2.06	1.405	0.210	128	78	125	68	50
Severe	6	2.01 (-38)	0.325 (+9)	2.89 (0)	2.04 (-4)	1.278 (-12)	0.199 (-6)	135 (-13)	78 (-7)	120 (-2)	63 (-3)	46 (-6)
Complete*	6	3.25	0.297	2.89	2.12	1.451	0.212	156	84	123	65	49
Very severe	8	1.56 (-53)	0.331 (+10)	2.90 (-3)	2.11 (-5)	1.201 (-23)	0.200 (-7)	121 (-36)	79 (-7)	122 (-5)	61 (-10)	45 (-12)
Complete*	8	3.30	0.301	3.00	2.23	1.568	0.215	188	85	128	68	51

* Plants receiving complete nutrients

Figures given in parenthesis indicate the percentage variation from normal value

The concentrations of other nutrients were also affected by N deficiency at varying magnitude. Pronounced decrease could be observed in the case of Mg and Fe which recorded a reduction by 23 per cent (1.201%) and 36 per cent (121 ppm) respectively, at the very severe stage. The extent of reduction during the initial stage was 21 per cent (1.030%) in Mg and 2 per cent (121 ppm) in respect of Fe. The elements P, Zn and B have also registered a slight decrease by 10 per cent and 12 per cent during initial and very severe stages, respectively.

Omission of N from the growing medium resulted in a decrease in foliar concentration of N by 53 per cent (1.56%), Mg by 23 per cent (1.201%) and Fe by 36 per cent (121 ppm).

3.2 Phosphorus deficiency

Table 13 represents the data pertaining to the foliar composition of nutrients at different stages of P deficiency.

Phosphorus deficiency was associated with a decrease in foliar content of P amounting to 33 per cent in the initial stage which increased upto 65 per cent in a period of three and a half months (very severe stage). Initial symptoms of P deficiency occurred when the leaf concentration of P was reduced to 0.2 per cent. During the course of development of deficiency, the P content continued to reduce and reached 0.11 per cent at the very severe stage.

Table 13. Foliar composition of nutrients at different stages of phosphorus deficiency

Stages of phosphorus deficiency	Months after treatment	Macronutrients (%)						Micronutrients (ppm)				
		N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B
Initial	10	3.25 (-2)	0.200 (-33)	2.98 (-1)	2.11 (-4)	1.453 (-2)	0.200 (-2)	188 (-1)	83 (-2)	118 (-2)	65 (-4)	48 (0)
Complete*	10	3.30	0.299	3.00	2.20	1.482	0.204	190	85	121	68	48
Medium	12	3.31 (+2)	0.178 (-41)	3.01 (-2)	2.21 (-1)	1.498 (-0.1)	0.210 (-2)	196 (+0.5)	85 (-2)	122 (-2)	71 (+1)	51 (+2)
Complete*	12	3.24	0.300	3.08	2.18	1.500	0.215	195	87	125	70	50
Severe	13	3.30 (-1)	0.115 (-63)	3.00 (-1)	2.09 (-7)	1.512 (-1)	0.213 (-3)	199 (+0.5)	82 (-5)	125 (-2)	70 (0)	48 (-2)
Complete*	13	3.33	0.310	3.04	2.25	1.501	0.219	198	86	127	70	49
Very severe	13.5	3.31 (-1)	0.110 (-65)	3.02 (-1)	2.11 (-6)	1.500 (-0.5)	0.211 (-4)	200 (-1)	85 (-2)	125 (-1)	72 (+1)	49 (-2)
Complete*	13.5	3.35	0.310	3.06	2.25	1.493	0.220	203	87	126	71	50

* Plants receiving complete nutrients

Figures given in parenthesis indicate the percentage variation from normal value

The P content of the healthy vines varied between 0.299 per cent and 0.310 per cent during a period of 13.5 months. Omission of P from the growing medium could not influence the foliar concentration of other nutrients to a considerable extent.

Visual symptoms of P deficiency was concurred with a reduction in foliar concentration of P by 65 per cent (0.11%). Not much variation from the normal value could be observed with respect to the foliar contents of other nutrients.

3.3 Potassium deficiency

The results on the effect of K deficiency on the foliar composition of nutrients are presented in Table 14 and Fig.6.

Deficiency of K was associated with a depression in leaf K content. The percentage of K during the initial stage of deficiency was 2.10 per cent as against the normal value of 2.95 per cent during the corresponding period. Right from the initiation of deficiency, the K content went on decreasing and registered a value as low as 1 per cent (normal value was 2.87%) during the very severe stage. The extent of reduction was 29 per cent at the initial state which was increased upto 65 per cent within a period of two months.

Concomitant to the decrease in K content, pronounced increases in foliar Ca and Mg levels was observed (Fig.6).

Table 14. Foliar composition of nutrients at different stages of potassium deficiency

Stages of potassium deficiency	Months after treatment	Macronutrients (%)						Micronutrients (ppm)				
		N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B
Initial	5	3.11 (-0.3)	0.290 (-0.3)	2.10 (-29)	2.00 (-3)	1.418 (+1)	0.200 (-5)	125 (-2)	76 (-3)	121 (-3)	69 (+1)	45 (-10)
Complete*	5	3.12	0.291	2.95	2.06	1.405	0.210	128	78	125	68	50
Medium	5.5	3.00 (-3)	0.293 (-1)	1.50 (-48)	2.25 (+13)	1.632 (+17)	0.213 (+1)	150 (+1)	81 (+1)	122 (-1)	63 (-2)	49 (-2)
Complete*	5.5	3.10	0.295	2.90	2.00	1.411	0.210	149	80	123	64	50
Severe	6	3.18 (-2)	0.291 (-2)	1.20 (-58)	2.48 (+17)	1.713 (+18)	0.211 (-0.5)	156 (0)	80 (-5)	121 (-2)	66 (+2)	51 (+4)
Complete*	6	3.25	0.297	2.89	2.12	1.451	0.212	156	84	123	65	49
Very severe	7	3.21 (-1)	0.295 (-1)	1.00 (-65)	2.65 (+25)	1.800 (+24)	0.210 (+5)	160 (+1)	85 (-1)	124 (-1)	62 (-2)	50 (0)
Complete*	7	3.24	0.298	2.87	2.12	1.448	0.200	158	86	125	63	50

* Plants receiving complete nutrients

Figures given in parenthesis indicate the percentage variation from normal value

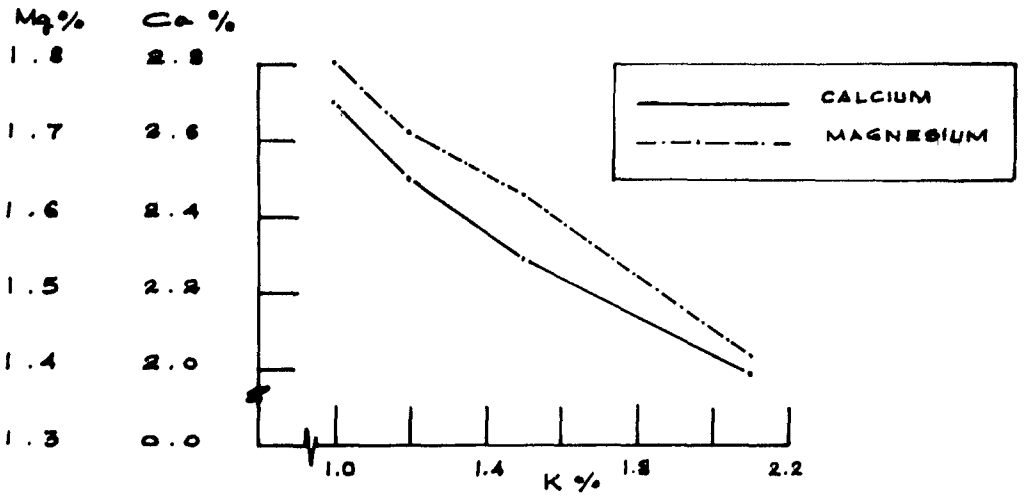


FIG: 6. EFFECT OF POTASSIUM ON FOLIAR CALCIUM AND MAGNESIUM

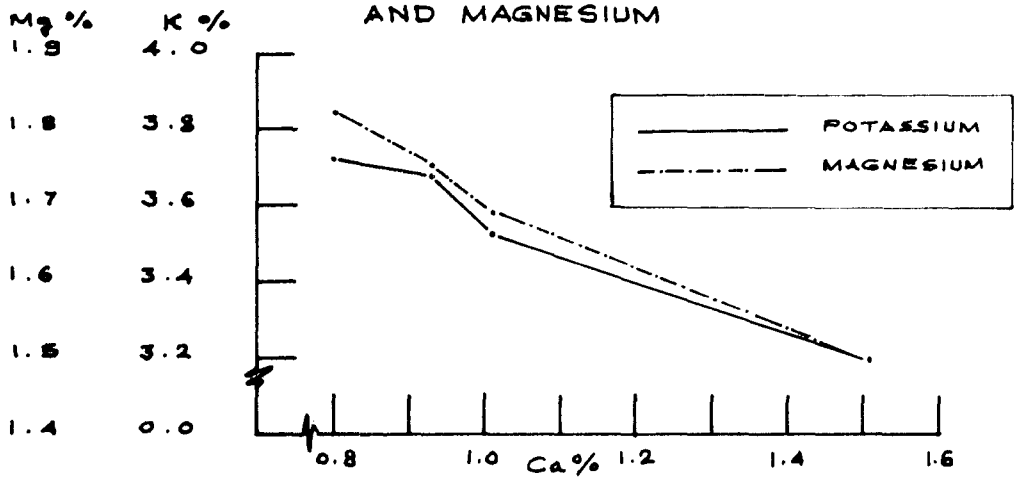


FIG: 7. EFFECT OF CALCIUM ON FOLIAR POTASSIUM AND MAGNESIUM

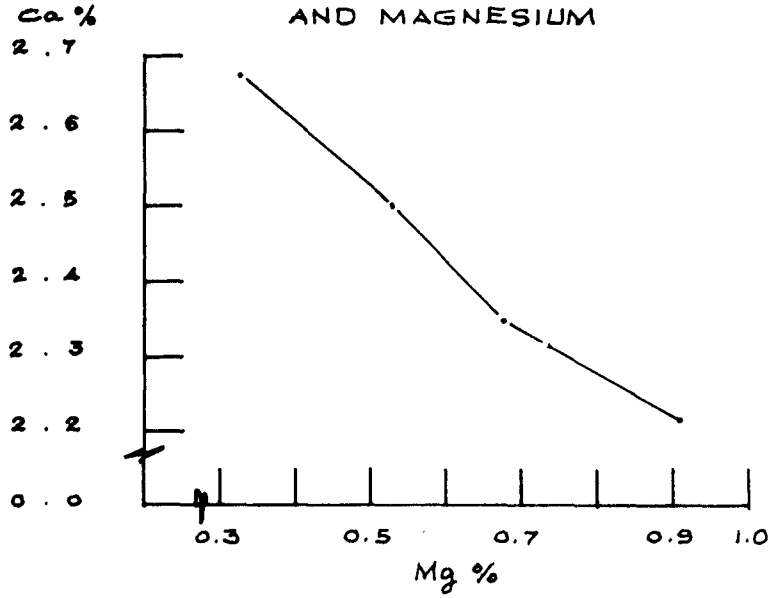


FIG: 8. EFFECT OF MAGNESIUM ON FOLIAR CALCIUM

The increase in Ca content was as much as 25 per cent (2.65%) and that of Mg was 24 per cent (1.80%). The actual content of Ca in leaves during the initial stage was 2 per cent (3% less than normal) which increased upto 2.65 per cent within a period of two months. The Mg content of the K deficient vines ranged between 1.418 per cent and 1.800 per cent during a period of seven months. Potassium failed to establish any profound influence on the concentration of other macro and micro-nutrients.

There was reduction in foliar concentration of K by 65 per cent (1.00%) and increase in Ca and Mg contents by 25 per cent (2.65%) and 24 per cent (1.80%) respectively, due to K deficiency. The results suggested that foliar level of K for normal vegetative growth was a value above 2.1 per cent.

3.4 Calcium deficiency

The data on the foliar nutrient concentration at different stages of Ca deficiency are furnished in Table 15 and depicted in Fig.7.

Results indicated that there was an appreciable reduction in foliar Ca content of plants receiving minus Ca treatment. The Ca content of the healthy vines ranged between 2.25 per cent and 2.31 per cent whereas that of Ca

Table 15. Foliar composition of nutrients at different stages of calcium deficiency

Stages of calcium deficiency	Months after treatment	Macronutrients (%)						Micronutrients (ppm)				
		N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B
Initial	14	3.00 (-9)	0.293 (-2)	3.20 (+3)	1.51 (-32)	1.502 (+1)	0.215 (-2)	201 (-2)	89 (+1)	121 (-3)	71 (+1)	50 (-2)
Complete*	14	3.30	0.300	3.12	2.25	1.480	0.219	205	88	125	70	51
Medium	15.5	3.20 (-5)	0.309 (-0.6)	3.51 (+15)	1.01 (-56)	1.689 (+11)	0.220 (-2)	210 (+1)	87 (-4)	126 (-4)	65 (-4)	48 (-4)
Complete*	15.5	3.37	0.311	3.05	2.30	1.513	0.225	208	91	131	68	50
Severe	16	3.08 (-8)	0.318 (+4)	3.68 (+19)	0.93 (-59)	1.750 (+16)	0.211 (-5)	212 (+1)	90 (0)	125 (-2)	70 (-3)	49 (+2)
Complete*	16	3.35	0.305	3.10	2.31	1.500	0.221	210	90	128	72	48
Very severe	17	3.21 (-2)	0.315 (+2)	3.72 (+18)	0.80 (-65)	1.816 (+21)	0.215 (-1)	211 (-2)	88 (-2)	129 (-1)	71 (-1)	50 (-2)
Complete*	17	3.29	0.310	3.14	2.30	1.491	0.218	215	90	130	72	51

* Plants receiving complete nutrients

Figures given in parenthesis indicate the percentage variation from normal value

deficient vines decreased with the increase in the severity of deficiency. During the initial stage, the actual foliar content of Ca was 1.51 per cent which was 32 per cent lower than the normal value. The extent of reduction was increased upto 65 per cent (actual foliar Ca content was 0.8%) in a period of three months which corresponded to the very severe stage.

The reduction in Ca content was also accompanied by a rise in leaf K and Mg by 18 and 21 per cent respectively (Fig.8). No marked variation was observed in the foliar concentration of other nutrients.

Deficiency of Ca was associated with a reduction in the foliar concentration of the element by 65 per cent (0.8%) and an increase in K and Mg by 18 and 21 per cent respectively. Above 1.51 per cent foliar Ca was found to be essential for normal growth.

3.5 Magnesium deficiency

The results pertaining to the foliar nutrient composition as influenced by Mg deficiency are presented in Table 16 and Fig. 8.

Deficiency of Mg concurred with a fall in the foliar concentration of Mg by 39 per cent during the initial stage which was increased upto 78 per cent within a period of three months (very severe stage). The actual content of Mg

Table 16. Foliar composition of nutrients at different stages of magnesium deficiency

Stages of magnesium deficiency	Months after treatment	Macronutrients (%)						Micronutrients (ppm)				
		N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B
Initial	11	3.20 (-0.3)	0.310 (+3)	3.16 (+2)	2.20 (+7)	0.913 (-39)	0.200 (-5)	195 (+1)	89 (+2)	125 (0)	66 (-3)	50 (-2)
Complete*	11	3.21	0.300	3.10	2.05	1.500	0.210	193	87	125	68	51
Medium	12	3.11 (-4)	0.299 (-3)	3.09 (+0.3)	2.35 (+8)	0.675 (-55)	0.211 (-2)	190 (-3)	85 (-2)	126 (+1)	69 (-1)	48 (-4)
Complete*	12	3.24	0.300	3.08	2.18	1.500	0.215	195	87	125	70	50
Severe	13	3.08 (-8)	0.286 (-8)	3.05 (+0.3)	2.51 (+12)	0.531 (-65)	0.220 (+5)	197 (-1)	86 (0)	124 (-2)	71 (+1)	51 (+4)
Complete*	13	3.33	0.310	3.04	2.25	1.501	0.219	198	86	127	70	49
Very severe	14	3.20 (-3)	0.295 (-2)	3.22 (+3)	2.68 (+19)	0.330 (-78)	0.218 (-0.4)	200 (-2)	85 (-3)	121 (-3)	68 (-3)	50 (-2)
Complete*	14	3.30	0.300	3.12	2.25	1.480	0.219	205	88	125	70	51

* Plants receiving complete nutrients

Figures given in parenthesis indicate the percentage variation from normal value

decreased from 0.913 to 0.330 per cent from initial to very severe stage. The concentrations of Mg in the healthy vines during the corresponding periods were 1.5 per cent and 1.48 per cent respectively.

The Ca content of the Mg deficient vines increased with the advancement of deficiency (Fig.8). The concentration of Ca was 2.2 per cent during the initial stage of Mg deficiency which was increased upto 2.68 per cent at the very severe stage. The magnitude of increase over the healthy vine was 7 per cent and 19 per cent during the corresponding periods. Though K content also registered an increasing trend, the extent of increase was only upto 3 per cent. No appreciable variation was observed with respect to the foliar content of other nutrients due to Mg deficiency.

Magnesium deficient vines registered a reduction in foliar Mg by 78 per cent (0.33%) and an increase in Ca content by 19 per cent (2.68%).

3.6 Sulphur deficiency

The data on the influence of the element S on the concentration of foliar nutrients are furnished in Table 17.

There was a high degree of reduction in the foliar S content due to the omission of S from the growing medium.

Table 17. Foliar composition of nutrients at different stages of sulphur deficiency

Stages of sulphur deficiency	Months after treatment	Macronutrients (%)						Micronutrients (ppm)				
		N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B
Initial	3	2.61 (+2)	0.275 (+4)	2.69 (-3)	1.52 (+1)	1.088 (-2)	0.121 (-33)	120 (+0.8)	70 (-1)	100 (+5)	58 (+5)	43 (+5)
Complete*	3	2.56	0.265	2.78	1.50	1.111	0.180	119	71	95	55	41
Medium	4	2.95 (-2)	0.281 (+0.4)	2.80 (-5)	1.71 (+2)	1.291 (-0.8)	0.088 (-55)	121 (-2)	74 (-1)	108 (+4)	62 (+2)	47 (-2)
Complete*	4	3.01	0.280	2.96	1.68	1.301	0.195	123	75	104	61	48
Severe	4.5	3.00 (-4)	0.283 (-0.7)	2.91 (-1)	1.85 (-6)	1.395 (-0.4)	0.063 (-70)	123 (-2)	76 (-3)	115 (+5)	63 (-3)	50 (+2)
Complete*	4.5	3.11	0.285	2.94	1.97	1.400	0.210	125	78	110	65	49
Very severe	5	3.03 (-3)	0.290 (-0.3)	2.90 (-2)	2.00 (-3)	1.412 (+0.5)	0.040 (-80)	126 (-2)	77 (-1)	122 (-2)	65 (-4)	51 (+2)
Complete*	5	3.12	0.291	2.95	2.06	1.405	0.210	128	78	125	68	50

* Plants receiving complete nutrients

Figures given in parenthesis indicate the percentage variation from normal value

The extent of decrease was to the tune of 33 per cent during the initial stage which increased upto 80 per cent within a period of two months. The actual S content of the deficient vines varied from 0.121 to 0.04 per cent and that of healthy vine from 0.18 to 0.21 per cent during a period of five months (from initial to very severe stage). The influence of S on the foliar level of other nutrients was found to be very meagre.

There was a reduction in foliar S by 80 per cent (0.04%) due to S deficiency. It was also observed that the foliar level of S should be above 0.121 per cent for normal growth of young vines.

3.7 Iron deficiency

From the data presented in Table 18 it could be observed that the visual symptoms of Fe deficiency was associated with a steep reduction in the foliar concentration of that element. The quantum of reduction ranged between 29 ppm and 131 ppm from initial to very severe stage. During the initial stage of deficiency, the extent of decrease was 24 per cent which increased to 68 per cent in about five months (very severe stage). The influence of Fe on the leaf content of other nutrients was negligible.

There was reduction in foliar content of Fe by 68 per cent (61 ppm) due to Fe deficiency. The growth of

Table 18. Foliar composition of nutrients at different stages of iron deficiency

Stages of iron deficiency	Months after treatment	Macronutrients (%)						Micronutrients (ppm)				
		N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B
Initial	4	3.22 (+7)	0.281 (+0.4)	2.87 (-3)	1.61 (-4)	1.193 (-8)	0.190 (-3)	94 (-24)	74 (-1)	103 (-1)	58 (-5)	49 (+2)
Complete*	4	3.01	0.280	2.96	1.68	1.301	0.195	123	75	104	61	48
Medium	5	3.19 (+2)	0.285 (-2)	2.91 (-1)	1.92 (-7)	1.285 (-9)	0.200 (-5)	88 (-31)	76 (-3)	122 (-2)	66 (-3)	51 (+2)
Complete*	5	3.12	0.291	2.95	2.06	1.405	0.210	128	78	125	68	50
Severe	7	3.20 (-1)	0.296 (-7)	2.98 (+4)	2.00 (-6)	1.369 (-5)	0.210 (+5)	75 (-53)	83 (-3)	126 (+0.8)	70 (+11)	50 (0)
Complete*	7	3.24	0.298	2.87	2.12	1.448	0.200	158	86	125	63	50
Very severe	9	3.30 (+0.3)	0.299 (-2)	3.00 (-3)	2.06 (-6)	1.481 (-2)	0.215 (-0.5)	61 (-68)	85 (0)	125 (-3)	71 (+3)	51 (+4)
Complete*	9	3.29	0.304	3.10	2.18	1.506	0.216	192	85	129	69	49

* Plants receiving complete nutrients

Figures given in parenthesis indicate the percentage variation from normal value

young vine was not affected by omission of Fe until the leaf concentration of Fe was reduced to 94 ppm.

3.8 Manganese deficiency

The data relating to the foliar composition of nutrients at different stages of Mn deficiency are presented in Table 19.

There was reduction in foliar Mn content, the amount of reduction being 30 ppm and 56 ppm during initial and very severe stages respectively. The rate of reduction has increased with the severity of deficiency and reached 66 per cent (29 ppm) by the tenth month which was only 36 per cent (54 ppm) during the initial stage. A slight reduction in Fe content was also observed which amounted to 14 per cent (161 ppm) at the severe stage and 8 per cent (175 ppm) during the very severe stage.

The reduction in foliar Mn content due to Mn deficiency was 66 per cent (29 ppm). Concurrent with Mn deficiency a slight reduction in Fe by 14 per cent was also observed. The Mn content of plants under complete nutrient treatment ranged between 84 ppm and 86 ppm while at the initial stage of deficiency it was 54 ppm.

3.9 Copper deficiency

Table 20 represents the data on the foliar concentration of nutrients at different stages of Cu deficiency.

Table 19. Foliar composition of nutrients at different stages of manganese deficiency

Stages of manganese deficiency	Months after treatment	Macronutrients (%)						Micronutrients (ppm)				
		N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B
Initial	6	3.11 (-4)	0.285 (-4)	2.92 (+1)	2.20 (+4)	1.450 (+3)	0.200 (-6)	152 (-3)	54 (-36)	121 (-2)	60 (-8)	45 (-8)
Complete*	6	3.25	0.297	2.89	2.12	1.451	0.212	156	84	123	65	49
Medium	7	3.26 (+0.6)	0.300 (+0.7)	2.90 (+1)	2.20 (+4)	1.500 (+4)	0.210 (+5)	155 (-2)	40 (-53)	124 (-0.8)	62 (-2)	48 (-4)
Complete*	7	3.24	0.298	2.87	2.12	1.448	0.200	158	86	125	63	50
Severe	8	3.25 (-2)	0.300 (-0.3)	3.00 (0)	2.22 (-4)	1.513 (-4)	0.213 (-1)	161 (-14)	36 (-58)	126 (-2)	65 (-4)	50 (-2)
Complete*	8	3.30	0.301	3.00	2.23	1.568	0.215	188	85	128	68	51
Very severe	10	3.20 (-3)	0.301 (+0.7)	2.98 (-0.7)	2.20 (0)	1.500 (+1)	0.208 (+2)	175 (-8)	29 (-66)	129 (+7)	67 (-1)	50 (+4)
Complete*	10	3.30	0.299	3.00	2.20	1.482	0.204	190	85	121	68	48

* Plants receiving complete nutrients

Figures given in parenthesis indicate the percentage variation from normal value

Table 20. Foliar composition of nutrients at different stages of copper deficiency

Stages of copper deficiency	Months after treatment	Macronutrients (%)						Micronutrients (ppm)				
		N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B
Initial	13	2.95 (-11)	0.315 (+2)	3.00 (-1)	2.26 (+0.4)	1.451 (-3)	0.205 (-6)	190 (-4)	88 (+2)	50 (-61)	71 (+1)	45 (+10)
Complete*	13	3.33	0.310	3.04	2.25	1.501	0.219	198	86	127	70	49
Medium	14	3.08 (-7)	0.311 (-4)	3.10 (-0.6)	2.20 (-2)	1.468 (-0.8)	0.215 (-2)	200 (-2)	89 (+1)	46 (-63)	68 (-3)	48 (-6)
Complete*	14	3.30	0.300	3.12	2.25	1.480	0.219	205	88	125	70	51
Severe	14.5	3.10 (-6)	0.299 (+3)	3.09 (+3)	2.11 (-4)	1.500 (+3)	0.211 (-4)	202 (-3)	85 (-6)	37 (-71)	72 (+6)	46 (-4)
Complete*	14.5	3.30	0.289	3.00	2.20	1.450	0.220	208	90	128	68	48
Very severe	15	3.26 (-3)	0.310 (+3)	3.20 (-1)	2.25 (-3)	1.503 (+5)	0.220 (+1)	205 (-2)	87 (-3)	30 (-76)	70 (-1)	49 (-2)
Complete*	15	3.35	0.302	3.24	2.31	1.431	0.218	210	90	126	71	50

* Plants receiving complete nutrients

Figures given in parenthesis indicate the percentage variation from normal value

The absence of Cu in the growing medium has highly affected the concentration of that element in the leaf. During the initial stage of deficiency, the foliar content of Cu was 50 ppm which was 61 per cent less than that of the normal vines (127 ppm). The extent of reduction was 76 per cent (30 ppm) at the fifteenth month after treatment. However, there was not much variation in the foliar concentration of other nutrients due to Cu deficiency.

The reduction in foliar Cu due to Cu deficiency was 76 per cent (30 ppm). The initial symptoms of Cu deficiency were expressed when the leaf Cu was reduced to 50 ppm.

3.10 Zinc deficiency

The data furnished in Table 21 revealed that visual symptoms of Zn deficiency concurred with a profound drop in foliar concentration of Zn. The quantum of reduction ranged between 38 ppm and 57 ppm from initial to very severe stage (in a period of 16 months). At the initial stage the extent of reduction was 54 per cent (32 ppm) which increased with the increase in severity of deficiency and registered 79 per cent (15 ppm) decrease in about four months. The variation in other nutrients due to Zn deficiency was negligible.

Table 21. Foliar composition of nutrients at different stages of zinc deficiency

Stages of zinc deficiency	Months after treatment	Macronutrients (%)						Micronutrients (ppm)				
		N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B
Initial	12	3.25 (+0.3)	0.285 (-5)	3.15 (+2)	2.20 (+1)	1.400 (-7)	0.200 (-7)	192 (-2)	88 (+1)	122 (-2)	32 (-54)	45 (-10)
Complete*	12	3.24	0.300	3.08	2.18	1.500	0.215	195	87	125	70	50
Medium	13	3.08 (-8)	0.300 (-3)	3.00 (-1)	2.34 (+4)	1.450 (-3)	0.216 (-1)	196 (-1)	90 (+5)	125 (-2)	25 (-64)	47 (-4)
Complete*	13	3.33	0.310	3.04	2.25	1.501	0.219	198	86	127	70	49
Severe	15	3.00 (-10)	0.315 (+4)	3.25 (+0.3)	2.19 (-5)	1.511 (+6)	0.219 (-4)	200 (-5)	92 (+2)	128 (-2)	20 (-72)	46 (-8)
Complete*	15	3.35	0.302	3.24	2.31	1.431	0.218	210	90	126	71	50
Very severe	16	3.23 (-4)	0.311 (+2)	3.00 (-3)	2.20 (-5)	1.500 (0)	0.218 (-1)	208 (-1)	91 (+1)	128 (0)	15 (-79)	49 (+2)
Complete*	16	3.35	0.305	3.10	2.31	1.500	0.221	210	90	128	72	48

* Plants receiving complete nutrients

Figures given in parenthesis indicate the percentage variation from normal value

There was a reduction of 79 per cent (15 ppm) in the foliar concentration of Zn due to Zn deficiency. The foliar level of Zn at which the first visible symptom of deficiency expressed was 32 ppm while in the plants which received complete nutrient treatment, it ranged between 70 ppm and 72 ppm.

3.11 Boron deficiency

The data in Table 22 indicated that plants exhibited B deficiency symptoms when the concentration of the same in leaf was reduced to 20 ppm which was 59 per cent less than the normal value. The magnitude of reduction was increased with the advancement of deficiency and reached as high as 76 per cent (12 ppm). However, B failed to establish any pronounced effect on the foliar concentration of other nutrients.

Boron deficiency was associated with a fall in leaf B content by 76 per cent (12 ppm). The B content of vines receiving complete nutrient solution ranged between 49 ppm and 51 ppm.

4. Recovery studies

When the deficiency symptoms were visually confirmed, one plant each from the medium and the severe stages was given full nutrient solution and observed for recovery.

Table 22. Foliar composition of nutrients at different stages of boron deficiency

Stages of boron deficiency	Months after treatment	Macronutrients (%)						Micronutrients (ppm)				
		N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B
Initial	9	3.30 (+0.3)	0.305 (+0.3)	3.00 (-3)	2.10 (+4)	1.486 (-1)	0.209 (-3)	190 (-1)	82 (-4)	125 (-3)	70 (+1)	20 (-59)
Complete*	9	3.29	0.304	3.10	2.18	1.506	0.216	192	85	129	69	49
Medium	11	3.18 (-1)	0.312 (+4)	3.21 (+4)	2.15 (+5)	1.509 (+0.6)	0.200 (-5)	191 (-1)	85 (-2)	131 (+5)	65 (-4)	15 (-71)
Complete*	11	3.21	0.300	3.10	2.05	1.500	0.210	193	87	125	68	51
Severe	12	3.00 (-7)	0.298 (-0.7)	3.18 (+3)	2.00 (-8)	1.512 (+0.8)	0.210 (-2)	188 (-4)	85 (-2)	128 (+2)	68 (-3)	14 (-72)
Complete*	12	3.24	0.300	3.08	2.18	1.500	0.215	195	87	125	70	50
Very severe	13	3.25 (-2)	0.311 (+0.3)	3.21 (+6)	2.20 (-2)	1.505 (+0.3)	0.216 (-1)	191 (-4)	83 (-3)	126 (-0.8)	69 (-1)	12 (-76)
Complete*	13	3.33	0.310	3.04	2.25	1.501	0.219	198	86	127	70	49

* Plants receiving complete nutrients

Figures given in parenthesis indicate the percentage variation from normal value

When the plants were recovered of the visual deficiency symptoms it was confirmed by foliar analysis for the nutrient in question. In cases like K deficiency, severe deficiency of N, Ca, Cu etc. where the recovery of the affected leaves was not possible, the new growth, however, was free from the deficiency. The results of the recovery studies are furnished in Table 23.

From the table it could be seen that the medium stage of N deficiency could be recovered by one week whereas it took three weeks for the recovery of the severe deficiency symptoms. The N percentages of the recovered vines were 2.73 and 2.60 respectively of the medium and the severe stages.

With regard to the recovery of P deficiency it was observed that once the deficiency has attained the severe stage it was not possible to recover the plants from the malady. But, if P could be supplied at the medium stage, the recovery was observed within a period of four weeks and the P content during that stage was 0.23 per cent.

Table 23 indicated that plants suffering from K deficiency at the medium and the severe stages could be recovered within two and three weeks respectively. The K contents of the recovered plants were 2.45 and 2.28 per cent respectively.

Table 23. Recovery of macro and micronutrient deficiencies

Treatments	Stages of deficiency	Time taken for recovery(weeks)	Foliar nutrient content after recovery (macro in % and micro in ppm)
+ N	Medium	1	2.73
	Severe	3	2.60
+ P	Medium	4	0.23
	Severe	NR	-
+ K	Medium	2	2.45
	Severe	3	2.28
+ Ca	Medium	3	1.82
	Severe	5	1.68
+ Mg	Medium	2	1.21
	Severe	3	1.09
+ S	Medium	2	0.15
	Severe	NR	-
+ Fe	Medium	1	102
	Severe	2	98
+ Mn	Medium	2	75
	Severe	3	68
+ Cu	Medium	2	68
	Severe	4	55
+ Zn	Medium	2	57
	Severe	3	54
+ B	Medium	3	35
	Severe	NR	-

NR - not recovered

The results of the study suggested that correction of Ca deficiency required comparatively longer period of 3 and 5 weeks respectively, at the medium and the severe stages. The Ca content of the medium deficient vines at the recovered stage was 1.82 per cent and that at the severe stage after recovery was 1.68 per cent.

It was revealed that Mg deficiency at the medium and the severe stages could be rectified in two and three weeks respectively, after application of Mg. The Mg contents of the recovered vines were 1.21 per cent (medium) and 1.09 per cent (severe).

The severe stage of S deficiency could not be corrected by giving S whereas the deficiency at the medium stage was recovered in about two weeks. The foliar S concentration of the recovered vine was 0.150 per cent.

Iron deficiency was the one which was recovered within the shortest period. The deficiency at the medium stage could be corrected within a week and that at the severe stage in two weeks after the application of Fe. The leaf concentrations of the element has increased to 102 ppm and 98 ppm in recovered vines.

Application of full nutrient solution could correct Mn deficiency completely. The time taken for recovery of vine at the medium stage was two weeks and that at the severe stage

was three weeks. The concentrations of the nutrient of the recovered vines were 75 ppm (medium) and 68 ppm (severe).

For the recovery of Cu deficiency at the severe stage it took comparatively longer period of one month whereas that at medium stage could be recovered within two weeks. The Cu content of leaf at the recovered stage was 68 ppm and 55 ppm for the medium and the severe stages of deficiency respectively.

The medium and the severe stages of Zn deficiency could be corrected within two and three weeks respectively, after the application of full nutrient solution. The foliar concentration of Zn in recovered vines of the medium and the severe stages has also increased to 57 ppm and 54 ppm respectively.

Boron deficiency at the severe stage could not be rectified. However, when full nutrient solution was applied to the plant under the medium stage of deficiency it was possible to recover the plants from the disorder within three weeks. The recovered vine recorded 35 ppm B in leaves.

Seasonal variation and relationships of foliar nutrient levels with yield

In order to determine the relationships of foliar nutrient levels with yield which is a prerequisite for the development of foliar diagnosis technique in black pepper several aspects have been studied in detail. As information is already available on the choice of the plant part for this purpose, no study has been conducted on this aspect. The first fully matured leaves on the fruiting branches of the vines were invariably sampled for the determination of foliar nutrient concentrations (De Waard, 1969).

Dynamics of nutrient concentrations in the leaf as influenced by season, the relationships of macro and micronutrient compositions of leaves with yield and interrelationships among the foliar nutrient concentrations were the three major aspects studied in detail. It may be, however, noted that the data on Cu concentration in leaves were excluded for the reason that the vines were regularly sprayed with Cu fungicides against wilt disease. Consequently, inspite of the best efforts to make the leaves free of Cu contamination, the results of analysis were far from satisfactory.

1. Seasonal variation in leaf nutrient status

Data on the foliar composition of macro and micronutrients

at different intervals of sampling during 1981 and 1982 are furnished in Table 24 and Fig. 9 to 11.

1.1 Nitrogen

During 1981, the total N content of the leaves varied from 2.23 to 2.71 per cent with maximum in June and minimum in April. There was not much difference in the N levels between December and April. During August it was reduced to 2.46 per cent and again increased and by October a level almost close to that in June was attained. It could be observed from Fig. 9(c) that the same trend was followed in the year 1982 also. But in general, the N content was slightly low as compared with the previous season. It ranged from 2.37 to 2.65 per cent in December and June respectively.

1.2 Phosphorus

The leaf P content followed the same pattern in both the years (Fig. 9a). The lowest level (0.16% in both the years) was recorded during April and highest in June (0.21% in 1981 and 0.20% in 1982). During October it was 0.18 per cent and in December 0.17 per cent in both the years. The P content in leaf was almost constant from December to April.

1.3 Potassium

As in the case of N, leaf K also exhibited two peaks,

Table 24. Seasonal variation in nutrient status of pepper leave

Nutrient elements	1981					1982				
	April	June	August	October	December	April	June	August	October	December
N (%)	2.23	2.71	2.46	2.62	2.27	2.49	2.65	2.46	2.54	2.37
P "	0.160	0.210	0.200	0.180	0.170	0.160	0.200	0.180	0.180	0.170
K "	1.33	1.56	1.03	1.57	1.39	1.13	1.71	1.54	1.75	1.50
Ca "	2.41	2.20	2.42	2.62	2.84	2.52	2.37	2.40	2.53	2.75
Mg "	0.404	0.440	0.720	0.508	0.572	0.353	0.452	0.550	0.464	0.680
S "	0.093	0.094	0.081	0.100	0.097	0.080	0.084	0.073	0.079	0.070
Fe ppm	154	126	142	129	166	176	154	159	146	191
Mn "	74.0	46.5	58.7	70.8	81.6	84.7	84.3	75.2	74.9	87.9
Zn "	32.0	36.0	34.0	33.9	40.3	30.0	26.7	39.7	39.8	48.1

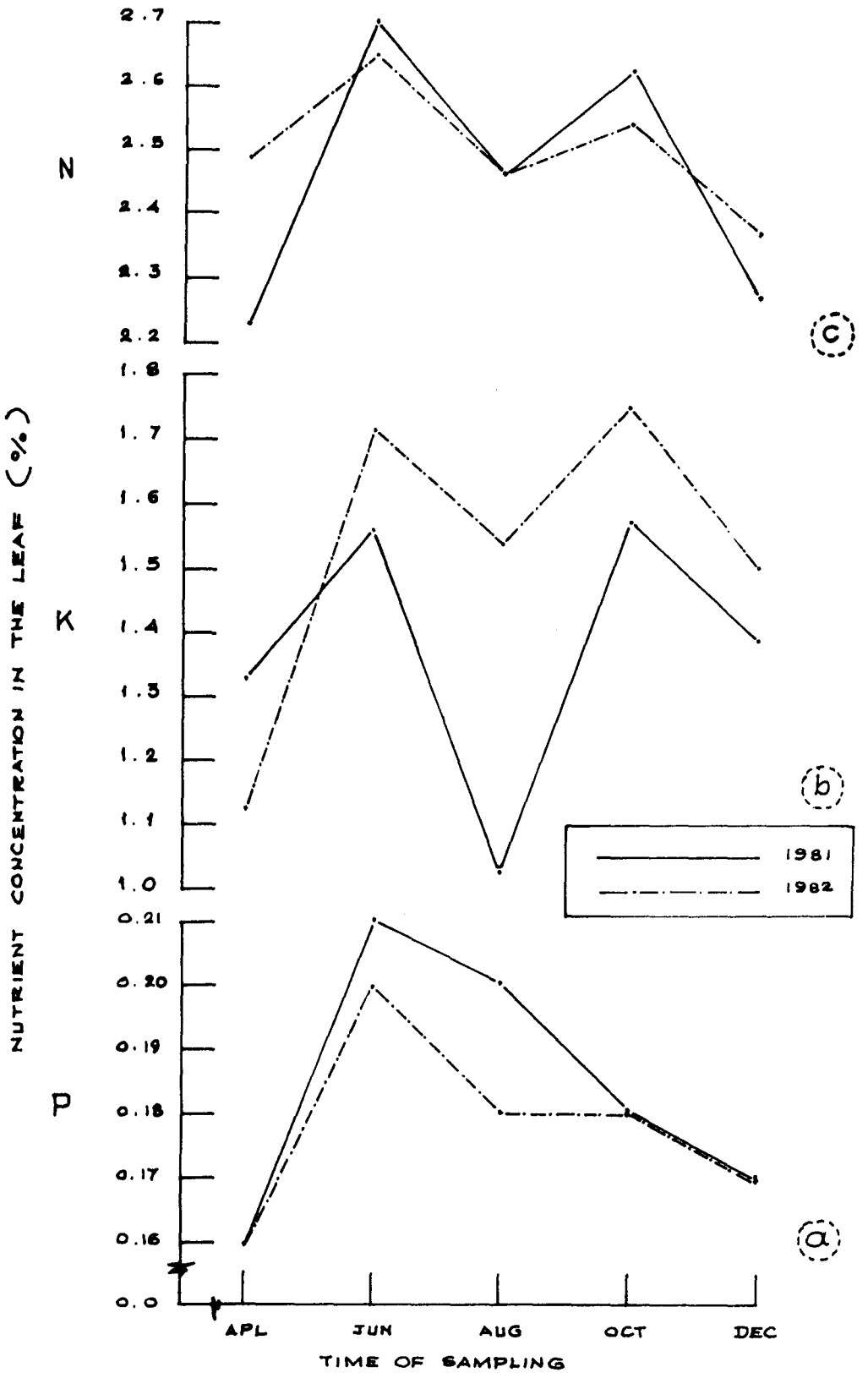


FIG: 9. SEASONAL VARIATION IN FOLIAR LEVELS OF N, P AND K

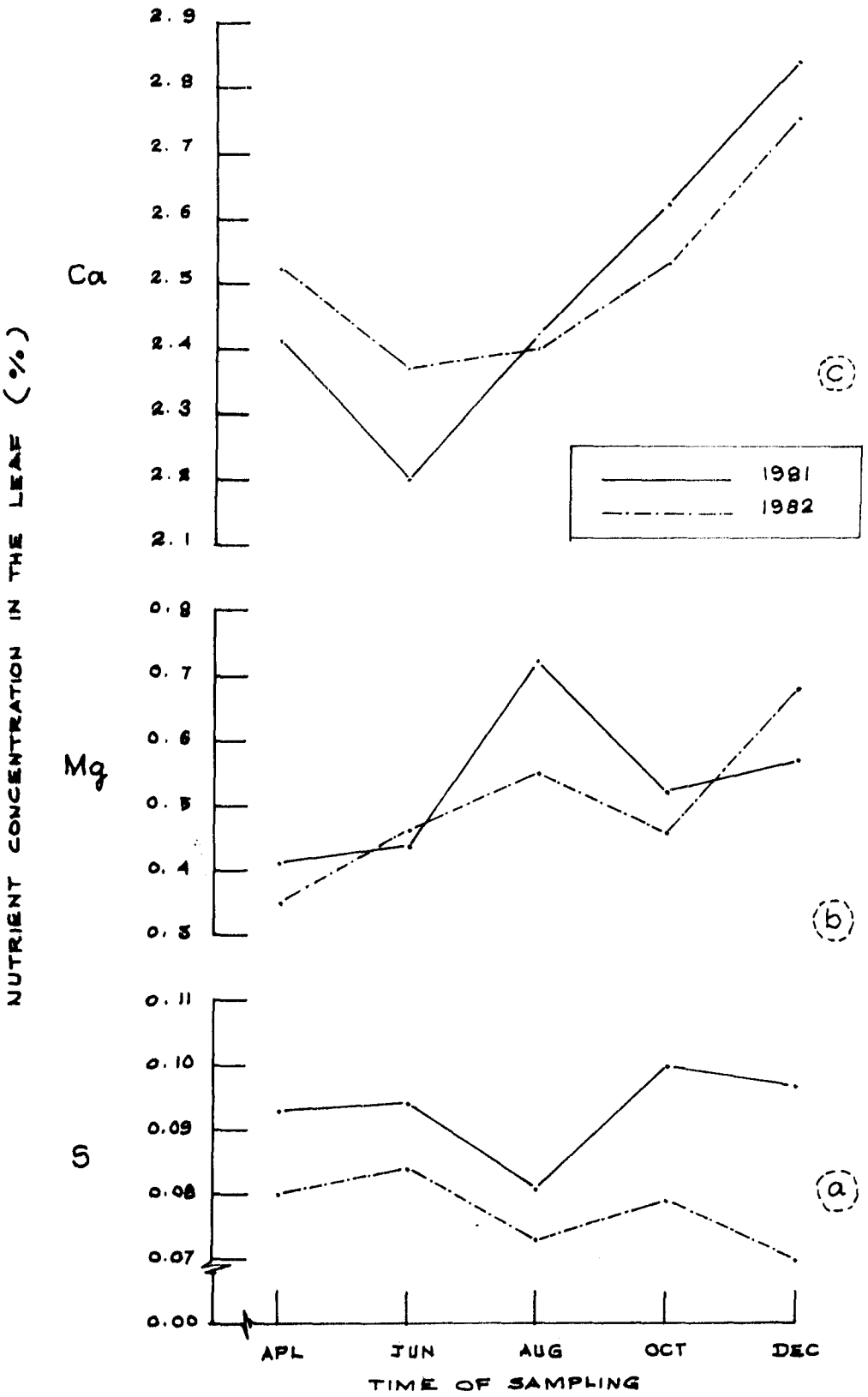


FIG: 10. SEASONAL VARIATION IN FOLIAR LEVELS OF Ca, Mg AND S

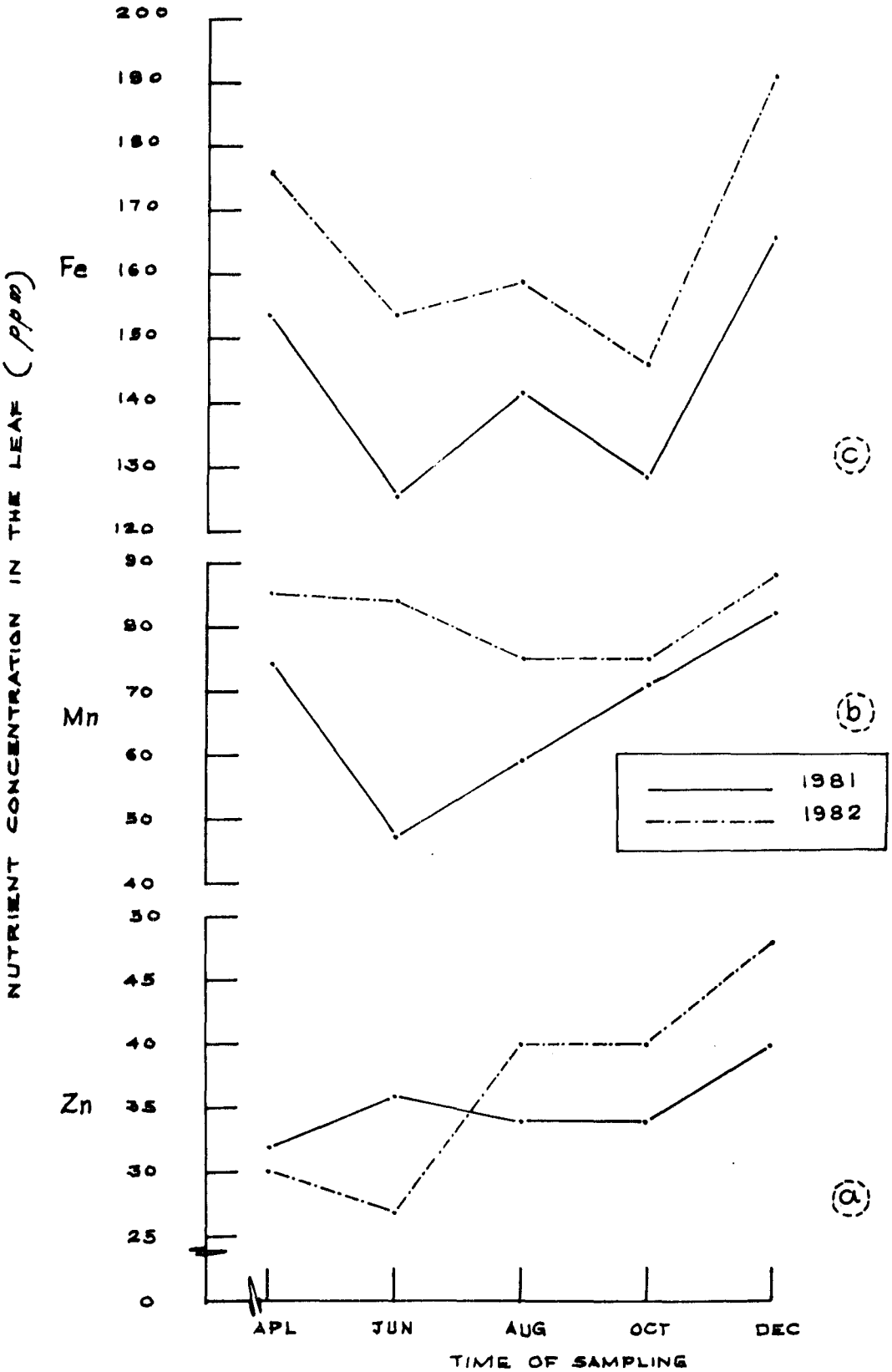


FIG: 11. SEASONAL VARIATION IN FOLIAR LEVELS OF Fe, Mn AND Zn

one in October and the other in June (Fig. 9b), the highest being in October. The highest values were 1.77 per cent and 1.57 per cent in 1982 and 1981 respectively. Lowest K content was recorded in April (1.33%) during 1981 and in August (1.54%) during 1982. Between the two years, K contents were higher in all the months except April during 1982 as compared to those obtained in 1981.

1.4 Calcium

In contrast to other macronutrients, Ca content in leaf showed a steady increase from June to December in both the years studied (Table 24 and Fig. 10c). It was maximum in December and minimum in June. During 1981, the Ca content varied from 2.20 to 2.84 per cent. The corfesponding values in 1982 were 2.37 and 2.75 per cent.

1.5 Magnesium

It could be seen from Table 24 and Fig. 10(b) that Mg content was highest during August 1981 (0.72%) followed by a sudden decrease in October (0.51%) and a slight increase from October to December (0.57%). Almost the same pattern was observed during 1982 but with the maximum content in December (0.68%). It was minimum in April (0.40% in 1981 and 0.35% in 1982) which went on increasing till August.

1.6 Sulphur

Sulphur content in leaf showed two peaks, one in June

and the other in October (Fig. 10a). The percentage of S ranged from 0.093 to 0.100 in the year 1981 and from 0.070 to 0.084 in 1982. It was maximum in October and in June during 1981 and 1982 respectively. Lowest S content was recorded in August 1981 and December 1982.

1.7 Iron

The concentration of Fe in leaf followed the same trend in 1981 and 1982 seasons (Table 24 and Fig. 11c). Iron content ranged from 126 to 166 ppm during the year 1981, and from 146 to 191 ppm in 1982. In both the years, the maximum Fe content was found in December. The lowest level of Fe accumulation in leaf was found to be during the month of June in 1981 and in October during the year 1982.

1.8 Manganese

During the year 1981, the leaf Mn content showed a steady increase from June (46.5 ppm) to December (81.6 ppm), the months which represented the periods of minimum and maximum Mn contents respectively (Fig. 11b). Maximum Mn content (87.9 ppm) was recorded during December itself in 1982 also but the minimum (74.9 ppm) was during the period October (Table 24). The difference in Mn content from December to April was very little (81.6 to 74.0 ppm in 1981 and 87.9 ppm to 84.7 ppm in 1982).

1.9 Zinc

Zinc content ranged from 32.0 to 40.3 ppm with the minimum in April and maximum in December during the year 1981 (Fig. 11a). The minimum and maximum levels obtained during the year 1982 were 26.7 and 48.1 ppm respectively. The foliar concentration of Zn went on increasing from June to December in 1982 whereas in 1981 it decreased from June to October followed by a sudden increase.

2. Relationships of foliar nutrient levels with yield

To find out the nature and magnitude of the relationships of foliar nutrient levels with yield, the total number of plants selected for the investigation were grouped into 25 yield classes separately for each year (1981 and 1982). The class interval, mean yield and the number of plants in each class for 1981 and 1982 are furnished in Tables 25 and 26 respectively.

The class mean for nutrient levels at different intervals of sampling for both the years was subjected to statistical analysis for determining their correlations with yield. Linear, and quadratic models were tried to examine their goodness of fit and to choose the better model on the basis of the amount of variation explained by each. The data are furnished in Tables 27 to 31.

Table 25. Classification of pepper plants based on green yield for the year 1981

Class number	Class interval (kg)	No. of plants	Mean yield (kg)
1	0.060 - 0.250	7	0.177
2	0.251 - 0.500	10	0.389
3	0.501 - 0.750	14	0.612
4	0.751 - 1.000	10	0.888
5	1.001 - 1.250	7	1.187
6	1.251 - 1.500	7	1.380
7	1.501 - 1.750	4	1.645
8	1.751 - 2.000	8	1.895
9	2.001 - 2.250	8	2.150
10	2.251 - 2.500	5	2.346
11	2.501 - 2.750	6	2.604
12	2.751 - 3.000	9	2.887
13	3.001 - 3.250	5	3.170
14	3.251 - 3.500	5	3.396
15	3.501 - 3.750	6	3.610
16	3.751 - 4.000	6	3.913
17	4.001 - 4.250	4	4.148
18	4.251 - 4.500	6	4.408
19	4.501 - 4.750	5	4.690
20	4.751 - 5.250	7	5.114
21	5.251 - 5.750	10	5.594
22	5.751 - 6.750	8	6.365
23	6.751 - 7.750	11	7.357
24	7.751 - 9.000	7	8.474
25	9.001 - 13.120	13	11.068

Table 26. Classification of pepper plants based on green yield for the year 1982

Class number	Class interval (kg)	No. of plants	Mean yield (kg)
1	0.045 - 0.100	5	0.072
2	0.101 - 0.200	9	0.171
3	0.201 - 0.300	7	0.250
4	0.301 - 0.350	5	0.344
5	0.351 - 0.400	9	0.376
6	0.401 - 0.500	6	0.438
7	0.501 - 0.600	4	0.578
8	0.601 - 0.700	7	0.650
9	0.701 - 0.800	4	0.755
10	0.801 - 0.900	5	0.844
11	0.901 - 1.000	5	0.956
12	1.001 - 1.250	5	1.150
13	1.251 - 1.500	5	1.451
14	1.501 - 1.600	7	1.591
15	1.601 - 1.750	8	1.688
16	1.751 - 2.000	7	1.877
17	2.001 - 2.250	4	2.138
18	2.251 - 2.750	8	2.605
19	2.751 - 3.250	8	3.028
20	3.251 - 4.000	6	3.700
21	4.001 - 4.250	4	4.118
22	4.251 - 4.500	5	4.024
23	4.501 - 6.000	4	5.288
24	6.001 - 7.250	4	6.788
25	7.251 - 9.800	4	7.988

Table 27. Coefficients of linear and quadratic correlations of foliar nutrients on yield of pepper during April

Nutrients	1981			1982		
	Linear		Quadratic	Linear		Quadratic
	r	R^2	R^2	r	R^2	R^2
N	0.016	0.000	0.044	-0.195	0.038	0.084
P	0.900	0.810**	0.864**	0.305	0.093	0.201
K	0.877	0.770**	0.827**	0.833**	0.695**	0.716**
Ca	0.803	0.644**	0.793**	0.673	0.452**	0.487**
Mg	0.850	0.722**	0.780**	0.815	0.644**	0.665**
S	0.611	0.373**	0.442**	0.412	0.170*	0.257
Fe	-0.030	0.001	0.001	0.206	0.043	0.043
Mn	0.076	0.006	0.026	0.278	0.077	0.078
Zn	-0.174	0.030	0.074	0.166	0.027	0.139

* Significant at P = 0.05

** Significant at P = 0.01

Table 28. Coefficients of linear and quadratic correlations of foliar nutrients on yield of pepper during June

Nutrients	1981			1982		
	Linear		Quadratic	Linear		Quadratic
	r	R^2	R^2	r	R^2	R^2
N	-0.050	0.003	0.049	-0.064	0.004	0.027
P	0.564	0.318**	0.494**	0.462	0.213**	0.271
K	0.681	0.464**	0.464**	0.914	0.836**	0.934**
Ca	0.920	0.847**	0.860**	0.741	0.548**	0.641**
Mg	0.830	0.689**	0.695**	0.821	0.675**	0.675**
S	0.188	0.035	0.396*	0.653	0.426**	0.504**
Fe	-0.114	0.013	0.041	-0.075	0.006	0.009
Mn	0.199	0.039	0.056	0.149	0.022	0.329
Zn	-0.032	-0.001	0.001	0.419	0.176	0.183

* Significant at P = 0.05

** Significant at P = 0.01

Table 29. Coefficients of linear and quadratic correlations of foliar nutrients on yield of pepper during August

Nutrients	1981			1982		
	Linear		Quadratic	Linear		Quadratic
	r	R^2	R^2	r	R^2	R^2
N	-0.160	0.026	0.139	0.006	0.000	0.004
P	0.125	0.016	0.122	0.108	0.012	0.083
K	0.419	0.176*	0.189	0.600	0.360**	0.399*
Ca	0.744	0.554**	0.604**	0.772	0.596**	0.688**
Mg	0.873	0.763**	0.843**	0.770	0.592**	0.593**
S	0.148	0.022	0.169	0.542	0.294**	0.311*
Fe	0.103	0.011	0.012	-0.009	0.000	0.015
Mn	-0.083	0.007	0.079	0.323	0.104	0.195
Zn	-0.324	0.275	0.378	0.205	0.042	0.065

* Significant at P = 0.05

** Significant at P = 0.01

Table 30. Coefficients of linear and quadratic correlations of foliar nutrients on yield of pepper during October

Nutrients	1981			1982		
	Linear		Quadratic	Linear		Quadratic
	r	R^2	R^2	r	R^2	R^2
N	0.189	0.036	0.040	0.341	0.117	0.228
P	0.352	0.124	0.306*	0.910	0.828**	0.928**
K	-0.055	0.003	0.103	0.585	0.342**	0.392*
Ca	0.774	0.553**	0.562**	0.891	0.794**	0.908**
Mg	0.782	0.611**	0.616**	0.811	0.657**	0.658**
S	0.073	0.005	0.113	0.221	0.049	0.162
Fe	0.321	0.153	0.154	0.311	0.097	0.224
Mn	-0.172	0.030	0.030	0.260	0.067	0.113
Zn	-0.084	0.007	0.095	0.282	0.080	0.125

* Significant at P = 0.05

** Significant at P = 0.01

Table 31. Coefficients of linear and quadratic correlations of foliar nutrients on yield of pepper during December

Nutrients	1981			1982		
	Linear		Quadratic	Linear		Quadratic
	r	R^2	R^2	r	R^2	R^2
N	-0.217	0.047	0.056	0.261	0.068	0.090
P	0.096	0.009	0.105	0.860	0.740**	0.851**
K	0.018	0.000	0.022	0.483	0.233**	0.236
Ca	0.719	0.517**	0.520**	0.876	0.767**	0.798**
Mg	0.813	0.690**	0.749**	0.538	0.290**	0.303*
S	0.222	0.049	0.049	0.351	0.123	0.188
Fe	0.304	0.092	0.177	0.235	0.055	0.189
Mn	-0.113	0.013	0.028	0.271	0.073	0.133
Zn	-0.116	0.013	0.051	0.222	0.049	0.050

* Significant at P = 0.05

** Significant at P = 0.01

Foliar levels of K, Ca and Mg in the month of April in both years were found to be positively correlated with the yield of corresponding years (Table 27).

From Table 28, it may be observed that the macronutrients P, K, Ca and Mg were positively correlated with yield at one per cent level during June 1981 and 1982. The coefficients of correlation of N with yield was negative during June in both the years.

During August 1981 and 1982, the leaf nutrient levels of Ca and Mg showed highly significant positive correlations with yield (Table 29). The levels of K and S in the leaves in the month of August 1982 also exhibited highly significant positive linear correlation with yield.

Foliar Ca and Mg observed in October and December 1981 showed highly significant positive correlation with yield. During the corresponding periods in 1982, in addition to the above nutrients, P and K levels in the foliage were also found to be positively correlated with yield at highly significant level (Tables 30 and 31).

It may be noted that wherever significant linear correlations were obtained, quadratic function also yielded significant relationship. The coefficients of determination were invariably higher for quadratic model than for the linear model.

In view of the generally high correlations observed between foliar composition of most of the nutrients in April 1981 and June 1982 with the corresponding season's yield, those relationships are represented graphically. The constants of linear and quadratic equations for all the foliar nutrients during April 1981 and June 1982 are furnished in Tables 32 and 33 respectively. The data pertaining to the foliar nutrient concentrations of different yield classes along with the mean yield for April 1981 and June 1982 are furnished in Table 34 and 35 respectively and that for the remaining periods in 1981 and 1982 are given in Appendices IV to XI.

2.1 Nitrogen

The data in Table 34 revealed that the N content corresponding to the highest yield class was 2.14 per cent during April 1981 and that during June 1982 was 2.39 per cent (Table 35). However, it may be noted that during both the years the lowest yield classes registered higher values (2.54% in 1981 and 2.51% in 1982) as compared to that of the highest yield classes of the corresponding season. The highest level of foliar N (2.59%) was recorded by the 13th yield class in April 1981 and by the 23rd yield class (2.75%) in June 1982.

Table 32. Linear and quadratic regression equation components for the period April 1981

Nutrients	Linear model $y = a + bx$			Quadratic model $y = a + bx + cx^2$			
	a	b	R^2	a	b	c	R^2
N	3.18	0.173	0.000	27.64	-6.50	-25.40	0.044
P	-29.23	203.90	0.810**	-871.05	3306.47	57.68	0.864**
K	-8.86	9.49	0.770**	-15.71	9.38	7.50	0.827**
Ca	-7.75	4.82	0.644**	-19.54	5.04	20.69	0.793**
Mg	-2.88	16.34	0.722**	-4.44	24.19	1.10	0.780**
S	-2.75	61.12	0.373**	254.67	-819.07	-13.43	0.442**
Fe	4.36	-0.005	0.001	0.015	-0.00007	2.76	0.001
Mn	2.57	0.014	0.006	-0.203	0.002	9.88	0.026
Zn	11.44	-0.251	0.030	6.60	-0.106	-98.81	0.074

** Significant at P = 0.01

Table 33. Linear and quadratic regression equation components for the period June 1982

Nutrients	Linear model $y = a + bx$			Quadratic model $y = a + bx + cx^2$			
	a	b	R^2	a	b	c	R^2
N	6.45	-1.65	0.004	248.70	-47.89	-320.44	0.027
P	-16.20	92.29	0.213**	-1139.42	3028.15	108.65	0.271
K	-5.19	4.23	0.836**	-8.95	3.69	5.82	0.934**
Ca	-9.11	4.67	0.548**	-20.22	5.38	19.02	0.641**
Mg	-1.73	8.19	0.675**	6.76	1.21	-1.38	0.675**
S	-2.61	54.70	0.426**	-87.63	734.08	3.75	0.504**
Fe	3.93	-0.012	0.006	0.213	-0.0007	-13.58	0.009
Mn	-0.185	0.028	0.022	-0.090	0.0009	3.59	0.329
Zn	-5.43	0.284	0.176	0.917	-0.012	-13.76	0.183

** Significant at P = 0.01

Table 34. The mean foliar nutrient contents of different yield classes for April 1981

Class No.	Mean yield (kg)	Macronutrients (%)						Micronutrients (ppm)		
		N	P	K	Ca	Mg	S	Fe	Mn	Zn
1	0.18	2.54	0.146	1.02	1.76	0.203	0.074	155	60	30
2	0.39	2.30	0.143	0.97	1.68	0.205	0.096	153	56	31
3	0.16	2.02	0.143	1.01	2.04	0.326	0.083	161	72	30
4	0.89	2.19	0.145	1.20	2.24	0.337	0.168	153	82	32
5	1.19	2.29	0.156	0.88	1.93	0.371	0.083	130	81	29
6	1.38	2.56	0.150	1.25	2.16	0.316	0.074	162	65	30
7	1.65	2.49	0.156	1.30	2.00	0.190	0.090	133	63	31
8	1.90	2.28	0.154	1.06	1.91	0.243	0.090	136	52	33
9	2.15	1.78	0.150	1.23	2.04	0.436	0.080	167	77	34
10	2.35	1.54	0.155	1.26	2.54	0.260	0.068	141	101	34
11	2.60	2.24	0.157	1.09	2.56	0.358	0.098	168	88	33
12	2.89	2.23	0.161	1.27	2.16	0.419	0.089	164	85	33
13	3.17	2.59	0.162	1.40	2.60	0.264	0.100	144	80	31
14	3.40	2.08	0.158	1.33	2.48	0.446	0.092	148	85	30
15	3.61	1.82	0.148	1.50	2.62	0.505	0.097	172	90	31

Table 34. (Contd.)

Clsss No.	Mean yield (kg)	Macronutrients (%)						Micronutrients (ppm)		
		N	P	K	Ca	Mg	S	Fe	Mn	Zn
16	3.91	2.32	0.157	1.40	2.23	0.257	0.105	169	67	31
17	4.15	2.23	0.167	1.29	1.71	0.455	0.123	195	84	31
18	4.41	2.09	0.165	1.12	2.48	0.480	0.108	149	73	35
19	4.69	2.40	0.168	1.34	1.90	0.408	0.110	131	42	34
20	5.11	2.36	0.175	1.51	2.77	0.449	0.117	138	51	33
21	5.59	2.30	0.165	1.59	2.66	0.522	0.108	148	59	31
22	6.37	2.29	0.170	1.58	2.90	0.526	0.106	139	81	31
23	7.36	2.13	0.174	1.69	3.00	0.525	0.104	160	85	31
24	8.47	2.51	0.180	1.82	3.01	0.580	0.155	144	57	33
25	11.07	2.14	0.190	1.76	2.93	0.570	0.160	156	88	30

Table 35. The mean foliar nutrient contents of different yield classes for June 1982

Class No.	Mean yield (kg)	Macronutrients (%)						Micronutrients (ppm)		
		N	P	K	Ca	Mg	S	Fe	Mn	Zn
1	0.07	2.51	0.212	1.09	1.64	0.250	0.058	154	73	21
2	0.07	2.51	0.212	1.09	1.64	0.250	0.058	154	73	21
3	0.25	2.72	0.191	1.22	2.07	0.361	0.064	154	84	24
4	0.34	2.61	0.214	1.18	1.84	0.292	0.054	148	81	28
5	0.38	2.72	0.198	1.11	2.07	0.340	0.082	151	78	26
6	0.44	2.65	0.190	1.29	2.03	0.488	0.073	176	78	28
7	0.58	2.49	0.188	1.33	2.53	0.228	0.085	138	78	24
8	0.65	2.68	0.193	1.62	2.19	0.400	0.076	173	83	27
9	0.76	2.48	0.198	1.53	2.33	0.255	0.073	148	88	27
10	0.84	2.72	0.190	1.54	2.38	0.222	0.080	149	84	21
11	0.96	2.58	0.200	1.21	2.20	0.482	0.120	164	88	35
12	1.15	2.75	0.193	1.54	2.32	0.380	0.072	178	99	24
13	1.45	2.64	0.220	1.63	2.65	0.402	0.096	132	80	30
14	1.59	2.62	0.183	1.83	2.45	0.324	0.092	171	77	28
15	1.69	2.72	0.194	1.77	2.56	0.425	0.084	148	88	27

Table 35. (Contd.)

Class No.	Mean yield (kg)	Macronutrients (%)						Micronutrients (ppm)		
		N	P	K	Ca	Mg	S	Fe	Mn	Zn
16	1.88	2.65	0.217	1.92	2.48	0.457	0.116	158	94	27
17	2.14	2.56	0.203	1.93	2.65	0.478	0.090	174	87	26
18	2.61	2.69	0.201	1.90	2.45	0.558	0.093	143	90	26
19	3.03	2.65	0.196	2.03	2.70	0.604	0.074	172	85	30
20	3.70	2.48	0.214	2.21	2.83	0.468	0.078	143	92	25
21	4.12	2.55	0.203	2.27	2.93	0.915	0.105	151	84	28
22	4.02	2.44	0.196	2.21	2.70	0.702	0.100	140	84	28
23	5.29	2.76	0.190	2.50	2.73	0.900	0.063	162	88	27
24	6.79	2.62	0.203	2.52	2.70	0.505	0.137	143	89	29
25	7.99	2.39	0.200	1.85	2.78	0.600	0.150	169	77	32

2.2 Phosphorus

Despite the apparently higher coefficient of determination for quadratic model, during April 1981 the plots of the observed values followed typical linear model (Fig. 12). The quadratic curve also followed a pattern closely ressembling linear model in that most of the values fall in the linear portion of the curve. The quadratic relationship between yield and P during June 1982 was not significant. The plots of the observed values during June 1982 was highly scattered and failed to fit either model (Fig.13).

The highest yield class recorded the maximum foliar P content (0.19%) during April 1981 (Table 34). The concentration of P in the leaf corresponding to the highest yield class was 0.20 per cent during June 1982 (Table 35) which was lower than the maximum observed value (0.217%) registered by the 16th class. However, the lowest yield class recorded a higher value (0.212%) than that recorded by the highest yield class.

2.3 Potassium

Both linear and quadratic functions yielded significant R^2 values, the coefficient of determination being higher for the quadratic model. From Fig. 14 and 15, it may be noted that the plots followed linear pattern in April 1981 and

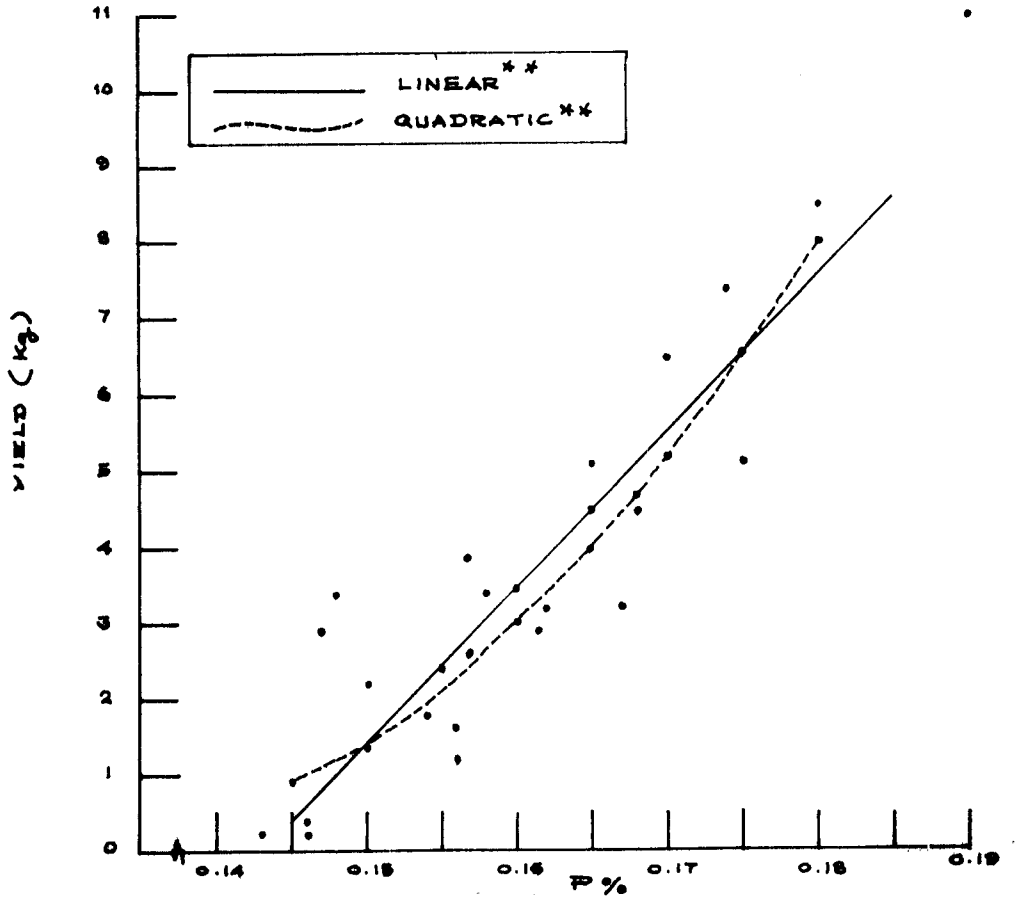


FIG: 12. RELATIONSHIP BETWEEN FOLIAR PHOSPHORUS DURING APRIL 1981 AND YIELD

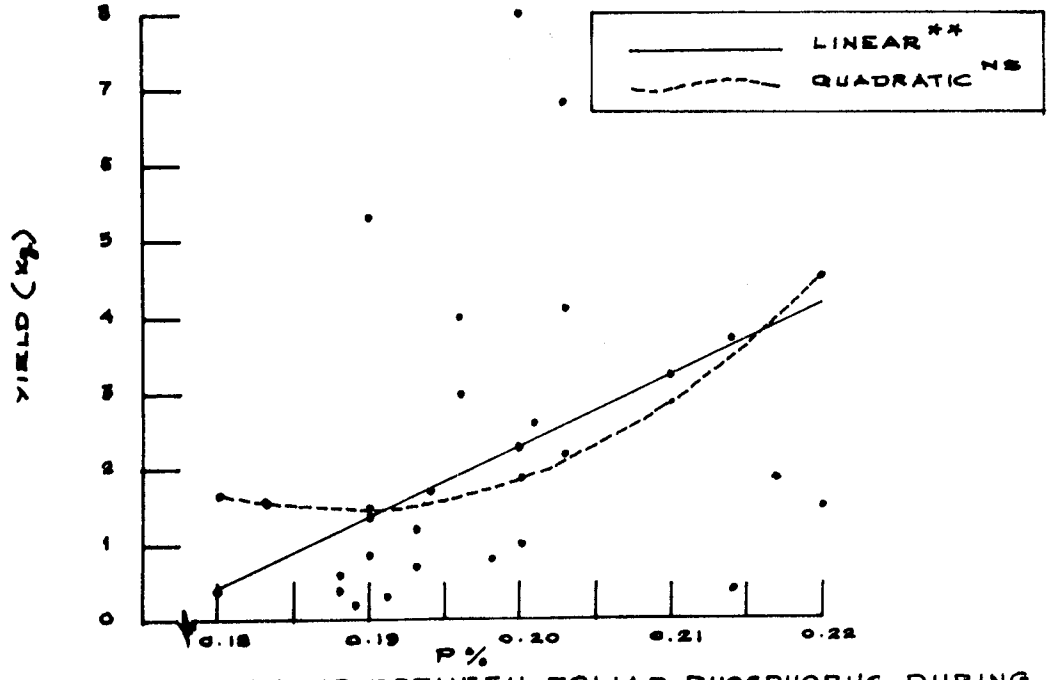


FIG: 13. RELATIONSHIP BETWEEN FOLIAR PHOSPHORUS DURING JUNE 1982 AND YIELD

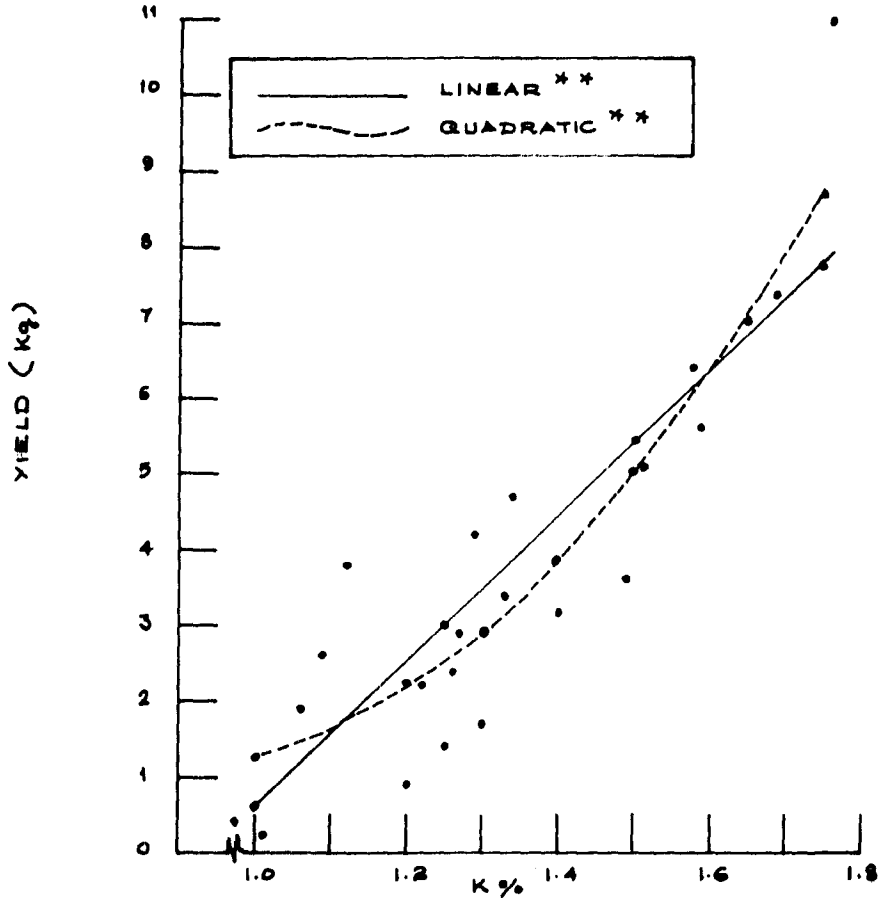


FIG: 14. RELATIONSHIP BETWEEN FOLIAR POTASSIUM DURING APRIL 1981 AND YIELD

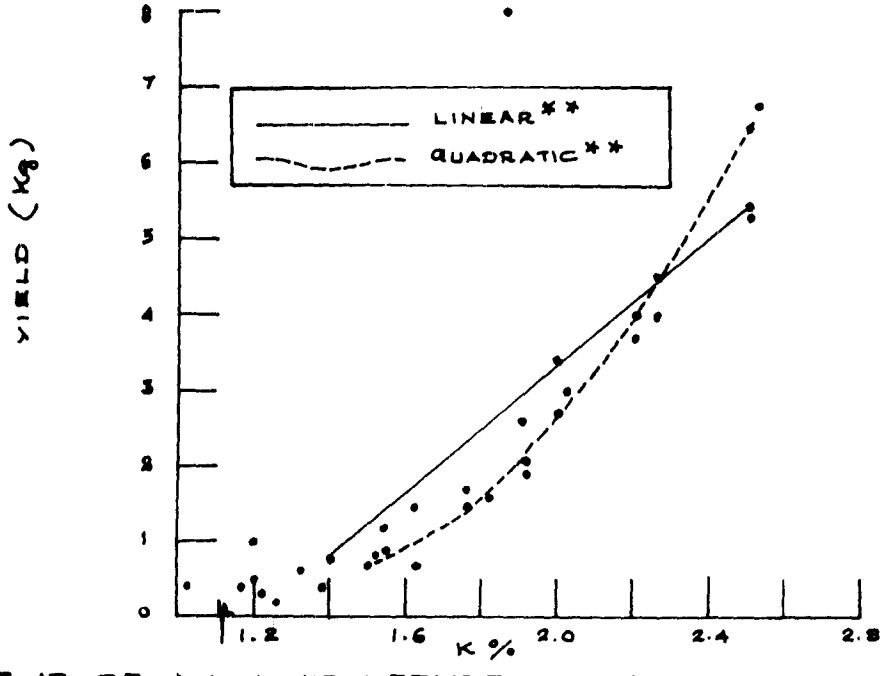


FIG: 15. RELATIONSHIP BETWEEN FOLIAR POTASSIUM DURING JUNE 1982 AND YIELD

June 1982. In this case also most of the values were confined to the linear portion of the quadratic curve. During June 1982 majority of the points were concentrated to the portion below 1.6 per cent.

The highest yield class recorded a mean K content of 1.76 per cent during April 1981 (Table 34) whereas it was 1.85 per cent during June 1982 (Table 35). The maximum leaf K was recorded by the 24th class in both the years.

2.4 Calcium

Though the R^2 values for quadratic models were higher than that of linear models (Tables 32 and 33), the plots followed almost linear trend as in P and K (Fig. 16 and 17) during both the years. The foliar Ca level corresponding to the highest yield class of April 1981 was 3.02 per cent which was the maximum recorded value for the season (Table 34). But during June 1982 a lower level of foliar Ca (2.78%) was registered by the highest yield class (Table 35), the maximum value being 2.93 per cent recorded by the class 21.

2.5 Magnesium

The linear and quadratic regressions between yield and foliar Mg were highly significant during both the years (Tables 32 and 33). The scatter diagram and the fitted

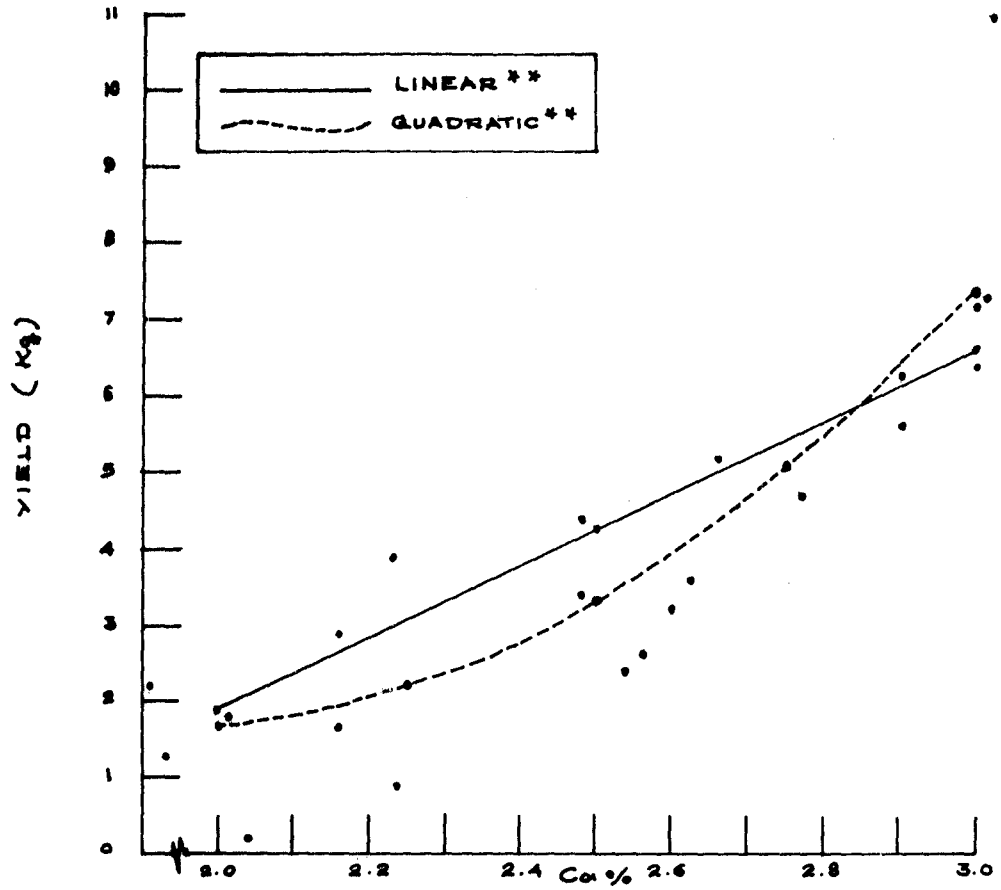


FIG: 16 RELATIONSHIP BETWEEN FOLIAR CALCIUM DURING APRIL 1981 AND YIELD

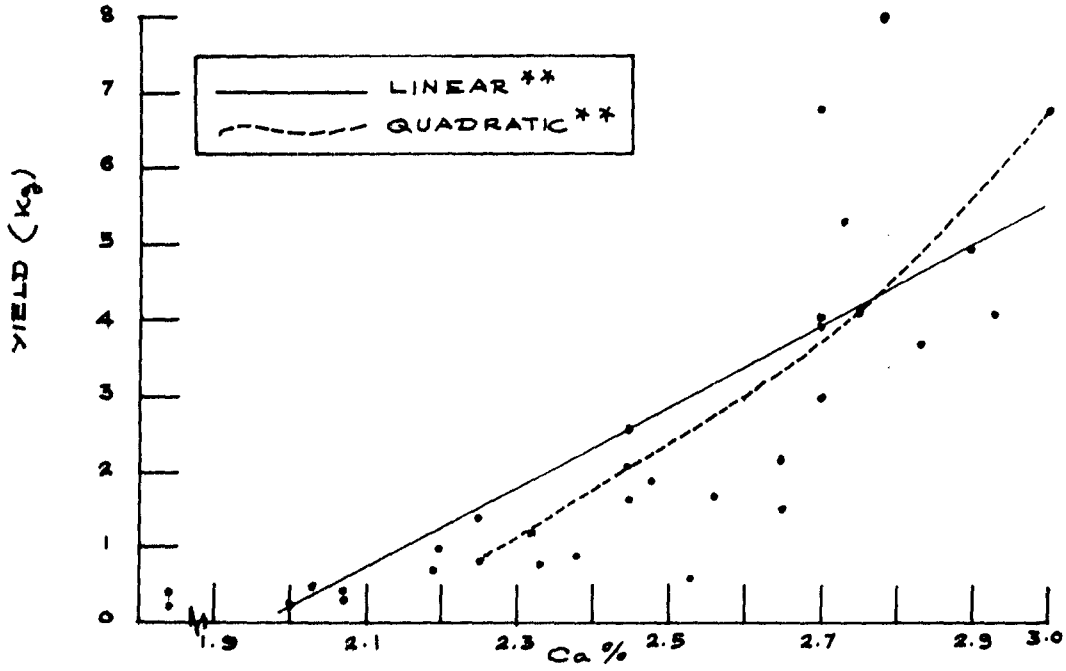


FIG: 17. RELATIONSHIP BETWEEN FOLIAR CALCIUM DURING JUNE 1982 AND YEALD

curves are shown in Fig. 18 and 19. From the plots it may be observed that more than 75 per cent of the points were confined to the portion representing 0.2 to 0.5 per cent Mg in June 1982 whereas they were uniformly scattered for the period April 1981. The foliar Mg levels of the highest yield classes of April 1981 and June 1982 were 0.57 and 0.60 per cent respectively (Tables 34 and 35).

2.6 Sulphur

As in the case of other macronutrients, S also recorded highly significant linear and quadratic relationships with yield (Tables 32 and 33). The scatter diagrams are furnished in Fig. 20 and 21. It may be observed from Table 35 that the highest yield class of June 1982 recorded a S content of 0.15 per cent which was the maximum value for 1982.

2.7 Iron

The data furnished in Tables 32 and 33 showed that there existed no significant correlation between Fe and yield. The Fe contents in leaf corresponding to the highest yield classes during April 1981 and June 1982 were 156 and 169 ppm respectively (Tables 34 and 35). However, the maximum Fe content of 195 ppm during 1981 was recorded by the class 17 whereas during 1982 the 12th class registered the maximum value (178 ppm).

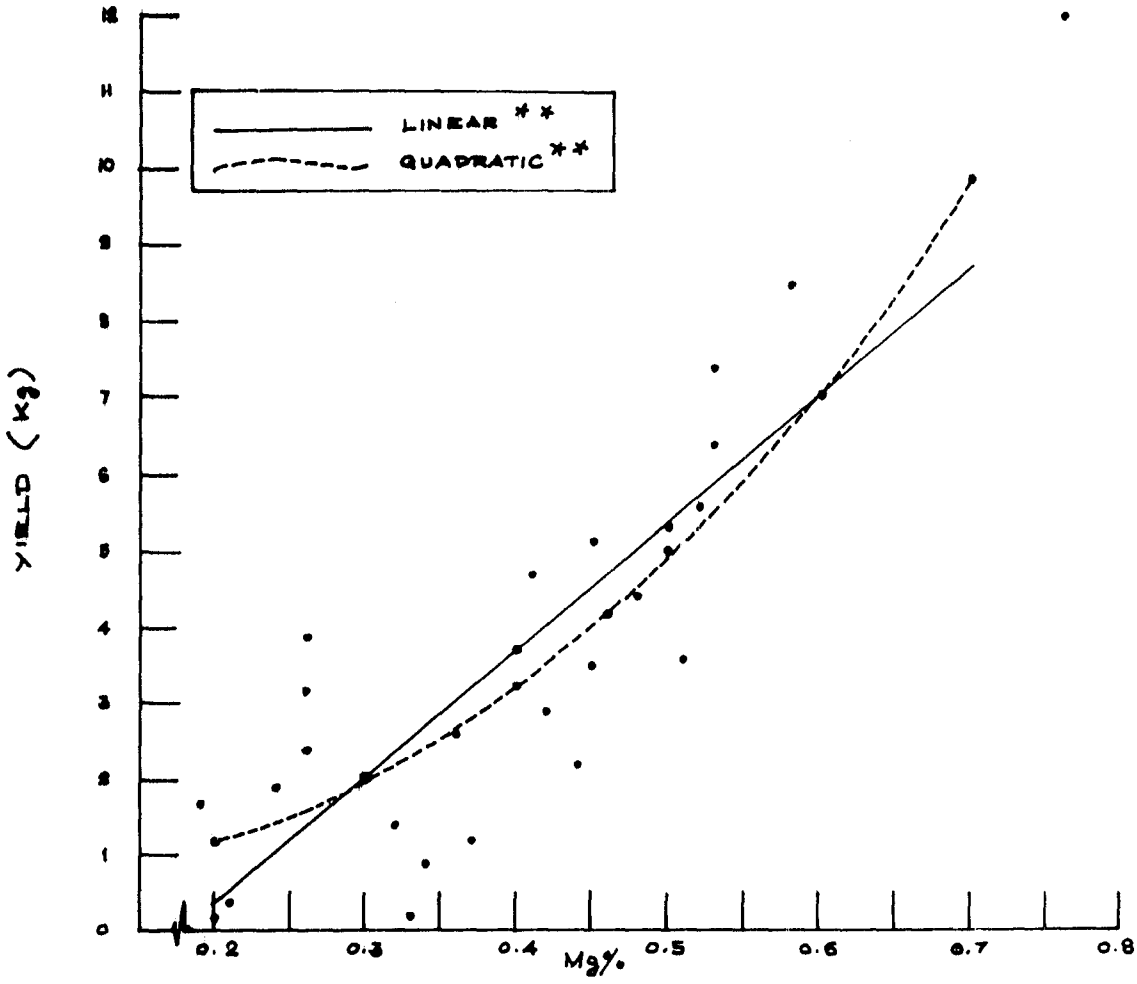


FIG: 18 RELATIONSHIP BETWEEN FOLIAR MAGNESIUM DURING APRIL 1981 AND YIELD

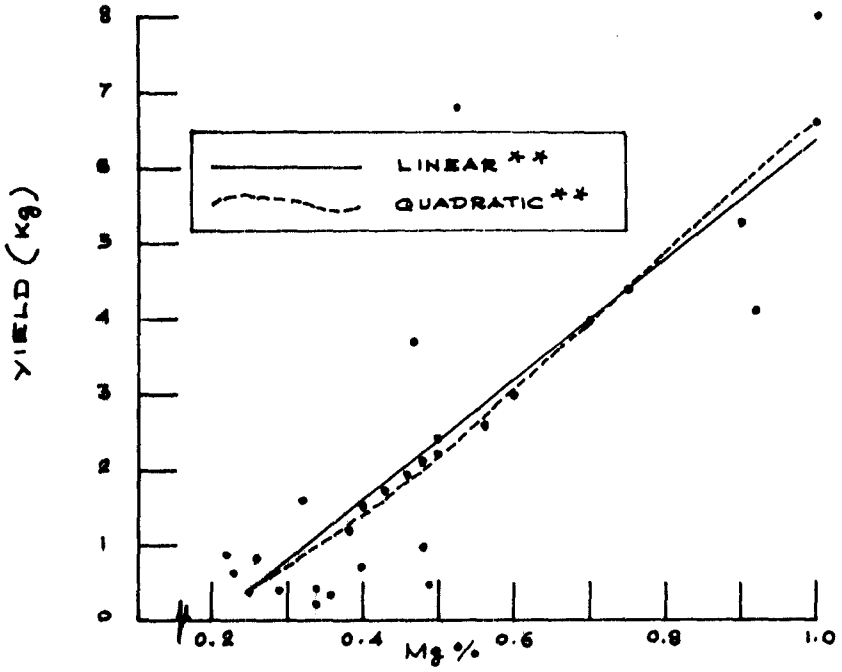


FIG: 19. RELATIONSHIP BETWEEN FOLIAR MAGNESIUM DURING JUNE 1982 AND YIELD

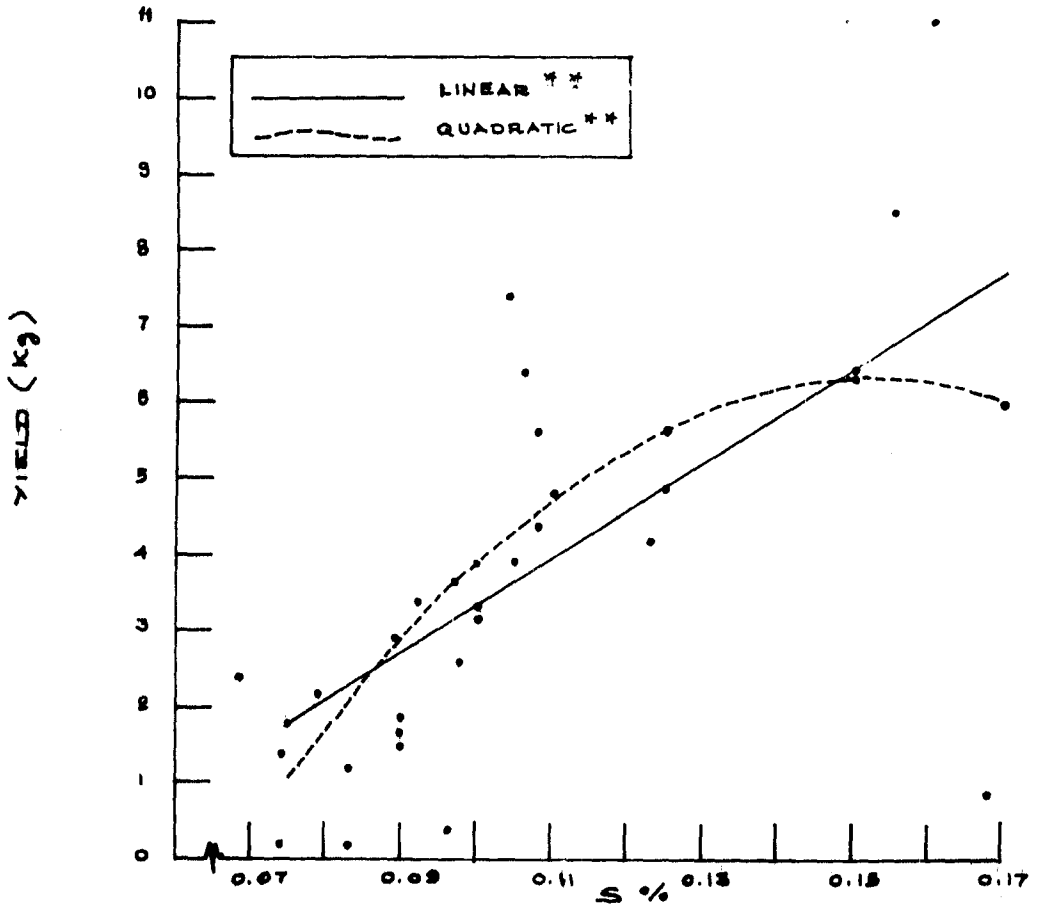


FIG: 20. RELATIONSHIP BETWEEN FOLIAR SULPHUR DURING APRIL 1981 AND YIELD

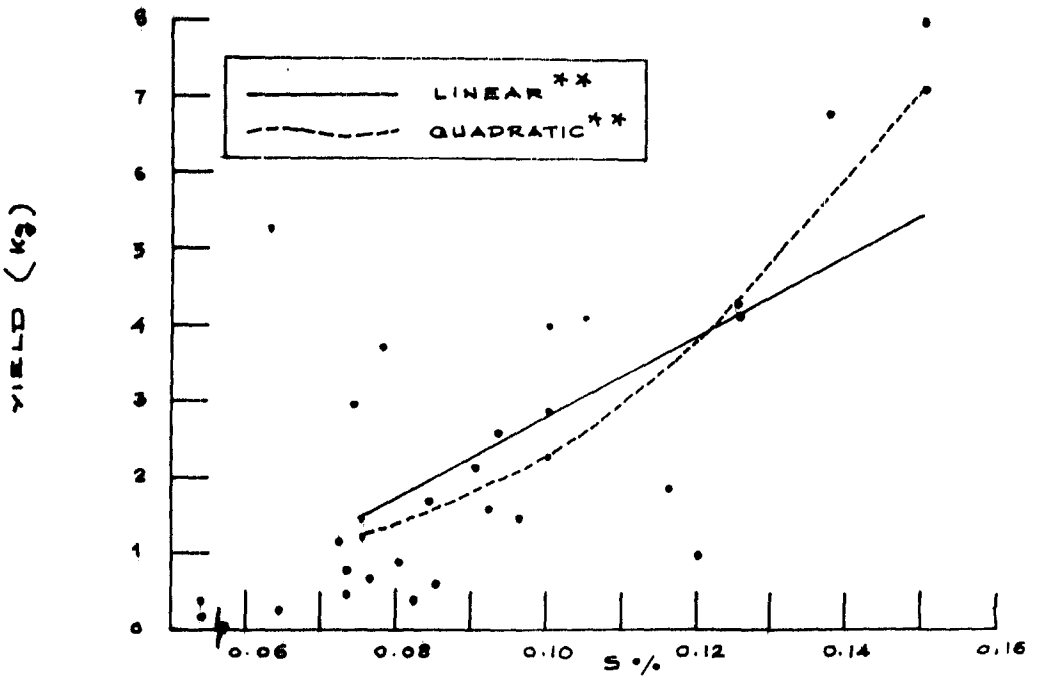


FIG: 21. RELATIONSHIP BETWEEN FOLIAR SULPHUR DURING JUNE 1982 AND YIELD

2.8 Manganese

No significant correlation could be observed between leaf Mn and yield during both the years (Tables 32 and 33). The highest yield classes of April 1981 and June 1982 recorded 88 and 77 ppm Mn in the leaves respectively (Tables 34 and 35). However, the maximum foliar Mn content was registered by the 10th class during 1981 (101 ppm) and by the 12th class during 1982 (99 ppm).

2.9 Zinc

The foliar Zn levels did not show significant correlation with yield during April 1981 and June 1982 (Tables 32 and 33). The foliar Zn contents corresponding to the highest yield classes of 1981 and 1982 were 30 and 32 ppm respectively (Tables 34 and 35). The maximum Zn content was 35 ppm during both the years which corresponds to the 18th class of 1981 and the 11th class of 1982.

3. Path coefficient analysis

Since highly significant correlations between yield and foliar nutrient levels were obtained during April 1981 and June 1982, the data for those months were subjected to path coefficient analysis to estimate the direct and indirect effects of each nutrient on yield.

The results of the analysis for the period April 1981 are furnished in Table 36 and Fig. 22. The nine nutrient elements contributed almost complete variability in yield of pepper (R^2 = 0.9993). The element P had the maximum positive direct effect (0.487) on yield followed by K (0.251), Ca (0.179) and Mg (0.162). The nutrients N (-0.067), Mn (-0.105) and Zn (-0.032) recorded negative direct effects on yield.

Nitrogen was found to have very little influence on yield either directly or via. other nutrients. Though the direct effect of N was negative, the total correlation with yield was positive because of the positive indirect effects through P, K, S, Mn and Zn. The highly significant positive correlation of P with yield (r = 0.900) was as a result of the positive direct and indirect effects via. other nutrients such as K (0.174), Ca (0.111), Mg (0.114), S (0.031) and Zn (0.002). Except N and Fe all other nutrients registered positive indirect effect on yield via. K. Though the direct effect of K on yield was less (0.251), the total correlation with yield was highly significant. This was because of high indirect effect via. P (0.338), Ca (0.144) and Mg (0.112).

All the macro and micronutrients except Mn recorded positive indirect effects through Ca and Mg. In both the cases the indirect effects by N, S and micronutrients were negligible. The indirect effects of P, K and Mg via. Ca were

Table 36. Direct and indirect effects of foliar nutrient levels during April 1981 on yield of pepper

Foliar nutrients	r+	Direct effects	Indirect effects via. foliar nutrient								
			N	P	K	Ca	Mg	S	Fe	Mn	Zn
N	0.016	-0.067		0.071	0.011	-0.025	-0.033	0.010	-0.016	0.064	0.011
P	0.900**	0.487	-0.010		0.174	0.111	0.114	0.031	-0.010	0.000	0.002
K	0.877**	0.251	-0.003	0.338		0.144	0.112	0.036	0.001	-0.006	0.006
Ca	0.803**	0.179	0.009	0.303	0.201		0.115	0.032	0.008	-0.035	0.006
Mg	0.850**	0.162	0.014	0.348	0.174	0.127		0.038	0.008	-0.026	0.009
S	0.611**	0.066	-0.010	0.231	0.137	0.086	0.093		0.001	0.004	0.004
Fe	-0.030	0.065	0.016	-0.074	0.001	-0.022	0.021	0.001		0.041	0.004
Mn	0.076	-0.105	0.041	0.000	0.014	0.059	0.039	-0.003	0.025		0.006
Zn	-0.174	-0.032	0.002	-0.026	-0.045	-0.036	-0.043	-0.007	-0.008	0.020	

+ Correlation coefficients between yield and foliar nutrient levels

** Significant at P = 0.01

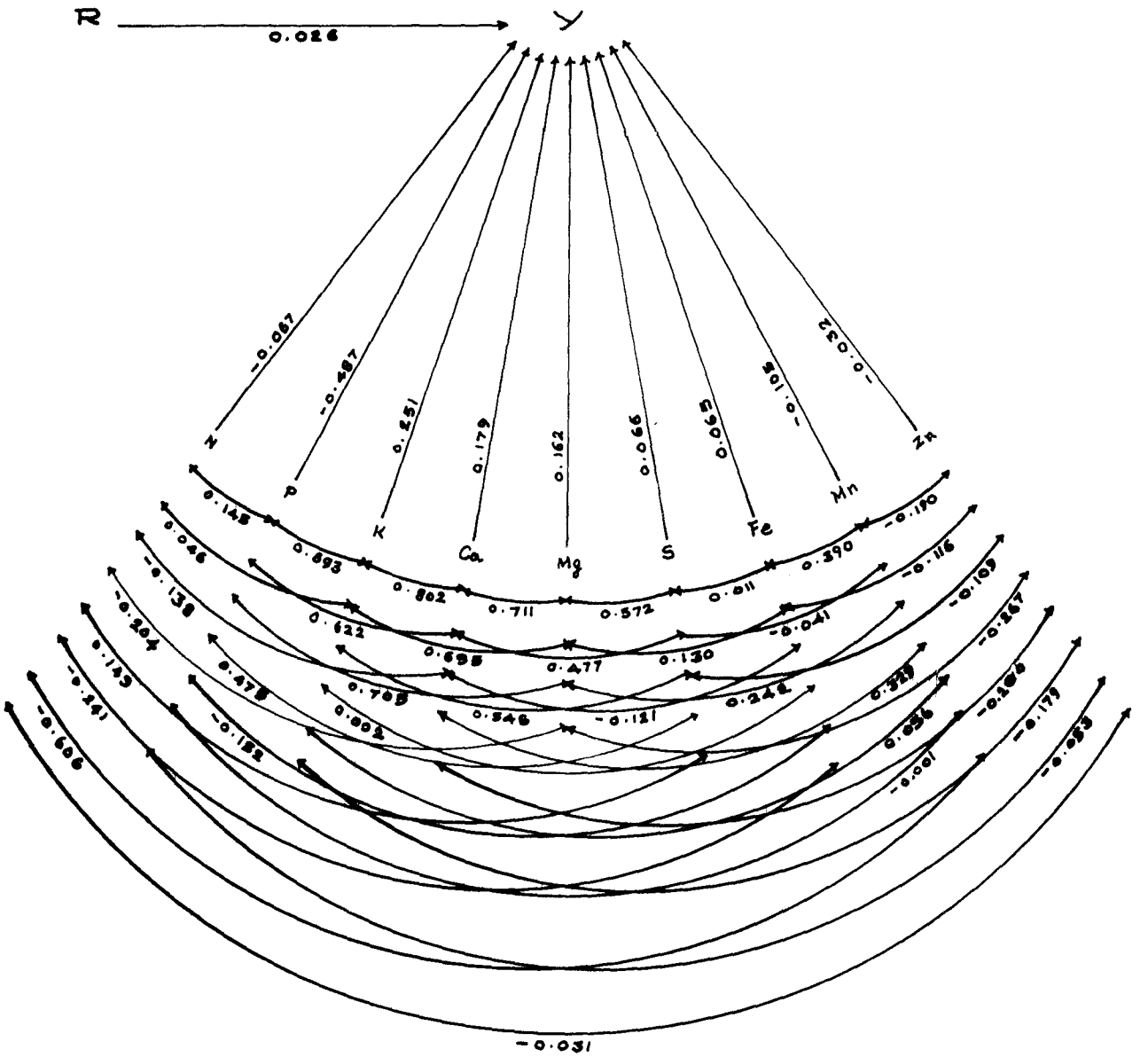


FIG: 22, PATH DIAGRAM INDICATING DIRECT AND INDIRECT EFFECTS OF FOLIAR NUTRIENT LEVELS DURING APRIL 1981 ON YIELD

0.303, 0.201 and 0.115 respectively. The highly significant positive correlation of Mg with yield (r = 0.850) was mainly due to the positive indirect effects of P (0.348), K (0.174) and Ca (0.127). The correlation between foliar S and yield was positive and highly significant (r = 0.611) though the direct effect of S on yield was only 0.066. This resulted because of the positive indirect effects of other nutrients except N through S. The two elements which showed profound influence on yield via. S were P (0.231) and K (0.137).

With regard to the micronutrients (Fe, Mn and Zn) there was not much effect (direct and indirect) on yield. The negative correlation between Fe and yield resulted from the negative indirect effects through P (-0.074) and Ca (-0.022). Though the direct effect of Mn on yield was negative, the total correlation between Mn and yield was positive (r = 0.076) because of the positive indirect effects of all other nutrients, except S. Unlike other nutrients, the direct effect of Zn on yield (-0.032) as well as the indirect effects of the rest of the nutrients (except N and Mn) via. Zn were negative which resulted in a negative correlation between Zn and yield (-0.174).

The direct and indirect effects of foliar nutrients during June 1982 on yield are presented in Table 37 and Fig.23.

Table 37. Direct and indirect effects of foliar nutrient levels during June 1982 on yield of pepper

Foliar nutrients	r+	Direct effects	Indirect effects via. foliar nutrient								
			N	P	K	Ca	Mg	S	Fe	Mn	Zn
N	-0.064	-0.027		-0.019	-0.016	0.035	0.020	-0.048	-0.018	0.002	0.007
P	0.462**	0.043	0.012		0.246	-0.064	0.113	0.117	0.016	-0.004	-0.019
K	0.914**	0.843	0.001	0.013		0.285	0.226	0.134	0.005	-0.005	-0.016
Ca	0.741**	-0.329	0.003	0.008	0.729		0.191	0.143	0.015	-0.005	-0.016
Mg	0.821**	-0.295	-0.002	0.017	0.644	-0.213		0.117	0.000	-0.003	-0.025
S	0.653**	0.251	0.005	0.020	0.450	-0.188	0.138		0.010	-0.003	-0.029
Fe	-0.075	-0.075	-0.006	-0.009	-0.050	0.067	0.039	-0.032		-0.002	-0.006
Mn	0.149	-0.026	0.002	0.006	0.157	-0.048	0.031	0.031	-0.006		0.002
Zn	0.419	-0.050	0.004	0.016	0.274	-0.108	0.145	0.147	-0.010	0.001	

+ Correlation coefficients between yield and foliar nutrient levels

** Significant at P = 0.01

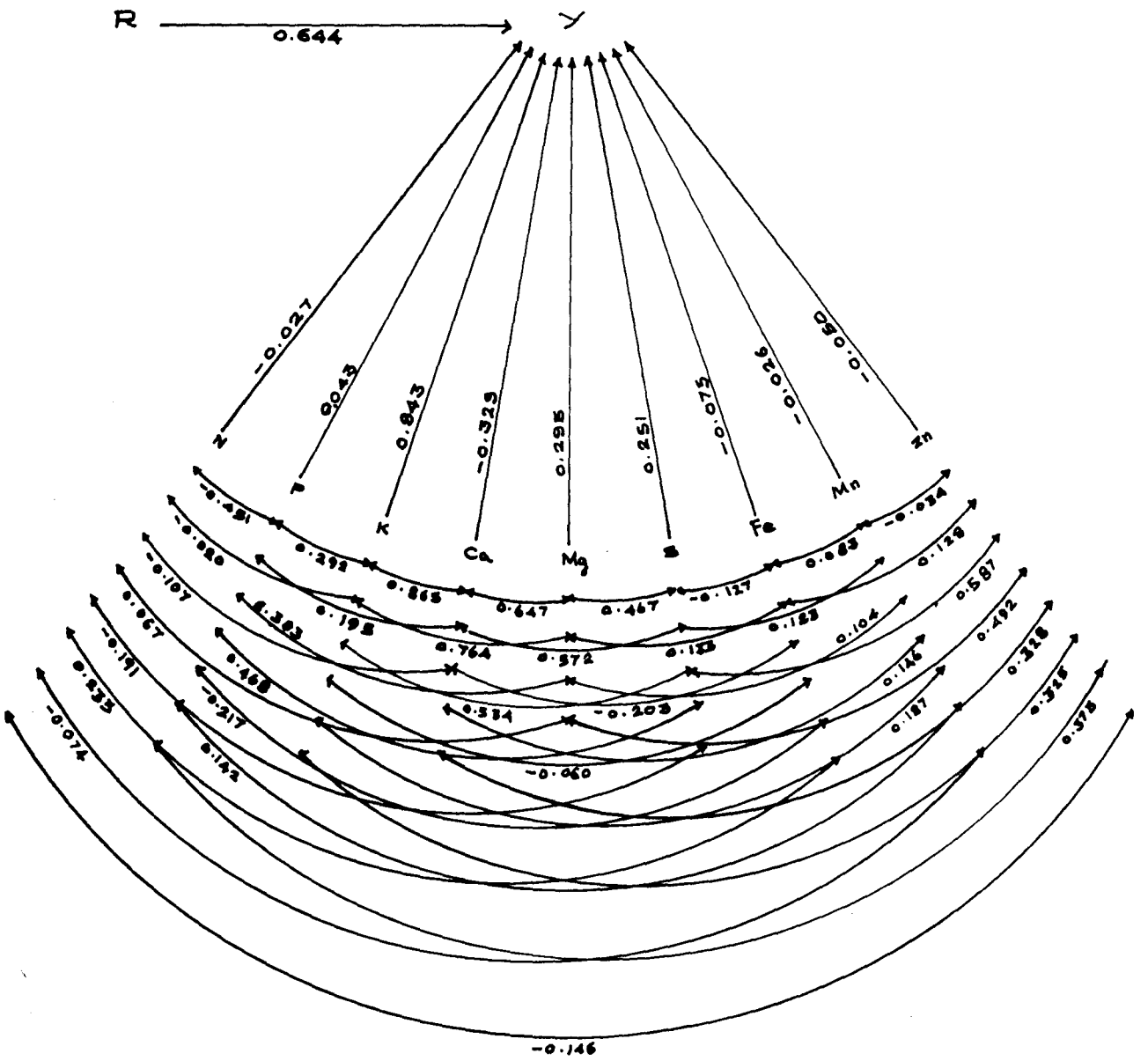


FIG: 23. PATH DIAGRAM INDICATING DIRECT AND INDIRECT EFFECTS OF FOLIAR NUTRIENT LEVELS DURING JUNE 1982 ON YIELD

When the yield was considered as a function of foliar nutrient contents, the component characters explained 99.59 per cent variation in yield (R^2 = 0.9959). The element K had the maximum value of positive direct effect on yield (0.843) followed by S (0.251). All the micronutrients studied and the macronutrients such as N, Ca and Mg registered negative direct effects on yield, the highest value being -0.329 for Ca followed by Mg (-0.295).

There was not much effect of N either directly or through other nutrients on yield of pepper. Phosphorus, though having a correlation of 0.462 with yield, had only a low value of 0.043 as direct effect. The high positive correlation between yield and P was because of the positive indirect effects of K (0.246), Mg (0.133) and S (0.117). The highly significant positive correlation of K with yield was mainly because of the very high positive direct effect. The influence of K on yield via. secondary nutrients was also very high.

The nutrient Ca had a negative direct effect on yield, though the total correlation was positive (r = 0.741). The positive correlation resulted from its very high positive indirect effects via. K (0.729), Mg (0.191) and S (0.143). As in the case of Ca, Mg also had a highly significant positive correlation with yield (r = 0.821) though the direct effect was negative. This is because of the positive

indirect effect of K (0.644) and S (0.117) via. Mg. The highly significant positive correlation between yield and S (r = 0.653) was as a result of positive direct effect (0.251) and positive indirect effects of K (0.450) and Mg (0.138).

The micronutrients such as Fe, Mn and Zn failed to influence yield either directly or via. other nutrients to a considerable extent. However, they registered negative direct effects. The element K had contributed much for the positive correlation of Mn and Zn with yield.

DISCUSSION

Black pepper (*Piper nigrum* L.) is an economically important spice crop not only for the state but also for the entire country. A balanced nutrition is an absolute necessity for keeping a plant healthy and productive. This is true with regards to pepper also. Practically no work has been done in India regarding the optimum requirement of nutrients and also on the 'hunder signs' when a particular element is deficient. Hence, the present study has been undertaken with two main objectives i.e., (i) to develop nutrient deficiency symptoms and correct the same by appropriate method and (ii) to find out the seasonal variation in foliar nutrient status and their relationships with yield, utilizing the existing fertilizer experiment at Pepper Research Station, Panniyur.

The results are critically discussed in this chapter based on the works done elsewhere. The necessity of further studies in this direction has also been pointed out

Nutrient deficiency

1. Macronutrients

1.1 Nitrogen

The N deficiency symptom first manifested as pale green colour of the older leaves, which one month after attained

uniform deep yellow or orange yellow. With the advancement of deficiency, yellowing spread to younger leaves also but the intensity of discolouration was low towards the growing point. Concurrent with the development of foliar symptoms, growth retardation and reduction in leaf size were also observed. At the very severe stage, the whole lamina became necrotic and brown. These symptoms initially developed at the leaf tips and margins.

The chlorotic symptoms are natural since 70 per cent of leaf N is present in chloroplast (Stocking and Ongun, 1962). The symptom expression was similar to that explained by De Waard (1969) for pepper. However, De Waard did not observe differences in intensity of chlorosis based either on age or position of leaf. The present study clearly indicated that the early symptoms appeared on the older leaves and it spread to the younger leaves only when the intensity of deficiency was high. This is expected because of the mobilisation of N from older leaves to the younger ones where metabolic activities are more. It is well established that N is highly mobile in plants. The results obtained by Gauch (1972) fully agree with the above observations. The studies conducted by other workers on perennial crops like coffee (Cooli et al., 1958), citrus (Reuther et al., 1958 and Jones and Embleton, 1959) and avacado (Jones, 1975) also agree with the present findings.

Due to N deficiency, there was 56 per cent decrease in shoot growth, 53 per cent reduction in number of leaves, 20 per cent reduction in internodal length, 63 per cent reduction in leaf area index and 51 per cent reduction in total dry matter production during a period of eight months. The growth was completely arrested in six months. The reduction in vegetative growth is quite natural since N is involved in all the processes associated with protoplasm, enzymic reactions and photosynthesis (Gauch, 1972 and Jones, 1975).

Withdrawal of N from the nutrient solution resulted in a decrease in foliar concentration of N by 53 per cent, Mg by 23 per cent, Fe by 36 per cent and an increase in P by 10 per cent. Deficiency symptom was manifested when the foliar concentration of the element was reduced to 2.45 per cent. Working with the same crop De Waard (1969) observed that less than 2.70 per cent N in leaf exhibited N deficiency symptoms. Chapman (1949) reported less than 2.00 per cent N in N deficient leaves of citrus. According to De Waard (1969) the reduction in foliar N during complete deficiency stage amounted to 25 per cent coupled with a reduction in Mg content by 18 per cent and increase in foliar P by 44 per cent. The N - P antagonism was reported by Bessis (1967) also in a number of other perennial crops. The positive correlation of N with Mg and Fe may be due to the involvement of these elements in

the chlorophyll synthesis. Iron also functions in nitrate and nitrite reductions (Betts and Hewitt, 1966 and Joy and Hageman, 1966).

The visual symptoms of N deficiency was confirmed by the remission of the symptoms and recoupment of foliar N level on application of N. The recovered vine recorded 2.60 per cent N in the leaf which was higher than that at the initial stage of deficiency and slightly lower than that of the plants receiving complete nutrients (3.30%). This variation is natural because of the accumulation of N in leaves of the healthy vines.

1.2 Phosphorus

The first visible symptom of P deficiency appeared ten months after treatment, as bright green to bluish green colour of older leaves. Two months later, the affected leaves turned purple or bronze green followed by necrosis of the leaf tips and margins. During the very severe stage of deficiency, the necrosis spread to the inner portion of the lamina and the necrotic area exhibited burnt appearance. The lamina showed downward curling at the margins where necrosis has been initiated. Later on, the leaves dropped off. No new growth was produced and the vines presented a wilted condition with drooping of the very few leaves that remained on the vine.

The purple colour of the leaves can be attributed to the formation of anthocyanin pigments due to P deficiency (Gauch, 1972). De Waard (1969) also reported similar symptoms of P deficiency; except that he could not observe necrotic symptoms. This may probably be due to the fact that they appear only at the later stages. The leaves with burnt areas were also reported by Haas (1936) in lemon and orange, due to P deficiency. The symptoms observed during the present investigations were in full agreement with those explained by Bingham (1975) in tree crops and bushes, Wallace (1953) in apple, Lineberry and Burkhart (1943) in strawberry and Hoagland and Chandler (1932) in peach.

Phosphorus deficiency resulted in a reduction by 27 per cent in shoot growth, 32 per cent in number of leaves, 45 per cent in dry weight of roots and 28 per cent in total dry matter content. The growth and development were practically nil from the twelfth month onwards. The retardation of growth in P deficient plants can be explained by the fact that P as a constituent of nucleoproteins is involved in the unique portion of protoplasm concerned with cell division (Gauch, 1972). Phosphate also plays a key role in energy metabolism and getting incorporated into ATP, it forms the part and parcel of 'energy currency' of all living cells (Epstein, 1978). With the result, P deficiency

disrupts all the metabolic activities. Being actively involved in photosynthesis, the deficiency of P may also affect the vegetative growth (Arnon, 1959).

The visual symptoms of P deficiency were concurred with a reduction in the foliar concentration of the element by 65 per cent. Not much variation from the normal value could be observed with respect to the foliar contents of other nutrients. Initial symptoms of P deficiency appeared at 0.20 per cent foliar P. According to De Waard (1969) also, omission of P was reflected by the reduction of foliar P by 43 per cent and no influence of P on the foliar levels of other nutrients could be observed. However, the level of P in the leaves showing 'intermediate level' of deficiency was much lower than that observed during the present investigation (0.11%) which may be attributed to the variations in the experimental conditions and the genotype. In citrus and grapes, the plants which showed P deficiency contained less than 0.1 per cent foliar P (Bingham and Martin, 1956 and Bergman et al., 1958).

The results of the study suggested that once the P deficiency attained severe stage, it was not possible to recover the plants from the malady. But if P could be supplied at medium stage of deficiency, the recovery was observed within four weeks. The foliar level of P at that time was 0.23 per cent which provided valid information for the confirmation of the deficiency symptoms.

1.3 Potassium

Potassium deficiency symptom was characterized by the necrosis of the tips of older leaves. With the advancement of deficiency, the necrotic spot which appeared at the tip of the lamina progressed downwards and covered about two-thirds of the lamina. The affected leaves were otherwise healthy. During the very sèvere stage of deficiency, the symptom was exhibited by all the leaves on the lower two-thirds of the vine. The affected leaves even with the very severe symptoms showed no tendency for abscission. The work of De Waard (1969) on pepper also agrees with the present findings. Potassium being highly mobile within the plant, the deficiency symptom can naturally be expected on the older leaves first. Ulrich and Okhi (1975) described the general symptom of K deficiency in perennial crops as tip and marginal scorch of the recently matured leaves. The K deficiency symptoms described by Purseglove (1977) in pepper also agree with the results of the present investigation.

Omission of K from the growing medium was associated with a decrease in shoot growth by 11 per cent, number of leaves by 12 per cent, internodal length by 4 per cent and dry matter content by 11 per cent. There was no arrest in growth at any stage of K deficiency although the rate of growth was below normal. Potassium being involved in

translocation, the deficiency of K will result in decreased translocation of photosynthates from leaves to other portions (Hartt, 1969). Potassium is also found to be necessary for glycolysis, oxidative phosphorylation, photophosphorylation and for adenine synthesis (Evans and Sorger, 1966). Therefore, K deficiency may inhibit starch synthesis which could be the result of reduced energy supply. The reduced vegetative growth was due to the above reasons.

There was a reduction in the foliar concentration of K by 65 per cent and an increase in Ca and Mg content by 25 and 24 per cent, respectively, due to K deficiency. The results suggested that the foliar level of K for normal vegetative growth was a value above 2.1 per cent. According to De Waard (1969) the depression in the leaf concentration of K due to K deficiency was 40 per cent. The antagonistic effect of K with Ca (+36%) and Mg (+27%) was also observed by De Waard. The foliar level of K observed by De Waard below which deficiency symptoms were manifested was 2.0 per cent which was closely related with the present finding.

The results of the recovery studies indicated that once the scorching took place, the process is irreversible which may be due to the damage of the tissues in that area. Further spread of the symptoms to the upper leaves could, however, be prevented by the application of K. The foliar

K content of the recovered plants was 2.28 per cent.

1.4 Calcium

Calcium deficiency symptom appeared as tiny brown necrotic pinhead spots on chlorotic area near the margins of younger leaves. Later, the necrotic spots enlarged and were surrounded by yellow halo. This was closely followed by interveinal chlorosis and die back of the vine tips. Thereafter, black necrotic areas developed near the leaf margins, followed by shedding of the affected leaves.

The symptoms expressed were similar to those explained by De Waard (1969) in black pepper. Chapman (1975a) described the Ca deficiency symptoms in a number of other perennial crops which are in agreement with the present findings. Calcium being immobile within the plant, its deficiency symptoms first appear on the younger leaves. Chlorotic symptoms may be due to the inhibition of N metabolism when Ca is deficient in the plant (Paulsen and Harper, 1968). Since Ca is essential for imparting mechanical strength to tissues, the deficiency of Ca may result in shedding of the leaves (Rasmussen, 1967).

Deficiency of Ca resulted in a reduction by 6 per cent in shoot growth, 8 per cent in internodal length, 61 per cent in dry matter of roots and 6 per cent in total dry matter. The growth was completely arrested at 15.5 months after

treatment. Gauch (1940) observed that Ca deficiency symptoms first appeared in the roots making the root tips slimy and black. Rios and Pearson (1964) also emphasized the importance of Ca for the growth and development of roots. Calcium being a major component of the middle lamella of cell walls, it imparts rigidity to cell wall and is necessary for growth and development (Uhrstrom, 1969).

Deficiency of Ca was associated with a reduction in the foliar concentration of the element by 65 per cent and an increase in K and Mg by 18 and 21 per cent, respectively. Calcium deficiency symptoms were manifested when the foliar level of Ca was reduced to 1.51 per cent. De Waard (1969) observed 1.12 per cent Ca (33% reduction over normal) in the leaves of pepper at 'intermediate' level of Ca deficiency whereas at the 'complete deficiency' level it was 0.86 per cent (48% reduction over normal). The foliar level of Ca at very severe stage of deficiency under the present investigation was only 0.80 per cent. The considerable loss of Ca may have been compensated by a rise in foliar Mg by 60 per cent.

For the correction of Ca deficiency, a comparatively longer period (3-5 weeks) was required. The Ca content of the recovered vines were 1.82 (medium) and 1.68 per cent (severe).

1.5 Magnesium

Deficiency of Mg was first manifested on the older leaves as pale yellow discolouration of their margins and tips, which later developed into oval shaped interveinal chlorotic areas. The major veins remained green whereas the laterals turned yellow. Thereafter, small interveinal necrotic spots appeared which later enlarged and coalesced to form necrotic patches, followed by defoliation.

Since Mg constitutes 2.7 per cent of the weight of chlorophyll, chlorotic symptoms are generally observed on Mg deficient plants. Unlike Ca, Mg is mobile within the plant system and hence deficiency symptoms first appeared on the older leaves. De Waard (1969) also described symptoms of Mg deficiency as observed during the present investigation. According to Embleton (1975), the general symptom of Mg deficiency was chlorosis which started from the leaf margins and tips, and progressed inward interveinally. The results of the studies conducted in other perennial crops such as cacao (Hewitt and Bull, 1956), rubber, (Boynton and Brickson, 1954), citrus and grapes (Tanaka, 1960) also agree with the present findings.

The results on the effect of Mg deficiency on vegetative growth showed that there was a decrease of 13 per cent in shoot growth, 7 per cent each in the number of leaves, leaf area index and dry weight of roots, 13 per cent in the dry weight

of shoot, 25 per cent in the dry weight of leaves and 15 per cent in total dry matter. Magnesium deficiency resulted in stunted growth from the thirteenth month after treatment. The reduction observed in the vegetative growth could well be explained as due to the reduced photosynthesis resulting from Mg deficiency.

Magnesium deficient vines registered a reduction in the foliar Mg by 39 per cent (0.913%) during the initial stage and 78 per cent (0.0330%) during the very severe stage of deficiency. Concurrent with the fall in Mg, the Ca content of the leaves increased by 19 per cent. According to De Waard (1969), Mg deficiency symptoms manifested when the foliar level of Mg fell below 0.20 per cent. He further observed that the deficiency of Mg depressed the leaf concentration of the element by 60 to 68 per cent, accompanied by a rise in the leaf Ca by 17 to 33 per cent. Antagonistic effect between Mg and Ca has also been reported by Emmert (1961).

It was possible to recover the Mg deficiency symptoms in two to three weeks time by the application of Mg. The Mg content of the recovered leaves was 1.09 to 1.21 per cent.

1.6 Sulphur

The initial symptom of S deficiency appeared as pale green to silvery white discolouration of the younger leaves which later turned to uniform yellow. Subsequently,

multitude of tiny necrotic spots appeared on the affected leaves, followed by the development of black necrotic areas involving about two-thirds distal portion of the laminae. Die back of the vine tips and premature shedding of the affected leaves were also observed.

The early symptoms were similar to those of N deficiency except that here the younger leaves were chlorotic rather than the older ones. This is because unlike N, S is immobile within the plant. According to Gauch (1972), a general overall yellowing of the younger leaves occurred due to S deficiency. The S deficiency symptoms described by Storey and Leach (1933) in tea also agreed with the present findings.

Due to S deficiency, there was a decrease of 48 per cent in shoot growth, 63 per cent in number of leaves, 17 per cent in leaf area index, 28 per cent in dry matter of roots, 63 per cent in dry matter of shoot, 65 per cent in dry matter of leaves and 63 per cent in total dry matter content. The growth was completely arrested by fourth month after treatment. Sulphur being a constituent of the aminoacids found in plants, the deficiency of the element will definitely inhibit protein synthesis which in turn will affect the growth and development. The conspicuous reduction in length of vines and number of leaves may be due to the die back of the vine tips.

The foliar level of S was reduced to 0.121 per cent and 0.040 per cent, respectively during the initial and very severe stages of S deficiency. The magnitude of reduction during the corresponding periods was 33 and 80 per cent. Leaf analysis value of S deficient citrus plants was 0.03 to 0.10 per cent (Chapman and Brown, 1941).

S deficiency at severe stage could not be corrected by the application of S. However, medium deficiency symptoms were recovered within two weeks and the foliar ^{S} concentration of the recovered vine was 0.150 per cent.

Among the macronutrients, the earliest deficiency symptoms were manifested by the element S (three months after treatment), followed by N (4th month), K (5th month), P (10th month), Mg (11th month) and Ca (14th month). Except in the case of Ca and S, the deficiency symptoms were first manifested on the older leaves because of the mobile nature of those elements within the plant system. Chlorosis was the general symptom of deficiency exhibited by the macronutrients other than P and K. A uniform yellowing of the lamina was observed in the case of N and S deficiencies whereas interveinal chlorosis occurred due to the deficiency of Ca and Mg. Eventhough leaf necrosis was observed during the advanced stages of deficiency of all the macronutrients (except Mg), it was possible to distinguish among them since the pattern of necrosis was specific to each element. In the case of N deficiency, the colour of the necrotic area was

brown whereas it was grey and charcoal black in the case of P and K deficiencies, respectively. The necrotic area was confined to the leaf margins and the portion of lamina other than the necrotic area was green in the case of Ca deficiency. In contrast to Ca deficiency, the entire lamina became chlorotic first and then only the necrotic areas developed in the case of S deficiency. There was also no specific pattern for the development of necrotic area in this case. Shedding of the very severely affected leaves was another common feature observed due to the deficiency of macronutrients, except K.

With regard to the vegetative growth, the deficiency of S was found to affect the plant most seriously as evidenced by the reduction in dry matter production. May be that the deficiency of S affected the plant during the early stage of growth as compared to other elements. The magnitude of reduction in number of leaves was also maximum in S deficient plants (63%). A profound reduction in the size of leaf was observed only in the case of N deficient vines (63%). The two elements which drastically affected the root growth were Ca (61%) and P (45%). The results on dry matter production indicated that among the macronutrients, S exhibited maximum influence on the vegetative growth, for, the deficiency of the element completely arrested the growth at 4.5 months after treatment. In the case of N and P deficiencies, the growth of vines stopped at the sixth and

thirteenth month , respectively, after treatment. However, cessation of growth was not observed in the case of deficiencies of K, Ca and Mg, although the reduction in the rate of growth increased with the advancement of deficiency.

Visual symptoms of nutrient deficiencies were concurred with a marked reduction in the foliar levels of the concerned elements. The deficiency of macronutrients could be clearly identified by visual symptoms only at the medium stage. The foliar levels of macronutrients of the affected plants at that stage were as follows:

N	-	2.200%	Ca	-	1.010%
P	-	0.178%	Mg	-	0.675%
K	-	1.500%	S	-	0.088%

Antagonistic effects could also be observed among K, Ca and Mg whereas the deficiency of N, P and S were found to have no striking influence on the foliar levels of other nutrients.

The recovery studies conducted also helped to confirm the nutrient deficiency symptoms. Medium and severe deficiency symptoms of N, K, Ca and Mg could be recovered by the application of the respective nutrients. However, in the case of P and S, only the medium deficiency symptoms could be recovered. The deficiency of N took minimum time (one week) for recovery whereas severe deficiency of Ca

could be recovered only after five weeks. The foliar level of nutrients in the recovered vines was higher than that observed at the initial stage of deficiency in all the cases.

2. Micronutrients

2.1 Iron

The initial symptoms of Fe deficiency were noticed as interveinal chlorosis of the top two to three immature leaves. The symptoms gradually spread to the lower leaves also. During the severe stage, the finest veins of the affected leaves turned chlorotic while the green bands along the major veins were retained. The above stage was followed by premature leaf fall and stunted growth. Though not a part of chlorophyll, Fe is essential for chlorophyll synthesis (Bogorad, 1966). Therefore, chlorotic symptoms may be expected when Fe is deficient within the plant. Appearance of deficiency symptoms on the younger leaves may be because Fe is immobile within the plant system. The general symptoms characteristic of Fe deficiency reported by Gauch (1972) and Wallihan (1975) also agree with the present findings.

Due to Fe deficiency, the shoot growth was reduced by 37 per cent, number of leaves by 33 per cent, internodal length by 10 per cent, dry matter of shoot by 39 per cent,

dry matter of leaves by 31 per cent and total dry matter by 35 per cent. The growth was practically nil from the seventh month onwards due to Fe deficiency. The reduction in growth may be expected since Fe is actively involved in photosynthesis (Betts and Hewitt, 1966). It also influences growth by its involvement in nitrate and nitrite reduction processes (Joy and Hageman, 1966).

During the initial stage of deficiency, the foliar level of Fe was 94 ppm (-24%) which went on decreasing and recorded 61 ppm (-68%) at very severe stage. The deficiency of Fe did not affect the leaf concentration of other elements. The Fe deficiency symptoms could be recovered within a period of one to two weeks. The level of Fe in the leaves of the recovered vine was 98 to 102 ppm.

2.2 Manganese

Interveinal chlorosis of the younger leaves was the first visual symptom of Mn deficiency. As the intensity of deficiency increased, the chlorotic area covered almost complete of the interveinal portion making the major veins and laterals more prominent. Later on, pale yellow colour of the chlorotic areas changed to bronze yellow, followed by abscission of the affected leaves and retarded growth. Low concentration of chlorophyll may be expected in the case of Mn deficiency due either to the reduction in number or disorganization of chloroplasts (Homann, 1967). The

results of the work carried out by Labanauskas (1975) on citrus also corroborate with the present findings.

Due to Mn deficiency there was reduction in shoot growth by 10 per cent, number of leaves by 12 per cent, internodal length and leaf area index by seven per cent each, dry matter of root, shoot and leaves by 14, 16 and 11 per cent respectively and total dry matter content by 14 per cent. However, no complete arrest of growth was observed due to Mn deficiency. The reduction in vegetative growth is quite natural since Mn is essential for chlorophyll synthesis.

The leaf analysis value of Mn corresponding to the initial stage of deficiency was 54 ppm which was 36 per cent less than the normal. The magnitude of reduction reached 66 per cent (29 ppm) at the very severe stage. Application of Mn could correct Mn deficiency within two to three weeks. The concentration of the element in the leaves of the recovered vine was 68 to 75 ppm.

2.3 Copper

The first symptom of Cu deficiency was interveinal chlorosis of young leaves which later intensified and spread to the entire laminae including veins. With the advancement of deficiency, dark brown necrotic spots developed towards the tip and margins of the affected leaves. Terminal growth

was arrested and new growth initiated from the base of the vine. During the severe stage, the lamina became deep bronze and the necrotic spots coalesced to form large black necrotic areas near the tips and margins. Downward curling of the necrotic margins and shedding of the very severly affected leaves were also observed. Since Cu is necessary for the formation of the precursor of chlorophyll, the deficiency of the element may naturally produce chlorotic symptoms. The bronze colouration may be attributed to the accumulation of gum due to non-oxidation of phenols in the absence of Cu (Epstein, 1978). Reuther and Labanauskas (1975) also observed die back of the growing point coupled with chlorosis and necrosis of the younger leaves as the general symptoms of Cu deficiency in most of the perennial crops.

Copper deficiency resulted in a reduction of shoot growth by 10 per cent, number of leaves by 7 per cent, dry matter of root by 15 per cent, dry matter of shoot by 10 per cent and total dry matter production by 6 per cent. Growth of vine in terms of dry matter production was completely arrested by 14.5 months after treatment. The involvement of Cu in chlorophyll synthesis and oxidation reduction reactions may be contributing to the reduction in vegetative growth and die back symptoms.

The initial symptoms of Cu deficiency were exhibited when the foliar level of Cu was reduced to 50 ppm (61%).

The magnitude of reduction during the very severe stage was 76 per cent (30 ppm).

Deficiency symptoms of Cu could be recovered within a period of two to four weeks. The foliar Cu content at the recovered stage was 55 to 68 ppm.

2.4 Zinc

The first visible symptom of Zn deficiency was manifested as interveinal chlorosis of younger leaves as in the case of Fe, Mn and Cu. However, chlorosis was restricted to the interveinal area only, leaving a prominent network of dark green veins. The size of the new leaves produced was very much reduced. The terminal growth was retarded and a number of lateral branches with shortened internodes and small leaves were produced from the terminal portion of the vine which resulted in bunching or rosetting. Abscission of leaf was seldom observed. The results of the studies conducted by Nair et al. (1968) in citrus agree with the present findings. Chapman (1975b) also reported interveinal chlorosis, reduced internodal length and little leaf as the characteristic symptoms of Zn deficiency in most of the perennial crops.

Due to Zn deficiency the magnitude of reduction in shoot growth was 16 per cent, internodal length 20 per cent, leaf area index 40 per cent, dry matter of root 14 per cent, dry

matter of shoot 16 per cent and total dry matter 9 per cent. The number of leaves showed an increase by 6 per cent. There was no complete inhibition of growth due to Zn deficiency as evidenced by the total dry matter production. Tsui (1948) established the necessity of Zn for the synthesis of tryptophan (from indole and serene), a precussor of IAA, the principal endogenous hormone responsible for cell elongation. Tsui's conclusion has been supported by Salami and Kenefick (1970). The profound decrease in internodal length due to Zn deficiency may be attributed to the aforesaid function of the element. When Zn is deficient within the plant, RNA concentration gets reduced by the activation of oxidative enzyme resulting in decreased protein synthesis which may also contribute to the reduction in vegetative growth. The increase in number of leaves could be well explained by the increased production of lateral shoots during Zn deficiency.

Initial symptoms of Zn deficiency was associated with a reduction in foliar concentration of Zn by 54 per cent (32 ppm) which further increased to 79 per cent (15 ppm) at the very severe stage. In healthy vines, the level of foliar Zn ranged between 70 and 72 ppm.

Medium and severe deficiencies of Zn could be corrected within two and three weeks, respectively, after the application of Zn. The foliar concentrations of the recovered vines were 57 and 54 ppm, respectively.

2.5 Boron

Boron deficiency was first observed as the failure of development of the terminal buds. The terminal leaves became abnormal in size and when mature, interveinal chlorotic patches were visible on the laminae. Gradually, the affected leaves became thick, brittle and presented a mottled appearance with bright orange colour. Consequently, the lower side of the lamina became grey brown making the veins prominent with pale green colour in grey brown interveinal background. Very severely affected leaves showed black necrotic areas near margins which got detached from the laminae. The leaves even with the very severe symptoms were retained on the plant one more week and finally dropped off. The failure of terminal bud development may be related to the effect on B on RNA metabolism (Gauch, 1972). During B deficiency water relations become abnormal and leaves and stem appear desiccated and hence have a stiff woody feel. Results of the studies conducted by Eaton (1944) in grapes fully conform to the B deficiency symptoms observed during the present investigation. Bradford (1975) also observed the general symptoms of B deficiency as die back of terminal growth and thickening, brittleness, curling and chlorosis of terminal leaves.

Due to B deficiency, there was a decrease of 31 per cent in length of vine, 30 per cent in number of leaves 10 per cent

in dry matter of roots, 31 per cent in dry matter of shoot, 13 per cent in dry matter of leaves and 22 per cent in total dry matter production. In contrast to other vegetative characters, the leaf area index recorded an increase by 18 per cent. The vegetative growth was completely arrested by the twelfth month after treatment. Since B has a specific regulatory step in carbohydrate metabolism (Lee and Aronoff, 1967), the reduction in growth can normally happen due to B deficiency. Another contributing factor to the pronounced reduction in growth may be the effect of B in terminal bud development. Abnormal size of leaves due to B deficiency has also been reported by Gonzales and Camacho (1952) in coffee. However, the reason for such an abnormality has to be further investigated since the available literature on B fails to suggest a possible reason.

Boron deficiency was associated with a fall in leaf B to the tune of 59 per cent (20 ppm) at the initial stage which further reduced to 12 ppm (-76%) at the very severe stage. The foliar B content of healthy vines ranged between 49 and 51 ppm.

The deficiency symptoms of B at severe stage could not be recovered by the application of B. However, medium deficient plant could be recovered within a period of three weeks. The recovered vine has recorded 35 ppm B in leaves.

If an attempt is made to compare the deficiencies of different micronutrients, it may be seen that the deficiency

symptoms of Fe were manifested at an early stage (four months after treatment) as compared to the rest of the micronutrients. Iron was followed by Mn (6th month), B (9th month), Zn (12th month) and Cu (13th month). A common observation made with respect to the deficiency symptoms expressed by the micronutrients is the manifestation of interveinal chlorosis as the initial symptom except in the case of B. However, the chlorotic symptoms were specific to the respective elements. Interveinal chlorosis caused by Fe deficiency differed from others by the presence of green bands along the major veins. Manganese deficiency was characterized by bronze yellow colour of the chlorotic areas whereas in the case of Cu deficiency the entire lamina including the veins became chlorotic at the severe stage. The chlorotic symptom due to Zn deficiency was unique in that even the fine veins were green in colour which deeply contrasted with the interveinal chlorotic area. In contrast to other micronutrients, B deficiency was characterized by large, brittle and mottled terminal leaves. Since all the micronutrients are comparatively immobile, the deficiency symptoms were first manifested on the younger leaves.

There was marked reduction in length of vines as a result of Fe and B deficiencies. In the case of Zn deficiency, the number of leaves increased and the size of leaves very much reduced while in the case of B deficiency the size of leaves profoundly increased. Striking decrease in internodal length

was observed only in the case of Zn deficiency. Inhibition of growth as evidenced by dry matter production occurred by the seventh month after treatment due to Fe deficiency, by the twelfth month due to B deficiency and at 14.5 months after treatment due to Cu deficiency. However, complete arrest of growth was not observed due to Mn and Zn deficiencies, although the rate of growth was below the normal.

Deficiency symptoms of micronutrients were associated with marked reduction in the foliar levels of the concerned nutrients. The following are the foliar levels of micronutrients corresponding to the severe stage at which the deficiency symptoms could be easily diagnosed:

Fe	-	88 ppm	Zn	-	25 ppm
Mn	-	40 ppm	B	-	15 ppm
Cu	-	46 ppm			

It may also be noted that the deficiency of one micronutrient failed to influence the foliar concentration of other micro and macronutrients at the concentrations used.

The micronutrient deficiency symptoms could be recovered by the application of the respective nutrients. However, B deficiency at severe stage could not be recovered. The deficiency which was recovered within the minimum period of one week was that of Fe whereas severe deficiency of Cu required four weeks for the complete recovery. As expected,

the foliar level of micronutrients in the recovered vines were higher than those at the initial stage of deficiency.

Seasonal variation and relationships of foliar nutrient levels with yield

1. Seasonal variation in foliar nutrient status

1.1 Macronutrients

The total foliar N content varied from 2.23 to 2.71 per cent during 1981 and from 2.37 to 2.65 per cent during 1982. Though there was slight variation in the leaf concentration of N between the two years, the trend was the same in both the years. Two peaks were observed, one in June and the other in October, the highest being in June (Fig. 9c). It is likely that the increase in the concentration of foliar N with the onset of flowering is due to the increased uptake of N from soil after the receipt of monsoon showers (Appendices I and II). The increase in N content during October may be due to the absorption of N from the fertilizer added in August. The higher foliar N level of pepper during June was also observed by other workers like Geetha (1981), Kurian (1982) and Sushama *et al*. (1984).

The results indicated that the P content of leaf was highly influenced by the season of sampling (Fig. 9a). The pattern of variation was the same during both the years.

The lowest level of foliar P (0.16%) was recorded during April in both the years and highest in June (0.21% in 1981 and 0.20% in 1982). After June, a steady decrease was observed upto the harvest (December). The higher content of P in leaf during June may be attributed to the high uptake from soil as well as the accumulation during the preceding months due to slow rate of growth and leaf production prior to flushing. The low level of foliar P during October, the period followed by the application of phosphatic fertilizer may be because the additional quantity may be counteracted by the increasing demand for the element by the developing berries. A steady decrease from July to November was reported by Kurian (1982) also.

The data presented in Table 25 revealed that leaf K exhibited two peaks, one in June and the other in October (Fig. 9b), the highest being in October. The level of foliar K ranged between 1.33 and 1.57 per cent during 1981 and 1.54 and 1.77 per cent in 1982. The high accumulation of K during October may be due to the increased uptake of K applied to the soil prior to sampling. The present finding is in conformity with the reports of Kurian (1982) and Sushama et al. (1984). As in the case of N and P, the increased level of K in the leaf during June may be attributed to the increased rate of absorption of the nutrient from the soil consequent to the onset of monsoon. The conspicuous decrease of K during August may be due to higher rate of

translocation to the developing berries. The low accumulation of K in the leaf during April may probably be due to the very limited absorption of the element due to limited moisture in the soil.

In general, the foliar Ca content of the experimental plants was high during both the years. During 1981, the Ca content varied from 2.20 to 2.84 per cent. The corresponding values in 1982 were 2.37 and 2.75 per cent, respectively. De Waard (1969) observed the seasonal variation in foliar Ca level of pepper in Sarawak to range between 1.42 and 1.86 per cent. The variation between the observations of the two studies may be due to the differences in the genotypes, soil and climatic conditions prevailing in these two localities. The concentration of Ca in leaves was minimum during June and thereafter increased upto December which was in full agreement with the finding of Kurian (1982). The gradual and steady increase in foliar Ca from flowering to harvest may probably be because the soil was able to provide a steady supply of Ca to the plants, irrespective of the period of fertilizer application. The results also suggested that the initial level of Ca in the leaves was sufficient to meet the increased requirement of the element at the time of flushing and berry development. The Ca content of the berries as reported by De Waard (1969) is very low (0.45%) which may partially account for the appreciable accumulation of the element in the leaves over a period of time.

Unlike other nutrients, foliar Mg registered the highest peak of 0.72 per cent in August 1981. However, the maximum value in 1982 (0.68%) corresponded to the month of December. But the trend of variation was the same in both the years (Fig. 10b). The lowest level was observed in April (0.41% in 1981 and 0.35% in 1982). Magnesium, being a constituent of chlorophyll, may be mobilised from the leaves to the developing berries which may be the reason for the steep fall in foliar Mg during October. The increased demand of Mg at the berry maturing stage has also been reported by De Waard (1969). The increased accumulation of Mg in the leaf during August may be attributed to the increased absorption from the soil when moisture is not limiting in the soil.

The variation in foliar S followed a pattern similar to that of K. Though not very conspicuous, two peaks were observed, one in June and the other in October. The foliar S ranged from 0.093 to 0.100 per cent during 1981 and from 0.069 to 0.084 per cent in 1982. These results show that the magnitude of variation is not much influenced by the seasons.

1.2 Micronutrients

The micronutrients Fe, Mn and Zn, in general showed the same trend of variation during both the years, except that Fe registered a decrease during October (Fig.11). However,

in both the years maximum foliar concentration was recorded during December. The foliar levels of these micronutrients showed a decreasing trend from April to June and an increasing trend thereafter. The micronutrients Fe, Mn and Zn are mainly involved in the vegetative growth rather than in the reproductive phase. Iron and Mn are involved in chlorophyll synthesis (Bogorad, 1966 and Gauch, 1972) and Zn is essential for the production of the endogenous hormone, IAA which is responsible for cell elongation (Tsui, 1948). Therefore, it is likely that during the course of development of berries, the above micronutrients may get accumulated in the leaves. The reduction in foliar concentration of micronutrients from April to June may be attributed to the dilution of the element to the developing foliage since the period corresponds to the active flushing stage.

2. Relationships between foliar nutrient levels and yield

To determine the nature and the extent of relationships between foliar nutrient levels and yield, the experimental plants were grouped into 25 yield classes separately for each year. From the linear and quadratic models tried, it was observed that wherever significant linear correlations were obtained, quadratic functions also yielded significant relationships. However, the coefficients of determination were invariably higher for the quadratic models.

Highly significant positive linear and quadratic correlations existed between the yield and all the macronutrients except N. However, no significant correlation could be observed between the yield and any one of the micronutrients in both the years. In view of the generally high correlations observed between the yield and the foliar nutrient levels in April 1981 and June 1982, constants of linear and quadratic equations during those periods were worked out to examine their goodness of fit and to select the better model on the basis of variation expalined by each.

Though the coefficients of determination were higher for the quadratic models, the path of the curves (Fig. 12 to 21) failed to suggest foliar critical levels of the elements except in the case of S. This may be due to the fact that majority of the observed values were confined to the linear portion of the quadratic curves.

2.1 Macronutrients

The correlation coefficient between yield and foliar N was positive during 1981 and negative in 1982. The negative correlation coefficient indicates that the level of N already present in leaf was enough to support a high yield and any further addition by means of fertilizers and manures might have resulted in profused vegetative growth thereby reducing the yield. The foliar N levels corresponding to the

highest yield classes during 1981 and 1982 were 2.14 and 2.39 per cent, respectively. However, the values observed were lower than that reported by De Waard (1969) in Sarawak as critical value of N (2.70 to 2.80%).

Despite the apparently significant positive effect of foliar P on yield as reflected in the quadratic regression component, the mode of influence as given in Fig. 12 suggests that it is not possible to establish a critical level for this nutrient. However, since there existed a highly significant linear relationship, it may be assumed that the foliar concentration of P has not reached the critical level. The quadratic relationship between yield and leaf P during 1982 was not significant. The foliar P contents corresponding to the highest yield classes during 1981 and 1982 were 0.19 and 0.20 per cent respectively. According to De Waard (1969) the range of foliar P value in pepper was 0.18 to 0.32 per cent.

As in the case of P, most of the observed values for leaf K were also confined to the linear portion of the quadratic model, irrespective of the higher R^2 value for the quadratic model. The highest yield classes recorded a mean foliar K content of 1.76 per cent during 1981 and 1.85 per cent during 1982 which were lower than the critical level of 2.00 to 2.62 per cent reported by De Waard (1969).

The foliar Ca content exhibited a highly significant positive correlation with yield during both the years. However, as in the case of P and K, it was not possible to fix

the critical level of foliar Ca. The foliar Ca contents corresponding to the highest yield classes during 1981 and 1982 ranged between 2.78 and 2.93 per cent. In general, the foliar Ca content of the experimental plants was high as compared with that of 1.66 to 1.68 per cent reported by De Waard (1969). However, in another experiment he observed the foliar Ca level to range between 1.56 and 2.40 per cent. The higher Ca content may be due to the fact that the experimental plants were receiving 500 g lime every year which might have resulted in the accumulation of Ca in the leaves.

The results revealed that the coefficients of linear and quadratic correlations between yield and foliar Mg were highly significant during both the years. The fitted curves showed that the quadratic models followed almost the linear paths since majority of the values were confined to the linear portion of the quadratic curves. The foliar Mg levels of the highest yield classes of 1981 and 1982 were 0.57 and 0.60 per cent respectively. As in the case of Ca, the critical value of Mg reported by De Waard (1969) is lower (0.20 to 0.30%) than that observed during the present investigations.

The foliar S also showed highly significant linear and quadratic relationships with yield. The pattern of the quadratic curve for 1981 (Fig.20) suggested a critical level

of the element. The S content corresponding to the peak of the curve was 0.15 per cent. The quadratic model for 1982 represented almost linear function. However, the foliar S level corresponding to the highest yield class of 1982 was also 0.15 per cent. This may suggest that the critical level of foliar S could be fixed as 0.15 per cent.

2.2 Micronutrients

The foliar levels of micronutrients such as Fe, Mn and Zn failed to establish any significant correlation with yield during both the years (Tables 32 and 33). The Fe contents in leaf corresponding to the highest yield classes during 1981 and 1982 were 156 and 169 ppm, respectively whereas the corresponding values for Mn were 88 and 77 ppm. The highest yield classes of 1981 and 1982 recorded 30 and 32 ppm foliar Zn respectively.

From the foregoing discussions, it may be suggested that the five major nutrients which exhibit profound influence on the yield of pepper could be P, K, Ca, Mg and S. However, it was not possible to fix a critical level for any of the nutrients except S. This was because the nutrients N, Fe, Mn and Zn did not show any significant correlation with yield. In the case of other nutrients, eventhough, the foliar levels gave significant correlation, the linear scattering of the data against yield did not permit to arrive at critical values. In the case of S, the critical level was found to be 0.15 per cent. With regard to other nutrients, the following range

in foliar levels corresponding to the highest yield classes of 1981 and 1982 could be suggested as the 'tentative critical levels'.

N	-	2.1 to 2.4%	Mg	-	0.5 to 0.6%
P	-	0.19 to 0.20%	Fe	-	156 to 169 ppm
K	-	1.8 to 1.9%	Mn	-	77 to 88 ppm
Ca	-	2.8 to 2.9%	Zn	-	30 to 32 ppm

2.3 Path coefficient analysis

In view of the highly significant correlations obtained between yield and most of the foliar nutrients during April 1981 and June 1982, the data for these months were further subjected to path coefficient analysis. The results of the analysis suggested that the nine nutrient elements namely N, P, K, Ca, Mg, S, Fe, Mn and Zn could explain the variability in yield of pepper almost completely (99.93% in 1981 and 99.59% in 1982). Among the nutrients, the element K had the maximum positive influence on yield directly as well as by the effects of other nutrients such as P, Ca, Mg and S via. K. The indirect effect of K on yield through the aforesaid nutrients was also very high. The highly significant influence of K on berry development has been reported by other scientists also (De Waard, 1969 and Sushama et al., 1984). The magnitude of the direct effect of P on yield could be considered next to that of K. There was considerable positive indirect effect of P on yield via. other elements such as K, Ca, Mg and S. The indirect effects

of macronutrients other than N on yield through P were marginal. Sushama et al. (1984) also reported significant effect of P on berry development. She observed a high level of P (0.30%) in pepper berries at six months of maturity which was reduced to 0.22 per cent at full maturity. However, De Waard (1969) reported only 0.096 per cent P in the ripe berries.

During the two seasons, Ca and Mg showed highly significant positive correlation with yield though the direct effects during 1982 were negative. The high positive indirect effects of other macronutrients (except N) via. Ca and Mg could be attributed to the positive correlation. The positive relationship between yield and foliar Mg is in agreement with the finding of De Waard (1969). There was not much influence on yield by Ca and Mg through other nutrients. Sulphur was also found to have considerable positive influence on yield through direct effect and via. positive indirect effects of P, K and Mg. The effects (direct and indirect) of nutrients such as N, Fe, Mn and S on yield were very meagre. However, the direct effects of them on yield were negative. The coefficients of correlation between yield and the above nutrients were also negative. Sushama et al. (1984) also could not observe any significant influence of N on yield.

Summary

SUMMARY

The present investigations were carried out from 1981 to 1985 at the Pepper Research Station, Panniyur and College of Horticulture, Vellanikkara with a view to induce macro and micronutrient deficiency symptoms by sand culture and to study the seasonal variation and relationships of foliar nutrient levels with yield of black pepper. The results of the study are summarized below:

Nutrient deficiency

The N deficiency symptom was first manifested as pale green colour of the older leaves which attained uniform deep yellow followed by necrosis of the whole laminae. Reduction in shoot growth (56%), number of leaves (53%), leaf area index (63%), dry matter of roots (39%) and total dry matter production (51%) was also observed in a period of eight months as compared to the plants receiving complete nutrient solution. Due to N deficiency there was a decrease in foliar level of N by 53 per cent (1.6%), Mg by 23 per cent and Fe by 36 per cent. The visual symptoms of N deficiency could be recovered within a period of one to three weeks.

The first visible symptom of P deficiency appeared as bright bluish green colour of older leaves which turned purple or bronze green. During the advanced stage of

deficiency, ash coloured necrotic areas developed on the lamina followed by leaf shedding. Phosphorus deficiency resulted in reduction of vine length (27%), number of leaves (32%), weight of roots (45%) and total dry matter (28%). Visual symptoms of P deficiency was concurred with a reduction in foliar concentration of the element by 65 per cent (0.11%). Phosphorus deficiency at medium stage could be corrected within one month whereas it was not possible to recover the severe symptoms.

Potassium deficiency symptom was characterized by the black necrotic area on the older leaves which first appeared at the tips and margins, progressed towards the proximal end and covered about two-thirds of the laminae. Omission of K from the growing medium was associated with a decrease in length of vine (11%), number of leaves (12%) and total dry matter (11%). There was reduction in foliar concentration of K by 65 per cent (1.0%) and increase in Ca and Mg levels by 25 and 24 per cent respectively, due to K deficiency. Though the affected leaves could not be recovered, it was possible to prevent further spread of the symptoms within two to three weeks after the application of K.

Calcium deficiency symptom appeared as tiny brown necrotic pinhead spots on chlorotic area near the margins of younger leaves which later enlarged and surrounded by

yellow halo. This was accompanied by interveinal chlorosis and die back. Subsequently, black necrotic areas near the margins were developed followed by shedding of affected leaves. Deficiency of Ca resulted in a marked reduction in root growth which extended up to 61 per cent. Concurrent with the manifestation of Ca deficiency, there was a reduction in the foliar level of the element to the tune of 65 per cent and an increase in K and Mg by 18 and 21 per cent respectively. For the correction of Ca deficiency, comparatively longer period of three to five weeks were required.

Deficiency of Mg was first manifested on the older leaves as pale yellow discolouration of margins and tips which developed into oval shaped interveinal chlorotic areas. However, the lateral veins turned yellow. With the advancement of deficiency, small interveinal necrotic spots appeared which enlarged and coalesced to form necrotic patches followed by defoliation. The effect of Mg deficiency on vegetative growth was comparatively low. However, the dry weight of leaves recorded a reduction by 25 per cent and total dry weight by 15 per cent. Magnesium deficient vines registered a reduction in foliar Mg by 78 per cent (0.33%) and an increase in foliar Ca by 19 per cent. It was possible to correct Mg deficiency symptoms in two to three weeks time by the application of Mg.

The initial symptom of S deficiency appeared as pale green to silvery white discolouration of the younger leaves which turned to uniform yellow. Thereafter, tiny necrotic spots appeared on the lamina followed by the development of black necrotic areas, die back and premature leaf fall. Due to S deficiency, there was a decrease of 48 per cent in shoot growth, 63 per cent in number of leaves and 65 per cent in total dry matter. The foliar level of S was reduced to the extent of 80 per cent (0.04%) due to S deficiency. It was observed that S deficiency at severe stage could not be corrected whereas medium deficiency symptoms could be recovered within a period of two weeks.

Among the macronutrients, the earliest deficiency symptoms were manifested by the element S (3rd month) followed by N (4th month), K (5th month), P (10th month), Mg (11th month) and Ca (14th month). The growth of S deficient plants was completely arrested at 4.5 months after treatment. In the case of deficiencies of N and P, the growth of vine was stopped at the sixth and thirteenth month respectively, after treatment. However, cessation of growth was not observed in the case of deficiencies of K, Ca and Mg although the reduction in rate of growth has increased with the advancement of deficiency.

The Fe deficiency symptom was manifested as interveinal chlorosis of the younger leaves. During the severe stage

the fine veins turned chlorotic while the green bands along the major veins were retained. Finally, premature defoliation and stunted growth were noticed. Due to Fe deficiency, the shoot growth was reduced by 37 per cent, number of leaves by 33 per cent and total dry matter by 35 per cent. Visual symptoms of Fe deficiency was associated with a reduction in foliar level of the element by 68 per cent (61 ppm). The deficiency symptoms could be corrected in a period of two weeks after the application of Fe.

Interveinal chlorosis of the younger leaves followed by bronzing and defoliation were the visual symptoms associated with Mn deficiency. Due to Mn deficiency there was reduction in shoot growth (10%), number of leaves (12%) and total dry matter (14%). The magnitude of reduction in foliar Mn due to deficiency of the element was 66 per cent (29 ppm). Application of Mn could correct the deficiency within two to three weeks time.

Copper deficiency was expressed as interveinal chlorosis of young leaves which later spread to the entire laminae. With the advancement of deficiency the laminae became deep bronze and black necrotic areas developed near the tips and margins followed by defoliation. Copper deficiency resulted in a reduction in length of vine by 10 per cent and total dry matter by 6 per cent. Visual symptoms of Cu deficiency was concurred with a reduction of 76 per cent (30 ppm) in

foliar Cu. Deficiency symptoms of Cu could be recovered within a period of two to four weeks.

Zinc deficiency was manifested as interveinal chlorosis of younger leaves with a prominent network of dark green veins. Little leaf and rosetting were also observed at the advanced stage. Deficiency of Zn was concurred with a reduction of 16 per cent in length of vine, 20 per cent in internodal length, 40 per cent in leaf area index and 9 per cent in total dry matter. The foliar level of Zn was reduced to 15 ppm (-79%) due to Zn deficiency. Recovery of the affected plant was complete within a period of two to three weeks.

Deficiency of B was first expressed as the failure of development of terminal bud. The terminal leaves became abnormal in size and when mature, interveinal chlorotic patches appeared on the upper surface of the laminae and the corresponding area on the lower surface became grey brown. The affected leaves became thick, brittle and presented a mottled appearance with bright orange colour followed by necrosis and shedding. Due to B deficiency, there was a decrease of 31 per cent in length of vine, 30 per cent in number of leaves and 22 per cent in total dry matter. The leaf area index recorded an increase by 18 per cent. Boron deficiency was associated with a fall in leaf B to the tune of 76 per cent (20 ppm).

Though, severe deficiency symptoms of B could not be recovered, the correction of medium deficiency symptoms was possible within a period of three weeks.

Among the micronutrients, the deficiency symptom of Fe was manifested at an early stage (4th month) as compared to Mn (6th month), B (9th month), Zn (12th month) and Cu (13th month). Complete arrest of growth was not observed in the case of Mn and Zn deficiencies. However, cessation of growth was noticed at the seventh, twelfth and 14.5 months after treatment due to deficiencies of Fe, B and Cu respectively.

Relationships of foliar nutrients with yield

The total foliar N content varied from 2.23 to 2.71 per cent with peaks in June and October, the highest being in June. The lowest level of foliar N was recorded during April. The leaf P content ranged from 0.16 to 0.21 per cent with the maximum in June and minimum in April. As in the case of N, leaf K also exhibited two peaks, one in June and the other in October, the highest being in October. The level of foliar K ranged between 1.33 and 1.77 per cent with minimum in April and August during 1981 and 1982, respectively. The ca content in leaves varied from 2.2 to 2.8 per cent which was minimum in June and maximum in December. The minimum (0.35%) foliar content of Mg was observed during April and the maximum during August (0.72%) and December (0.68%) in 1981

and 1982, respectively. The foliar S ranged from 0.069 to 0.100 per cent with the minimum in December and the maximum in October.

The micronutrients Fe, Mn and Zn in general showed a decreasing trend from April to June and thereafter increased and registered maximum level in December. The foliar Fe content varied from 126 to 191 ppm, Mn from 47 to 88 ppm and Zn from 27 to 48 ppm.

Highly significant positive linear and quadratic correlations existed between yield and the macronutrients except N. However, no significant correlation could be observed between yield and the micronutrients (Fe, Mn and Zn). Though the coefficients of determination were higher for quadratic model, the path of curves failed to suggest foliar critical levels of the elements (except for S) because majority of the observed values were confined to the linear portion of the quadratic curves. The critical level of S was found to be 0.15 per cent. The 'tentative critical levels' suggested for the other nutrients are as follows:

N	-	2.1 to 2.4%	P	-	0.19 to 0.20%
K	-	1.8 to 1.9%	Ca	-	2.8 to 2.9%
Mg	-	0.5 to 0.6%	Fe	-	156 to 169 ppm
Mn	-	77 to 88 ppm	Zn	-	30 to 32 ppm

The nine nutrient elements namely N, P, K, Ca, Mg, S, Fe, Mn and Zn could explain the variability in yield of pepper almost completely. The element K had the maximum positive direct effect on yield followed by P, Ca, Mg and S. Though very meagre, the direct effects of N, Fe, Mn and Zn on yield were negative.

Based on the findings of the present investigations, the five important nutrient elements which highly influence the yield of black pepper could be identified as K, P, Ca, Mg and S.

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* Original not seen

APPENDIX-I Weather data of the experimental area for the year 1981.

Month	Total rain fall (mm)	No.of rainy days	R.H.% (mean)	Temperature °C (mean)		Soil Temp. (°C)at 15 cm depth	Bright sunshine hours (mean)
				Max.	Min.		
January	-	-	82.5	34.7	21.9	26.2	9.64
February	2.0	1	83.9	36.5	22.3	29.3	10.09
March	8.3	2	84.3	37.3	24.9	32.3	9.77
April	79.0	5	88.6	36.0	26.2	32.3	8.69
May	85.1	9	89.9	35.5	26.1	30.2	8.67
June	1387.8	28	94.0	29.4	25.0	24.3	2.95
July	1034.2	24	92.4	29.1	24.6	25.4	3.03
August	768.5	26	93.6	29.5	24.6	26.0	2.68
September	462.3	18	89.3	29.2	24.8	27.4	4.37
October	174.4	14	94.6	31.3	24.8	28.7	5.49
November	124.5	9	94.7	32.0	23.0	26.8	7.31
December	20.0	3	92.3	34.0	21.8	33.1	8.65

APPENDIX-II Weather data of the experimental area for the year 1982

Month	Total rain fall (mm)	No.of rainy days	R.H.% (mean)	Temperature °C (mean)		Soil Temp. (°C)at 15 cm depth	Bright sunshine hours (mean)
				Max.	Min.		
January	-	-	90.3	34.2	21.6	26.7	9.50
February	-	-	90.9	34.7	23.4	29.5	10.16
March	10.5	3	89.4	35.8	24.6	31.9	8.65
April	-	-	91.2	36.8	26.8	33.2	8.81
May	109.5	8	90.9	35.4	26.7	30.3	6.65
June	1865.0	22	90.1	29.4	24.2	25.8	1.77
July	893.8	29	93.8	29.3	24.3	22.3	-
August	1052.2	28	93.7	29.0	24.0	22.6	-
September	61.8	11	93.7	30.5	22.9	24.5	4.41
October	135.6	10	91.6	32.9	24.5	27.5	6.75
November	72.6	6	90.1	32.7	22.6	28.3	7.81
December	-	-	94.7	35.1	22.5	28.3	8.08

APPENDIX-III Nutrient status of experimental field during January 1981

Treatments	Organic carbon (%)	Total N (%)	Available P (ppm)		Available K (ppm)
			Bray	Triple acid	
n_o	4.93	0.263	62	96	181
n_1	4.86	0.259	52	96	205
n_2	4.64	0.296	55	91	164
P_o	4.75	0.252	58	95	160
P_1	4.93	0.261	57	91	181
P_2	4.77	0.286	55	96	160
K_o	4.77	0.260	57	94	126
K_1	4.79	0.275	56	95	175
K_2	4.89	0.272	56	93	201

APPENDIX-IV The mean foliar nutrient contents of different yield classes for June 1981

Class No.	Mean yield (kg)	Macronutrients (%)						Micronutrients (ppm)		
		N	P	K	Ca	Mg	S	Fe	Mn	Zn
1	0.18	2.76	0.191	1.32	1.64	0.184	0.071	124	51	38
2	0.39	2.68	0.186	1.36	1.96	0.316	0.091	131	42	35
3	0.16	2.58	0.204	1.21	1.82	0.288	0.079	123	47	34
4	0.89	2.59	0.204	1.38	1.82	0.323	0.088	132	51	36
5	1.19	2.97	0.207	1.44	1.85	0.449	0.090	141	43	44
6	1.38	2.76	0.201	1.25	2.00	0.271	0.069	125	42	33
7	1.65	2.75	0.218	1.91	2.36	0.248	0.093	108	41	39
8	1.90	2.64	0.213	1.38	2.02	0.312	0.089	126	39	35
9	2.15	2.50	0.200	1.56	2.00	0.376	0.093	125	51	32
10	2.35	2.53	0.198	1.18	2.11	0.286	0.055	131	50	35
11	2.60	2.88	0.205	1.37	1.99	0.450	0.094	140	50	38
12	2.89	2.83	0.189	1.53	2.07	0.450	0.099	112	45	46
13	3.17	3.00	0.214	1.38	2.18	0.274	0.112	122	45	36
14	3.40	2.58	0.222	1.35	2.15	0.382	0.090	137	46	42
15	3.61	2.68	0.208	1.78	2.07	0.693	0.080	121	38	40
16	3.91	2.88	0.210	1.79	1.98	0.413	0.092	147	48	35
17	4.15	2.65	0.198	1.67	2.24	0.403	0.083	163	51	35
18	4.41	2.73	0.195	1.67	2.25	0.515	0.108	126	50	30
19	4.69	2.54	0.196	1.49	2.51	0.402	0.094	116	38	28
20	5.11	2.76	0.223	1.55	2.40	0.450	0.119	108	41	33
21	5.59	2.70	0.212	1.97	2.57	0.596	0.106	128	45	36
22	6.37	2.67	0.213	1.83	2.53	0.569	0.106	107	47	38
23	7.36	2.58	0.221	1.57	2.65	0.641	0.093	129	54	37
24	8.47	2.65	0.238	2.06	2.60	0.573	0.122	135	52	33
25	11.07	2.77	0.231	1.88	3.06	0.796	0.119	117	48	40

APPENDIX-V The mean foliar nutrient contents of different yield classes for August, 1981

Class No.	Mean yield (kg)	Macronutrients (%)						Micronutrients (ppm)		
		N	P	K	Ca	Mg	S	Fe	Mn	Zn
1	0.18	2.56	0.193	0.89	1.71	0.453	0.066	134	62	36
2	0.39	2.53	0.184	1.01	2.32	0.649	0.078	138	51	36
3	0.16	2.35	0.187	0.93	2.07	0.634	0.087	136	61	35
4	0.89	2.48	0.193	1.00	2.01	0.477	0.077	138	61	34
5	1.19	2.51	0.199	1.09	2.25	0.510	0.071	157	66	37
6	1.38	2.49	0.210	0.92	2.43	0.651	0.061	147	58	34
7	1.65	2.36	0.196	1.00	2.21	0.358	0.100	120	69	35
8	1.90	2.67	0.201	1.34	2.29	0.589	0.074	163	54	37
9	2.15	2.49	0.205	0.78	2.05	0.605	0.086	137	55	33
10	2.35	2.53	0.197	0.87	2.25	0.752	0.065	129	51	32
11	2.60	2.41	0.357	0.72	2.38	0.588	0.064	129	57	33
12	2.89	2.40	0.191	0.93	2.43	0.600	0.076	147	64	34
13	3.17	2.64	0.196	1.04	2.74	0.528	0.080	162	67	38
14	3.40	2.40	0.202	1.07	2.65	0.798	0.064	146	61	36
15	3.61	2.40	0.192	1.34	2.48	0.682	0.085	140	57	37
16	3.91	2.50	0.212	0.97	2.12	0.637	0.085	148	55	31
17	4.15	2.29	0.195	0.90	2.17	0.773	0.100	135	59	33
18	4.41	2.63	0.198	1.04	2.76	0.830	0.085	157	51	34
19	4.69	2.25	0.206	0.72	2.82	0.958	0.094	142	53	33
20	5.11	2.71	0.202	1.02	2.60	0.859	0.100	145	52	37
21	5.59	2.49	0.196	1.20	2.60	0.896	0.090	131	56	32
22	6.37	2.27	0.201	1.23	2.51	0.936	0.026	171	61	33
23	7.36	2.39	0.207	1.37	2.71	0.915	0.085	132	64	32
24	8.47	2.62	0.202	1.17	2.89	0.994	0.105	145	60	30
25	11.07	2.35	0.206	1.14	2.84	0.997	0.081	139	58	32

APPENDIX-VI The mean foliar nutrient contents of different yield classes for October, 1981

Class No.	Mean yield (kg)	Macronutrients (%)						Micronutrients (ppm)		
		N	P	K	Ca	Mg	S	Fe	Mn	Zn
1	0.18	2.56	0.167	1.43	2.22	0.309	0.105	126	75	31
2	0.39	2.47	0.168	1.23	2.26	0.503	0.108	121	64	37
3	0.16	2.63	0.164	1.70	2.24	0.504	0.096	130	74	31
4	0.89	2.61	0.182	1.33	2.33	0.376	0.095	127	76	31
5	1.19	2.66	0.161	1.61	2.43	0.423	0.103	127	73	32
6	1.38	2.55	0.239	1.71	2.33	0.270	0.107	108	64	28
7	1.65	2.46	0.180	1.84	2.24	0.377	0.180	147	73	38
8	1.90	2.62	0.174	1.60	2.50	0.364	0.124	117	69	31
9	2.15	2.67	0.176	1.70	2.77	0.480	0.247	126	67	34
10	2.35	2.53	0.193	1.51	2.35	0.316	0.120	125	80	29
11	2.60	2.80	0.185	1.38	2.52	0.388	0.112	129	80	30
12	2.89	2.71	0.209	1.77	2.37	0.381	0.110	131	77	32
13	3.17	2.80	0.174	1.61	2.81	0.500	0.108	122	79	31
14	3.40	2.48	0.186	1.92	2.68	0.450	0.110	123	68	32
15	3.61	2.83	0.185	1.80	2.67	0.530	0.103	120	84	34
16	3.91	2.46	0.183	1.60	2.50	0.447	0.120	137	53	33
17	4.15	2.62	0.183	1.40	2.44	0.503	0.123	141	74	33
18	4.91	2.71	0.183	1.66	3.03	0.728	0.272	128	85	32
19	4.69	2.70	0.164	1.30	2.36	0.600	0.106	123	69	31
20	5.11	2.79	0.195	1.40	2.77	0.564	0.116	127	67	31
21	5.59	2.56	0.200	1.62	2.92	0.675	0.110	129	59	32
22	6.37	2.51	0.203	1.54	2.74	0.588	0.120	139	72	31
23	7.36	2.66	0.201	1.56	2.78	0.612	0.105	134	69	35
24	8.47	2.72	0.208	1.46	2.99	0.858	0.142	126	66	32
25	11.07	2.61	0.190	1.55	2.95	0.698	0.129	132	72	31

APPENDIX-VII The mean foliar nutrient content of different yield classes for December, 1981

Class No.	Mean yield (kg)	Macronutrients (%)						Micronutrients (ppm)		
		N	P	K	Ca	Mg	S	Fe	Mn	Zn
1	0.18	2.33	0.167	1.19	2.00	0.357	0.108	149	75	39
2	0.39	2.28	0.168	1.28	2.50	0.480	0.112	149	69	39
3	0.16	2.37	0.161	1.35	2.27	0.471	0.107	169	83	38
4	0.89	2.36	0.169	1.41	2.25	0.344	0.094	156	83	40
5	1.19	2.27	0.167	1.44	2.82	0.573	0.104	170	89	41
6	1.38	2.18	0.166	1.13	2.65	0.583	0.109	158	72	38
7	1.65	2.19	0.192	1.51	2.77	0.433	0.140	183	89	39
8	1.90	2.26	0.169	1.67	2.66	0.525	0.132	177	81	43
9	2.15	2.48	0.180	1.38	2.84	0.589	0.060	181	85	40
10	2.35	2.26	0.187	1.61	2.63	0.508	0.115	146	95	444
11	2.60	2.43	0.163	1.11	2.82	0.435	0.140	147	90	43
12	2.89	2.37	0.183	1.54	2.59	0.511	0.116	167	93	41
13	3.17	2.32	0.184	1.31	2.78	0.536	0.124	156	93	43
14	3.40	2.34	0.162	1.46	2.99	0.636	0.116	159	89	43
15	3.61	2.40	0.177	1.92	2.76	0.540	0.113	164	96	40
16	3.91	2.14	0.180	1.39	2.78	0.580	0.127	174	79	40
17	4.15	2.39	0.165	1.40	3.12	0.643	0.152	178	78	42
18	4.41	2.28	0.168	1.47	3.45	0.598	0.143	160	82	45
19	4.69	2.34	0.178	1.11	3.10	0.654	0.102	167	71	38
20	5.11	2.32	0.188	1.44	3.01	0.663	0.101	162	73	41
21	5.59	2.14	0.176	1.51	3.13	0.667	0.142	177	66	40
22	6.37	2.34	0.168	1.28	3.18	0.771	0.104	167	83	40
23	7.36	2.19	0.168	1.39	3.18	0.682	0.113	180	86	41
24	8.47	2.30	0.172	1.35	3.10	0.643	0.117	167	75	38
25	11.07	2.18	0.165	1.38	3.21	0.852	0.134	168	82	37

APPENDIX-VIII The mean foliar nutrient contents of different yield classes for April, 1982

Class No.	Mean yield (kg)	Macronutrients (%)						Micronutrients (ppm)		
		N	P	K	Ca	Mg	S	Fe	Mn	Zn
1	0.07	2.48	0.147	0.85	1.84	0.162	0.046	163	75	23
2	0.17	2.41	0.160	1.07	2.02	0.202	0.128	199	77	31
3	0.25	2.69	0.149	0.88	2.26	0.214	0.079	189	81	28
4	0.34	2.48	0.156	0.99	1.98	0.206	0.070	170	82	31
5	0.38	2.66	0.156	0.91	2.18	0.242	0.099	161	83	28
6	0.44	2.57	0.160	1.03	2.25	0.467	0.223	193	76	33
7	0.58	2.49	0.148	1.10	2.70	0.138	0.102	163	76	26
8	0.65	2.57	0.160	1.28	2.34	0.310	0.089	176	81	32
9	0.76	2.25	0.163	0.96	2.50	0.348	0.100	176	88	32
10	0.84	2.64	0.154	1.04	2.75	0.306	0.094	168	84	24
11	0.96	2.34	0.160	0.94	2.38	0.433	0.130	181	88	44
12	1.15	2.56	0.152	1.05	2.48	0.264	0.100	183	89	27
13	1.45	2.48	0.170	1.01	2.75	0.344	0.102	125	81	33
14	1.59	2.56	0.158	1.18	2.72	0.328	0.106	204	76	32
15	1.69	2.48	0.157	1.20	2.68	0.320	0.106	163	88	30
16	1.88	2.45	0.164	1.09	2.67	0.386	0.137	162	94	31
17	2.14	1.86	0.145	1.40	3.08	0.325	0.108	174	84	28
18	2.61	2.35	0.166	1.17	2.60	0.414	0.116	178	94	34
19	3.03	2.49	0.163	1.28	2.86	0.419	0.095	184	83	31
20	3.70	2.30	0.154	1.19	2.99	0.360	0.103	175	90	28
21	4.12	2.32	0.167	1.40	2.87	0.693	0.123	172	82	32
22	4.02	2.58	0.174	1.29	2.88	0.554	0.120	176	88	31
23	5.29	2.62	0.153	1.12	2.95	0.700	0.105	183	94	31
24	6.79	2.39	0.166	1.59	2.90	0.410	0.155	189	86	33
25	7.99	2.39	0.175	1.77	2.80	0.945	0.180	188	78	32

APPENDIX-IX The mean foliar nutrient contents of different yield classes for August, 1982

Class No.	Mean yield (kg)	Macronutrients (%)						Micronutrients (ppm)		
		N	P	K	Ca	Mg	S	Fe	Mn	Zn
1	0.07	2.40	0.165	1.44	1.86	0.342	0.074	140	68	44
2	0.17	2.49	0.169	1.40	1.86	0.311	0.061	158	61	43
3	0.25	2.47	0.179	1.33	1.84	0.576	0.070	156	77	42
4	0.34	2.51	0.178	1.38	1.94	0.382	0.054	171	71	35
5	0.38	2.43	0.179	1.00	2.27	0.451	0.084	151	77	39
6	0.44	2.39	0.177	1.15	2.18	0.275	0.090	166	72	34
7	0.58	2.32	0.173	1.39	2.85	0.620	0.088	146	66	35
8	0.65	2.49	0.180	1.25	2.27	0.429	0.063	147	70	39
9	0.76	2.35	0.190	1.53	2.23	0.333	0.083	139	70	36
10	0.84	2.53	0.182	1.68	2.52	0.380	0.128	165	71	50
11	0.96	2.32	0.193	1.35	2.25	0.355	0.100	173	72	37
12	1.15	2.64	0.185	1.50	2.35	0.474	0.082	166	90	43
13	1.45	2.45	0.180	1.60	2.78	0.920	0.084	166	80	44
14	1.59	2.32	0.187	1.65	2.28	0.384	0.062	134	75	37
15	1.69	2.56	0.178	1.61	2.58	0.435	0.075	169	93	39
16	1.88	2.54	0.176	1.86	2.27	0.587	0.094	174	79	42
17	2.14	2.43	0.200	1.89	2.65	0.565	0.088	165	68	39
18	2.61	2.41	0.183	1.70	2.46	0.615	0.073	175	83	36
19	3.03	2.47	0.184	1.81	2.66	0.699	0.065	145	73	46
20	3.70	2.37	0.183	1.87	2.66	0.593	0.068	148	73	45
21	4.12	2.39	0.167	1.69	2.93	0.993	0.095	165	70	40
22	4.02	2.59	0.178	1.78	2.94	0.856	0.100	173	80	40
23	5.29	2.56	0.200	1.66	2.88	0.998	0.095	174	77	51
24	6.79	2.39	0.188	1.45	2.95	0.725	0.110	140	81	35
25	7.99	2.42	0.175	2.00	3.00	0.998	0.140	151	81	43

APPENDIX-X The mean foliar nutrient contents of different yield classes for October, 1982

Class No.	Mean yield (kg)	Macronutrients (%)						Micronutrients (ppm)		
		N	P	K	Ca	Mg	S	Fe	Mn	Zn
1	0.07	2.54	0.160	1.69	1.92	0.338	0.084	132	68	37
2	0.17	2.43	0.160	1.59	2.00	0.288	0.051	142	61	40
3	0.25	2.43	0.166	1.54	2.01	0.420	0.073	144	76	40
4	0.34	2.50	0.170	1.57	2.16	0.290	0.056	139	71	37
5	0.38	2.48	0.163	1.29	2.24	0.276	0.067	138	77	39
6	0.44	2.43	0.162	1.33	2.22	0.278	0.095	148	71	36
7	0.58	2.42	0.172	1.83	2.38	0.515	0.092	131	68	37
8	0.65	2.49	0.174	1.36	2.46	0.234	0.174	132	70	42
9	0.76	2.52	0.175	1.81	2.08	0.238	0.068	154	70	388
10	0.84	2.51	0.176	1.81	2.63	0.356	0.112	148	70	47
11	0.96	2.53	0.180	1.80	2.33	0.307	0.120	160	71	36
12	1.15	2.67	0.165	1.85	2.57	0.424	0.066	143	87	44
13	1.45	2.67	0.185	1.85	2.58	0.806	0.098	149	79	45
14	1.59	2.42	0.180	1.87	2.43	0.352	0.060	135	75	38
15	1.69	2.68	0.180	2.01	2.55	0.504	0.075	158	87	38
16	1.88	2.52	0.183	2.01	2.60	0.560	0.094	152	80	42
17	2.14	2.53	0.185	2.14	2.78	0.455	0.093	155	68	40
18	2.61	2.57	0.185	1.91	2.71	0.525	0.078	153	83	35
19	3.30	2.62	0.190	1.95	2.89	0.588	0.068	143	73	46
20	3.70	2.56	0.189	2.04	3.07	0.498	0.072	140	73	43
21	4.12	2.66	0.203	1.95	2.80	0.925	0.085	150	70	47
22	4.02	2.61	0.202	1.93	3.08	0.652	0.086	163	81	40
23	5.29	2.55	0.203	1.88	3.13	0.925	0.088	144	76	50
24	6.79	2.56	0.203	1.84	3.10	0.678	0.092	132	81	36
25	7.99	2.52	0.208	2.12	3.30	0.965	0.130	167	76	42

?ENDIX-XI The mean foliar nutrient contents of different yield classes for December, 1982

ass o.	Mean yield (kg)	Macronutrients (%)						Micronutrients (ppm)		
		N	P	K	Ca	Mg	S	Fe	Mn	Zn
1	0.07	2.37	0.143	1.41	2.22	0.577	0.076	144	74	35
2	0.17	2.22	0.141	1.28	2.12	0.233	0.042	143	69	36
3	0.25	2.37	0.146	1.11	2.14	0.370	0.069	181	88	43
4	0.34	2.30	0.152	1.30	2.34	0.540	0.040	146	79	43
5	0.38	2.29	0.156	1.11	2.40	0.468	0.053	149	81	34
6	0.44	2.28	0.157	0.97	2.30	0.742	0.062	180	76	52
7	0.58	2.29	0.152	1.65	2.65	0.680	0.095	202	74	60
8	0.65	2.38	0.160	1.30	2.57	0.387	0.071	197	78	41
9	0.76	2.38	0.163	1.72	2.25	0.623	0.050	243	89	47
10	0.84	2.40	0.156	1.45	2.52	0.466	0.088	188	91	48
11	0.96	2.42	0.153	1.62	2.68	0.478	0.108	222	85	54
12	1.15	2.48	0.160	1.57	2.67	0.382	0.056	205	98	57
13	1.45	2.43	0.173	1.53	2.43	0.988	0.100	222	98	58
14	1.59	2.19	0.172	1.58	2.83	0.482	0.050	156	86	47
15	1.69	2.55	0.178	1.75	2.70	0.737	0.056	185	101	54
16	1.88	2.32	0.177	1.50	2.83	0.753	0.080	201	92	52
17	2.14	2.31	0.185	1.93	2.73	0.960	0.075	246	93	53
18	2.61	2.36	0.186	1.72	3.13	0.635	0.186	193	98	54
19	3.03	2.47	0.193	1.62	3.49	0.894	0.054	207	104	55
20	3.70	2.41	0.191	1.65	3.36	0.645	0.063	209	96	48
21	4.12	2.48	0.193	1.79	3.57	0.970	0.090	206	89	60
22	4.02	2.42	0.198	1.60	3.20	0.734	0.068	209	97	54
23	5.29	2.39	0.197	1.65	3.25	0.972	0.098	191	94	52
24	6.79	2.39	0.200	1.58	3.45	0.653	0.080	203	98	57
25	7.99	2.35	0.200	1.67	3.53	0.860	0.115	180	71	38

INVESTIGATIONS ON THE NUTRITION OF BLACK PEPPER [Piper nigrum L.]

By

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ABSTRACT OF THE THESIS

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ABSTRACT

Detailed studies were conducted in black pepper (var. Panniyur 1) from 1981 to 1985 at the Pepper Research Station, Panniyur and College of Horticulture, Vellanikkara with a view to induce nutrient deficiency symptoms by sand culture and to find out the relationships of foliar nutrients with yield.

Deficiency symptoms of macronutrients except Ca and S were first manifested on the older leaves while that of micronutrients on younger leaves. Symptoms of N deficiency were expressed as uniform yellowing followed by necrosis whereas purple to bronze yellowing with ash coloured necrotic areas were the symptoms of P deficiency. Potassium deficiency symptom was characterized by tip and marginal necrosis which later progressed to the two-thirds distal portion of the lamina. Calcium deficiency symptoms appeared as tiny brown necrotic spots on chlorotic area near margins which later enlarged to form black necrotic areas. Visible symptom of Mg deficiency was oval interveinal chlorotic area followed by black necrotic patches. Sulphur deficiency was manifested as uniform yellowing with brown necrotic spots. There was profound reduction in vegetative growth due to deficiency of macronutrients. The reduction in shoot growth and leaf area index was maximum in the case of deficiency of N (56 and 63% respectively) followed by S (48 and 17% respectively). The reduction in root growth was quite high due to deficiency of Ca (61%), P (45%) and N (39%).

Interveinal chlorosis was the initial symptom of deficiency of all micronutrients. However, the symptoms were specific to the concerned nutrients. Iron chlorosis was characterized by the presence of green bands along the major veins whereas bronze yellow colour of the interveinal areas was the specific symptom of Mn deficiency. Bronze colour of the entire lamina with necrotic tips and margins were the symptoms of Cu deficiency. Zinc deficiency was unique with little leaf and rosetting. Due to B deficiency, the leaves became large, thick and brittle with orange yellow mottles on upper surface and grey brown interveinal patches on lower surface. Unlike macronutrients, there was no marked reduction in vegetative growth due to deficiency of micronutrients except Fe and B which recorded 35 and 22 per cent reduction respectively, in total dry matter production. Boron deficient plants registered 18 per cent increase in leaf area index.

The growth of the vine was completely arrested at comparatively early stage (4.5 months after treatment) due to S deficiency followed by N (6th month), Fe (7th month), B (12th month), P (13th month) and Cu (14.5 months after treatment). There was no cessation of growth in the case of deficiencies of other nutrients.

Visual symptoms of deficiencies were concurred with a marked reduction in the foliar levels of the concerned elements. Antagonistic effects among K, Ca and Mg were also observed. In all other cases, deficiency of one element failed to influence

the foliar level of others. The deficiency symptoms could be recovered by the application of the deficient nutrient element which provided valid information for the confirmation of the deficiency symptoms.

The foliar levels of macronutrients except Ca registered two peaks, one in June and the other in October while the lowest level was during April. The nutrients namely Ca, Fe, Mn and Zn, in general showed a decreasing trend from April to June and thereafter increased and reached maximum level in December.

Highly significant positive correlations were showed by P, K, Ca and Mg with yield. The critical level of S was found to be 0.15%. The 'tentative critical levels' suggested for the other elements studied are as follows:

N	-	2.1 to 2.4%	P	-	0.19 to 0.20%
K	-	1.8 to 1.9%	Ca	-	2.8 to 2.9%
Mg	-	0.5 to 0.6%	Fe	-	156 to 169 ppm
Mn	-	77 to 88 ppm	Zn	-	30 to 32 ppm

The two most important nutrient elements which are highly essential for the production of pepper could be identified as K and P in view of their high direct and indirect effects on yield.