EVALUATION OF NUTRIENT UPTAKE IN BLACK PEPPER (*Piper nigrum* L.)

By

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THESIS

Submitted in partial fulfilment of the requirements for the degree

Doctor of Philosophy in Horticulture

Faculty of Agriculture
Kerala Agricultural University

COLLEGE OF HORTICULTURE
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1990

DECLARATION

I hereby declare that this thesis entitled "**Evaluation of nutrient uptake in 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,
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Certified that this thesis entitled '**Evaluation of nutrient uptake in black pepper** (*Piper nigrum* L.)' is a record of research work done independently by **Smt.C.K. Geetha** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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Introduction

INTRODUCTION

Black pepper (*Piper nigrum* L.), the 'King of Spices', still retains its crown, enjoying a vital role in our national economy. Native to Western Ghats of India, pepper has been a dominant commodity in the international trade since time immemorial.

The area under pepper in India is 1.58 lakh hectares which constitutes 51.5 per cent of the global area. For the past half a century, pepper production in India has been highly fluctuating. In 1940's India's share in the world production was 80 per cent and thereafter it scaled down to 28 per cent in late 1980's and 38 per cent in 1988. As against this, countries like Malaysia, Indonesia and Brazil steadily improved their position, contributing sizeably to world production and trade. Today Malaysia, Indonesia and Brazil have surpassed India's annual production (George, 1990).

The world production and export of pepper showed a spectacular growth during the period from 1960 to 1980, the average being 6.8 per cent and 10.3 per cent, respectively. The average annual growth rate of Indian production during this period was 0.4 per cent as against 35.0 per cent in Brazil, 21.0 per cent in Malaysia and 8.0 per cent in Indonesia (Abraham, 1990).

Among the spices exported from India, pepper ranked first, amounting to 36.6 per cent of the total export in 1988-89 (99886 tonnes). This accounted for 58.3 per cent of the total earnings (Rs.274136 crores) during the year (George, 1990).

The average productivity of pepper in India is the lowest, at 311 kg/ha, in comparison with the average productivity of 1570 kg, 2000 kg and 523 kg per hectare obtained in Brazil, Malaysia and Indonesia, respectively (George, 1990).

About 97 per cent of the total area under black pepper in the country and 98 per cent of the total production is in Kerala. Though Kerala is the native home of black pepper the average yield of this valuable spice is only 0.3 kg/standard. The Food and Agricultural Organisation has projected the demand for pepper at 1.62 lakh tonnes in 1995. In order to maintain the present 38 per cent share of the world market, India has to export 65,000 tonnes of pepper by 1995, after meeting the internal demand of 30,500 tonnes (George, 1990). This emphasises the need to increase the production to cope with the increasing demand for export as well as internal consumption.

The main reasons for the low productivity of pepper in Kerala are, the use of poor genetic stock, retention of senile and unproductive vines, under nutrition, imbalanced manuring, non-adoption of proper agronomic measures and incidence of pests and diseases.

One of main aspects in the cultivation of pepper is nutrition. Field trials on the nutrition of black pepper have been carried out in India and abroad. But, a major problem in taking up research on basic aspects of perennial crops like pepper is that the execution of the work in the field often turns out to be unwieldy and impractical. This is expected as these plants are large and voluminous and special techniques have to be adopted for field work. Pot culture studies using bush pepper, which are rather handy in management and are gaining popularity in urban Horticulture, have not been carried out in India or abroad. Information as to whether this can be used as a substitute for vine pepper to work on fundamental aspects of pepper nutrition, is also lacking.

In Kerala, about 70 varieties of pepper are reported to be under cultivation. Only about half a dozen of them are good yielders and also their efficiency in the uptake of nutrients have not been studied so far. Besides this, information on the soil zone of maximum nutrient absorption in black pepper is of value in formulating a rational method of fertilizer application. With all these points in view the present trials have been taken up with the following objectives:

i) To study the pattern of growth and nutrient uptake in bush pepper and vine pepper.

ii) To evaluate the relative efficiencies of black pepper varieties in the utilization of applied P.

iii) to ascertain the soil zone of maximum nutrient absorption in pepper vines.

Review of Literature

REVIEW OF LITERATURE

Literature on aspects pertaining to this study on black pepper and few other horticultural crops are reviewed here.

2.1. Mineral nutrition

Though black pepper is an important export oriented spice crop of India, information about the nutrients required by this crop, their uptake and effect on plant growth and nutrition, is very meagre. The available information relates to that of Indian, Malaysian and Indonesian workers. Considerable work on extraction and identification of the oleoresin and the alkaloids of pepper has been made but work relating to inorganic nutrition of pepper is only of recent origin.

2.1.1. Nutritional requirement

Manurial experiments were conducted in Kerala as early as in 1920 (Nambiar et al., 1965) at Panniyur under the Department of Agriculture, Madras. However, details of many experiments are not available as there has not been any published report regarding this.

In Sarawak, the systems and methods of application of fertilizers were developed largely through experience and tradition. The jungle land, which was cleared for pepper planting, provided the raw material for the preparation of burnt earth (Harden and White, 1934; Bergman, 1940), which served as a fertilizer for the vine, at the rate of 18 kg/vine/year. The burnt earth had a pH of 7-8, compared to 4-5 for fresh soil and a CaO content of 0.3 per cent. The addition had three fold effects, viz., (i) it altered the physical characteristics of the rooting medium (ii) it increased the pH value and (iii) it supplied the nutrients. The actual quantities of nutrients added to soil by following this process was small, but these were offered in a form ideally suited for uptake by the roots.

Chaney (1951) established the phosphatic source of nutrients for black pepper grown on red soils of Vietnam. Marinet (1953) indicated the necessity of liming acid soils for pepper cultivation, though no definite pH limits were recommended.

De Waard and Sutton (1960) opined that the use of fertilizers by the farmers of Sarawak, lowered the pH in soil, reduced the uptake of calcium and magnesium and increased the K/Ca + Mg ratio in the leaf. According to De Waard (1964), the nutrient removal of the variety Kutching (1729 vines/ha) was 252.04 kg

N, 31.75 kg P_2O_5 and 224.04 kg K_2O per hectare. De Waard (1969) also worked out 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 were expected to occur. Removal of inorganic nutrients from soil by seventeen year old vines was reported by Sim (1971) as 233 kg N, 39 kg P_2O_5, 207 kg K_2O, 30 kg MgO and 105 kg CaO per hectare.

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. In 1973 he further observed that 12 oz of urea and 16 oz of muriate of potash/plant/year gave the highest economic yields in sandy soils of Sarawak.

Nagarajan and Pillai (1975) reported that Panniyur-1 is more nutrient exhaustive than Kalluvally for N, P, K, Ca and Mg after analysing the lateral fruiting shoots of one year growth from mature pepper vines. The order of contents of nutrients removed was N $>$ K $>$ Ca $>$ Mg $>$ P. One hectare of pepper vines (numbering 1200), with an average yield of 1 kg dry pepper per vine, removed 34.0 kg nitrogen, 3.5 kg P_2O_5 and 32.0 kg K_2O, for the production of berries in Panniyur, Kerala (Pillai and Sasikumaran, 1976). Based on this a manurial schedule of 100 g N, 40 g P_2O_5 and 140 g K_2O per vine was recommended by them. 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.

De Waard (1978) found that addition of alkaline compounds to mounds prior to planting resulted in an increase in growth and earlier establishment of vines in Sarawak. According to Bataglia et al. (1976), the foliar concentration of N was the maximum in autumn, but declined in winter. Phosphorus was the highest in summer and declined thereafter whereas K was high in summer, reached a peak in autumn and declined in winter.

Pillai et al. (1979) based on a study in the variety Panniyur-1 concluded that higher levels of N adversely affected the yield and accordingly they fixed 60 g N/vine/year as the maximum limit. Kumar and Cheeran (1981) conducted a study on the nutrient requirement of pepper vines trained on dead standards and reported that their requirement was adequately met with 75 g N and 50 g P_2O_5/vine/year. Response of black pepper to lime application has been reported by Purseglove et al., 1981).

Geetha (1981) observed that the N, P and K content in the flowering laterals was higher during flowering and spike development (from June to November) but the same was found to decrease from November to December. 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. Kurian (1982) stated that there was no significant difference in levels of N, P and Mg in pepper leaves from July to September. Concentration of K was the highest during the above period. The N and P content gradually decreased from July and the berries matured in November whereas the K content slightly increased in September, followed by a decrease in November.

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. Sankar (1985) reported that annual nutrient removal by a five year old vine through harvest of 1.284 kg dry pepper was 38.5 g N, 36.7 g K, 14.9 g Ca, 13.7 g Mg, 2.2 g P, 1.4 g S, 218 mg Fe, 155 mg Mn, 28 mg Zn and 47 mg Cu.. Nybe (1986) observed that foliar level of macronutrients, except Ca, registered two peaks, one in June and the other in October, while the lowest level was in April. The nutrients such as Ca, Fe, Mn and Zn in general showed a decreasing trend from April to June and thereafter increased and reached the maximum in December. Highly significant positive correlations were showed by P, K, Ca, Mg and S with yield. The critical level of S was 0.15 per cent and tentative critical level of N, P and K were 2.00 to 2.40 per cent, 0.19 to 0.20 per cent and 1.80 to 1.90 per cent, respectively.

Chepote et al. (1986) studied the effect of NPK fertilization on the production of Piper nigrum in Southern Bahia. The mean yield of dry pepper ranged from 2883 kg/ha in the unfertilized plots to 7413 kg/ha in plots receiving N:P:K at 200:240:160 kg/ha + Dolomite limestone at 1 t/ha + fritted micronutrients at 4.8 kg/ha. Wahid (1987) studied the effect of fertilizing and pruning the live supports on pepper plant yield in Indonesia and the best results were obtained with pruning the support trees three times a year, and the application of 400 g fertilizer (12 N: 12 P: 17 K: 2 Mg)/vine, four times a year. According to Pillai et al. (1987), the optimum levels of N, P and K for Piper nigrum cv. Panniyur-1 was 50 g N, 100 g P_2O_5 and 150 g K_2O/vine/year.

2.1.2. Micronutrient nutrition

With regard to the micronutrient nutrition, very few studies have been conducted. Sim (1973) estimated the trace element content of the reproductive tissues in mature vines varying in age from below 1 year to above 1 year in Sarawak. The quantity of 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 also reported by Sim (1974) in Sarawak pepper gardens. Purseglove et al. (1981) recognised the necessity for micronutrient application to black pepper in Sarawak and recommended 28 g trace elements per vine.

Wahid et al. (1982), after studying the nutrition of 'slow wilt' affected pepper, found no difference in micronutrient level in the leaves of pepper, although the healthy leaves had more K compared to the unhealthy.

2.1.3. Foliar diagnosis

Foliar diagnosis through analysis of leaf tissue is regarded as a tool for assessing the nutrient status of the plants in detecting the "hidden hunger" or "visual deficiency" of one or more elements. De Waard (1969) was the first to introduce foliar diagnosis in black pepper. According to him, the first mature leaf with petiole, from fruit bearing high order branches, could be designated as the best reflex of nutrients. The nutrient content of leaves varied from 2.7 to 3.1 per cent for N and from 0.10 to 0.16 per cent for K. The concentration of K remained unchanged in leaves from 7 am to 1 pm whereas N content decreased from early morning to late afternoon, which was not significant from 7 am to 10 am. Sim (1974) also reported that leaf nutrients gave a better correlation with yield than soil nutrients.

Pillai and Sasikumaran (1976) studied the N, P, K, Ca and Mg levels in root, stem, leaf and spike of four year old Panniyur-1 pepper and reported that N and K were the highest and P the lowest in the leaves. Results of the study conducted by Sushama et al. (1982) also 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. Sushama et al. (1984) further reported that the period just prior to flushing (i.e., last week of May) of pepper was the best suited for collection of leaf samples for foliar diagnosis.

2.1.4. Plant diseases and pepper nutrition

This is an area in which much investigation is called for, as malnutrition most often results in disease, in all biological species. Some work has been done in India and abroad regarding this. However no systematic studies have been so far attempted.

De Waard and Sutton (1960) attributed the dropping and yellowing of pepper growing in highly acid soils, to Al toxicity. De Waard (1979) referred the key role played by nutrients, especially K, in the development of yellow leaf disease complex in black pepper in the island of Bangka, Indonesia and stated that a fertilizer mixture having 400 kg N, 180 kg P, 480 kg K, 425 kg Ca and 112 kg Mg when applied to one hectare with appropriate 'mulching' controlled the disease and gave an average yield of 2.0-2.5 kg dry pepper berries per vine. Mustika et al. (1988) could reduce the severity of yellow disease in black pepper by fertilizer (NPK 15:15:15) at 250 g/plant/year and either aldicarb (50 g/plant) or manozeb (12 g/plant) or both.

Nambiar et al. (1965) worked out tentative ratios of $\frac{K_2O}{N}$ (total), $\frac{K_2O}{N}$ (available) and $\frac{CaO + K_2O + MgO}{N}$ in soil and found that slow wilt of pepper occurred when these ratios were below 14.10, 0.15 and 3.80, respectively. Wahid et al. (1982) analysed leaf samples from 'slow wilt' affected plants and found that K levels of the leaves of healthy vines were considerably higher than those of disease affected ones. The pot culture studies conducted by them indicated N deficiency as a cause for the 'yellow leaf disease'.

2.1.5. Nutritional deficiencies in black 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. He 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.

Nybe (1986) could induce deficiency symptoms of macro and micro nutrients by sand culture experiments in Kerala. Deficiency symptoms of macronutrients, except Ca and S, were first manifested on the older leaves. Symptoms of N deficiency were expressed as uniform yellowing followed by necrosis, whereas purple to bronze yellow colour and ash coloured necrotic areas were the symptoms of P deficiency. K deficiency was characterized by tip and marginal necrosis which later progressed to the distal 2/3 portion of the lamina. Vegetative growth was considerably reduced due to deficiency of macro and micronutrients. Ca, P, N and S showed profound influence on shoot growth. Visual symptoms of deficiencies were concurred with a marked reduction in the foliar level of the concerned element. The deficiency symptoms could also be recovered by the application of the deficient nutrient element and thus the deficiency of the element was confirmed.

2.2. Root distribution

Research on root system is of particular importance as roots are responsible for the uptake of water and nutrients besides providing anchorage to the plant. An understanding of the root density is essential for developing a scientifically sound and efficient method of fertilizer use in crop gardens.

The classical methods of investigating root systems include excavation, needle board method, monolith method etc. Such methods have been in vogue to study the overall root distribution patterns of crop plants, irrespective of the type and function of the roots. The traditional methods are suitable only for investigating a few plants because of the labour involved in digging profiles, tracing and mapping the roots etc. Isotopic technique, in contrast, offer a quick and reliable means of determining the distribution pattern of roots. Two methodologies have been commonly adopted. One is plant injection technique (Raez _et al._, 1964) and the other, soil injection technique (Hall _et al._, 1953). The former is applicable only in small plants for studying the root distribution pattern while the iatter is suitable with any plant for studying the distribution of active roots which are directly responsible for water and nutrient absorption from soil. The soil injection technique has been extensively used for studying the root activity patterns of tree crops. The method involves soil injection of the tracer at various depths and radial distances from the plant, followed by determination of the absorbed radioactivity in the plant.

Generally ^{32}P, a hard beta emitter, is used for this purpose as tracer because of its convenient half life (14.3 days) and ease of measurement, eventhough many others including ^{15}N, ^{86}Rb and non radioactive Sr (IAEA, 1975; Ellis and Barnes, 1973; Fox and Lipps, 1964) are sometimes used. The radioactivity recovered in the plant from a particular soil zone depends on the proportion of active roots in that zone. In small plants such as cereals, total radioactivity absorbed by the plant can be determined. However, when bulk of the plant is too large as in tree crops, the determination of total radioactivity absorbed by the plant will be a difficult proposition. In such cases, IAEA (1975) recommended the radioassay of a suitable plant part to evaluate the uptake of the applied label from various root zones.

2.2.1. Fruit trees

Ulrich *et al.* (1947), from a study in California on the root activity of grape vine in a red loam, employing radiophosphorus, reported an irregular distribution of roots around the vine. Ninety per cent of the roots were observed within a radius of 60.0 cm from the base though some laterals were found at a distance of only 2.5 cm from the vines. Dev *et al.* (1971), on studying the proliferation of roots occurring at different depths in three varieties of grapes by soil injection technique, found that roots occurring at different depths from 31 to 56 cm absorbed more ^{32}P and hence had more activity in the roots at that region.

Using ^{32}P - labelled superphosphate, Bojappa and Singh (1973) found that the maximum root activity of mango was upto 240 cm lateraly and 30 cm vertically in the soil. About 77 per cent of root activity was observed upto 60 cm in one trial and it was 85 per cent upto 30 cm depth in another trial. Absorption from the peripheral zone of 300 cm was 80 per cent in both experiments.

By selective placement of ^{32}P within rooting volume, Atkinson (1974) studied the distribution of root activity in apple trees and concluded that in 2 year old trees of cultivar Cox/M_9, maximum absorption of the radiolabel was from 30 cm depth as against from 90 cm depth in 25 year old trees of cultivar Fortune/M_9.

Experiments carried out in 30 year old orange trees to study the root activity pattern in summer and spring in a fine sandy clay loam of Spain (IAEA, 1975) revealed that during summer months, the highest activity was at 200 to 300 cm distance form the trees and at 30 cm depth. Early in spring, high root activity was observed near the tree (50 cm distance) at 60 and 30 cm depths. In mature 30 year old trees, the zone with highest root activity was farther away from the tree than in younger trees of 14 years (IAEA, 1975). From an experiment with 8 and 12 year old citrus trees in Taiwan, IAEA (1975) reported that in the former, the highest root activity was seen at 100 cm lateral distance/10 cm depth in spring season and for the latter in the winter season, the activity was higher near the soil surface within the 100 to 200 cm lateral distance.

Studies on the root activity pattern of cashew yielded information on the relative distribution of active roots in a soil cylinder of 4 m radius. The data indicated that the tree growing on laterite soil is more or less a surface feeder with preponderance of active roots in the surface 15 cm soil layer. It was observed that about 50 per cent of the active roots are confined to this layer and the root activity decreases with depth. The relative abundance of feeder roots at different lateral distances indicated that the root activity is negligible beyond 2 m distance from the tree. The root activity within 2 m radius around the tree accounts for 85 per cent of the total root activity (KAU, 1988).

Sobhana et al. (1989) studied the most active root zone of banana var. Nendran under irrigated and rainfed conditions. The data indicated that, in the case of irrigated banana, most of the active roots reside within a soil zone of 20 cm radius and 30 cm depth from the base of the plant. The rainfed crop had major portion of active roots in a soil zone of 40 cm radius upto a depth of 30 cm. As the lateral distance increased from 20 cm to 120 cm, a reduction was noticed in the root activity under both irrigated and rainfed conditions.

2.2.2. Plantation crops

Wet and dry season experiment in fruiting coffee trees in Columbia (IAEA, 1975) indicated that in wet season root activity at 30 cm distance/15 cm depth was significantly higher than at any other soil zone tested. In dry season , no indication was obtained of the zones of high and low root activities. Uptake was low in dry season. Experiments at Kenya on the root activity pattern of coffee (IAEA, 1975) revealed two zones, one near the soil surface upto a distance of 82.5 cm from the tree base and the other in the 45 to 75 cm depth at a distance of 30 cm from the trees. Experiments with one year old coffee plants growing on Salvador loamy sand (IAEA, 1975) indicated that nearly all roots were concentrated in the top layer of 30 cm. In two year old plants, the lateral spread of roots was upto 80 cm and for adult trees, it was 130 cm.

Wet and dry season experiments carried out on cacao at Ghana using tracer technique (IAEA, 1975) revealed highest root activity in the upper 2.5 cm soil layer. In both wet and dry seasons, the effect of distance on root activity was not significant, but there was an indication of high root activity near the soil surface at a distance of 90 to 150 cm.

The studies with cocoa led to the conclusion that more than 80 per cent of the feeder rooted within a depth of 60 cm from the surface. The roots were found to traverse horizontally beyond a distance of 1.5 m suggesting the possibility of inter twining of the roots of the adjoining trees planted at a spacing of 3 m. A high density of active roots of cocoa was also found in the upper soil layer. Broadcasting of fertilizers, rather than basin application, seems to be a better method of fertilizer application in cocoa garden (KAU, 1988).

From a study on the root activity pattern of coconut employing ^{32}P, Balakrishnamurthy (1971) suggested that maximum uptake occurred at a distance of 100 cm from the palm at a depth of 12 cm. The greatest root activity was observed in the upper 0 to 30 cm layer of soil close to the palm (within 150 cm) and intensity was more in wet season. Studies conducted in Sri Lanka using radiotracer on the efficiency of fertilizer utilization by coconut palms (IAEA, 1975) showed that nutrient uptake was maximum at a lateral distance of 50 cm and a decrease was observed with increase in radial distance. Activity was very high within a radius of 2 m and a depth of 10 to 45 cm. Results of the experiments on the root activity patterns of 15 and 60 year old coconut trees (tall var Laguna typica) in the Philippines in wet and dry seasons were reported by IAEA (1975). The highest zone of root activity was at 1 to 2 m distance and upto 15 cm depth. Results of the experiments carried out in wet and dry seasons in 50 year old coconut palms in sandy loam soil in Sri Lanka (IAEA, 1975) indicated that root activity in wet season was the highest at 1 m distance at 10 cm depth. In dry season, root activity was the highest at 0.5 m distance at 10 cm depth. Activity at lower depths and greater distance was high in the dry season. Anilkumar (1987) reported that in the case of coconut, feeder roots were practically nil in the top 0-25 cm soil layer and were mainly concentrated in the lower layers of 30-90 cm. The lateral spread of the root activity was more upto 2 m. His results justified the current practice of application of fertilizers in 2 m wide basin around the coconut palm.

Phosphorus-32 injection experiments were carried out to study the root activity pattern of young 17 year old and bearing oil palms in wet and dry seasons in Malaysia and Ivory Coast (IAEA, 1975). In Malaysia, during the wet season, the highest root activity was found at the soil surface, at a distance of 3 m from the tree. About 70 to 80 per cent of active roots were within 0 to 20 cm depth. In Ivory Coast, highest root activity was observed at 0 to 20 cm depth. Wet season activity was more intense and confined to the surface unlike in dry season where the activity showed a steep decline with depth.

Zaharah _et al_. (1989), after conducting fertilizer placement studies in mature oil palms using isotopic technique, concluded that fertilizers for mature oil palms grown on flat or undulating terrain can be applied all over the field and not necessarily around the base of the palm or at the palm canopy, as customarily being practiced.

Soong *et al.* (1971) studied the P uptake of *Hevea brasiliensis* by ^{32}P soil injection technique and subsequent analysis of the leaves and latex. Maximum root activity was found within a lateral distance of 3.6 m from the trees. Phosphorus uptake by mature rubber trees from the soil by using ^{32}P soil injection technique was investigated by Silva *et al.* (1979). Radio-activity in the latex, a reliable assay for determining distribution of active roots, was higher when ^{32}P application was done at a lateral distance of 0.75 m from the tree and at 15 cm depth.

2.2.3. Black pepper

In black pepper, very little work has been done on this aspect. Trerada and Chiha (1971) recorded the root development of black pepper vines in Brazil and found that 85 to 90 per cent of the feeder roots were confined to upper 30 cm.

Sankar (1985) made an investigation on the root activity pattern of black pepper vine and allied aspects using phosphorus-32. The application of radiophosphorus was done in equally spaced eight holes taken along the arc of a semicircle facing the vine. Combinations of four lateral distances (15, 30, 60 and 120 cm) from the vine and three depths (10, 20 and 40 cm) were compared in this experiment. The results indicated that the active root zone of black pepper vine, trailed either on Erythrina indica or on teak poles, was in a soil column of 30 cm radius around the vine. The active root system of Erythrina indica was found to be more extensive than the vine, leading upto 60 cm from the pepper plant.

Materials and Methods

MATERIALS AND METHODS

The present experiments on the evaluation of nutrient uptake in black pepper (<u>Piper nigrum</u> L.) were carried out at the Centre for Advanced Studies on Humid Tropical Tree Crops, College of Horticulture, Vellanikkara and at the Banana Research Station, Kannara. The investigations reported herein consist of three main aspects.

1. Pattern of growth and nutrient uptake in bush pepper and vine pepper
2. Varietal differences in the utilization of applied P
3. Soil zone of maximum nutrient absorption.

The first two aspects were studied with rooted black pepper cuttings grown in pots and the third with field grown vines. The weather data during the period under report are given in Appendix I and the physico chemical characteristics of the soil at the experimental site in Appendix II.

3.1. Pattern of growth and nutrient uptake in bush pepper and vine pepper

A pot culture experiment was undertaken in the green house of the College of Horticulture, Vellanikkara, from May 1986 to May 1988 to study the pattern of growth and nutrient uptake in bush pepper and vine pepper.

3.1.1. Preparation of soil

Sifted laterite soil of about 2 mm size was used for the study.

3.1.2. Pots, planting materials and planting

Square mud pots having a size of 37.5 cm and capacity of about 15 kg sifted laterite soil were used for raising pepper plants.

Laterals as well as runners collected from high yielding, healthy vines of the hybrid, Panniyur-1 were taken (Plates 1 to 3) and planted in polythene bags filled with potting mixture containing sand, soil and farm yard manure in the ratio 1:1:1 to get bush pepper and vine pepper, respectively (Fig.1). The mud pots were filled with sifted soil to one fourth volume, prior to planting the rooted cuttings. The rooted cuttings from the laterals (bush pepper) and runners (vine pepper) were transplanted to the pots in September 1986 at the rate of 3 plants/pot and watered. Then the container was filled to the capacity with soil to give a final quantity of 15 kg soil per pot.

The pots were arranged on concrete benches inside the green house wherein the sunlight was allowed to enter at about 75 per cent of its natural intensity. The vine pepper was trailed


1

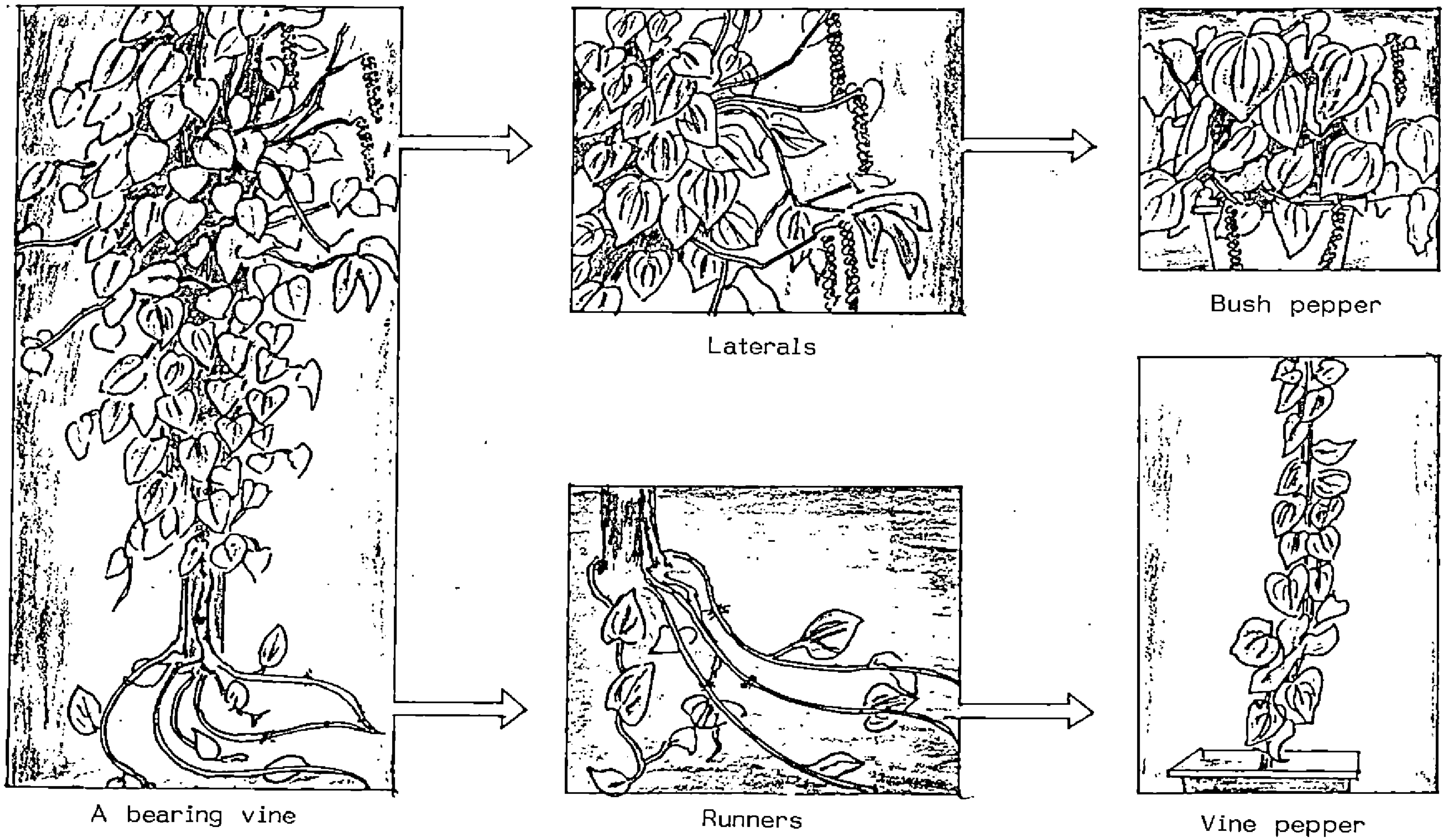
Plate 2. Laterals (used for raising bush pepper)

Plate 3. Runners (used for raising vine pepper)


2


3

Fig. 1. Routes for the production of bush pepper and vine pepper



on coir ropes suspended from the ceiling of the green house (Plates 4 & 5). The treatments were given after the establishment of the plants.

3.1.3. Treatments

In order to study the pattern of growth and nutrient uptake in bush pepper and vine pepper, N, P, K, Ca, Mg and S fertilizers were tried. Each fertilizer at five levels was replicated four times in a completely randomised design and there were six experiments each for bush pepper and vine pepper.

The different levels of nutrients tried in the study are given below:

N	0, 30, 60, 90, 120	kg/ha/year
P_2O_5	0, 15, 30, 45, 60	"
K_2O	0, 30, 60, 90, 120	"
CaO	0, 30, 60, 90, 120	"
MgO	0, 15, 30, 45, 60	"
SO_4	0, 15, 30, 45, 60	"

A basal dose of N, P_2O_5, K_2O, CaO, MgO and SO_4 was given at the rate of 100, 50, 100, 100, 50 and 50 kg/ha, respectively, withdrawing the nutrient being studied under each treatment. The plants received N, P_2O_5, K_2O, CaO, MgO and SO_4 through urea,

Plate 4 & 5. General view of the experimental area to study the pattern of growth and nutrient uptake in bush pepper and vine pepper


N2
N1
4


K4
5

sodium hexametaphosphate [Na $(PO_3)_6$], muriate of potash, lime, magnesium chloride ($MgCl_2 . 6H_2O$) and magnesium sulphate ($MgSO_4 . 7H_2O$), respectively. Potassium sulphate was used instead of magnesium sulphate in the case of Mg_0 treatment to supply SO_4.

Four plants were provided under each treatment, the number of plants under each nutrient level being 20. Thus there were altogether 120 plants each in bush pepper and vine pepper. The application of fertilizers was done in two equal splits, first at two months after transplanting (November) and thereafter at 6 months interval. The plants were grown for a period of 18 months, after which they were uprooted and the following observations recorded.

3.1.4. Observations on growth parameters

Individual plant observations on the plant height, number of leaves, total leaf area, number of roots, length of roots and dry matter production were recorded for bush pepper and vine pepper.

3.1.4.1. Plant height

The height of the plant in a pot was measured from soil surface upto the growing point using a flexible measuring tape and mean expressed in cm.

3.1.4.2. Number of leaves

The total number of leaves on the plant was counted and recorded.

3.1.4.3. Total leaf area

The length of the lamina from the base to the tip and breadth at the centre were measured. The leaf area for individual leaf was calculated as the product of the length and breadth and a factor 0.71, as suggested by Mohankumar and Prabhakaran (1980). The average leaf area was worked out for five different sized leaves in a plant. This was multiplied by the number of leaves to get total leaf area and was expressed in cm^2.

In the case of bush pepper, the number of primary branches and secondary branches was also counted and recorded.

3.1.4.4. Root length

The length of the root from the base to the tip was measured and expressed in cm.

3.1.4.5. Number of roots

The total number of main roots in a plant was counted and recorded.

The plants, after taking the observations on growth parameters were separated into root, stem and leaf portion. In the case of bush pepper, spikes also constituted one component.

3.1.4.6. Dry matter content

Different plant parts were cleaned free of dust and dried in cross flow air oven at 70°±2°C till constant weights were obtained.

3.1.4.7. Nutrient concentration

The aerial portion of the samples were analysed for N, P, K, Ca, Mg, S, Fe, Mn and Zn.

3.1.4.8. Nutrient uptake

Plant uptake was computed from the values of concentration of the nutrients and the dry weight of parts sampled.

3.2. Varietal differences in the utilization of applied P

Green house experiments were carried out at the Radiotracer Laboratory, Kerala Agricultural University, Vellanikkara, from July 1989 to April 1990 for the purpose of this study.

3.2.1. Planting material

Runners collected from the high yielding, healthy vines of eleven varieties from the Pepper Research Station, Panniyur, were used for the study. The varieties used are given in section 3.2.4.1. Three node cuttings were taken and planted in polythene bags filled with potting mixture containing sand, soil and farm yard manure in the ratio 1:1:1. They were kept under shade and watered regularly. Three month old cuttings of uniform growth in respect of height, number of leaves and leaf area were selected for transplanting to growth medium.

3.2.2. Preparation of soil

Sifted laterite soil of about 2 mm size was used for the study.

3.2.3. Preparation of pots and planting

Plastic buckets of 20 cm height with a diameter of 18 cm at the top and tapering to 12 cm at bottom were used. They were filled with sifted soil to one fourth the volume prior to planting the rooted cuttings. The rooted cuttings were removed from the polybags and one rooted cutting each was transplanted to the pots. The container was filled to capacity with soil to give a final quantity of 3 kg of 2 mm sifted laterite soil per pot.

The pots were arranged on concrete benches inside the green house at a spacing of 30 cm either way. About 50 per cent of the incident sunlight was allowed to enter the glass house. However air temperature and humidity were not under control. The plants were allowed to grow in pots for another three months. Treatments were given when they were 6 months old.

3.2.4. Treatments

3.2.4.1. Varieties

Eleven black pepper varieties were selected for the study, the general characters of which are given below:

3.2.4.1.1. Kuthiravally: Popular in Central Kerala, good yielder, vigorous vine, medium long spikes having female and bisexual flowers, medium sized berries.

3.2.4.1.2. Kottanadan: Popular in South Kerala, good yielder, vigorous vine, medium long spikes having high percentage bisexual flowers, medium sized berries having close setting.

3.2.4.1.3. Neelamundi: Suited for high altitude regions, average yielder, small spikes having female and bisexual flowers, medium sized berries having close setting.

3.2.4.1.4. Karimunda: Popular high yielding variety, vigorous growth, spikes medium long, predominantly bisexual flowers, dark green medium sized berries, high setting percentage, shade tolerant.

3.2.4.1.5. Panniyur-1. The first recommended hybrid variety evolved at Pepper Research Station, Panniyur, vigorous growth, high yield, long spikes having predominantly bisexual flowers, large and heavy berries, close setting of berries.

3.2.4.1.6. Aimpirian: Suited both for lower areas and high altitude regions, good yielder, vigorous growth, large leaves, spikes medium long with close setting.

3.2.4.1.7. Poonjarmunda: Grown in midland areas as a homestead crop, average yielder, medium long spikes with bisexual flowers, medium sized berries having good filling, driage high.

3.2.4.1.8. Kuthiyanikkodi: Grown in coastal and midland areas, average yielder, medium long spikes having female and bisexual flowers, medium sized berries.

3.2.4.1.9. Kutching: A popular variety of Sarawak, heavy yielder, vigorous vegetative growth, leaves with short petiole, less internodel length, profuse branching.

3.2.4.1.10. Kottakkodi: Popular in districts of North Kerala and South Kanara, average yielder, medium long spikes having bisexual and female flowers, medium sized berries.

3.2.4.1.11. Kanjiramundi: Grown in midland areas, average yielder, vigorous vine, long spikes having male and bisexual flowers, good driage.

3.2.4.2. P sources

Different phosphatic fertilizers, namely, nitrophosphate, amophos and superphosphate labelled with ^{32}P were used as P sources. The fertilizers were applied to each pot at the rate corresponding to 50 kg P_2O_5/ha. The quantity of labelled fertilizers applied/pot is given below.

3.2.4.2.1. Quantity of fertilizers applied per pot

^{32}P labelled fertilizer	Concentration as on 15-12-89	Quantity applied/ pot (mg)
Nitrophosphate (2.5% water soluble phosphate)	0.55 mCi/g P_2O_5	136.92
Amophos	0.60 mCi/g P_2O_5	334.80
Superphosphate	0.55 mCi/g P_2O_5	418.50

All the treatments (11 varieties x 3 P sources) were replicated thrice in a factorial randomised block design. Uniform plants were taken in each block. The crops received an uniform dose of 100 kg N and 100 kg K_2O per hectare through urea and muriate of potash, respectively.

The plants were allowed to grow for two and a half months after which the aerial plant parts were detached and biometric observations such as length of the vine, number of leaves and total leaf area were recorded. Different plant parts were separated, oven dried at 70±2°C in a cross flow air oven and their dry weights recorded till constant values were obtained. These samples were used for radioassay and nutrient analysis.

3.2.5. Radioassay

For the determination of ^{32}P activity in the plant samples, the method developed by Wahid et al. (1985) was followed. This method is based on the determination of ^{32}P activity by Cerenkov counting technique. The procedure involves wet digestion of oven dried and finely cut plant samples with 2:1 nitric acid-perchloric acid mixture and determination of radioactivity in the digest. One gram of leaf sample was weighed into a 250 ml conical flask followed by the addition of 15 ml diacid mixture. The flask with its contents were then heated on a hot plate at a low temperature until the initial frothing subsided. The digestion was continued at increased temperature until the digest became clear and its volume reduced to 2-3 ml. The flask with its contents was then cooled and the colourless digest was quantitatively transferred into a 20 ml glass scintillation counting vial with glass distilled water upto final volume of 20 ml, by repeated washings of the flask. The radioactivity was determined after 4 h in a microprocessor controlled liquid scintillation system (Rackbeta and LKB Wallace, Finland) adopting channel setting and the programme recorded for tritium counting by liquid scintillation techniques. The radioactivity per gram of dry matter was multiplied with the total dry matter to obtain the total radioactivity in the plant and was expressed in cpm.

3.2.6. P concentration

After the radioassay of the sample, the plant digest was carefully removed from the scintillation vial and made upto 100 ml in a standard flask. From this 5 ml was taken for the determination of P as suggested by Jackson (1958).

3.2.7. P uptake

Uptake of P was computed from the values of concentration of P and the dry weight of plant parts.

3.2.8. Specific activity of the absorbed P

Absorbed P was obtained from the total P uptake of the plant at the end of the experiment after subtracting the uptake of P prior to the application of ^{32}P labelled fertilizers and was expressed in mg.

The total radioactivity in the plant was divided by the absorbed phosphorus to obtain the specific activity of the absorbed P which was expressed in cpm per mg P.

3.2.9. Specific activity of the fertilizers

The quantity of nitrophosphate applied per pot was taken and first dissolved in 5 ml of concentrated nitric acid, transferred into a 20 ml glass scintillation counting vial and the volume made upto 20 ml by repeated washings with glass distilled water. The quantity of amophos and superphosphate applied per pot was dissolved in glass distilled water, transferred into a 20 ml glass scintillation counting vial and the volume made upto 20 ml by repeated washing. Then the radioactivity was determined.

After the radioassay of the sample, the fertilizers were carefully removed from the scintillation vial and made upto 100 ml in a standard flask. From this 1 ml was taken for the determination of P. The specific activity of the ^{32}P was then calculated as the ^{32}P content per unit weight of P and expressed in cpm per mg P.

3.2.10. Fertilizer and soil P uptake parameters

Uptake parameters of fertilizer and soil P were calculated as suggested by IAEA (1976).

3.2.10.1. Percentage P derived from fertilizers (% Pdff)

This was calculated using the following formula.

$$\% \text{ Pdff} = \frac{\text{Specific activity of the plant material for the absorbed P (cpm/mg P)}}{\text{Specific activity of the fertilizer (cpm/mg P)}} \times 100$$

3.2.10.2. Percentage P derived from soil (% Pdfs)

This was derived by deducting percentage P derived from fertilizers from 100.

3.2.10.3. Fertilizer P uptake

This was worked out using the following formula and expressed in mg/pot.

$$\text{Fertilizer P uptake} = \frac{\% \text{ Pdff} \times \text{Absorbed phosphorus}}{100}$$

3.2.10.4. Percentage uptake of applied fertilizers (P utilization)

This was computed by the following formula

$$\% \text{ P utilization} = \frac{\% \text{ Pdff} \times \text{Absorbed phosphorus}}{\text{Quantity of applied P}}$$

3.3. Soil zone of maximum nutrient absorption

This study was undertaken in order to find out the soil zone of maximum nutrient absorption in field grown black pepper vines and to develop a fertilizer placement method.

3.3.1. Experimental material

The experiment was conducted in two sites; one at the Banana Research Station, Kannara and the other at the Main Campus of Kerala Agricultural University, Vellanikkara. Black pepper var. Panniyur-1 was invariably used for the study. The pepper plants were about seven years old, receiving cultural and manurial practices as recommended by the Package of Practices (KAU, 1986). Pepper plants trailed on *Erythrina indica* and teak pole having uniform growth and vigour based on their height and canopy girth at the middle were selected for the study. The experiment was conducted during the period from August 1987 to October 1987.

3.3.2. Principle

The quantitative estimation of root activity was based on the absorption of ^{32}P at different lateral distances from the plant. The radioactivity recovered in the leaves as a result of absorption from different root zones is compared to arrive at root zone of maximum absorption of the applied label (IAEA, 1975).

3.3.3. Treatments

The experiment consisted of nine treatments, being the combinations of three lateral distances and three methods of application. The lateral distance from the vine was tried at 30, 45 and 60 cm. The methods of application tried were as follows:

a) application of the tracer in semicircle facing the vine

b) application of the tracer in semicircle opposite the vine

c) application of the tracer in full circle around the vine (Fig.2 and Plates 6 to 8).

Thus the total number of treatments compared in this way was nine. Each treatment was replicated thrice with one plant/treatment/replication.

The treatments were tried for pepper vines trailed both on teak pole and Erythrina indica standards. The amount of radio-activity dispersed per plant was same, whatever be the method of application.

3.3.4. Application of ^{32}P

An injection device for applying desired volume of ^{32}P solution developed by Wahid et al. (1988) was used for the purpose. It consists of a Lumac Dispensette (calibrated plunger for repeated delivery of desired volume of solution upto 5 ml) fitted to a one litre glass reservior bottle of 3 mm thickness embedded in paraffin wax in a suitable plastic bucket (20 cm dia x 19 cm ht.).

Fig. 2. Diagrammatic representation of ^{32}P application in semi-circle area facing or opposite the vine and in full circle area around the vine

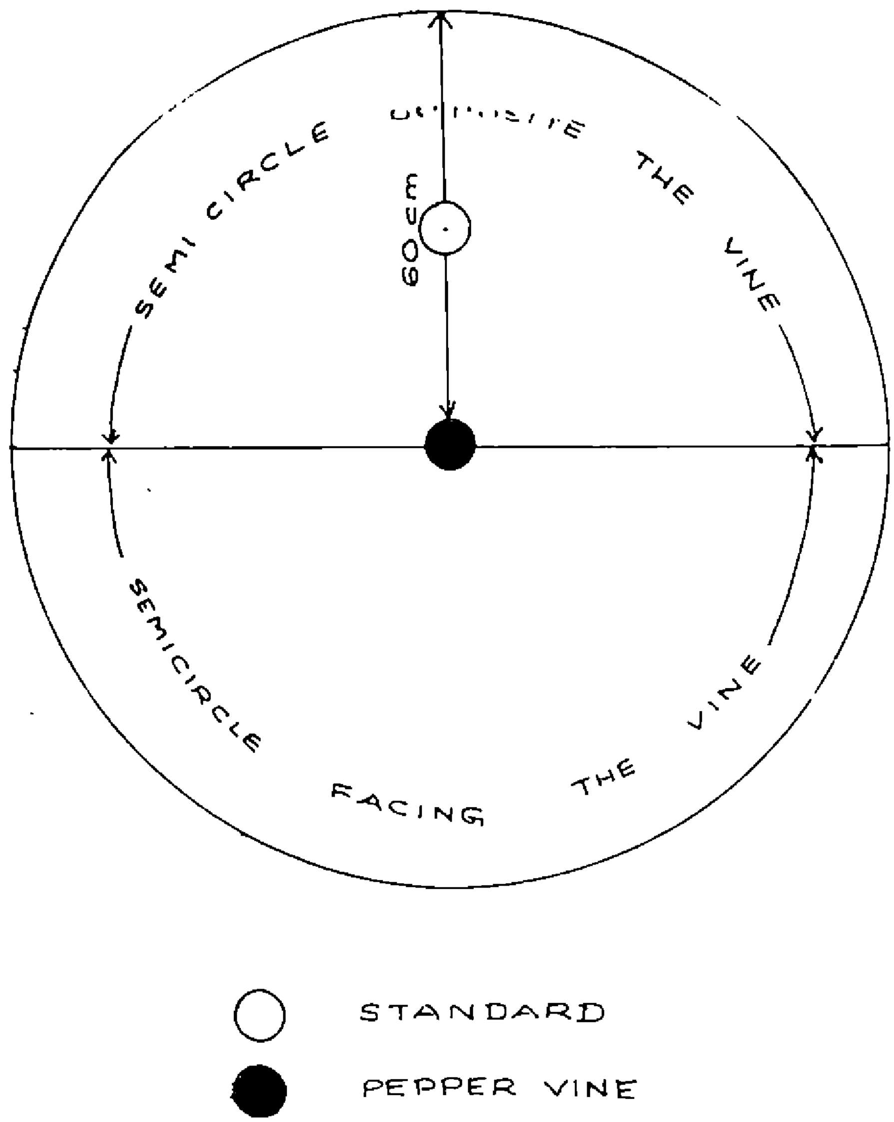


Plate 6. Semicircle area facing the vine for the application of ^{32}P solution

Plate 7. Semicircle area opposite the vine for the application of ^{32}P solution


6


7

Plate 8. Full circle area around the vine for the application of ^{32}P solution


8

The radioactivity in the supplied stock vial was transferred into the reservior bottle through a funnel. The vial was then washed 3 to 6 times with 1000 ppm carrier P solution (K H_2PO_4) and the washings were poured in the bottle. Finally enough carrier solution was added into the bottle to give 1 mCi (3.7×10^7 Bq) of ^{32}P/4 ml of the solution.

At the time of ^{32}P application, 4 ml of the solution was dispensed through the access tube into a long wooden handled (1 m) plastic mug of 2 litre capacity containing 1 litre water. This radioactive solution was applied uniformly on the soil surface as per the technical programme. The total radioactivity applied per vine corresponded to 1 mCi. A carrier concentration of 1000 ppm P was included in the radioactive solution to minimise soil fixation of ^{32}P and thereby making it more available to the plant (IAEA, 1975).

3.3.5. Leaf sampling

The extent of absorption of applied ^{32}P by the treated vines in relation to various treatments was adjudged by the radio-assay of leaf samples collected from them. The first mature leaf from fruiting branches on the lower 2/3 of the canopy as suggested by De Waard (1969) for leaf sampling in black pepper, were collected for radioassay. The samples were collected at two intervals, viz., 30 and 60 days after soil application of ^{32}P.

3.3.6. Radioassay of leaf samples

For the determination of ^{32}P activity in the leaf samples, the method developed by Wahid et al. (1985) was followed.

3.4. Chemical analyses

The dried plant samples were ground and chemically analysed for macro and micro nutrients as detailed below:

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

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

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

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

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

3.5. Statistical analysis

The recorded data were statistically analysed following the methods suggested by Panse and Sukhatma (1985).

A quadratic model adopted by Tejeda et al. (1980) has been used for testing the difference in responses of bush pepper and vine pepper to nutrients.

$$y = b_0 + b_1x + b_2x^2 + c_1x_1 + c_2x_2^2 + e$$

where,

y is the performance of the crop (dry matter/nutrient uptake)

x is the common dosage of the nutrient applied to bush pepper or vine pepper

x_1 is the same dosage of the nutrient applied to vine pepper (x_1 is zero for bush pepper)

e is the random error term and b_0, b_1, b_2, c_1 and c_2 are parameters to be estimated.

A significant c_1 indicates diffference in the slopes of the two response curves and a significant c_2 indicates difference in curvature of the two response curves.

Thus the differences between the two responses can be tested by testing the equality of c_1 and c_2 to zero. This can also be achieved by testing the significance of the difference in the regression sum of sqyares of the full model and the one deleting x_1 and x_1^2 (contribution of x_1 and x_1^2 to the variation of y in addition to that by x and x^2) against the residual mean square of the full model.

Results

RESULTS

Results of the studies on the evaluation of growth and nutrient uptake in black pepper are presented in this section.

4.1. Pattern of growth and nutrient uptake in bush pepper and vine pepper

The data generated from the pot culture experiments to study the growth and nutrient uptake in bush pepper and vine pepper, as influenced by different nutrient levels, during a growth period of eighteen months, are presented under two major heads, namely, growth parameters and uptake of nutrients.

4.1.1. Growth parameters

The growth parameters were affected by different levels of nutrients, both in bush pepper and vine pepper. The relevant data are furnished in Tables 1 to 4, Fig. 3 and 4 and Appendices III and IV.

4.1.1.1. Effect of N

Levels of N had pronounced effect on growth parameters such as number of secondary branches and leaves, total leaf area and dry matter production in bush pepper, whereas, plant height, number of primary branches, number of roots, length of roots and root dry weight were not significantly different (Table 1). Number

Table 1. Growth of bush pepper as influenced by N, P and K fertilization

Nutrient level (kg/ha)		Growth parameters												
		Plant height (cm)	Number of primary branches	Number of secondary branches	Number of leaves	Total leaf area (cm^2)	Number of roots	Root length (cm)	Dry matter yield (g/plant)					
									Root	Stem	Leaf	Spike	Aerial part	Total
N_0	0	50.88	2.78	5.68	27.90	2588.74	7.33	112.00	9.60	11.10	27.60	0.93	39.63	49.23
N_1	30	53.35	4.50	6.25	32.90	2745.48	5.83	107.50	10.98	11.45	31.78	2.60	45.83	56.81
N_2	60	48.80	3.93	7.93	36.00	3753.64	6.25	104.00	12.24	12.95	28.85	7.23	49.03	61.43
N_3	90	53.20	3.98	7.95	42.68	3544.28	7.50	113.50	11.68	13.63	32.65	2.73	49.01	60.69
N_4	120	56.45	4.15	11.23	42.93	4194.47	10.33	127.50	12.90	16.58	35.78	7.58	59.94	72.84
SEm±		3.47	0.52	0.94	3.15	363.74	1.34	15.46	1.38	1.15	2.14	1.60	5.45	5.03
CD (0.05)		NS	NS	2.83	9.49	1096.19	NS	NS	NS	3.48	3.18	4.83	16.41	21.43
P_0	0	57.60	4.18	7.78	33.33	3946.17	6.78	107.75	9.53	12.18	34.00	4.10	50.28	59.81
P_1	15	50.55	3.53	7.93	39.25	4116.26	7.60	125.75	13.23	15.53	37.03	4.48	57.04	70.27
P_2	30	56.75	4.25	7.08	47.00	3904.27	7.08	101.63	13.53	14.10	43.53	6.13	63.76	77.29
P_3	45	50.88	5.00	9.93	46.33	4728.54	6.93	120.50	16.70	17.60	45.08	6.03	68.71	85.41
P_4	60	52.00	5.00	8.15	51.60	5317.95	7.50	122.00	15.03	15.78	43.70	6.03	65.51	80.54
SEm±		2.85	0.37	1.01	3.82	328.90	1.41	7.00	1.37	1.07	2.57	2.39	3.76	5.03
CD (0.05)		NS	1.10	NS	11.51	982.18	NS	NS	4.13	3.24	7.75	NS	11.34	15.18
K_0	0	43.13	3.50	6.85	44.75	3536.49	4.65	112.50	7.03	12.75	42.50	4.40	59.65	66.68
K_1	30	43.25	3.68	7.23	45.03	3742.19	4.68	106.75	11.93	11.95	37.20	4.58	53.73	65.66
K_2	60	46.35	2.68	9.93	43.98	3569.31	9.40	124.00	11.33	11.93	33.40	2.70	48.03	59.36
K_3	90	45.53	2.65	6.65	42.90	3175.07	7.98	109.00	13.15	11.45	38.68	6.63	56.76	69.91
K_4	120	44.30	3.93	8.00	50.93	5359.07	8.33	122.50	14.35	15.33	45.60	4.78	65.71	80.06
SEm±		2.69	0.49	1.08	3.41	272.74	0.73	13.02	2.28	1.80	4.82	1.36	4.00	3.81
CD (0.05)		NS	NS	NS	NS	821.95	2.21	NS	NS	NS	NS	NS	12.05	11.50

Note: P and K levels are in terms of P_2O_5 and K_2O, respectively

of leaves, total leaf area, dry weight of aerial part as well as total were appreciably more at N_4 level (N @ 120 kg/ha). The N_0 level (N @ 0 kg/ha) was distinctly inferior in all these characters as compared to N_4 level (N @ 120 kg/ha).

Growth parameters such as plant height, number of leaves, total leaf area and aerial part as well as total dry weight in vine pepper were also influenced by the levels of N (Table 2). Plant height, number of leaves and total leaf area were markedly reduced at N_0 level (N @ 0 kg/ha) as compared to N_3 and N_4 levels (N @ 90 and 120 kg/ha, respectively). The dry matter production of plant parts, except that of root, was also significantly influenced by N levels wherein N_4 level (N @ 120 kg/ha) was significantly superior to N_0 level (N @ 0 kg/ha). Total dry matter production at N_4 level (N @ 120 kg/ha) was superior to all other levels.

4.1.1.2. Effect of P

Influence of levels of P on the growth of bush pepper is evident from Table 1. All the significantly different characters, except number of primary branches and total leaf area, were reduced under P_0 level (P_2O_5 @ 0 kg/ha) as compared to P_3 and P_4 levels (P_2O_5 @ 45 and 60 kg/ha, respectively). The dry matter production at P_3 level (P_2O_5 @ 45 kg/ha) was distinctly superior to P_0 (P_2O_5 @ 0 kg/ha) and was on par with other levels.

Table 2. Growth of vine pepper as influenced by N, P and K fertilization

Nutrient level (kg/ha)		Growth parameters									
		Plant height (cm)	Number of leaves	Total leaf area (cm^2)	Number of roots	Root length (cm)	Dry matter yield (g/plant)				
							Root	Stem	Leaf	Aerial part	Total
N_0	0	228.25	79.68	3474.95	21.08	63.00	10.55	25.33	24.15	49.49	60.03
N_1	30	364.00	88.63	3674.64	21.25	84.00	14.88	31.25	32.38	63.63	78.51
N_2	60	376.75	99.00	4074.99	17.08	89.25	17.20	36.20	35.25	71.45	88.65
N_3	90	378.75	111.65	4828.26	19.35	74.00	15.73	38.30	44.48	82.78	98.51
N_4	120	470.00	127.40	5116.75	18.50	83.00	17.40	55.43	46.98	102.41	119.81
SEm±		17.83	8.38	396.27	4.24	15.02	3.59	2.47	3.63	4.88	6.09
CD (0.05)		53.73	25.25	1194.24	NS	NS	NS	7.45	10.92	14.72	18.34
P_0	0	366.50	93.40	4085.89	19.70	64.00	9.15	28.88	29.38	57.96	67.11
P_1	15	420.75	93.93	3711.61	18.18	98.00	11.98	34.35	28.98	63.33	75.31
P_2	30	406.75	108.93	4849.49	17.50	79.13	11.35	41.58	43.23	84.81	96.16
P_3	45	513.00	141.83	6436.66	15.68	86.00	10.75	52.60	46.08	98.66	109.43
P_4	60	510.50	154.08	7125.36	23.33	95.50	13.93	46.23	47.50	93.73	107.66
SEm±		34.85	14.50	787.53	2.48	7.12	1.77	5.13	4.59	9.42	9.58
CD (0.05)		108.03	43.69	2373.39	7.46	21.46	NS	15.46	13.84	28.40	28.86
K_0	0	437.50	91.68	3751.76	15.15	71.50	8.83	41.20	33.53	74.73	83.56
K_1	30	508.50	116.93	4718.55	15.50	80.75	10.70	45.40	28.93	74.33	85.03
K_2	60	531.75	86.30	4693.21	18.83	78.75	13.45	41.68	35.15	76.83	90.28
K_3	90	581.25	107.25	5152.23	16.33	81.75	13.55	43.98	41.78	85.76	97.31
K_4	120	529.75	114.50	5664.80	18.83	87.00	13.80	55.15	46.88	102.03	115.83
SEm±		39.46	13.37	468.55	2.25	8.87	1.24	6.47	9.78	5.89	7.28
CD (0.05)		NS	NS	1412.08	NS	NS	NS	NS	NS	17.77	21.95

Note: P and K levels are in terms of P_2O_5 and K_2O, respectively

In vine pepper, all the growth parameters, except the dry weight of root, were influenced significantly by levels of P (Table 2). Significantly more total dry matter production was recorded at P_3 level (P_2O_5 @ 45 kg/ha) as compared to P_0 (P_2O_5 0 kg/ha) and P_1 (P_2O_5 @ 15 kg/ha) levels.

4.1.1.3. Effect of K

Levels of K had no noticeable effect on the growth parameters in bush pepper except in total leaf area, number of roots and dry weight (aerial part and total) of the plant (Table 1). In the case of total leaf area, K_4 (K_2O @ 120 kg/ha) level excelled all other levels. The K_4 level (K_2O @ 120 kg/ha) was significantly superior to K_0 level (K_2O @ 0 kg/ha) in the dry matter production (aerial part and total).

In vine pepper also, total leaf area was the maximum at K_4 level (K_2O @ 120 kg/ha) which was significantly superior to K_0 level (K_2O @ 0 kg/ha), but on par with others (Table 2). Total dry weight at K_4 level (K_2O @ 120 kg/ha) was significantly superior to all other levels, except K_3 (K_2O @ 90 kg/ha).

4.1.1.4. Effect of Ca

Effect of Ca recorded detectable differences with regard to the number of leaves, total leaf area, number of roots, length of root and dry weight of root in bush pepper (Table 3). Total

Table 3. Growth of bush pepper as influenced by Ca, Mg and S fertilization

Nutrient level (kg/ha)		Growth parameters												
		Plant height (cm)	Number of primary branches	Number of secondary branches	Number of leaves	Total leaf area (cm^2)	Number of roots	Root length (cm)	Dry matter yield (g/plant)					
									Root	Stem	Leaf	Spike	Aerial part	Total
Ca_0	0	48.15	3.58	7.33	39.23	3576.26	4.93	97.25	13.20	11.65	38.23	6.90	56.78	69.98
Ca_1	30	43.73	2.70	6.60	47.25	3587.41	6.33	117.25	13.03	16.15	33.35	4.73	54.23	67.26
Ca_2	60	54.73	3.78	8.15	53.68	4567.32	6.50	114.50	14.73	11.80	38.48	5.45	55.73	70.46
Ca_3	90	45.95	2.68	6.93	46.50	3974.99	7.18	130.25	14.28	13.88	35.15	2.60	51.63	65.91
Ca_4	120	52.03	3.18	7.75	41.68	3331.22	6.93	132.00	21.30	16.53	30.23	1.53	48.29	69.59
SEm±		2.81	0.41	0.70	2.60	254.70	0.35	12.58	1.82	2.62	5.95	1.40	9.49	10.03
CD (0.05)		NS	NS	NS	7.84	767.58	1.05	30.91	5.49	NS	NS	NS	NS	NS
Mg_0	0	48.85	4.25	7.60	44.25	3784.99	6.50	145.00	10.68	16.03	40.25	4.15	60.43	71.11
Mg_1	15	54.83	3.58	7.68	38.93	3514.30	6.60	129.75	12.35	16.13	32.63	6.55	55.31	67.66
Mg_2	30	54.55	3.00	6.58	39.00	3473.29	6.90	140.00	14.68	13.68	32.75	4.13	50.56	65.24
Mg_3	45	54.00	3.50	6.50	37.50	3446.54	8.68	135.50	16.98	12.18	34.40	5.70	52.28	69.26
Mg_4	60	60.00	3.85	9.68	45.43	4359.05	6.93	144.25	13.48	18.90	44.10	8.45	71.45	84.93
SEm±		2.35	0.33	0.60	2.60	373.00	1.03	10.95	1.75	1.89	2.94	1.70	4.66	4.03
CD (0.05)		NS	NS	1.80	NS	NS	NS	NS	NS	NS	NS	NS	10.03	10.14
S_0	0	48.23	3.60	5.40	43.68	3504.50	6.53	116.00	8.25	12.35	31.15	4.18	47.68	55.93
S_1	15	50.73	2.68	8.25	50.00	3940.29	6.73	126.00	13.83	14.28	32.23	6.60	53.11	66.94
S_2	30	46.58	3.00	9.58	52.03	4167.31	5.40	107.50	15.68	14.10	38.63	7.20	60.93	76.61
S_3	45	56.63	3.33	8.33	54.68	4451.36	7.18	127.25	14.30	14.45	36.45	10.90	61.80	76.10
S_4	60	52.28	3.43	6.30	56.35	4888.35	9.00	144.00	18.18	17.28	40.35	3.85	61.48	79.66
SEm±		2.48	0.49	0.71	3.96	267.29	1.01	6.92	1.94	2.08	3.30	2.03	3.34	3.61
CD (0.05)		NS	NS	2.14	NS	805.53	NS	20.85	5.86	NS	NS	NS	10.07	10.90

Note: Ca, Mg and S levels are in terms of CaO, MgO and SO_4, respectively

leaf area was appreciably more at Ca_2 level (CaO @ 60 kg/ha) and was on par with Ca_3 level (CaO @ 90 kg/ha). All the other characters were more at Ca_4 level (CaO @ 120 kg/ha).

Only the root characters showed marked differences due to the levels of Ca in vine pepper. In all the root characters studied, Ca_4 level (CaO @ 120 kg/ha) recorded the highest values (Table 4).

The superiority of Ca_4 level (CaO @ 120 kg/ha) over Ca_0 level (CaO @ 0 kg/ha), both in bush pepper and vine pepper, is also evident from Plate 9.

4.1.1.5. Effect of Mg

Among the growth parameters, the number of secondary branches and dry weight (aerial part and total) differed significantly in bush pepper at different levels of Mg (Table 3). The Mg_4 level (MgO @ 60 kg/ha) recorded significantly higher values and was superior to all others.

Levels of Mg influenced root length, dry weight (root, aerial part and total) in vine pepper also (Table 4). With regard to the total dry weight, Mg_0 level (MgO @ 0 kg/ha) was distinctly inferior to Mg_4 (MgO @ 60 kg/ha), and the latter was on par with others.

Plate 9. Root characters of bush pepper and vine pepper as influenced by Ca fertilization

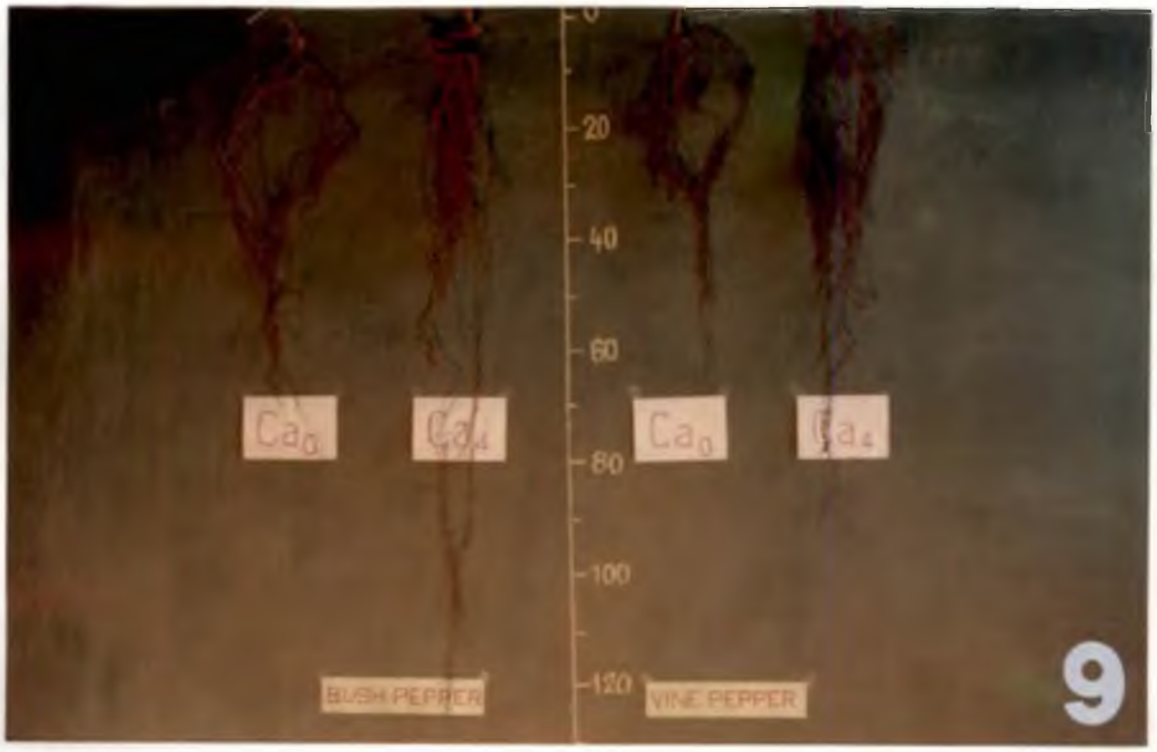

Ca0
Ca4
Ca0
Ca4
20
40
60
80
100
120
BUSH PEPPER
VINE PEPPER
9

Table 4. Growth of vine pepper as influenced by Ca, Mg and S fertilization

Nutrient level (kg/ha)		Plant height (cm)	Number of leaves	Total leaf area (cm^2)	Number of roots	Root length (cm)	Dry matter yield (g/plant)				
							Root	Stem	Leaf	Aerial part	Total
Ca_0	0	396.00	117.60	5332.54	12.83	80.00	11.23	58.13	49.28	107.41	118.69
Ca_1	30	452.50	101.00	5290.06	13.58	86.75	10.98	55.00	48.65	103.65	114.63
Ca_2	60	459.25	131.23	5505.17	13.75	87.00	11.70	59.65	51.75	111.40	123.10
Ca_3	90	483.50	118.15	5476.45	14.73	93.50	14.10	47.43	42.60	90.03	104.13
Ca_4	120	474.75	127.73	5919.53	17.58	94.75	15.23	53.50	45.70	99.20	114.43
SEm±		54.94	14.22	1016.63	0.98	3.45	1.77	8.90	3.94	12.14	13.32
CD (0.05)		NS	NS	NS	2.95	10.39	3.07	NS	NS	NS	NS
Mg_0	0	444.25	85.58	4307.44	12.50	71.50	12.03	45.18	36.30	81.48	93.51
Mg_1	15	520.25	112.15	4138.22	17.83	84.25	10.30	48.45	42.75	91.20	101.50
Mg_2	30	527.25	110.60	4354.02	15.90	86.50	16.55	51.28	41.90	93.18	109.73
Mg_3	45	540.25	119.68	4288.49	16.33	104.25	14.45	54.13	39.88	94.01	108.46
Mg_4	60	595.25	113.85	4250.28	15.90	119.50	11.73	64.13	39.83	103.96	115.69
SEm±		37.68	12.87	253.87	1.82	9.63	1.28	3.60	4.34	5.21	5.30
CD (0.05)		NS	NS	NS	NS	29.04	3.87	5.22	NS	15.71	15.98
S_0	0	452.75	94.68	4073.14	14.68	95.75	9.43	38.95	42.70	81.65	91.08
S_1	15	466.00	102.40	4636.33	12.90	112.00	10.13	37.88	46.10	83.98	94.11
S_2	30	487.75	123.60	4523.81	13.50	92.00	12.30	39.55	43.45	83.00	95.30
S_3	45	445.50	112.43	4279.06	13.00	108.25	12.30	50.70	48.55	99.25	111.55
S_4	60	514.75	102.40	4334.26	13.33	110.25	14.75	54.80	48.83	103.63	118.38
SEm±		15.28	9.51	296.40	1.24	12.08	1.37	3.85	7.63	5.22	6.00
CD (0.05)		46.04	NS	NS	NS	NS	NS	11.59	NS	15.73	18.08

Note: Ca, Mg and S levels are in terms of CaO, MgO and SO_4, respectively

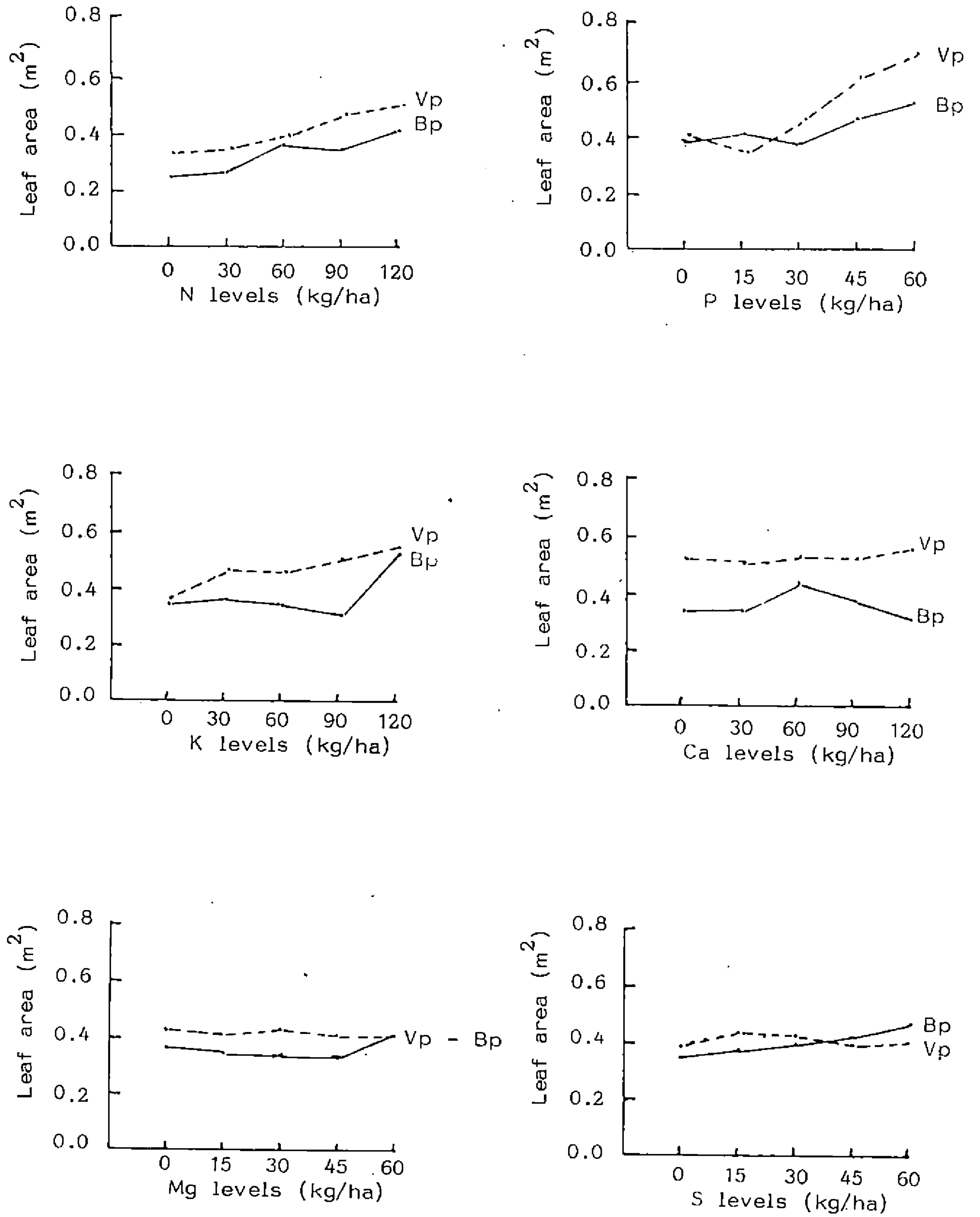
4.1.1.6. Effect of S

Levels of S markedly influenced the parameters of growth such as number of secondary branches, total leaf area, root length and dry weight (root, aerial part and total) in bush pepper (Table 3). All these parameters except the number of secondary branches were significantly inferior at S_0 level (SO_4 @ 0 kg/ha) to the highest levels of S application.

In vine pepper, plant height and dry weight (aerial part and total) differed significantly (Table 4), as influenced by the levels of S. The above characters recorded highest values at S_4 level (SO_4 @ 60 kg/ha) which was on par with S_3 (SO_4 @ 45 kg/ha) in dry matter production and with S_2 (SO_4 @ 30 kg/ha) in plant height.

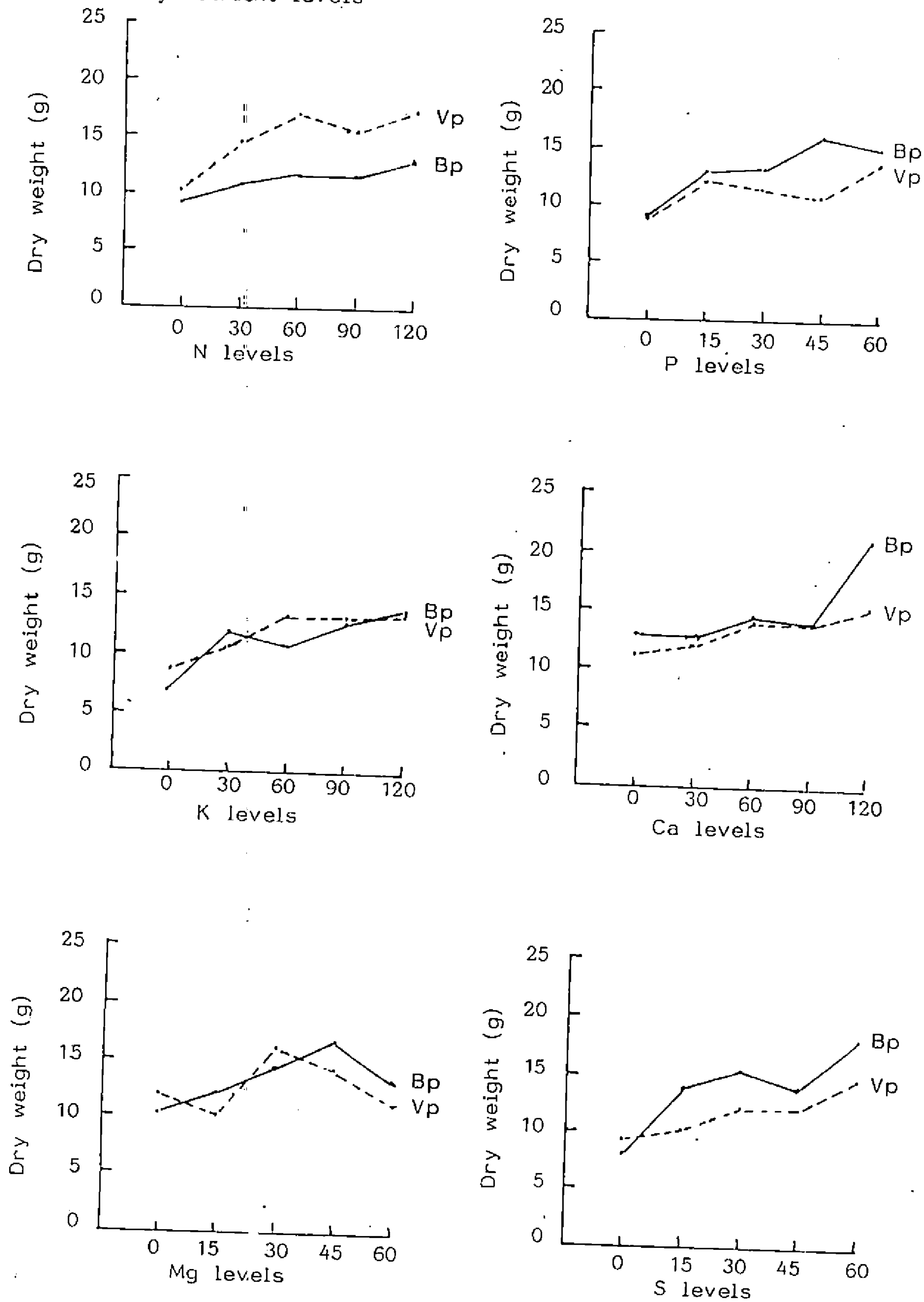
Emperical equations of linear and quadratic form were tried to examine the goodness of fit of these models in describing the biomass production (aerial part and total) in relation to nutrient levels, in bush pepper and vine pepper. The coefficients of determination (R^2) were found to be higher for the quadratic model (Table 5 and Appendix V). The variability in dry weight of aerial part as well as the total dry weight for N, P and S treatments, was found to be better explained by the quadratic model in bush pepper and vine pepper. In bush pepper, the linear model could not explain the variability in biomass production (either above

Fig. 3. Total leaf area in bush pepper and vine pepper as influenced by nutrient levels



Bp: Bush pepper; Vp: Vine pepper

Fig. 4. Root dry weight in bush pepper and vine pepper as influenced by nutrient levels



Bp: Bush pepper; Vp: Vine pepper

Table 5. Goodness of fit (R^2) of the mathematical models describing the biomass production in black pepper as influenced by nutrient levels

Variable y vs x	Type of plant	Linear model $y = a \pm bx$	Quadratic model $y = a \pm bx \pm cx^2$
Dry weight of aerial part vs levels of N	Bp	0.884	0.897
	Vp	0.977	0.986
Total dry weight vs levels of N	Bp	0.890	0.894
	Vp	0.979	0.980
Dry weight of aerial part vs levels of P	Bp	0.814	0.968
	Vp	0.863	0.906
Total dry weight vs levels of P	Bp	0.807	0.964
	Vp	0.909	0.946
Dry weight of aerial part vs levels of K	Bp	0.132	0.934
	Vp	0.791	0.996
Total dry weight vs levels of K	Bp	0.417	0.893
	Vp	0.881	0.998
Dry weight of aerial part vs levels of Ca	Bp	0.820	0.898
	Vp	0.333	0.335
Total dry weight vs levels of Ca	Bp	0.029	0.148
	Vp	0.183	0.183
Dry weight of aerial part vs levels of Mg	Bp	0.128	0.895
	Vp	0.888	0.889
Total dry weight vs levels of Mg	Bp	0.146	0.986
	Vp	0.909	0.939
Dry weight of aerial part vs levels of S	Bp	0.820	0.899
	Vp	0.824	0.900
Total dry weight vs levels of S	Bp	0.836	0.921
	Vp	0.886	0.948

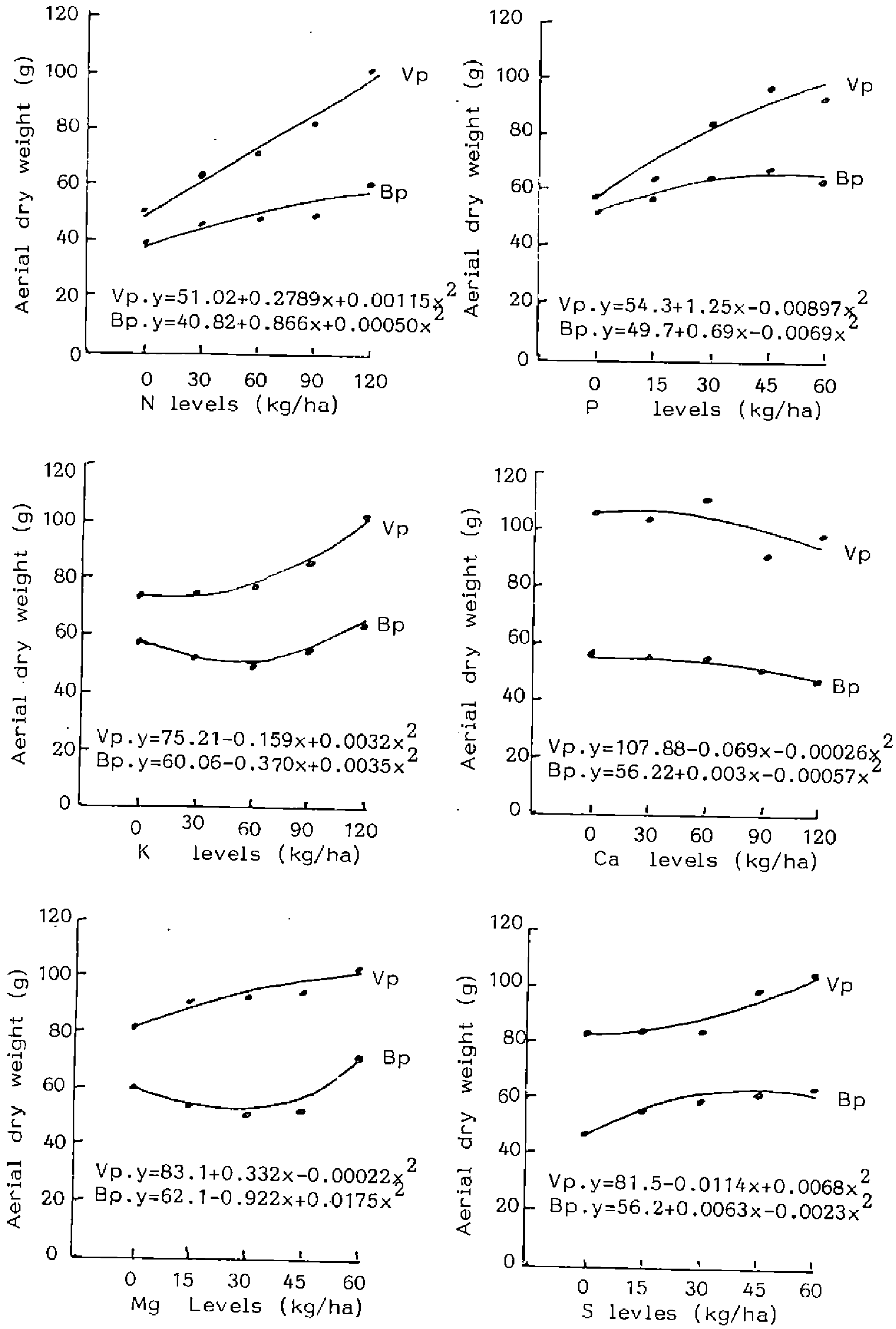
Bp - Bush pepper
Vp - Vine pepper

ground or total) for K and Mg treatments. But, R^2 was found to be significant when quadratic model was used to explain the variability, both in bush pepper and vine pepper. In vine pepper, both the models tried were unsuitable in explaining the dry weight of aerial part or the total dry weight in relation to Ca levels. But in bush pepper, the quadratic model was found to be better in explaining the variability in aerial biomass production (Fig. 5 and 6).

A model combining the responses in bush pepper and vine pepper using dummy variables was developed in order to test whether the differences in response curve for dry matter production (aerial part as well as total) in bush pepper was different from response curve obtained for vine pepper. Regression coefficients, R^2, mean square due to additional effects of vine pepper and their significance at five per cent and one per cent levels are given in Tables 6 and 7.

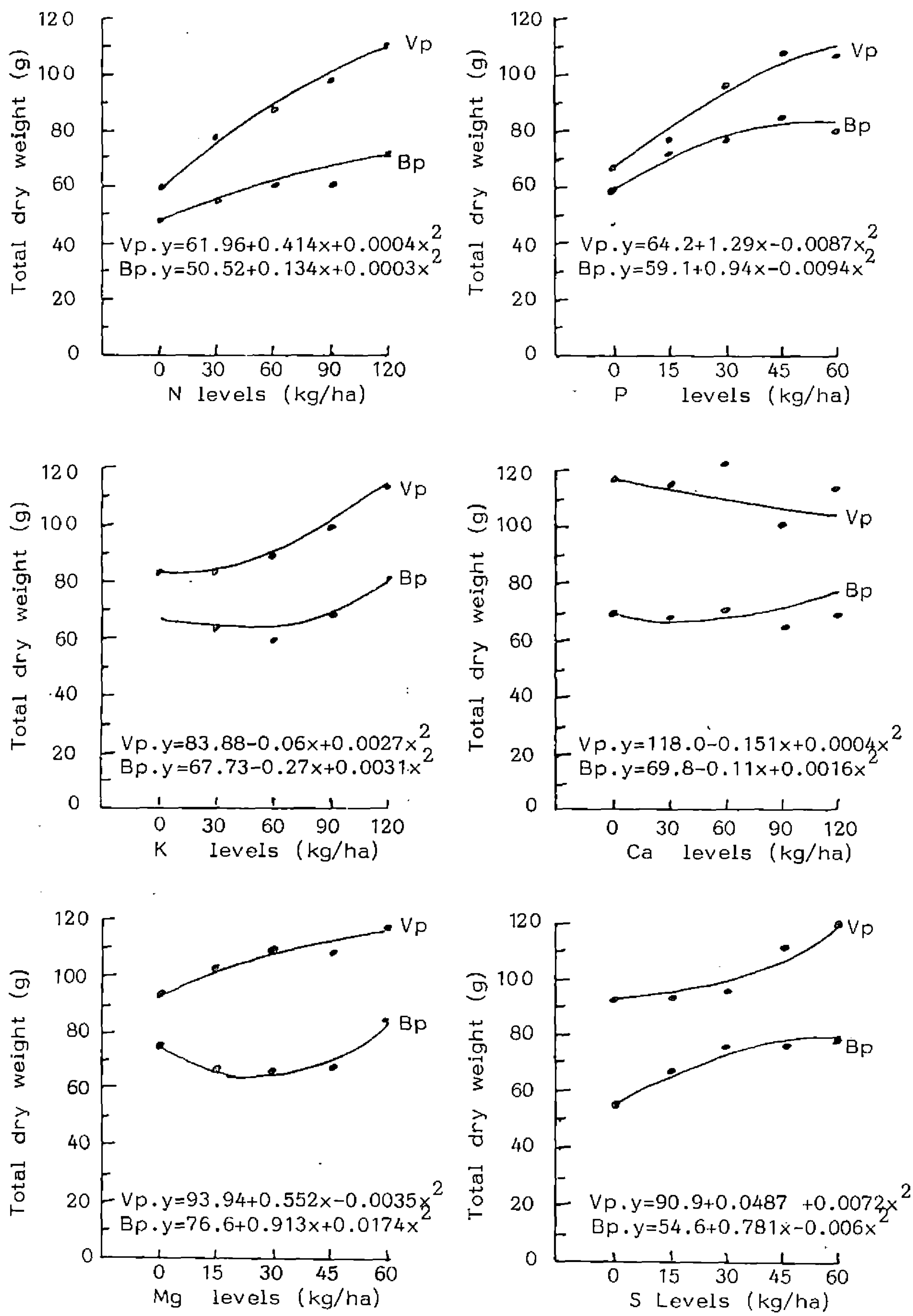
The estimated models for the response of the plant in terms of dry weight of aerial part to application of N, P, K and Mg were significant at one per cent level, while the response to S was significant at five per cent level. Estimated model for response to Ca was not significant at five per cent level (Table 6). The models explained 96.98 and 94.05 per cent of the variation in dry weight of aerial part as to the response to N and K, respectively

Fig. 5. Aerial biomass production in bush pepper and vine pepper as influenced by nutrient levels



Bp: Bush pepper; VP: Vine pepper

Fig. 6. Total biomass production in bush pepper and vine pepper as influenced by nutrient levels



Bp: Bush pepper; Vp: Vine pepper

Table 6. Quadratic model for comparison of response patterns in aerial biomass production in bush pepper and vine pepper

Regression coefficients						Mean square of the additional effect of vine pepper
b_0	b_1	b_2	c_1	c_2	R^2	
			Response to N			
45.9170	-0.0614	0.0014	0.4883*	-0.0012	0.9698**	934.45**
			Response to P			
51.9120	0.5560	-0.0052	0.8327	-0.0055	0.9400**	533.65**
			Response to K			
67.6340	-0.5902*	0.0049**	0.6515*	-0.0031	0.9405**	842.63**
			Response to Ca			
82.0510	-0.7468	0.0041	1.4275	-0.0089	0.7325	2251.77**
			Response to Mg			
72.5910	-1.5328*	0.0250*	2.4754*	-0.0328*	0.9134**	1461.47**
			Response to S			
68.8630	-0.7277	0.0068	1.4503	-0.0091	0.8951*	1697.83**

* Significant at five per cent level

** Significant at one per cent level

and was significant at one per cent level. When the regression coefficients were tested for significance, that corresponding to the linear additional effect of vine pepper alone was significant at five per cent level. The additional response of vine pepper over bush pepper, as a whole, was found to be significant at one per cent level. As regards the response to P and S, the models explained 94.00 and 89.51 per cent variation, respectively. But, none of the regression coefficients was found significantly different from zero. The additional response of vine pepper in the model, however, was significant at one per cent level. The estimated model for the response to applied Mg explained 91.34 per cent variation and was significant at one per cent level. The regression coefficients b_1, b_2 and c_1, c_2 were significantly different from zero, at five per cent level. The additional effect of vine pepper was also conspicuous at one per cent level.

The estimated models for the total dry weight as to the response to N, P, K and Mg were significant at one per cent level. They explained 96.70, 95.76, 95.36 and 94.19 per cent variation for N, P, K and Mg, respectively. The estimated models for total dry weight in bush pepper and vine pepper followed a similar pattern as that for dry weight of aerial part, except for S (Table 7). The additional response of vine pepper over bush pepper was significant at one per cent level in the case of all the nutrients considered.

Table 7. Quadratic model for comparison of response patterns in total biomass production in bush pepper and vine pepper

Regression coefficients						Mean square of the additional effect of vine pepper
b_0	b_1	b_2	c_1	c_2	R^2	
Response to N						
56.2380	-0.0317	0.0013	0.6118*	-0.0019	0.9670**	1202.92**
Response to P						
61.6400	0.7941*	-0.0076	0.6444	-0.0030	0.9576**	417.90**
Response to K						
75.7900	-0.5054*	0.0046*	0.6802*	-0.0033	0.9536**	860.70**
Response to Ca						
94.3850	-0.7693	0.0048	1.4079	-0.0091	0.7241	1998.47**
Response to Mg						
85.2720	-1.4166*	0.0236*	2.4719*	-0.0333*	0.9419**	1390.61**
Response to S						
73.5270	-0.1543	0.0045	1.2125	-0.0098	0.7854	909.41**

* Significant at five per cent level
** Significant at one per cent level

4.1.2. Uptake of nutrients

4.1.2.1. Nutrient distribution

Data pertaining to the distribution of nutrients in different parts of bush pepper and vine pepper are given in Tables 8 to 19, Fig. 7 and Appendices VI and VII.

4.1.2.1.1. Effect of N

Bush pepper plants that received N_0 level (N @ 0 kg/ha) showed lower concentration of nitrogen in stem and leaf (Table 8). The foliar N concentration was significantly higher at N_4 level (N @ 120 kg/ha) and was on par with N_2 and N_3 (N @ 60 and 90 kg/ha, respectively). The N_0 (N @ 0 kg/ha) plants also exhibited visible deficiency symptoms (Plate 10). Concomitant with the decrease in N level, the P level in the stem increased, which attained its peak at N_0 level (N @ 0 kg/ha). The concentrations of K, Ca, Mg, S, Fe, Mn and Zn did not vary much (Tables 9 and 10).

The trend observed in vine pepper was almost similar to that observed in bush pepper with respect to N concentration (Tables 11, 12 and 13, Plate 11). Nitrogen concentrations in stem and leaf were the highest at N_4 level (N @ 120 kg/ha). Phosphorus content in the stem differed significantly. The highest concentration of P was observed at N_1 level (N @ 30 kg/ha) which was on par


No
N4
BUSH PEPPER
10

Plate 11. Nitrogen deficiency symptoms in vine pepper


N4
No
VINE PEPPER
11

Table 9. Distribution of secondary nutrients (%) in bush pepper as influenced by N, P and K fertilization

Nutrient level (kg/ha)		Ca			Mg			S		
		Stem	Leaf	Spike	Stem	Leaf	Spike	Stem	Leaf	Spike
N_0	0	1.05	1.99	1.00	0.96	0.94	3.17	0.093	0.194	0.076
N_1	30	1.20	1.96	0.90	1.02	0.97	3.33	0.105	0.180	0.078
N_2	60	1.15	1.95	0.89	1.00	1.01	3.22	0.105	0.193	0.085
N_3	90	1.18	2.01	0.95	0.96	1.04	3.29	0.105	0.195	0.078
N_4	120	1.20	1.99	0.95	1.01	0.91	3.25	0.105	0.182	0.077
SEm±		0.07	0.08	0.08	0.09	0.12	0.16	0.017	0.012	0.009
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS
P_0	0	1.11	1.96	0.93	1.02	0.94	3.22	0.091	0.175	0.073
P_1	15	1.12	1.92	0.93	1.05	0.90	3.31	0.105	0.188	0.075
P_2	30	1.00	1.98	0.90	1.04	0.94	3.31	0.089	0.182	0.082
P_3	45	1.30	1.97	0.99	1.00	1.00	3.24	0.106	0.196	0.075
P_4	60	1.09	1.98	0.98	1.00	0.92	3.25	0.101	0.181	0.072
SEm±		0.06	0.10	0.07	0.05	0.11	0.10	0.022	0.012	0.011
CD (0.05)		0.17	NS	NS	NS	NS	NS	NS	NS	NS
K_0	0	1.08	2.05	0.90	1.01	1.03	3.10	0.105	0.192	0.077
K_1	30	1.08	2.06	0.91	1.04	0.96	3.16	0.106	0.188	0.080
K_2	60	1.07	1.99	0.96	1.03	0.98	3.26	0.102	0.186	0.102
K_3	90	1.01	1.93	0.92	0.99	0.99	3.32	0.092	0.189	0.081
K_4	120	1.07	1.99	0.90	1.01	0.92	3.44	0.097	0.190	0.085
SEm±		0.10	0.15	0.05	0.08	0.10	0.13	0.014	0.012	0.017
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS

Note: P and K levels are in terms of P_2O_5 and K_2O, respectively.

Table 10. Distribution of micronutrients (ppm) in bush pepper as influenced by N, P and K fertilization

Nutrient level (kg/ha)		Fe			Mn			Zn		
		Stem	Leaf	Spike	Stem	Leaf	Spike	Stem	Leaf	Spike
N_0	0	317.75	735.50	313.00	58.83	227.40	32.15	67.85	55.85	25.85
N_1	30	305.75	732.25	324.75	61.45	331.20	30.58	69.40	56.90	24.40
N_2	60	404.00	638.50	348.00	58.25	340.50	34.03	68.33	52.08	27.68
N_3	90	314.50	636.75	324.25	59.43	406.93	39.40	71.40	56.40	26.40
N_4	120	257.75	620.25	336.25	66.55	457.83	43.03	71.38	54.88	27.38
SEm±		38.04	66.00	22.62	7.78	59.65	4.60	5.66	4.81	1.85
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS
P_0	0	276.50	654.00	354.00	64.70	385.23	35.50	66.20	51.20	23.70
P_1	15	378.75	599.75	349.75	62.10	403.68	37.43	62.33	49.98	22.48
P_2	30	352.50	675.00	325.00	64.35	434.33	39.28	70.78	58.28	30.10
P_3	45	420.00	628.25	351.00	65.10	369.95	38.68	69.25	59.25	29.25
P_4	60	297.00	586.75	336.75	68.98	357.25	39.95	66.93	56.93	33.13
SEm±		30.26	19.89	14.46	8.63	38.68	3.24	6.12	3.26	1.67
CD (0.05)		91.22	59.95	NS	NS	NS	NS	NS	NS	NS
K_0	0	329.50	536.50	329.00	60.83	341.43	36.38	59.00	46.50	23.00
K_1	30	344.00	603.50	328.50	60.10	433.18	38.28	62.18	47.78	25.28
K_2	60	321.00	648.50	348.75	63.38	448.13	35.60	66.75	53.50	26.00
K_3	90	382.25	574.50	325.25	64.03	383.55	38.60	65.83	53.33	28.33
K_4	120	334.75	669.00	321.50	64.10	393.93	39.43	65.35	59.68	27.18
SEm±		33.04	48.23	19.81	6.83	58.67	3.54	11.05	5.35	4.51
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS

Note: P and K levels are in terms of P_2O_5 and K_2O, respectively.

Table 11. Distribution of major nutrients (%) in vine pepper as influenced by N, P and K fertilization

Nutrient level (kg/ha)		N		P		K	
		Stem	Leaf	Stem	Leaf	Stem	Leaf
N_0	0	1.07	1.45	0.141	0.113	2.19	2.98
N_1	30	1.04	1.83	0.150	0.116	2.26	2.88
N_2	60	1.16	1.91	0.143	0.113	2.21	2.88
N_3	90	1.25	1.81	0.144	0.106	2.35	2.93
N_4	120	1.35	2.01	0.129	0.106	2.13	2.90
SEm±		0.16	0.12	0.006	0.018	0.14	0.12
CD (0.05)		0.06	0.34	0.018	NS	NS	NS
P_0	0	1.21	1.86	0.119	0.107	2.03	3.03
P_1	15	1.48	1.99	0.125	0.119	1.93	3.00
P_2	30	1.31	1.82	0.103	0.125	1.95	3.03
P_3	45	1.51	1.86	0.141	0.113	1.97	2.79
P_4	60	1.35	1.90	0.125	0.105	2.07	2.79
SEm±		0.19	0.18	0.010	0.016	0.08	0.23
CD (0.05)		NS	NS	NS	NS	NS	NS
K_0	0	1.20	2.09	0.128	0.100	2.21	2.78
K_1	30	1.34	1.79	0.132	0.114	2.08	2.83
K_2	60	1.29	1.83	0.122	0.115	2.07	2.82
K_3	90	1.47	2.12	0.140	0.126	2.17	2.84
K_4	120	0.98	2.01	0.124	0.097	2.04	2.92
SEm±		0.16	0.20	0.010	0.012	0.13	0.14
CD (0.05)		NS	NS	NS	NS	NS	NS

Note: P and K levels are in terms of P_2O_5 and K_2O, respectively

Table 12. Distribution of secondary nutrients (%) in vine pepper as influenced by N, P and K fertilization

Nutrient level (kg/ha)		Ca		Mg		S	
		Stem	Leaf	Stem	Leaf	Stem	Leaf
N_0	0	0.89	1.99	0.95	0.94	0.104	0.189
N_1	30	1.07	1.99	1.02	0.96	0.102	0.180
N_2	60	1.13	1.99	0.89	0.94	0.111	0.191
N_3	90	1.06	1.96	1.04	0.98	0.105	0.183
N_4	120	1.07	1.97	0.97	0.90	0.101	0.184
SEm±		0.16	0.08	0.07	0.14	0.016	0.010
CD (0.05)		NS	NS	NS	NS	NS	NS
P_0	0	1.14	1.96	1.05	0.94	0.113	0.187
P_1	15	1.05	2.00	0.98	1.01	0.110	0.187
P_2	30	1.02	1.97	0.99	1.00	0.094	0.195
P_3	45	1.07	1.94	0.97	0.91	0.113	0.195
P_4	60	1.12	2.02	0.98	0.96	0.117	0.187
SEm±		0.09	0.09	0.06	0.09	0.020	0.010
CD (0.05)		NS	NS	NS	NS	NS	NS
K_0	0	1.10	2.07	1.04	0.97	0.114	0.183
K_1	30	0.93	2.10	0.96	0.96	0.122	0.199
K_2	60	1.05	2.10	0.96	0.98	0.093	0.200
K_3	90	1.03	1.99	1.01	0.97	0.102	0.191
K_4	120	1.07	2.02	0.98	0.99	0.097	0.194
SEm±		0.09	0.20	0.08	0.14	0.016	0.010
CD (0.05)		NS	NS	NS	NS	NS	NS

Note: P and K levels are in terms of P_2O_5 and K_2O, respectively.

Table 13. Distribution of micronutrients (ppm) in vine pepper as influenced by N, P and K fertilization

Nutrient level (kg/ha)		Fe		Mn		Zn	
		Stem	Leaf	Stem	Leaf	Stem	Leaf
N_0	0	389.00	675.25	59.83	306.08	68.85	51.48
N_1	30	311.50	661.75	64.23	359.45	63.70	53.43
N_2	60	346.50	584.25	63.00	340.90	73.18	53.03
N_3	90	379.00	671.25	62.93	421.75	73.08	56.18
N_4	120	486.75	694.00	65.73	452.38	73.10	54.28
SEm±		77.59	79.77	4.61	37.25	6.07	3.53
CD (0.05)		NS	NS	NS	NS	NS	NS
P_0	0	422.75	731.75	61.45	399.98	67.93	50.68
P_1	15	506.00	587.75	62.08	412.65	61.80	51.55
P_2	30	416.50	628.75	61.48	393.50	66.28	50.28
P_3	45	483.25	661.75	64.03	379.78	66.43	54.10
P_4	60	417.75	668.25	67.35	392.23	65.53	54.78
SEm±		23.36	28.20	3.52	54.78	6.24	2.65
CD (0.05)		70.42	85.15	NS	NS	NS	NS
K_0	0	426.25	553.00	61.35	354.90	67.23	53.60
K_1	30	414.00	616.00	63.30	443.98	64.45	50.90
K_2	60	396.75	689.00	63.50	343.65	62.65	51.90
K_3	90	380.00	650.00	62.80	324.55	66.78	52.15
K_4	120	469.25	550.75	64.93	420.70	68.35	54.60
SEm±		90.49	61.92	4.50	65.47	12.35	3.70
CD (0.05)		NS	NS	NS	NS	NS	NS

Note: P and K levels are in terms of P_2O_5 and K_2O, respectively.

with N_0, N_2 and N_3 (N @ 0, 60 and 90 kg/ha, respectively). But the concentrations of other nutrient elements did not vary much.

4.1.2.1.2. Effect of P

Levels of P did not influence the concentrations of nutrients in different parts of bush pepper, except for Ca concentration in the stem and Fe concentration in the stem and leaf (Table 8, 9 and 10). Concentration of Ca was the highest at P_3 (P_2O_5 @ 45 kg/ha) which was distinctly superior to other levels. In the stem P_3 (P_2O_5 @ 45 kg/ha) recorded the highest value, P_0 (P_2O_5 @ 0 kg/ha) recorded the lowest Fe content which was on par with all other levels, except P_1 and P_3 (P_2O_5 @ 15 and 45 kg/ha, respectively). The foliar level of Fe was significantly more at P_2 level (P_2O_5 @ 30 kg/ha) which was significantly superior to P_4 (P_2O_5 @ 60 kg/ha) and on par with all others.

In vine pepper plants which did not receive application of P, the concentrations of nutrients were not significantly different from those which received P. However, Fe content of leaf and stem was influenced by applied levels of P (Tables 11, 12 and 13). In the stem, the highest content of Fe was observed at P_1 (P_2O_5 @ 15 kg/ha) level which was on par with P_3 (P_2O_5 @ 45 kg/ha). The concentration of Fe in the leaf was more at P_0 level (P_2O_5 @ 0 kg/ha) which was on par with P_3 (P_2O_5 @ 45 kg/ha) and P_4 (P_2O_5 @ 60 kg/ha) levels.

4.1.2.1.3. Effect of K

Influence of K levels on the nutrient concentration in bush pepper was not significant in different plant parts (Tables 8, 9 and 10).

Similar trend was observed in vine pepper also (Tables 11, 12 and 13).

4.1.2.1.4. Effect of Ca

Significant differences could not be noticed in the concentration of any of the nutrients in different plant parts of bush pepper (Tables 14, 15 and 16).

Results obtained in vine pepper also showed the above trend (Tables 17, 18 and 19).

4.1.2.1.5. Effect of Mg

Effect of different levels of Mg on the concentrations of nutrients in different plant parts was not significant (Tables 14, 15 and 16).

Foliar P concentration differed significantly at different levels of Mg in vine pepper (Table 17). Maximum content of P was recorded at Mg_4 ((MgO @ 60 kg/ha) which was significantly superior to other levels. The concentrations of other nutrients were not significantly different (Tables 17, 18 and 19).

Table 14. Distribution of major nutrients (%) in bush pepper as influenced by Ca, Mg and S fertilization

Nutrient level (kg/ha)		N			P			K		
		Stem	Leaf	Spike	Stem	Leaf	Spike	Stem	Leaf	Spike
Ca_0	0	1.29	1.70	2.07	0.131	0.110	0.105	2.01	2.99	3.09
Ca_1	30	1.33	1.79	2.27	0.128	0.106	0.094	2.00	2.88	3.23
Ca_2	60	1.11	2.07	2.29	0.125	0.125	0.091	2.16	3.05	3.23
Ca_3	90	1.10	2.00	2.24	0.128	0.120	0.104	2.16	2.77	3.16
Ca_4	120	1.76	2.09	2.24	0.122	0.122	0.103	2.05	2.88	3.07
SEm±		0.18	0.10	0.21	0.020	0.013	0.014	0.15	0.13	0.11
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS
Mg_0	0	1.42	1.68	2.28	0.141	0.110	0.106	2.05	2.72	2.98
Mg_1	15	1.14	2.05	2.28	0.141	0.141	0.069	1.99	2.88	3.28
Mg_2	30	1.16	1.87	2.08	0.119	0.110	0.094	2.15	2.82	3.21
Mg_3	45	1.39	2.10	2.01	0.103	0.116	0.116	2.05	2.90	3.31
Mg_4	60	1.38	1.81	2.17	0.147	0.147	0.091	2.03	2.86	3.27
SEm±		0.30	0.13	0.16	0.020	0.017	0.011	0.09	0.14	0.17
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS
S_0	0	1.36	1.90	2.20	0.172	0.150	0.103	1.98	2.84	3.21
S_1	15	1.14	1.87	2.08	0.147	0.141	0.104	1.97	2.83	3.46
S_2	30	1.15	1.99	2.12	0.147	0.138	0.107	2.03	2.93	3.42
S_3	45	1.15	2.07	2.01	0.147	0.135	0.093	2.03	2.97	3.36
S_4	60	1.08	1.99	2.05	0.120	0.132	0.105	2.05	2.87	3.16
SEm±		0.25	0.22	0.13	0.003	0.023	0.013	0.10	0.14	0.19
CD (0.05)		NS	NS	NS	0.012	NS	NS	NS	NS	NS

Note: Ca, Mg and S levels are in terms of CaO, MgO and SO_4, respectively

Table 15. Distribution of secondary nutrient (%) in bush pepper as influenced by Ca, Mg and S fertilization

Nutrient level (kg/ha)		Ca			Mg			S		
		Stem	Leaf	Spike	Stem	Leaf	Spike	Stem	Leaf	Spike
Ca_0	0	1.03	1.88	0.87	1.03	0.94	3.17	0.097	0.187	0.083
Ca_1	30	1.13	2.01	0.97	1.01	0.91	3.25	0.093	0.186	0.087
Ca_2	60	1.08	1.96	1.01	1.04	0.92	3.27	0.097	0.189	0.072
Ca_3	90	1.09	1.98	0.98	1.06	0.93	3.23	0.093	0.182	0.083
Ca_4	120	1.25	1.90	0.98	1.02	0.91	3.22	0.105	0.181	0.083
SEm±		0.09	0.13	0.05	0.07	0.09	0.12	0.016	0.013	0.007
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS
Mg_0	0	1.11	2.05	0.90	1.00	1.21	2.96	0.102	0.174	0.083
Mg_1	15	1.06	2.09	0.85	0.99	1.01	3.18	0.105	0.182	0.069
Mg_2	30	1.06	2.00	0.97	0.97	0.98	3.29	0.100	0.190	0.068
Mg_3	45	1.06	2.05	0.95	1.04	1.03	3.40	0.105	0.198	0.079
Mg_4	60	1.05	2.06	0.90	1.00	1.01	3.32	0.097	0.187	0.074
SEm±		0.08	0.08	0.06	0.07	0.15	0.14	0.012	0.013	0.005
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS
S_0	0	1.09	1.93	0.90	1.02	0.95	3.33	0.055	0.141	0.069
S_1	15	1.06	2.11	0.90	1.06	0.95	3.53	0.094	0.171	0.075
S_2	30	1.06	2.04	0.80	1.07	0.84	3.45	0.114	0.187	0.073
S_3	45	1.02	1.96	0.91	1.01	0.86	3.40	0.102	0.177	0.076
S_4	60	1.05	2.00	1.01	1.04	0.95	3.34	0.114	0.204	0.088
SEm±		0.08	0.18	0.07	0.07	0.10	0.15	0.010	0.012	0.009
CD (0.05)		NS	NS	NS	NS	NS	NS	0.030	0.040	NS

Note: Ca, Mg and S levels are in terms of CaO, MgO and SO_4, respectively

Table 16. Distribution of micronutrients (ppm) in bush pepper as influenced by Ca, Mg and S fertilization

Nutrient level (kg/ha)		Fe			Mn			Zn		
		Stem	Leaf	Spike	Stem	Leaf	Spike	Stem	Leaf	Spike
Ca_0	0	300.50	676.75	326.75	62.48	416.10	40.15	65.13	56.08	26.08
Ca_1	30	388.25	673.75	348.75	62.23	391.25	34.10	64.68	56.35	26.35
Ca_2	60	402.75	681.75	356.75	70.48	405.48	40.53	63.80	56.55	26.55
Ca_3	90	325.50	709.00	337.00	74.53	423.43	40.43	66.60	53.10	28.10
Ca_4	120	326.75	747.75	325.75	72.20	361.95	39.25	71.73	53.33	28.33
SEm±		29.07	69.02	9.63	5.35	41.11	3.25	4.85	2.45	1.79
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS
Mg_0	0	429.75	719.50	344.50	68.00	327.68	33.03	67.05	52.30	27.30
Mg_1	15	304.25	586.75	341.25	67.75	348.28	35.68	71.50	54.15	26.65
Mg_2	30	460.00	558.70	348.75	67.13	374.23	38.08	67.98	50.63	28.13
Mg_3	45	343.75	662.25	362.25	67.10	384.73	39.23	74.55	56.18	26.18
Mg_4	60	451.50	763.50	356.00	64.73	364.28	36.95	66.68	54.20	26.78
SEm±		80.44	79.45	12.94	7.87	23.75	2.55	8.15	2.93	2.19
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS
S_0	0	436.25	657.75	332.75	64.33	359.68	36.25	68.75	50.88	25.90
S_1	15	392.25	702.25	302.25	74.68	321.15	35.65	70.55	54.55	27.05
S_2	30	469.25	643.50	343.50	74.43	420.40	40.35	83.78	55.98	28.45
S_3	45	309.00	799.25	337.50	67.68	335.45	36.53	78.48	56.05	26.18
S_4	60	410.75	816.25	338.75	71.13	393.40	38.53	85.15	56.93	27.80
SEm±		124.82	90.16	25.83	4.73	46.99	3.82	5.76	5.52	1.60
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS

Note: Ca, Mg and S levels are in terms of CaO, MgO and SO_4, respectively.

Table 17. Distribution of major nutrients (%) in vine pepper as influenced by Ca, Mg and S fertilization

Nutrient level (kg/ha)		N		P		K	
		Stem	Leaf	Stem	Leaf	Stem	Leaf
Ca_0	0	1.38	1.89	0.131	0.119	1.95	3.01
Ca_1	30	1.29	1.98	0.128	0.100	2.11	2.77
Ca_2	60	1.52	1.92	0.125	0.103	2.05	2.91
Ca_3	90	1.44	1.96	0.128	0.100	1.94	2.60
Ca_4	120	1.41	1.98	0.122	0.125	2.09	2.93
SEm±		0.28	0.18	0.013	0.015	0.09	0.18
CD (0.05)		NS	NS	NS	NS	NS	NS
Mg_0	0	1.19	1.89	0.105	0.110	2.08	2.83
Mg_1	15	1.47	1.90	0.100	0.111	2.15	2.93
Mg_2	30	1.21	1.96	0.110	0.110	2.10	2.80
Mg_3	45	1.17	1.81	0.103	0.116	2.03	2.93
Mg_4	60	1.68	2.02	0.097	0.147	2.10	2.96
SEm±		0.23	0.20	0.009	0.009	0.15	0.12
CD (0.05)		NS	NS	NS	0.026	NS	NS
S_0	0	1.79	1.91	0.103	0.172	2.24	2.83
S_1	15	1.26	2.00	0.110	0.172	2.06	3.01
S_2	30	1.23	1.93	0.114	0.147	2.02	2.88
S_3	45	1.30	2.11	0.119	0.147	1.94	2.95
S_4	60	1.44	2.32	0.107	0.116	2.09	2.80
SEm±		0.28	0.22	0.016	0.012	0.14	0.14
CD (0.05)		NS	NS	NS	0.019	NS	NS

Note: Ca, Mg and S levels are in terms of CaO, MgO and SO_4, respectively.

Table 18. Distribution of secondary nutrients (%) in vine pepper as influenced by Ca, Mg and S fertilization

Nutrient level (kg/ha)		Ca		Mg		S	
		Stem	Leaf	Stem	Leaf	Stem	Leaf
Ca_0	0	1.08	1.84	0.98	0.93	0.102	0.194
Ca_1	30	1.02	2.06	0.98	0.98	0.105	0.180
Ca_2	60	1.05	1.99	0.93	0.97	0.097	0.190
Ca_3	90	1.10	2.03	1.02	0.96	0.101	0.188
Ca_4	120	1.02	1.98	1.00	0.99	0.105	0.188
SEm±		0.09	0.15	0.11	0.10	0.016	0.016
CD (0.05)		NS	NS	NS	NS	NS	NS
Mg_0	0	1.02	2.03	1.03	0.90	0.093	0.196
Mg_1	15	1.07	2.06	1.02	0.97	0.105	0.191
Mg_2	30	1.06	2.02	1.08	1.04	0.093	0.191
Mg_3	45	1.08	1.99	0.97	1.00	0.097	0.190
Mg_4	60	1.07	2.05	1.02	0.98	0.105	0.180
SEm±		0.08	0.12	0.06	0.15	0.016	0.016
CD (0.05)		NS	NS	NS	NS	NS	NS
S_0	0	1.06	2.05	1.04	0.99	0.052	0.138
S_1	15	0.99	1.91	0.95	0.98	0.114	0.178
S_2	30	1.06	1.92	1.04	0.97	0.105	0.194
S_3	45	1.06	2.02	0.95	0.92	0.105	0.197
S_4	60	1.07	1.97	1.04	0.92	0.114	0.202
SEm±		0.09	0.13	0.08	0.10	0.010	0.016
CD (0.05)		NS	NS	NS	NS	0.031	0.035

Note: Ca, Mg and S levels are in terms of CaO, MgO SO_4, respectively

Table 19. Distribution of micronutrients (ppm) in vine pepper as influenced by Ca, Mg and S fertilization

Nutrient level (kg/ha)		Fe		Mn		Zn	
		Stem	Leaf	Stem	Leaf	Stem	Leaf
Ca_0	0	481.50	640.25	62.63	408.30	64.13	51.73
Ca_1	30	379.00	676.25	62.00	385.43	66.53	53.03
Ca_2	60	391.50	666.25	67.13	411.89	61.30	52.05
Ca_3	90	372.00	720.50	69.00	397.53	67.68	55.38
Ca_4	120	391.75	761.00	66.20	402.25	68.03	57.53
SEm±		88.53	75.15	3.66	70.80	47.44	2.44
CD (0.05)		NS	NS	NS	NS	NS	NS
Mg_0	0	354.25	641.00	66.98	348.38	70.48	51.83
Mg_1	15	435.00	676.25	66.63	350.90	69.08	52.33
Mg_2	30	395.00	674.50	68.03	428.13	73.60	57.10
Mg_3	45	343.75	579.75	65.65	381.33	70.55	60.30
Mg_4	60	540.25	619.25	64.18	435.35	64.25	50.30
SEm±		65.29	49.22	5.00	61.21	9.12	5.32
CD (0.05)		NS	NS	NS	NS	NS	NS
S_0	0	358.50	775.25	63.83	339.05	71.25	55.50
S_1	15	376.25	623.25	72.28	353.10	68.43	51.43
S_2	30	384.75	618.25	72.28	365.55	70.58	53.38
S_3	45	386.50	547.75	63.73	359.28	66.83	52.85
S_4	60	362.25	666.00	71.25	379.35	75.63	52.40
SEm±		34.11	67.36	3.32	38.88	8.17	3.91
CD (0.05)		NS	NS	NS	NS	NS	NS

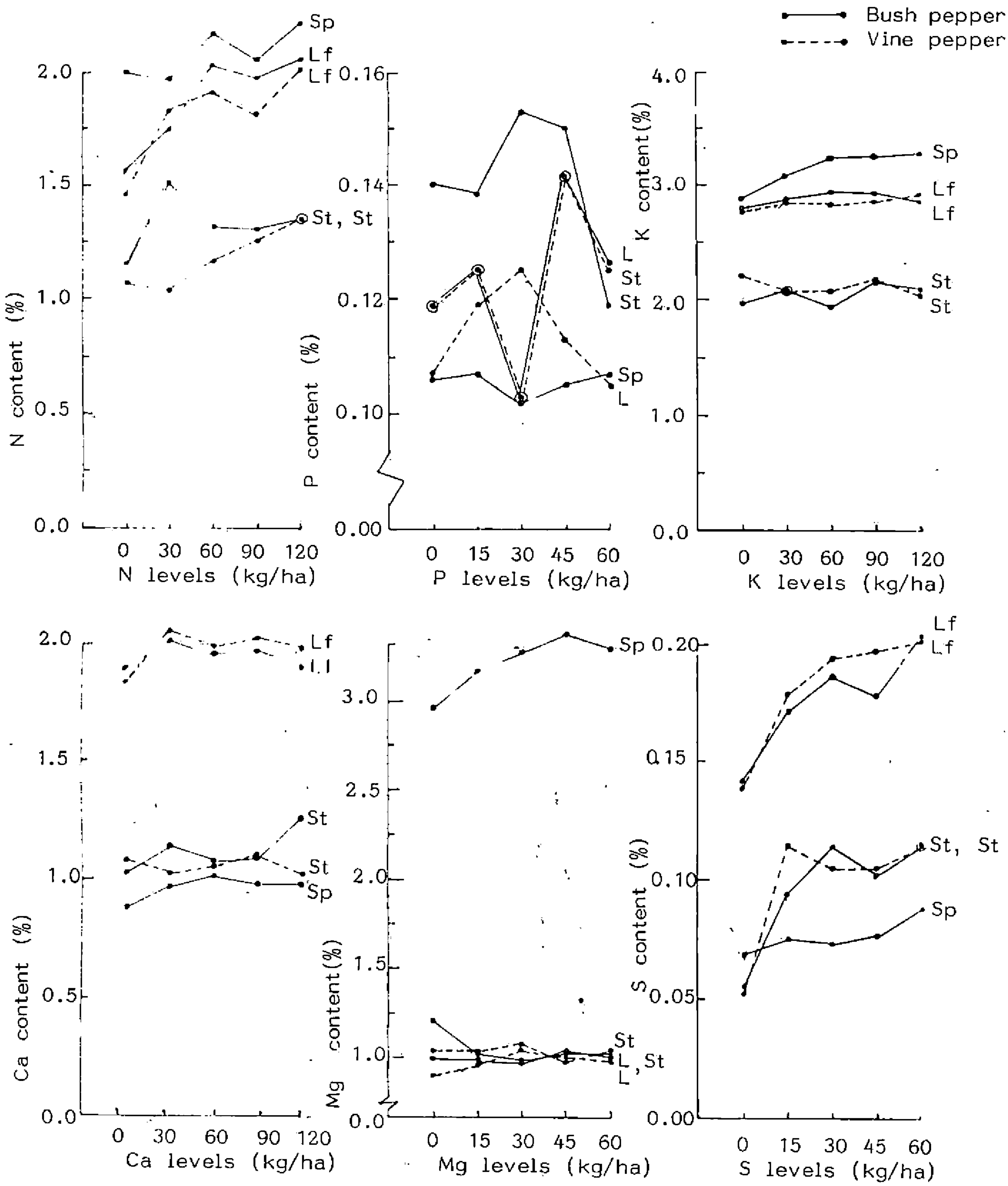
Note: Ca, Mg and S levels are in terms of CaO, MgO and SO_4, respectively

4.1.2.1.6. Effect of S

In bush pepper, levels of S significantly influenced the concentration of P in the stem (Table 14) and S both in the stem and in the leaf (Table 15). Significantly higher content of P was recorded at S_0 (S @ 0 kg/ha). The S_4 level (S @ 60 kg/ha) had the lowest value for P, which was distinctly different from other levels of S. Significantly lower values of S concentration, both in the stem and in the leaf, was recorded at S_0 level (SO_4 @ 0 kg/ha). S_4 level (SO_4 @ 60 kg/ha) recorded the highest value in both the cases, though in the stem S_2 level (SO_4 @ 30 kg/ha) also had the same value. The concentrations of other nutrients did not change significantly (Tables 14, 15 and 16).

In vine pepper, the P concentration of leaf differed significantly (Table 17) and the value recorded at S_0 level (SO_4 @ 0 kg/ha) was the highest, which was on par with S_1 (SO_4 @ 15 kg/ha) and significantly superior to all others. Influence of levels of S on the concentrations of S both in the stem and in the leaf also was significant (Table 18). The S_0 level (SO_4 @ 0 kg/ha) was significantly inferior when compared to other levels in both the parts, maximum being at S_4 level (SO_4 @ 60 kg/ha). S_1, S_2, S_3 and S_4 levels (SO_4 @ 15, 30, 45 and 60 kg/ha, respectively) were on par. Significant differences were not observed in the concentrations of other nutrients (Table 19).

Fig. 7. Nutrient distribution in bush pepper and vine pepper as influenced by their levels of application



St: Stem, Lf: Leaf, Sp: Spike

4.1.2.2. Nutrient uptake

Data pertaining to the nutrient uptake, as influenced by different nuutrient levels in bush pepper, are presented in Tables 20 and 22 and that of vine pepper in Tables 21 and 23 and Appendices VIII and IX.

4.1.2.2.1. Effect of N

Of the nine elements studied, uptake of all the nutrients, except S, Fe and Zn was significantly influenced by levels of N in bush pepper (Table 20). Maximum uptake of all the elements was recorded at N_4 level (N @ 120 kg/ha) and was significantly superior to N_0 level (N @ 0 kg/ha) which recorded the minimum value.

Vine pepper recorded significant differences on the uptake of all the nutrients at different levels of N (Table 21). Significantly higher values as compared to N_0 level (N @ 0 kg/ha) were recorded at N_4 level (N @ 120 kg/ha) whereas the values were the lowest at N_0 level (N @ 0 kg/ha) in the uptake of all the nutrients.

4.1.2.2.2. Effect of P

Uptake of N, P, K, Ca, Mg, S and Fe differed significantly at different levels of P in bush pepper (Table 20). Maximum values

Table 20. Uptake of nutrients by bush pepper as influenced by N, P and K fertilization

Nutrient level (kg/ha)		N	P	K	Ca	Mg	S	Fe	Mn	Zn
N_0	0	0.60	56.10	1.01	0.68	0.40	66.05	24.04	6.96	2.33
N_1	30	0.77	60.83	1.29	0.77	0.41	71.21	27.59	11.26	2.66
N_2	60	0.92	56.40	1.34	0.77	0.65	75.58	26.17	10.99	2.56
N_3	90	0.89	57.17	1.32	0.84	0.57	80.53	26.42	14.22	2.90
N_4	120	1.05	73.08	1.63	0.98	0.75	88.78	28.99	17.81	3.35
SEm±		0.30	9.21	0.13	0.11	0.06	11.17	5.53	2.74	0.45
CD (0.05)		0.17	14.20	0.39	0.21	0.19	NS	NS	8.26	NS
P_0	0	0.94	66.32	1.36	0.84	0.58	72.58	27.10	13.94	2.63
P_1	15	1.03	76.08	1.53	0.92	0.64	88.84	29.63	16.23	2.91
P_2	30	1.18	85.53	1.76	1.06	0.76	97.17	36.24	20.02	3.66
P_3	45	1.24	98.89	1.86	1.17	0.79	112.32	37.85	17.65	4.03
P_4	60	1.05	79.58	1.77	1.10	0.76	99.06	32.25	16.36	3.76
SEm±		0.12	4.07	0.10	0.55	0.07	8.16	2.42	3.11	0.50
CD (0.05)		0.19	12.00	0.29	0.16	0.20	24.60	7.32	NS	NS
K_0	0	1.16	81.90	1.57	1.05	0.70	98.53	28.28	15.94	2.78
K_1	30	1.01	62.15	1.46	0.94	0.61	86.20	27.82	16.99	2.62
K_2	60	0.82	58.12	1.29	0.82	0.60	77.36	26.47	15.81	2.66
K_3	90	1.12	72.94	1.60	0.95	0.71	88.71	28.74	15.81	2.99
K_4	120	1.20	77.90	1.82	1.13	0.72	105.63	37.18	19.28	3.80
SEm±		0.14	12.31	0.01	0.08	0.10	11.80	4.09	2.88	0.61
CD (0.05)		NS	NS	0.29	0.25	NS	NS	NS	NS	NS

Note: P and K levels are in terms of P_2O_5 and K_2O, respectively
N, K, Ca and Mg expressed as g/plant
P, S, Fe, Mn and Zn expressed as mg/plant

Table 21. Uptake of nutrients by vine pepper as influenced by N, P and K fertilization

Nutrient level (kg/ha)		N	P	K	Ca	Mg	S	Fe	Mn	Zn
N_0	0	0.62	62.67	1.27	0.71	0.46	72.31	26.39	8.78	3.01
N_1	30	0.91	84.85	1.63	0.98	0.64	89.84	31.14	13.66	3.69
N_2	60	1.12	91.08	1.82	1.11	0.65	106.80	33.54	14.47	4.52
N_3	90	1.26	99.38	2.19	1.27	0.84	122.00	47.01	21.04	5.29
N_4	120	1.66	126.41	2.54	1.52	0.96	140.46	71.11	24.61	6.67
SEm±		0.07	12.54	0.10	0.11	0.08	17.61	5.06	1.78	0.56
CD (0.05)		0.21	37.78	0.30	0.32	0.24	53.06	15.26	5.39	1.68
P_0	0	0.88	65.28	1.47	0.90	0.57	87.23	33.60	13.49	3.43
P_1	15	1.09	77.65	1.53	0.92	0.57	91.67	34.41	14.10	3.64
P_2	30	1.36	96.66	2.13	1.28	0.83	123.98	44.50	19.55	4.98
P_3	45	1.66	124.41	2.33	1.48	0.93	149.32	54.20	21.05	5.87
P_4	60	1.48	107.41	2.20	1.48	0.92	144.02	51.29	21.77	6.10
SEm±		0.16	11.04	0.25	0.12	0.01	12.37	4.21	4.32	0.92
CD (0.05)		0.49	33.27	0.74	0.35	0.14	37.29	12.20	NS	NS
K_0	0	1.20	84.63	1.87	1.14	0.76	108.53	36.45	14.46	4.48
K_1	30	1.14	89.08	1.76	1.05	0.72	111.58	35.71	14.23	4.41
K_2	60	1.17	90.14	1.86	1.19	0.75	106.72	41.20	14.72	4.43
K_3	90	1.57	113.90	2.13	1.27	0.86	122.32	44.25	16.33	5.11
K_4	120	1.50	110.79	2.49	1.54	1.00	144.45	51.70	23.32	6.30
SEm±		0.28	13.67	0.17	0.08	0.05	16.19	7.78	4.35	0.96
CD (0.06)		NS	NS	0.52	0.24	0.17	NS	NS	NS	NS

Note: P and K levels are in terms of P_2O_5 and K_2O, respectively
N, K, Ca and Mg expressed as g/plant
P, S, Fe, Mn and Zn expressed as mg/plant

were recorded at P_3 level (P_2O_5 @ 45 kg/ha) in all the nutrients. P_0 (P_2O_5 @ 0 kg/ha) on the other hand had the lowest uptake.

The trend observed in vine pepper was also similar (Table 21).

4.1.2.2.3. Effect of K

In bush pepper, uptake of only two elements, viz., K and Ca, differed significantly (Table 20) and in both the cases maximum values were recorded at K_4 level (K_2O @ 120 kg/ha).

In the case of vine pepper, uptake of K, Ca and Mg showed significant differences (Table 21). Here too, maximum uptake of all the nutrients was recorded at K_4 level (K_2O @ 120 kg/ha), which was on par with K_3 level (K_2O @ 90 kg/ha) in the uptake of K and Ca.

4.1.2.2.4. Effect of Ca

Influence of levels of Ca on the uptake of nutrients was not significant either in bush pepper or in vine pepper (Tables 22 and 23, respectively).

4.1.2.2.5. Effect of Mg

Influence of Mg levels on the uptake of P, K, Mg and Fe was pronounced in bush pepper (Table 22). Maximum uptake was recorded at Mg_4 level (MgO @ 60 kg/ha).

Table 22. Uptake of nutrients by bush pepper as influenced by Ca, Mg and S fertilization

Nutrient level (kg/ha)		N	P	K	Ca	Mg	S	Fe	Mn	Zn
Ca_0	0	0.94	64.10	1.58	0.89	0.70	88.69	31.63	16.69	3.09
Ca_1	30	0.92	61.15	1.41	0.91	0.62	80.17	30.41	14.12	3.01
Ca_2	60	1.00	70.27	1.60	0.93	0.66	86.28	32.90	16.64	3.06
Ca_3	90	0.91	66.48	1.35	0.87	0.56	78.73	30.32	16.00	2.87
Ca_4	120	0.98	58.71	1.26	0.77	0.49	73.41	28.53	12.02	2.85
SEm±		0.19	13.98	0.22	0.13	0.13	13.53	5.15	2.19	0.56
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS
Mg_0	0	1.02	76.67	1.54	1.06	0.79	90.55	36.77	14.37	3.28
Mg_1	15	1.02	74.02	1.47	0.93	0.68	80.41	26.26	12.66	3.10
Mg_2	30	0.87	58.07	1.34	0.84	0.59	79.43	26.05	13.33	2.69
Mg_3	45	1.01	55.86	1.44	0.89	0.66	85.56	29.36	14.27	2.99
Mg_4	60	1.24	102.11	1.93	1.20	0.93	106.95	45.07	17.56	3.87
SEm±		0.14	9.07	0.11	0.10	0.07	8.45	3.60	1.51	0.39
CD (0.05)		NS	27.35	0.15	NS	0.21	NS	10.84	NS	NS
S_0	0	0.85	69.44	1.28	0.76	0.55	53.73	27.26	12.11	2.54
S_1	15	0.90	76.00	1.42	0.89	0.69	73.25	30.34	11.65	2.94
S_2	30	1.13	83.15	1.67	0.90	0.72	93.68	33.97	17.59	3.53
S_3	45	1.16	82.52	1.74	1.07	0.82	86.63	37.41	13.59	3.53
S_4	60	1.08	77.44	1.63	1.02	0.69	105.17	41.35	17.16	3.88
SEm±		0.17	12.12	0.06	0.12	0.06	6.57	3.00	1.99	0.38
CD (0.05)		NS	NS	0.17	NS	0.08	19.79	9.07	NS	NS

Note: Ca, Mg and S levels are in terms of CaO, MgO and SO_4, respectively

N, K, Ca and Mg expressed as g/plant

P, S, Fe, Mn and Zn expressed as mg/plant

Table 23. Uptake of nutrients by vine pepper as influenced by Ca, Mg and S fertilization

Nutrient level (kg/ha)		N	P	K	Ca	Mg	S	Fe	Mn	Zn
Ca_0	0	1.73	133.73	2.65	1.56	1.03	154.70	58.88	23.98	6.32
Ca_1	30	1.66	117.30	2.50	1.54	1.00	145.93	52.09	22.18	6.23
Ca_2	60	1.99	125.04	2.74	1.65	1.06	154.70	58.23	25.27	6.33
Ca_3	90	1.52	102.11	2.04	1.39	0.88	127.07	48.86	20.13	5.55
Ca_4	120	1.65	121.33	2.48	1.47	0.99	143.99	55.61	22.12	6.27
SEm±		0.27	18.80	0.33	0.16	0.15	20.22	7.03	7.52	0.82
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS
Mg_0	0	1.23	87.50	2.02	1.17	0.80	113.08	39.80	15.37	4.98
Mg_1	15	1.66	96.70	2.23	1.37	0.89	131.49	49.93	18.64	5.64
Mg_2	30	1.45	101.82	2.21	1.38	0.98	128.88	47.12	21.20	6.12
Mg_3	45	1.36	102.09	2.27	1.37	0.93	127.33	45.14	18.83	6.20
Mg_4	60	1.89	120.39	2.52	1.51	1.04	139.04	66.58	21.45	6.08
SEm±		0.14	7.25	0.19	0.07	0.05	15.72	4.00	3.15	0.81
CD (0.05)		0.42	21.87	NS	0.20	0.16	NS	12.04	NS	NS
S_0	0	1.51	113.95	2.08	1.29	0.83	79.53	48.44	17.49	5.17
S_1	15	1.41	120.96	2.17	1.26	0.82	124.17	42.72	19.03	4.90
S_2	30	1.34	109.98	2.05	1.27	0.82	123.84	41.86	18.62	5.10
S_3	45	1:67	132.64	2.42	1.51	0.92	150.37	46.42	20.66	5.90
S_4	60	1.90	115.16	2.48	1.56	1.02	159.18	52.36	22.42	6.65
SEm±		0.13	18.63	0.03	0.07	0.12	14.88	6.90	3.42	0.69
CD (0.05)		0.38	NS	0.10	0.22	NS	44.84	NS	NS	NS

Note: Ca, Mg and S levels are in terms of CaO, MgO and SO_4, respectively

N, K, Ca and Mg expressed as g/plant

P, S, Fe, Mn and Zn expressed as mg/plant

Levels of Mg recorded profound influence on the uptake of N, P, Ca, Mg and Fe by vine pepper (Table 23). As in bush pepper, here also Mg_4 level (Mgo @ 60 kg/ha) recorded the maximum uptake.

4.1.2.2.6. Effect of S

Levels of S recorded pronounced influence on the uptake of K, Mg, S and Fe by bush pepper (Table 22). In the uptake of K and Mg, highest values were recorded at S_3 (SO_4 @ 45 kg/ha) whereas in S and Fe, S_4 (SO_4 @ 60 kg/ha) was superior. Except for Mg uptake, the levels S_2, S_3 and S_4 (SO_4 @ 30, 45 and 60 kg/ha, respectively) were on par. For Mg uptake S_3 and S_2 levels (SO_4 @ 45 and 30 kg/ha, respectively) were on par.

In vine pepper, uptake of N, K, Ca and S differed significantly (Table 23). Maximum values were recorded at S_4 level (SO_4 @ 60 kg/ha) which was on par with S_3 (SO_4 @ 45 kg/ha) for the uptake of N, K and Ca and with all the levels, except S_0 (SO_4 @ 0 kg/ha), for S.

The nutrient uptake in bush pepper and vine pepper could be explained by mathematical models, when nutrient uptake was considered as the dependent variable (Table 24 and Appendix X). The quadratic equation was found to be better in describing the

Table 24. Goodness of fit (R^2) of the mathematical models describing nutrient uptake in black pepper as influenced by nutrient levels

Variable y vs x	Type of plant	Linear model $y = a \pm bx$	Quadratic model $y = a \pm bx \pm cx^2$
Total N uptake vs levels of N	Bp	0.910	0.924
	Vp	0.976	0.978
Total P uptake vs levels of P	Bp	0.418	0.779
	Vp	0.779	0.860
Total K uptake vs levels of K	Bp	0.270	0.883
	Vp	0.743	0.996
Total Ca uptake vs levels of Ca	Bp	0.505	0.976
	Vp	0.285	0.338
Total Mg uptake vs levels of Mg	Bp	0.096	0.952
	Vp	0.817	0.839
Total S uptake vs levels of S	Bp	0.861	0.901
	Vp	0.893	0.930

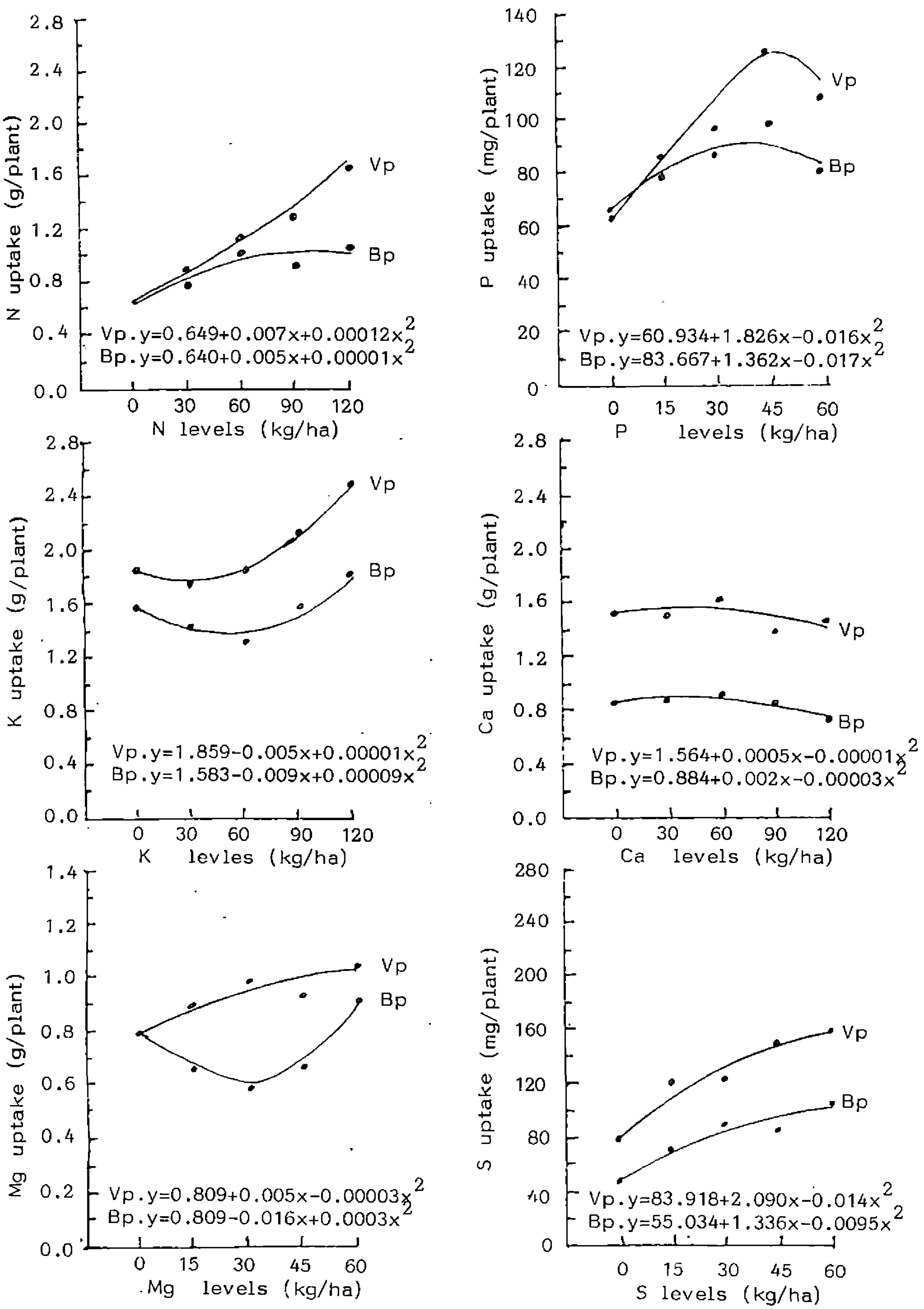
Bp - Bush pepper
Vp - Vine pepper

uptake of nutrients in relation to levels in bush pepper and vine pepper (Fig. 8). But, neither of the equations tried could explain the Ca uptake at different levels of Ca in vine pepper. The dependence of Ca uptake on levels of Ca was found to be better explained by the quadratic model in bush pepper. This equation explained 97.60 per cent and 33.80 per cent variability in bush pepper and vine pepper, respectively.

The responses in nutrient uptake in bush pepper and vine pepper were combined and tested to find out whether the difference in response curves in bush pepper is significantly different from that in vine pepper. The regression coefficients, R^2, mean square of the additional effects of vine pepper and their significance at five per cent and one per cent levels, are presented in Table 25.

The models fitted for the response to N, P, K, Mg and S were significant, while that to Ca was not significant. The estimated models explained 97.63 and 91.45 per cent of the variation in nutrient uptake as to the responses to N and S, respectively and was significant at one per cent level. None of the regression coefficients was found significantly different from zero, but the additional response of vine pepper in the model was significant at one per cent level, indicating significant difference in responses between bush pepper and vine pepper.

Fig. 8. Nutrient uptake in bush pepper and vine pepper as influenced by their levels of application



Bp: Bush pepper; Vp: Vine pepper

Table 25. Quadratic model for comparison of response patterns in nutrient uptake in bush pepper and vine pepper

Regression coefficients						Mean square of the additional effect of vine pepper
b_0	b_1	b_2	c_1	c_2	R^2	
Response to N in N uptake						
0.6450	0.0044	0.00001	0.0024	0.00001	0.9763**	0.1450**
Response to P in P uptake						
62.3010	1.4411	-0.0182	0.3054	0.0033	0.8625*	376.3600
Response to K in K uptake						
1.7210	-0.0127*	0.0001*	0.0115*	-0.0001	0.9415**	0.2850**
Response to Ca in Ca uptake						
-0.3230	0.0212*	-0.0001	3.4319	-2.0950	0.7021	0.7500**
Response to Mg in Mg uptake						
0.8100	-0.0158**	0.0003**	0.0212**	-0.0003**	0.9568**	0.0700**
Response to S in S uptake						
69.4760	0.4973	0.0010	2.4313	-0.0256	0.9145**	2411.5150**

* Significant at five per cent level
** Significant at one per cent level

As to the response to P, the estimated model explained 86.25 per cent of the variation in P uptake and was significant at five per cent level. But none of the regression coefficients was significantly different from zero. The additional response of vine pepper in the model was also not significant.

About 94.15 per cent of the variation in K uptake as the response to applied K was explained by the estimated model and was significant at one per cent level. When the regression coefficients were tested for significance, the linear and quadratic effect of K and the linear additional effect of vine pepper differed significantly from zero at five per cent level. The mean square of the additional effect of vine pepper was also significant at one per cent level. As regards the response to Mg, the estimated model explained 95.68 per cent of the variation in Mg uptake and was significant at one per cent level. The regression coefficients corresponding to the linear and the quadratic effect of Mg and those due to the additional effect of vine pepper for Mg uptake were significant at one per cent level. The additional response of vine pepper over bush pepper was also significant at one per cent level.

4.2. Varietal differences in the utilization of applied P

The results of the studies on the relative efficiencies of eleven black pepper varieties in the utilization of applied P are presented below. For characters in which interaction between variety and source was not significant, only mean values are given in the Tables.

4.2.1. Growth parameters

Data pertaining to the growth parameters such as length of the vine, number of leaves, total leaf area and dry matter content of the pepper varieties are presented in Table 26 and the influence of P sources on these parameters in black pepper, in Table 27 (Appendix XI).

4.2.1.1. Length of the vine

Significant differences between varieties were recorded with regard to the length of the vine. Karimunda recorded the maximum length which was significantly superior to all, except Aimpirian. All other varieties were on par.

Effect of P sources on the length of the vine in black pepper was not significant.

4.2.1.2. Number of leaves

The varieties recorded detectable differences with regard to the number of leaves produced by the vine. Kutching recorded the maximum and was significantly superior to all others, except Neelamundi, Kottanadan, Kuthiravally and Poonjarmunda.

Table 26. Variability in growth among black pepper varieties

Sl. No.	Variety	Vine length (cm)	Number of leaves	Total leaf area (cm^2)	Dry matter yield(g/plant)		
					Stem	Leaf	Total
1.	Kuthiravally	140.40	22.21	762.54	4.71 (47.15)	5.28 (52.85)	9.99
2.	Kottanadan	150.91	22.41	852.14	4.46 (44.64)	5.53 (55.36)	9.99
3.	Neelamundi	153.92	23.22	872.78	5.02 (49.60)	5.10 (50.40)	10.12
4.	Karimunda	180.12	18.10	582.65	5.88 (60.12)	3.90 (39.88)	9.78
5.	Panniyur-1	148.80	20.83	804.65	4.99 (49.31)	5.13 (50.69)	10.12
6.	Aimpirian	165.84	21.21	830.21	5.12 (45.88)	6.04 (54.12)	11.16
7.	Poonjarmunda	142.72	21.80	789.81	4.34 (42.51)	5.87 (57.49)	10.21
8.	Kuthiyanikkodi	139.90	16.01	437.54	3.40 (47.62)	3.74 (52.38)	7.14
9.	Kutching	143.42	26.10	604.68	4.84 (54.94)	3.97 (45.06)	8.81
10.	Kottakkodi	148.82	17.01	687.63	4.36 (54.30)	3.67 (45.70)	8.03
11.	Kanjiramundi	148.14	19.31	758.28	4.61 (49.68)	4.67 (50.32)	9.28
SEm±		13.62	2.91	121.39	0.89	0.81	1.25
CD (0.05)		22.20	4.70	198.03	NS	1.32	1.06

Figures in parentheses indicate the percentage of the total

Table 27. Growth of black pepper as influenced by P sources

Sl. No.	Source	Vine length (cm)	Number of leaves	Total leaf area (cm^2)	Dry matter yield (g/plant)		
					Stem	Leaf	Total
1.	Nitrophosphate	146.30	21.50	753.15	4.56 (50.00)	4.56 (50.00)	9.12
2.	Amophos	152.30	21.90	723.06	4.37 (48.45)	4.65 (51.55)	9.02
3.	Superphosphate	157.00	18.90	700.96	5.18 (49.86)	5.21 (50.14)	10.39
SEm±		13.62	2.91	121.39	0.89	0.81	1.25
CD (0.05)		NS	2.40	NS	NS	NS	1.06

Figures in parentheses indicate the percentage of the total

Of the three P sources tested, amophos and nitrophosphate were on par and significantly superior to superphosphate in the production of leaves in black pepper.

4.2.1.3. Total leaf area

There were marked differences among varieties with regard to the total leaf area. Neelamundi recorded the maximum leaf area which was significantly superior to Kuthiyanikkodi, Karimunda and Kutching and on par with others.

Influence of P sources on the total leaf area in black pepper was not significant.

4.2.1.4. Dry matter production

Significant differences were recorded with respect to the dry matter content of the leaf and total dry matter production. In the total dry matter production, Aimpirian was significantly superior to all varieties except Poonjarmunda, Panniyur-1 and Neelamundi. The total dry weight of the varieties ranged from 7.14 to 11.16 g/plant. The range values in the percentage contribution by the stem and leaf were 42.51 to 60.12 and 39.88 to 57.49, respectively.

Influence of P sources on total dry matter production was significant. Of the sources of P tried, superphosphate was found to be the best and was significantly superior to amophos and nitro-phosphate.

Interaction between variety and source was not significant for all the growth parameters studied (Appendix XI).

4.2.2. Fertilizer P utilization

4.2.2.1.. P concentration

The P concentration in the stem was not significant among black pepper varieties, whereas P in the leaf differed significantly (Table 28 and Appendix XII). The leaf P content in Karimunda (0.191%) was significantly superior to all other varieties.

Among the different sources of P tested, none showed significant differences in the phosphorous concentration of the stem or the leaf (Table 29 and Appendix XII).

4.2.2.2. P uptake

Data pertaining to the uptake and the percentage contribution by the stem and leaf and the total uptake of P by black pepper varieties are given in Table 28. Influence of P sources on P uptake by black pepper is given in Table 29 (Appendix XII).

Among the varieties significant differences in the P uptake were noticed. Maximum uptake was recorded by Karimunda (15.21 mg/plant) and this was on par with Aimpirian (14.65 mg/plant),

Table 28. Variability in the concentration and uptake of P among black pepper varieties

Sl. No.	Variety	P concentration (%)		P uptake (mg/plant)		
		Stem	Leaf	Stem	Leaf	Total
1.	Kuthiravally	0.114	0.108	5.45 (49.14)	5.64 (50.86)	11.09
2.	Kottanadan	0.116	0.111	5.34 (46.07)	6.25 (53.93)	11.59
3.	Neelamundi	0.108	0.111	5.52 (49.86)	5.55 (50.14)	11.07
4.	Karimunda	0.139	0.191	8.49 (55.82)	6.72 (44.18)	15.21
5.	Panniyur-1	0.114	0.096	5.39 (52.48)	4.88 (47.52)	10.27
6.	Aimpirian	0.139	0.114	7.63 (52.08)	7.02 (47.92)	14.65
7.	Poonjarmunda	0.142	0.113	6.06 (49.51)	6.18 (50.49)	12.24
8.	Kuthiyanikkodi	0.137	0.132	4.52 (49.89)	4.54 (50.11)	9.06
9.	Kutching	0.167	0.144	8.40 (59.45)	5.73 (40.55)	14.13
10.	Kottakkodi	0.153	0.135	6.68 (59.22)	4.60 (40.78)	11.28
11.	Kanjiramundi	0.138	0.106	6.39 (55.95)	5.03 (44.05)	11.42
SEm±		0.025	0.022	1.83	1.01	2.29
CD (0.05)		NS	0.036	NS	1.65	3.73

Figures in parentheses indicate the percentage of the total

Table 29. P concentration and uptake by black pepper as influenced by P sources

Sl. No.	Source	P concentration (%)		P uptake (mg/plant)		
		Stem	Leaf	Stem	Leaf	Total
1.	Nitrophosphate	0.128	0.121	5.82 (52.67)	5.23 (47.33)	11.05
2.	Amophos	0.136	0.131	5.97 (50.85)	5.77 (49.15)	11.74
3.	Superphosphate	0.137	0.119	7.27 (55.08)	5.94 (44.97)	13.21
SEm±		0.025	0.022	1.83	1.01	2.29
CD (0.05)		NS	NS	NS	NS	NS

Figures in parentheses indicate percentage of the total

Kutching (14.13 mg/plant), Poonjarmunda (12.24 mg/plant) and Kottanadan (11.59 mg/plant). Minimum uptake was observed in Kuthiyanikkodi (9.06 mg/plant).

Sources of P tested had no influence on the total P uptake by the plant (Table 29).

4.2.2.3. Specific activity for the absorbed P

The differences were not conspicuous with respect to the specific activity of the stem and leaf for the absorbed P by the black pepper varieties (Table 30 and Appendix XIII). However, the specific activity of the whole plant recorded significant differences. The variety Aimpirian had the maximum specific activity (933.2 cpm/mg P) and was significantly superior to all others except Kuthiravally (766.7 cpm/mg P) and Neelamundi (698.9 cpm/mg P). The least value (186.1 cpm/mg P) was recorded by Kanjiramundi.

The different P sources also influenced the specific activity of the absorbed P in black pepper (Table 31 and Appendix XIII). Amophos, which recorded maximum specific activity (573.4 cpm/mg P), was significantly superior to nitrophosphate (309.2 cpm/mg P), but was on par with superphosphate (491.8 cpm/mg P).

Table 30. Specific activity of black pepper as influenced by variety

Sl. No.	Variety	Specific activity (cpm/mg P)		
		Stem	Leaf	Whole plant
1.	Kuthiravally	777.8	913.6	766.7
2.	Kottanadan	440.3	510.9	462.1
3.	Neelamundi	883.8	601.7	698.9
4.	Karimunda	431.0	490.3	399.8
5.	Panniyur-1	493.9	556.2	509.3
6.	Aimpirian	527.3	878.9	933.2
7.	Poonjarmunda	436.9	628.1	461.4
8.	Kuthiyanikkodi	497.3	578.5	482.6
9.	Kutching	1274.8	206.2	240.0
10.	Kottakkodi	471.8	315.5	299.6
11.	Kanjiramundi	270.2	450.8	186.1
	SEm±	556.1	307.5	223.1
	CD (0.05)	NS	NS	364.0

Table 31. Specific activity of black pepper as influenced by P sources

Sl. No.	Source	Specific activity (cpm/mg P)		
		Stem	Leaf	Whole plant
1.	Nitrophosphate	323.9	473.9	309.2
2.	Amophos	937.2	555.3	573.4
3.	Superphosphate	493.1	581.6	491.8
SEm±		556.1	307.5	223.1
CD (0.05)		482.3	NS	190.1

4.2.2.4. Fertilizer and soil P uptake parameters

Data on the fertilizer and soil P uptake parameters such as percentage Pdff, Pdfs, fertilizer P uptake and P utilization in black pepper varieties are given in Table 32 and the influence of P sources on these parameters in black pepper in Table 33 (Appendix XIII).

4.2.2.4.1. Pdff and Pdfs

The Pdff and Pdfs values did not show distinguishable differences with regard to the black pepper varieties tried.

The Pdff and Pdfs values did not show significant differences with regard to the P sources too.

4.2.2.4.2. Fertilizer P uptake

Of the eleven varieties tested, fertilizer P uptake was the highest in Kuthiravally (2.09 mg/plant) and was significantly superior to all others, except Neelamundi (1.49 mg/plant). Least fertilizer P uptake was recorded by Kottakkodi (0.37 mg/plant) which was on par with Kutching, Kanjiramundi, Kuthiyanikkodi and Aimpirian, the values being 0.43, 0.45, 0.88 and 1.02 mg/plant, respectively.

Of the different P sources tried, superphosphate recorded the maximum fertilizer P uptake (1.32 mg/plant) in black pepper.

Table 32. Variability in fertilizer P uptake among black pepper varieties

Sl. No.	Variety	Pdff* (%)	Pdfs** (%)	Fertilizer P uptake (mg/plant)	P utilizatio (%)
1.	Kuthiravally	40.37	59.33	2.09	7.05
2.	Kottanadan	30.81	69.19	1.19	4.03
3.	Neelamundi	32.27	67.73	1.49	5.08
4.	Karimunda	24.45	75.55	1.34	4.55
5.	Panniyur-1	24.31	75.69	1.19	4.03
6.	Aimpirian	31.20	68.80	1.02	3.47
7.	Poonjarmunda	23.49	76.51	1.09	3.70
8.	Kuthiyanikkodi	26.28	73.72	0.88	2.97
9.	Kutching	11.60	88.40	0.43	1.46
10.	Kottakkodi	13.54	86.46	0.37	1.18
11.	Kanjiramundi	13.01	86.99	0.45	1.69
	SEm±	11.56	11.66	0.42	1.44
	CD (0.05)	NS	NS	0.69	2.34

* P derived from fertilizer
** P derived from soil

Table 33. Utilization of fertilizer P by black pepper as influenced by P sources

Sl. No.	Source	Pdff* (%)	Pdfs** (%)	Fertilizer P uptake (mg/plant)	P utilization (%)
1.	Nitrophosphate	26.37	73.63	0.87	2.95
2.	Amophos	23.80	76.20	0.96	3.28
3.	Superphosphate	22.13	77.87	1.32	4.48
	SEm±	11.56	11.66	0.42	1.44
	CD (0.05)	NS	NS	0.36	1.22

* P derived from fertilizer
** P derived from soil

This was significantly superior to nitrophosphate (0.87 mg/plant), but was on par with amophos (0.96 mg/plant).

4.2.2.4.3. P utilization

The varieties recorded significant differences with regard to the P utilization. Of the varieties tested, maximum fertilizer P utilization was recorded by Kuthiravally (7.05%). This was significantly superior to all others, except Neelamundi (5.08%), which in turn was on par with all other varieties, except Kottakkodi (1.18%), Kutching ((1.46%) and Kanjiramundi (1.69%).

The different sources of P tested on the fertilizer P utilization in black pepper also revealed significant differences. Superphosphate was significantly superior (4.48%) to nitrophosphate (2.95%), but was on par with amophos (3.28%).

Combination effect of variety and source was absent for P concentration and uptake, specific activity of the absorbed P and fertilizer and soil P uptake parameters (Appendix XII and XIII).

4.2.3. Uptake of other nutrients

4.2.3.1. Nutrient distribution

The nutrient concentration in stem and leaf of black pepper varieties and the nutrient distribution as influenced by P sources in black pepper are given in Tables 34 to 39 and in Appendix XIV.

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4.2.3.1.1. Macronutrients

Appreciable differences were not obtained among black pepper varieties in the concentration of N, K and S, either in the stem or in the leaf (Table 34). Influence of sources of P on the concentration of N, K and S in black pepper was also not significant (Table 35). Variety and source combination effect was absent (Appendix XIV).

Concentration of Ca and Mg in the stem and in the leaf of black pepper varieties varied significantly with respect to varieties and P sources (Table 36 and 37, respectively). The variety Karimunda recorded the maximum Ca concentration in the stem (1.67%) which was significantly higher than all other varieties, except Kuthiyanikkodi (1.59%) and Kutching (1.52%). Kutching had significantly higher Ca concentration (2.74%) in the leaf whereas Kanjiramundi and Panniyur-1 recorded lower values (2.20%, each). Calcium concentration in the stem and in the leaf of black pepper was significantly higher when superphosphate was applied as the P source, whereas the effects of amophos and nitrophosphate were on par. Interaction between variety and source was evident. Amophos was the better source for Kuthiravally, for Ca concentration in the stem, whereas it was superphosphate for Panniyur-1, Aimpirian, Poonjarmunda and Kutching. For the leaf concentration of Ca, superphosphate was the better source for Karimunda (Table 36).

Table 34. Variability in N, K, S and Fe concentration among black pepper varieties

Sl. No.	Variety	N (%)		K (%)		S (%)		Fe (ppm)	
		Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf
1.	Kuthiravally	1.39	2.29	2.00	2.80	0.068	0.106	265.67	449.00
2.	Kottanadan	1.43	2.33	1.99	2.84	0.071	0.156	254.00	469.78
3.	Neelamundi	1.38	2.33	1.98	2.78	0.058	0.157	250.56	511.78
4.	Karimunda	1.40	2.30	2.02	2.85	0.061	0.149	289.22	487.11
5.	Panniyur-1	1.34	2.31	1.98	2.85	0.068	0.155	258.22	491.89
6.	Aimpirian	1.35	2.30	1.96	2.82	0.072	0.160	279.44	477.00
7.	Poonjarmunda	1.37	2.38	1.98	2.87	0.071	0.154	255.22	399.89
8.	Kuthiyanikkodi	1.39	2.32	1.94	2.79	0.067	0.152	257.00	420.22
9.	Kutching	1.38	2.38	1.97	2.76	0.062	0.155	257.22	436.89
10.	Kottakkodi	1.33	2.35	1.92	2.87	0.065	0.157	237.22	441.11
11.	Kanjiramundi	1.37	2.35	1.95	2.81	0.064	0.163	255.89	412.89
SEm±		0.07	0.09	1.00	0.09	0.008	0.010	15.78	45.15
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS

Table 35. Effect of P sources on N, K, S and Fe concentration in black pepper

Sl. No.	Source	N (%)		K (%)		S (%)		Fe (ppm)	
		Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf
1.	Nitrophosphate	1.36	2.32	1.98	2.79	0.063	0.157	259.76	470.18
2.	Amophos	1.39	2.34	1.97	2.84	0.068	0.151	264.03	451.52
3.	Superphosphate	1.37	2.33	1.97	2.83	0.068	0.161	256.12	441.27
SEm±		0.07	0.09	1.00	0.09	0.008	0.010	15.78	45.15
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS

Table 36. Variability in Ca concentration (%) among black pepper varieties as influenced by P sources

Sl. No.	Variety	Stem				Leaf			
		Nitro-phosphate	Amophos	Super-phosphate	Mean	Nitro-phosphate	Amophos	Super-phosphate	Mean
1.	Kuthiravally	0.87	1.83	1.06	1.25	2.24	2.56	2.28	2.36
2.	Kottanadan	1.47	1.38	0.93	1.26	2.32	1.72	2.81	2.28
3.	Neelamundi	1.24	1.23	1.47	1.31	2.49	1.87	2.46	2.27
4.	Karimunda	1.77	1.71	1.54	1.67	1.96	2.03	2.73	2.24
5.	Panniyur-1	1.22	1.15	1.81	1.39	2.09	1.97	2.54	2.20
6.	Aimpirian	1.35	1.08	1.79	1.40	2.50	2.55	2.01	2.35
7.	Poonjarmunda	1.38	1.28	1.67	1.44	2.10	2.12	2.61	2.28
8.	Kuthiyanikkodi	1.48	1.53	1.75	1.59	2.20	2.08	2.35	2.21
9.	Kutching	1.26	1.31	2.01	1.52	2.70	2.90	2.64	2.74
10.	Kottakkodi	1.04	1.43	1.31	1.26	2.00	2.55	2.23	2.26
11.	Kanjiramundi	1.13	1.31	1.21	1.25	1.83	2.52	2.25	2.20
	Mean	1.30	1.38	1.50		2.22	2.26	2.45	
	SEm±		0.09				0.19		
	CD (0.05) for comparing								
	Variety		0.15				0.31		
	Source		0.08				0.16		
	Variety x Source		0.27				0.54		

As regards the concentration of Mg in the stem, Kottanadan was significantly superior (0.90%) to all other varieties, except Neelamundi, Karimunda, Poonjarmunda (0.84%, each), Kanjiramundi (0.82%) and Kottakkodi (0.81%). The concentration of Mg in the leaf was distinctly higher in Kottakkodi (0.73%) and was on par with Neelamundi (0.72%) and Kanjiramundi (0.69%). Sources of P also influenced the Mg concentration in black pepper. In the stem the Mg concentration was significantly higher when nitrophosphate was used. But, it was on par with superphosphate with regard to the Mg concentration in the leaf. Here also interaction between variety and source was present. Amophos was the better source for Kuthiravally for Mg concentration in the stem. Superphosphate increased the Mg concentration of stem in Aimpirian and Kutching. As regards the leaf concentration of Mg, superphosphate was the better source for Panniyur-1 and Kutching, nitrophosphate for Poonjarmunda and Kottakkodi and amophos for Kuthiyanikkodi (Table 37).

4.2.3.1.2. Micronutrients

Neither the varieties nor the P sources influenced the Fe concentration in black pepper significantly (Table 34 and 35, respectively). The interaction between variety and source was also not significant (Appendix XIV).

Table 37. Variability in Mg concentration (%) among black pepper varieties as influenced by P sources

Sl. No.	Variety	Stem				Leaf			
		Nitro-phosphate	Amophos	Super-phosphate	Mean	Nitro-phosphate	Amophos	Super-phosphate	Mean
1.	Kuthiravally	0.89	0.97	0.73	0.86	0.66	0.58	0.67	0.64
2.	Kottanadan	1.01	0.94	0.76	0.90	0.59	0.63	0.55	0.59
3.	Neelamundi	0.89	0.85	0.78	0.84	0.75	0.70	0.71	0.72
4.	Karimunda	0.87	0.81	0.84	0.84	0.57	0.62	0.70	0.63
5.	Panniyur-1	0.87	0.92	0.81	0.87	0.62	0.47	0.71	0.60
6.	Aimpirian	0.82	0.85	0.94	0.87	0.63	0.61	0.62	0.62
7.	Poonjarmunda	0.84	0.81	0.88	0.84	0.75	0.54	0.64	0.64
8.	Kuthiyanikkodi	0.88	0.76	0.93	0.86	0.59	0.73	0.60	0.64
9.	Kutching	0.87	0.80	1.01	0.89	0.63	0.63	0.72	0.66
10.	Kottakkodi	0.87	0.80	0.75	0.81	0.82	0.67	0.70	0.73
11.	Kanjiramundi	0.83	0.78	0.85	0.82	0.62	0.68	0.76	0.69
	Mean	0.88	0.84	0.84		0.66	0.62	0.67	
	SEm±		0.02				0.03		
	CD (0.05) for comparing								
	Variety		0.04				0.05		
	Source		0.02				0.02		
	Variety x Source		0.07				0.08		

Concentration of Mn and Zn in black pepper varieties, as influenced by P sources, was significantly different (Table 38 and 39, respectively and Appendix XIV). Stem Mn concentration was maximum in Aimpirian (69.44 ppm) and that of leaf, in Kottanadan (507.78 ppm). Lowest value was recorded by Kutching (41.56 ppm) and Kottakkodi (298.89 ppm), in the stem and in the leaf, respectively. Of the three P sources, amophos significantly increased the Mn concentration in the leaf of black pepper, but it was on par with superphosphate in stem. Interaction between variety and source was evident. For Mn concentration in the stem superphosphate was the better source for Neelamundi and amophos for Kuthiyanikkodi and Kanjiramundi. Leaf Mn concentration was more in Aimpirian when superphosphate was used as the P source whereas amophos was the better source for Karimunda, Kuthiyanikkodi and Kutching (Table 38).

The concentration of Zn in the stem was the highest in Panniyur-1 (49.18 ppm) and was significantly superior to all others, except Karimunda (46.24 ppm), Neelamundi (44.84 ppm) and Kuthiyanikkodi (44.59 ppm). In the leaf the highest concentration of Zn was recorded in Neelamundi (43.12 ppm) and was on par with Kottanadan (40.83 ppm), Kuthiravally (40.78 ppm) and Kottakkodi (40.68 ppm). Influence of P sources on Zn concentration in black pepper was also evident, wherein, the highest value was

Table 38. Variability in Mn concentration (ppm) among black pepper varieties as influenced by P sources

Sl. No.	Variety	Stem				Leaf			
		Nitro-phosphate	Amophos	Super-phosphate	Mean	Nitro-phosphate	Amophos	Super-phosphate	Mean
1.	Kuthiravally	37.00	51.00	56.00	48.00	401.67	443.33	483.67	442.89
2.	Kottanadan	66.67	60.00	70.00	65.56	524.00	499.33	500.00	507.78
3.	Neelamundi	38.67	40.00	73.00	50.56	392.33	503.67	309.33	401.78
4.	Karimunda	37.00	49.33	58.00	48.11	317.00	613.00	388.67	439.56
5.	Panniyur-1	56.33	70.00	53.33	59.89	263.00	308.33	424.67	332.00
6.	Aimpirian	67.33	65.67	75.33	69.44	277.33	474.67	538.67	430.22
7.	Poonjarmunda	74.33	48.67	59.00	60.67	275.67	586.67	591.00	484.44
8.	Kuthiyanikkodi	43.67	75.67	45.67	55.00	359.00	509.67	328.33	399.00
9.	Kutching	43.00	41.33	40.33	41.56	279.00	446.33	284.67	336.67
10.	Kottakkodi	41.00	49.67	50.00	46.89	258.67	344.00	294.00	298.89
11.	Kanjiramundi	38.33	82.00	43.33	54.56	552.00	536.67	281.00	456.56
	Mean	49.39	57.58	56.73		354.52	478.70	402.18	
	SEm±		8.09				39.87		
	CD (0.05) for comparing								
	Variety		13.19				65.04		
	Source		6.89				33.97		
	Variety x Source		22.85				112.65		

Table 39. Variability in Zn concentration (ppm) among black pepper varieties as influenced by P sources

Sl. No.	Variety	Stem				Leaf			
		Nitro-phosphate	Amophos	Super-phosphate	Mean	Nitro-phosphate	Amophos	Super-phosphate	Mean
1.	Kuthiravally	38.96	40.27	46.62	41.95	34.52	54.75	33.07	40.78
2.	Kottanadan	39.45	30.56	58.41	42.81	45.69	41.70	35.11	40.83
3.	Neelamundi	43.80	37.03	53.69	44.84	45.82	38.67	44.88	43.12
4.	Karimunda	42.81	38.33	57.57	46.24	48.42	30.67	38.96	39.35
5.	Panniyur-1	40.93	39.14	67.47	49.18	38.15	41.90	34.16	38.07
6.	Aimpirian	37.94	39.55	42.47	39.99	37.98	40.60	32.14	36.90
7.	Poonjarmunda	35.14	35.84	37.90	36.29	38.69	38.47	33.98	37.05
8.	Kuthiyanikkodi	39.26	54.18	40.32	44.59	32.44	37.37	34.86	34.89
9.	Kutching	30.85	56.78	39.56	42.40	31.91	30.23	49.71	37.28
10.	Kottakkodi	31.63	42.81	44.30	39.58	50.08	40.25	31.70	40.68
11.	Kanjiramundi	39.01	42.67	37.48	39.72	38.13	35.72	34.90	36.25
Mean		38.16	41.56	47.80		40.17	39.12	36.68	
SEm±			3.20				1.90		
CD (0.05) for comparing									
	Variety		5.21				3.11		
	Source		2.72				1.62		
	Variety x Source		9.03				5.38		

recorded by superphosphate in the stem and nitrophosphate and amophos in the leaf. Superphosphate was the better source for stem concentration in Kottanadan, Neelamundi, Karimunda and Panniyur-1 and amophos for Kuthiyanikkodi and Kutching (Table 39). In the leaf concentration of Zn, amophos was the superior P source for Kuthiravally, superphosphate for Kutching and nitrophosphate for Karimunda and Kottakkodi.

On dry matter basis, the concentration of N, K, Ca and S was more accumulated in the leaf (2.33, 2.82, 2.31 and 0.151%, respectively). The concentration of P and Mg was more in the stem (0.133 and 0.85%, respectively). With regard to the micronutrients, accumulation of Fe and Mn was more in the leaf (454.32 and 411.80 ppm , respectively) than in the stem (259.97 and 54.57 ppm, respectively). Not much difference was observed in the concentration of Zn among the two plant parts (Fig. 9 and Appendix XV).

4.2.3.2. Nutrient uptake

4.2.3.2.1. Macronutrients

Data pertaining to the variability in nutrient uptake among black pepper varieties and the influence of P sources in black pepper are given in Tables 40 and 41, respectively and Appendix XVI. None of the varieties significantly influenced the uptake of the macronutrients N, K, Ca and Mg but the uptake of P and S

Fig. 9. Nutrient distribution in stem and leaf of black pepper

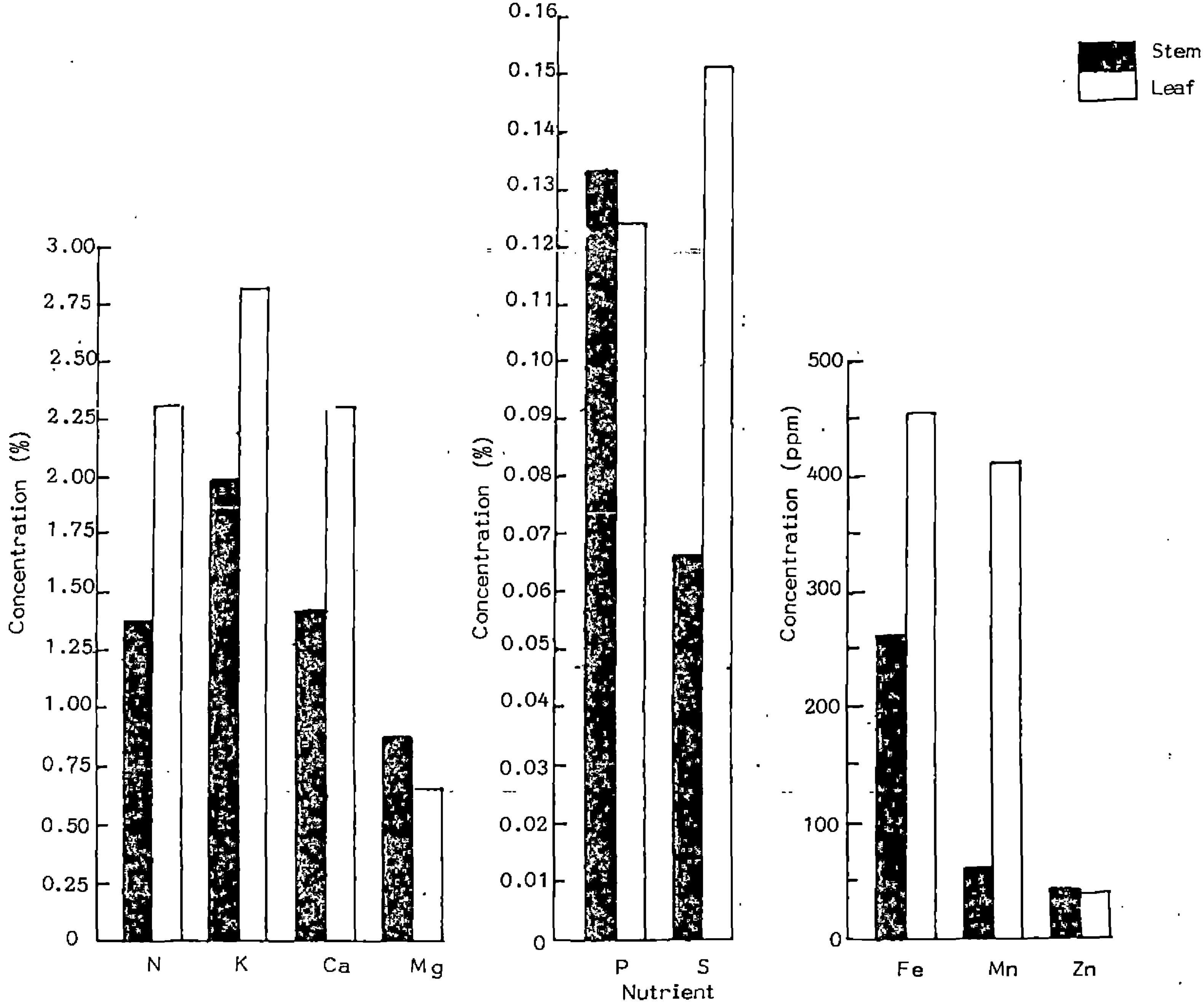


Table 40. Variability in nutrient uptake among black pepper varieties

Sl. No.	Variety	N	P	K	Ca	Mg	S	Fe	Zn
1.	Kuthiravally	0.19	11.09	0.24	0.17	0.07	11.61	3.66	0.41
2.	Kottanadan	0.19	11.59	0.25	0.18	0.07	11.56	3.69	0.42
3.	Neelamundi	0.19	11.07	0.24	0.18	0.07	10.68	3.87	0.45
4.	Karimunda	0.17	15.21	0.23	0.19	0.07	9.30	3.66	0.44
5.	Panniyur-1	0.19	10.27	0.24	0.19	0.08	11.08	3.84	0.43
6.	Aimpirian	0.20	14.65	0.27	0.20	0.08	13.23	4.30	0.42
7.	Poonjarmunda	0.19	12.24	0.26	0.19	0.08	11.72	3.46	0.37
8.	Kuthiyanikkodi	0.14	9.06	0.17	0.14	0.05	7.99	2.41	0.28
9.	Kutching	0.16	14.13	0.21	0.18	0.07	9.16	2.98	0.35
10.	Kottakkodi	0.14	11.28	0.19	0.14	0.06	8.83	2.65	0.32
11.	Kanjiramundi	0.17	11.42	0.22	0.16	0.07	10.40	3.07	0.35
	SEm±	0.04	2.29	0.07	0.03	0.01	1.54	0.57	0.06
	CD (0.05)	NS	3.73	NS	NS	NS	2.51	0.93	0.10

Note: N, K, Ca and Mg expressed as g/plant
P, S, Fe and Zn expressed as mg/plant

differed significantly. Details on the uptake of P are given in 4.2.2.2. In the uptake of S Aimpirian was significantly superior (13.23 mg/plant) to all others, except Poonjarmunda (11.72 mg/plant), Kuthiravally (11.61 mg/plant), Kottanadan (11.56 mg/plant) and Panniyur-1 (11.08 mg/plant).

Influence of P sources on the uptake of macronutrients was evident only in Ca, Mg and S. Of the three sources, superphosphate was significantly superior for Ca and S uptake (Table 41). In the case Mg uptake it was on par with nitrophosphate. Interaction between variety and source was absent (Appendix XVI).

4.2.3.2.2. Micronutrients

Variability in the uptake of micronutrients such as Fe and Zn (Table 40) and Mn (Table 42) was observed. Uptake of Fe was the maximum in Aimpirian (4.30 mg/plant) and was significantly superior to Kanjiramundi (3.07 mg/plant), Kutching (2.98 mg/plant), Kottakkodi (2.65 mg/plant) and Kuthiyanikkodi (2.41 mg/plant). Other varieties were on par. Kottanadan and Poonjarmunda recorded the maximum Mn uptake (3.12 mg/plant, each) and were significantly superior to all others, except Kuthiravally (2.59 mg/plant) and Aimpirian (3.03 mg/plant). Neelamundi recorded the maximum Zn uptake (0.45 mg/plant) and was significantly superior to Kottakkodi (0.32 mg/plant) and Kuthiyanikkoddi (0.28 mg/plant).

Table 41. Uptake of nutrients by black pepper as influenced by P sources

Sl. No.	Source	N	P	K	Ca	Mg	S	Fe	Zn
1.	Nitrophosphate	0.17	11.05	0.22	0.16	0.07	9.89	3.33	0.35
2.	Amophos	0.17	11.74	0.22	0.17	0.06	9.90	3.26	0.36
3.	Superphosphate	0.19	13.21	0.25	0.21	0.08	11.50	3.66	0.44
SEm±		0.04	2.29	0.07	0.03	0.01	1.54	0.57	0.06
CD (0.05)		NS	NS	NS	0.03	0.01	1.31	NS	0.05

Note: N, K, Ca and Mg expressed as g/plant
P, S, Fe and Zn expressed as mg/plant

Table 42. Variability in Mn uptake among black pepper varieties as influenced by P sources

Sl. No.	Variety	Mn uptake (mg/plant)			
		Nitro-phosphate	Amophos	Super-phosphate	Mean
1.	Kuthiravally	2.25	2.32	3.22	2.59
2.	Kottanadan	3.04	3.13	3.20	3.12
3.	Neelamundi	2.04	3.22	1.79	2.35
4.	Karimunda	1.21	2.31	2.27	1.93
5.	Panniyur-1	1.72	1.54	2.68	1.98
6.	Aimpirian	1.80	3.25	4.04	3.03
7.	Poonjarmunda	1.94	3.37	4.04	3.12
8.	Kuthiyanikkodi	1.25	1.74	1.88	1.62
9.	Kutching	1.29	2.04	0.94	1.42
10.	Kottakkodi	1.04	1.51	1.16	1.24
11.	Kanjiramundi	2.48	2.92	1.58	2.32
	Mean	1.82	2.49	2.44	
	SEm±		0.39		
	CD (0.05) for comparing				
	Variety		0.64		
	Source		0.33		
	Variety x Source		1.11		

Influence of P sources on the uptake of Zn and Mn was evident. Superphosphate was significantly superior among the three sources of P for the uptake of Zn, whereas it was amophos for Mn which was on par with superphosphate (Tables 41 and 42, respectively). Interaction between variety and source was absent for Fe and Zn uptake, whereas it was evident for the uptake of Mn (Appendix XVI). Of the different sources of P tried, amophos was the better source for Mn uptake in Neelamundi.

Of the nine elements studied, the maximum uptake was that of K (0.23 g/plant) with a range of 0.17-0.27 g. This was followed by N (0.18 g/plant) with a range of 0.14-0.20 g. Phosphorus uptake was too low (12.00 mg/plant) and was lesser than those of Ca and Mg (0.17 g and 0.07 g, respectively). The uptake of S was 10.45 mg/plant with a range of 7.99-13.23 mg. The mean values of Fe, Mn and Zn uptake were 3.42, 2.25 and 0.39 mg/plant, respectively (Appendix XVII). The order of nutrients removed by black pepper was K $>$ N $>$ Ca $>$ Mg $>$ P $>$ S $>$ Fe $>$ Mn $>$ Zn.

4.3. Soil zone of maximum nutrient absorption

Results pertaining to the studies to find out the soil zone of maximum nutrient absorption, using ^{32}P, are presented here.

4.3.1. Pepper vines trailed on teak pole

The radioactivity recovered in the leaves of pepper vines trailed on teak pole, as influenced by the method of application (semi circle area facing or opposite the vine and full circle area, at the radial distances of 30, 45 and 60 cm from the vine) for the 30th and 60th day after application, are given in Tables 43 and 44, respectively and in Appendix XVIII. In view of the large variation observed in the uptake of ^{32}P the statistical analysis was carried out after logarithmic transformation of the data.

Recovery of radioactivity in the leaves of the pepper vines was significantly influenced by the three lateral distances tried for 30th and 60th day after ^{32}P application. Maximum radioactivity was recovered in the leaves of the vines in which radiolabel was applied within a lateral distance of 30 cm from the vine (298.3 and 396.8 cpm/g, on 30th and 60th day of ^{32}P application, respectively) and was significantly superior to the other two distances tried, viz., 45 and 60 cm from the vine, which were on par.

Recovery of radioactivity in the leaves was not significantly influenced by ^{32}P application in semicircle facing or opposite the vine or in full circle around the vine on 30th day after application. Method of application influenced significantly the recovery of radioactivity for the 60th day after application. Application of

Table 43. Recovery of soil applied ^{32}P in the leaves (cpm/g) of the pepper vines trailed on teak pole as influenced by the method of application (log transformed data for the 30th day after application)

Lateral distance (cm)	Method of application: Semi-circle facing the vine	Semi-circle opposite the vine	Full circle around the vine	Mean
30	2.5742 (375.2)	2.0187 (104.2)	2.8309 (677.5)	2.4746 (298.3)
45	1.6940 (47.4)	1.5031 (31.8)	1.5599 (36.3)	1.5857 (38.5)
60	1.2531 (17.9)	1.2132 (16.3)	1.8636 (73.1)	1.4433 (27.8)
Mean	1.8404 (69.2)	1.5783 (37.9)	2.0848 (121.5)	
SEm±		0.3196		
CD (0.05) for comparing				
Lateral distance		0.5532		
Method of application		NS		
Lateral distance x Method of application		NS		

Figures in parentheses denote retransformed values

Table 44. Recovery of soil applied ^{32}P in the leaves (cpm/g) of the pepper vines trailed on teak pole as influenced by the method of application (log transformed data for the 60th day after application)

Lateral distance (cm)	Method of application			Mean
	Semi-circle facing the vine	Semi-circle opposite the vine	Full circle around the vine	
30	2.4414 (276.4)	2.2083 (161.5)	3.1460 (1400.0)	2.5986 (396.8)
45	1.8210 (66.2)	1.6290 (42.6)	1.7713 (59.1)	1.7404 (55.0)
60	1.3589 (22.9)	1.3923 (24.7)	1.6886 (48.8)	1.4799 (30.2)
Mean	1.8738 (74.8)	1.7432 (55.4)	2.2020 (159.4)	
SEm±		0.1930		
CD (0.05) for comparing				
Lateral distance		0.3340		
Method of application		0.3340		
Lateral distance x Method of application		NS		

Figures in parentheses denote retransformed values

the radiolabel in full circle area around the vine recovered maximum radioactivity in the leaves (159.4 cpm/g) which was significantly superior to the application in semicircle area opposite the vine (55.4 cpm/g), but on par with the application in semicircle area facing the vine (74.8 cpm/g). The interaction between the distance and method of application was absent.

Radioactivity recovered at different lateral distances, expressed as the percentage of the total activity, is given in Table 45. The data revealed that 81.82 per cent of the ^{32}P absorption occurred within 30 cm radius from the vine, beyond which the ^{32}P uptake decreased to less than 10.57 per cent.

4.3.2. Pepper vines trailed on _Erythrina indica_

The radioactivity recovered in the leaves of pepper vines trailed on _Erythrina indica_, as influenced by the method of application (semicircle area facing or opposite the vine and full circle area around the vine at the radial distances of 30, 45 and 60 cm from the vine), for the 30th and 60th day after application are given in Tables 46 and 47, respectively and in Appendix XVIII.

None of the three lateral distances or methods of application tried, showed significant difference in the recovery of radioactivity for the 30th and 60th day after application. The interaction

Table 45. Radioactivity recovered in the leaves of the pepper vines trailed on teak pole (expressed as the percentage of the total)

Treatment	Days after ^{32}P application	
	30	60
Lateral distance (cm)		
30	81.82	87.44
45	10.57	7.98
60	7.61	4.58
Total	100.00	100.00

Table 46. Recovery of soil applied ^{32}P in the leaves (cpm/g) of the pepper vines trailed on Erythrina indica as influenced by the method of application (log transformed data for the 30th day after application)

Lateral distance (cm)	Method of application: Semi-circle facing the vine	Semi-circle opposite the vine	Full circle around the vine	Mean
30	1.5497 (35.5)	2.0171 (104.0)	1.2888 (19.5)	1.6185 (41.6)
45	1.3951 (24.8)	1.5730 (37.4)	1.5012 (31.7)	1.4898 (30.9)
60	1.4903 (30.9)	1.3228 (21.0)	1.6681 (46.6)	1.4937 (31.2)
Mean	1.4784 (30.1)	1.6376 (43.4)	1.4860 (30.6)	
SEm±		0.3129		
CD (0.05) for comparing				
Lateral distance		NS		
Method of application		NS		
Lateral distance x Method of application		NS		

Figures in parentheses denote retransformed values

Table 47. Recovery of soil applied ^{32}P in the leaves (cpm/g) of the pepper vines trailed on Erythrina indica as influenced by the method of application (log transformed data for the 60th day after application)

Lateral distance (cm)	Method of application			Mean
	Semi-circle facing the vine	Semi-circle opposite the vine	Full circle around the vine	
30	1.5813 (38.1)	1.5126 (32.6)	1.5887 (38.8)	1.5609 (74.9)
45	1.7123 (51.6)	1.6000 (39.9)	1.5643 (36.7)	1.6255 (79.6)
60	1.5297 (33.9)	1.5355 (34.3)	1.5985 (39.7)	1.5546 (74.4)
Mean	1.6078 (40.5)	1.5494 (35.4)	1.5838 (38.4)	
SEm±		0.0961		
CD (0.05) for comparing				
Lateral distance		NS		
Method of application		NS		
Lateral distance x Method of application		NS		

Figures in parentheses denote retransformed values

between the distance and the method of application was not significant.

Radioactivity recovered at different lateral distances, expressed as the percentage of the total activity, is given in Table 48. Not much difference in the uptake of ^{32}P could be noticed in the case of vines trailed on *Erythrina indica*, at various lateral distances tried, for ^{32}P application.

Table 48. Radioactivity recovered in the leaves of the pepper vines trailed on *Erythrina indica* (expressed as the percentage of the total)

Treatment	Days after ^{32}P application	
	30	60
Lateral distance (cm)		
30	40.10	31.69
45	29.81	37.08
60	30.08	31.23
Total	100.00	100.00

Discussion

DISCUSSION

Growing black pepper as a bush is relatively a new technique gaining importance in urban Horticulture. The pattern of growth and behaviour in black pepper are dependent on the type of shoots used for propagation. When runners are used the plant behaves as a vine, whereas when laterals are used the plant grows like a bush. In perennial plantation crops conduct of research both on basic and practical aspects with standing crops in the field poses many problems, particularly because of the unwieldy nature of the plant itself. The use of bush pepper in this context will be more advantageous as the planting material is easy to handle and can be grown under controlled conditions. It is, however, not certain whether bush pepper can be considered as a suitable substitute for vine pepper in conducting research. This aspect formed the major part of the studies reported herein. Varietal differences and methods of fertilizer application of pepper vines were the other two aspects. The results generated are critically discussed here.

5.1. Pattern of growth and nutrient uptake in bush pepper and vine pepper

The results of the experiment are discussed under two broad heads, namely, growth parameters and uptake of nutrients, as influenced by the levels of nutrients in bush pepper and vine pepper.

5.1.1. Growth parameters

The main difference between the growth of bush pepper and vine pepper is the profused branching in bush pepper as compared to vine pepper. This is due to the plagiotropic growth in bush pepper (Plate 12) as compared to the orthotropic growth in vine pepper (Plate 13) which makes the former suitable to grow in pots. Topophysis, the phenomenon in which different parts of the plant show differences in growth and form of the vegetative offspring (Wright, 1976, Bonga, 1982) is manifested here in the persistance of growth form. Growth phases probably have an epigenetic basis ie., the cells of certain plant tissues translate only certain part of the total genetic information (the genome) they contain, without affecting the total genetic pool. This phenomenon has also been reported in Araucaria sp. (Bonga, 1982), cocoa (Wood and Lass, 1985), coffee (Wrigley, 1988) and nutmeg (Krishnamoorthy and Rema, 1989).

The different levels of nitrogen tried in bush pepper and vine pepper had profound influence on growth characters (Tables 1 and 2). At N_0 level (N @ 0 kg/ha) typical N deficiency symptoms were developed, both in bush pepper and vine pepper (Plates 10 and 11, respectively). The N deficiency symptoms were first manifested as pale green colour of the old leaves, which later turned into uniform deep yellow. Since 70 per cent of leaf N is present


BUSH PEPPE
12

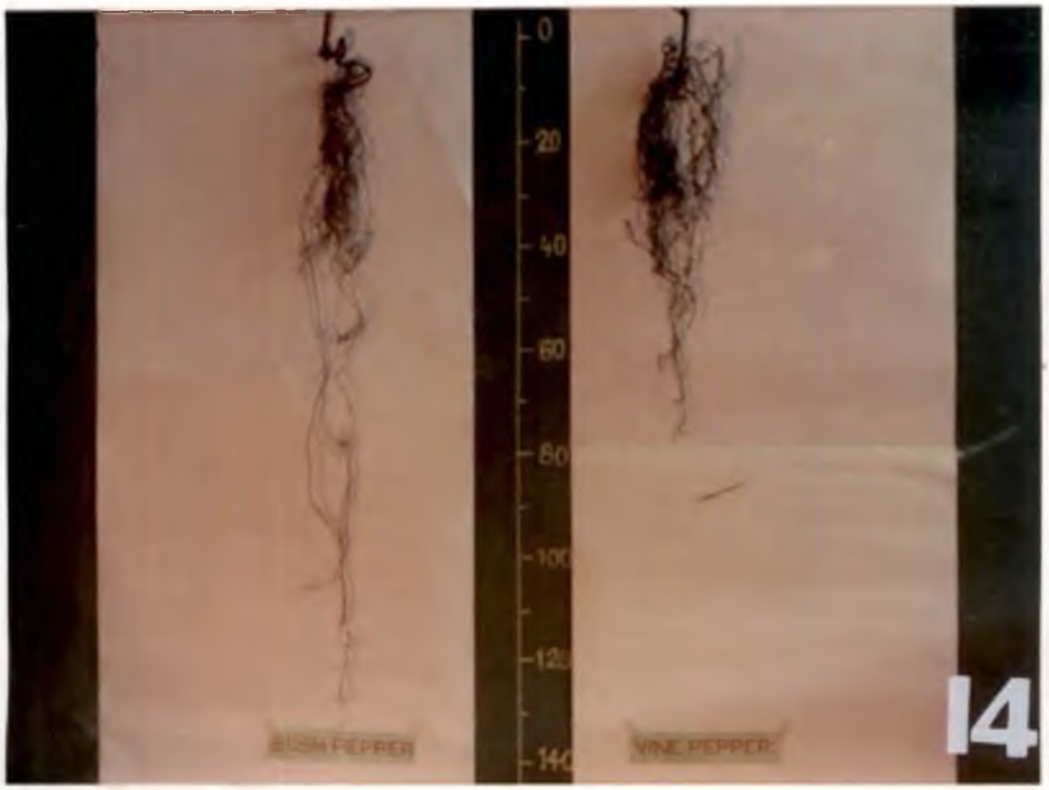

13

in chloroplast (Stocking and Ongum, 1962) deficiency of N had resulted in chlorosis. The symptom expression was similar to that explained by De Waard (1969) and Nybe and Nair (1986) for pepper. With the withdrawl of N from the fertilizer (N_0 level) there was a marked reduction in growth parameters, such as number of leaves, total leaf area and dry matter content, as compared to N_4 level (N @ 120 kg/ha).

Influence of P on the growth of bush pepper and vine pepper was evident. Reduction in plant height, number of leaves and total biomass production resulted in a reduced assimilation rate and crop growth in vine pepper at P_0 level (P_2O_5 @ 0 kg/ha). The reduction in growth at lower levels of P in bush pepper was due to lesser number of branches and leaves and reduced leaf area. Requirement of P for the vegetative growth of the plant has been emphasised by Arnon (1959) and Gauch (1972). Marked influence could be noticed in the total dry matter production due to the effect of K, in bush pepper and vine pepper.

The distinct reduction in root dry weight and other root characters for plants at lower levels of Ca application emphasises the essentiality of Ca for root growth. The finding is in line with that of Chapman (1975) in citrus, Nybe (1986) in pepper and Nazeem (1989) in clove. Influence of Mg on vegetative characters was discernible both in bush pepper and vine pepper. The treatment Mg_4 (MgO @ 60 kg/ha) resulted in markedly superior performance. The effect of Mg on vegetative growth has been reported elsewhere (Greulach, 1973; Cheung, 1980). Effect of S on the growth of bush pepper and vine pepper was markedly evident. Reduced vegetative growth has been noticed at S_0 level (SO_4 @ 0 kg/ha). This is in line with the findings of Lott et al. (1960) in coffee, Childers (1966) in apple, pear and grapes and Nybe (1986) in black pepper.

The overall behaviour of bush pepper and vine pepper at limiting nutrient levels (zero level of the various nutrients) was more or less similar. The plants produced less leaves and biomass (Tables 1 to 4). Eventhough a reduction in plant height was also observed in vine pepper this remained unaffected in bush pepper, perhaps due to the peculiar growth habit of the plant. It may be pointed out here that vine pepper expressed more vigour by producing more number of leaves. Though the length of roots was more in bush pepper the number of roots was more in vine pepper (Plate 14). The effect of varying nutrient levels is also reflected in the height of the vines, but, the height of the bush pepper remained more or less uniform irrespective of the fertilizer treatments. Nevertheless, bush pepper compensated this by putting forth more branches (Plate 15) in some cases, especially at increasing


0
20
40
60
80
100
120
140
BUSH PEPPER
VINE PEPPER
14

levels of N and S. Leaf area seems to be the most independant component in bush pepper contributing towards total biomass of the plant and responding to varying levels of nutrients. On the contrary, in vine pepper, the response to applied levels of nutrients was reflected mainly in terms of height of the plant as well as number of leaves. This would mean that the total leaf area per plant in bush pepper depends primarily on the increase in area per leaf, rather than the number of leaves produced. While in vine pepper the total leaf area is primarily depended on the number of leaves produced rather than increase in area per leaf (Plate 16). In both cases, however, the total biomass production is a good indicator of the response to applied fertilizers as revealed from the results obtained for application of N, P, K, Mg and S. In the case of Ca, both bush pepper and vine pepper did not indicate response in terms of either dry weight of aerial part or total dry weight. However, the effect of higher levels of Ca application was reflected in enhanced root production in both the cases. Indirectly this also shows that Ca is an important nutrient in promoting root growth in black pepper. Thus it may be concluded that qualitatively the comparison of the response to applied nutrients viz., N, P, K, Ca, Mg and S, between bush pepper and vine pepper holds good.

Plate 15. Branching habit of bush pepper and vine pepper

Plate 16. Leaves of bush pepper and vine pepper


VINE PEPPER
BUSH PEPPER
15


BUSH PEPPER
VINE PEPPER
16

Eventhough the foregoing discussion points to the possibility of considering bush pepper in place of vine pepper for response to the applied nutrients, it is necessary to examine whether the responses are quantitatively similar. Two mathematical models, linear and quadratic, were tried to examine this aspect (Table 5). Both these models explained the variability in biomass production (either aerial portion alone or total) more or less similarly for N, P and S treatments. The response of both bush and vine pepper to applied K was better explained by quadratic model than the linear model. In the case of Ca, the two models explained the variation in the biomass of the aerial part of bush pepper only. As to the response to applied Mg, quadratic equation was better fit than the linear model for bush pepper, while in vine pepper both the models were equally efficient. By and large the coefficients of determination obtained for quadratic function were higher than those obtained for linear model.

The model originally proposed by Tejeda et al. (1980) for the comparison of responses to a nutrient supplied by different fertilizer materials was employed for the comparison of the quadratic responses in dry matter production (aerial part and total) to different applied nutrients between bush pepper and vine pepper (Tables 6 and 7). The estimated models explained more than 90 per cent variability in dry matter production between bush pepper and vine pepper. The additional response of vine pepper over bush pepper in dry matter production was found significant at one per cent ievel in all the treatments.

From the foregoing discussion, it is clearly evident that on a quantitative evaluation, the dry matter production in relation to nutrient levels was different in bush pepper and vine pepper. The increased vegetative growth of vine pepper enhanced the biomass production, thereby contributing towards the overall superiority of vine pepper.

5.1.2. Uptake of nutrients

The influence of N on the N concentration, both in bush pepper and vine pepper, was distinct in stem and in leaf (Tables 8 and 11, respectively). In general, the absorption of N increased with increasing levels of applied N. However, its relationship with the absorbed P was inverse in the stem of bush pepper. Antagonism between N and P has been recorded earlier in black pepper (Nybe and Nair, 1986). Such relationship has also been reported in fruits like citrus (Smith, 1966) and apple (Stoilov and Lekhova, 1974). The foliar Fe concentration was found to increase at P_0 level (no P_2O_5) in bush pepper and vine pepper (Tables 10 and 13). Application of P was found to decrease leaf Fe content. Similar reports have been made by El-Gazzar et al. (1979) in orange, olive and guava and Nazeem (1989) in clove. However, in this study no regular pattern was noticed at varying levels of P. Marked influence on the nutrient concentration in plant parts could not be noticed in the case of plants that received either K (Tables 8 to 13) or Ca (Tables 14 to 19) treatments. The foliar P concentration was considerably reduced in plants receiving Mg_0 treatment (MgO @ 0 kg/ha) in vine pepper (Table 17). Magnesium is reported to act as a carrier of P to help in the solubilisation of P (Ananthanarayanan and Rao, 1979). Sulphur also had pronounced effect on the concentration of S, both in the stem and in the leaf of bush pepper as well as vine pepper (Tables 15 and 18, respectively). At lower levels of S the P concentration in the leaf of vine pepper and in the stem of bush pepper were markedly increased. Such relationship between S and P has also been reported by Lott et al. (1960) in coffee, Smith (1966) in citrus and Philip (1986) in nutmeg.

Among the nutrients tried in the experiment, applications of N and S alone increased their concentrations in bush pepper as well as vine pepper (Tables 8, 11 and 15, 18, respectively). Very low foliar level of nitrogen in plants that received no N could explain the appearance of foliar yellowing, characterestic of N deficiency in these plants.

Application of N enhanced the uptake of not only N, but also P, K, Ca, Mg and Mn in bush pepper while the uptake of all the nine nutrients was increased in vine pepper (Tables 20 and 21, respectively). Phosphorus application at higher levels increased the uptake of all the nutrients studied, except that of Mn and Zn, in both the plants (Tables 20 and 21, respectively). The quantities of K and Ca in bush pepper and K, Ca and Mg in vine pepper were improved at the highest level of applied K (Tables 20 and 21, respectively). Application of Ca, however, did not influence the uptake of Ca or other nutrients (Tables 22 and 23). In the case of Mg, maximum uptake of Mg was observed at the highest level of its application, in both the plants. A similar trend was also seen in the uptake of P, K and Fe in bush pepper (Table 22). In vine pepper, though the uptake of K was not significant Mg application had enhanced the uptake of N and Ca in addition to P, Mg and Fe (Table 23). Higher levels of S application also increased the uptake of Mg and Fe in bush pepper (Table 22) and N and Ca in vine pepper (Table 23), and K and S in both the types.

The response of bush pepper and vine pepper in terms of nutrient uptake could also be described by quadratic models (Table 24). The goodness of fit of linear and quadratic models was more or less same as was observed for dry matter production (Table 5). This indicates that response in terms of nutrient uptake was mainly due to the increase in dry matter production rather than the increase in nutrient concentrations in the plant (Tables 8 to 19).

The responses in nutrient uptake in bush pepper and vine pepper were combined and tested to find out the differences in responses in them to the applied nutrients. The estimated models explained most of the variability in nutrient uptake between bush pepper and vine pepper (Table 25). The differences in uptake between bush pepper and vine pepper were highly significant in respect of N, K, Ca, Mg and S. Vine pepper recorded additional response over bush pepper for the uptake of nutrients, which resulted from the increased biomass production in vine pepper. Both bush pepper and vine pepper, however, had similar response to P application, suggesting that no additional factors are contributing to the uptake of P.

5.2. Varietal differences in the utilization of applied P

The utilization of different sources of applied P (nitrophosphate, amophos and superphosphate) by eleven varieties of black pepper was evaluated employing ^{32}P labelled fertilizers. Besides, the growth of the vines was also compared.

5.2.1. Growth parameters

Length of the vine, number of leaves, total leaf area and dry matter production were the parameters subjected to analysis. These parameters are indices of plant vigour. Of these, length of the vine directly reflects the general growth of the vine, especially during the initial stages. In the present study the varietal differences were significant with respect to this character (Table 26). Karimunda recorded the maximum length followed by Aimpirian. The variety Kuthiyanikkodi produced the shortest vines. There were significant differences with respect to the number of leaves among varieties. The variety Kutching produced the maximum number which was on par with Neelamundi, Kottanadan, Kuthiravally and Poonjarmunda. Of all the growth parameters, total leaf area of the plant gave a better indication of the general vigour of the plant as it contributed to the dry matter production directly. The varietal influence on this character is evident from the significant differences observed among the varieties. Neelamundi produced the maximum leaf area of 872.78 cm^2 and Kuthiyanikkodi, the minimum (437.54 cm^2).

The varieties differed significantly in biomass production (Table 26). Aimpirian had the maximum dry weight of 11.16 g. This was on par with Poonjarmunda, Panniyur-1 and Neelamundi. In the case of leaves also an almost similar trend was observed.

The relative contribution from leaves and stem indicated almost equal share. However, the results obtained by Sankar (1985) in which the contribution from stem and leaf were 60 per cent and 16 per cent respectively, are not in accordance with the present study. This may be because of the difference in age of the vines (five year old) used in her study.

A general comparison of the genetic control of the growth parameters of black pepper suggests that, the expression of characters are more influenced by varieties. The trend in variation of all the characters studied was not similar among the varieties. The variety Kutching, which had the maximum leaf number, had relatively less leaf area. Similarly, Karimunda, which had produced the longest vines, had less number of leaves and low leaf area. In general, the varieties Neelamundi, Aimpirian, Kottanadan, Panniyur-1 and Poonjarmunda possessed better growth parameters whereas the variety Kuthiyanikkodi exhibited very poor growth.

The influence of different sources of P on growth parameters such as length of the vine and total leaf area was not significant, except for the number of leaves and total dry matter production by the plant (Table 27). Of the P sources, amophos and nitrophosphate were significantly superior to superphosphate in the production of leaves in black pepper. Superphosphate significantly influenced the dry matter production by the plant and this was superior to amophos and nitrophosphate. This finding is in line with that of Mandal et al. (1982), who observed increased dry matter production in groundnut, maize and spinach, when superphosphate was used as the P source, as compared to nitrophosphate and DAP. It might be probably due to the gypsm content of it. In another study using wheat, nitrophosphate was found to be equally effective as amophos (Biswas and Ghosh, 1985). In the present study also similar trend was obtained.

5.2.2. Fertilizer P utilization

The use of labelled fertilizer enables to evaluate quantitatively the relative contributions of P from the applied fertilizers and native sources towards the uptake by the plant.

The black pepper varieties differed significantly in foliar P concentration (Table 28). Variety Karimunda had the highest concentration of P in the leaf (0.191%) among the varieties, while Panniyur-1 registered lowest concentration (0.096%). The total P uptake by the varieties, however, was not consistant with this trend, primarily because of the differences in the biomass production among the varieties. Thus Karimunda absorbed the largest quantity of P and Kuthiyanikkodi the lowest. The uptake figures were 15.21 and 9.06 mg/plant, respectively. None of the applied P sources was found to influence total P uptake by the vine (Table 29).

For computing the contribution of fertilizer towards P uptake, the P uptake of the plant prior to fertilizer application was deducted from the total P uptake at the end of the experiment. The result did not indicate any significant difference in specific activity of stem or leaf (Table 30). Eventhough the mean values for different varieties varied, statistical significance was not obtained, perhaps because of the large standard error of the means. Nevertheless, the whole plant specific activity differed significantly, recording the highest value for Aimpirian and the lowest for Kanjiramundi. Fertilizer sources were also found to influence the specific activity of the plant (Table 31). Highest specific activity was obtained when labelled amophos was used as the P source.

Considerable variability exists among the black pepper varieties tried in respect of the utilization of P from different fertilizer materials. The variety Kuthiravally absorbed the maximum quantity of P (2.09 mg/plant) and variety Kottakkodi, the lowest (0.37 mg/plant). Data for P utilization also revealed a more or less similar trend. The utilization of P from the applied P sources ranged from 1.18 per cent for Kottakkodi to 7.05 per cent for Kuthiravally. The utilization of applied P was comparable with the dry matter of the plants. This view was supported by the findings of Rao and Sinha (1975) in wheat. Singh and Kamath (1989) opined that the utilization of applied P by safflower was more or less governed by the growth of the plant. When total P uptake of the plant was considered, variety Kuthiravally derived 40.37 per cent of its P requirement from the fertilizer, while in Kutching this amounted to 11.60 per cent (Table 32). Generally speaking, all the varieties, excepting Kuthiravally, depended mostly on native soil for their requirement. On an average, these varieties met 67.73 to 88.40 per cent of P requirement from soil P sources.

When P sources were compared, black pepper was found to prefer superphosphate and amophos to nitrophosphate (Table 33). This is expected because of the higher soluble P content of these sources, compared to that of nitrophosphate. The plants will prefer the more soluble source than relatively less soluble source. This observation is in accordance with the findings of Mandal et al. (1982) who also reported better availability of P in superphosphate as compared to nitrophosphate in a trial to find out the relative efficiency of different sources of phosphatic fertilizers for groundnut and succeeding crops in Saurashtra soils. The effectiveness of completely water soluble source of P might be due to the diffusion of P towards the root surface as compared to partially water soluble P carrier such as nitrophosphate. However, in the long run, the availability of P from nitrophosphate could be much more as a consequence of reaction of the material with acid soil.

5.2.3. Uptake of other nutrients

Nutrient composition and uptake as well as biomass production are dependent upon the genetic make up of the plant and the availability of the nutrients. Data obtained in the present study indicated that the differences due to varieties with respect to the concentration of Ca, Mg, Mn and Zn were significant (Tables 36, 37, 38 and 39). As regards the uptake, S, Fe, Mn and Zn showed significant differences among varieties (Tables 40 and 42).

The concentration of Ca in Karimunda was significantly higher when compared to Panniyur-1, a popular pepper hybrid in Kerala (Table 36). The problem of spike shedding in Panniyur-1 was reported to be very high compared to that in Karimunda (Geetha, 1981; Menon, 1981). The extent of spike shedding recorded by them were 18-23 per cent in Panniyur-1 and 2-3 per cent in Karimunda. The observation that the level of Ca in the stem is much higher in Karimunda than in Panniyur-1 assumes special significance in this context. The importance of Ca on the abscission of plant parts is now well recognized (Addicott and Lynch, 1955). Calcium pectate is an important constituent of middle lamella holding together the cells of the abscission zone. Ca deficiency would weaken the mechanical strength of the tissues resulting in shedding of plant parts (Rasmussen, 1967). Based on this assumption heavy incidence of spike shedding in Panniyur-1 could be attributed to the low uptake of Ca by this variety, whereas the reverse is true for Karimunda.

Magnesium concentration in the stem was the highest in Kottanadan and in the leaves in Kottakkodi. The least value was recorded by Kottakkodi and Kottanadan, in the stem and in the leaves, respectively (Table 37). Varietal differences were significant in the concentration of Mn in different plant parts (Table 38). The variety Aimpirian had the highest Mn content in the stem (69.44 ppm) and Kottanadan in the leaves (507.78 ppm). Very low values were recorded for Kutching (41.56 ppm) and Kottakkodi (298.89 ppm). Wide variation has also been reported in Mn content in coconut varieties and hybrids (Wahid et al. 1981). Panniyur-1 recorded significantly high content of Zn in the stem (49.18 ppm) and Neelamundi in the leaf (43.12 ppm) (Table 39). Increased spike length and berry size in Panniyur-1 may be because of the utilization of more Zn by the plant during the course of development of spike and berry. According to Tsui (1941), Zn is essential for the production of endogenous hormone, IAA, which is responsible for cell elongation.

Influence of P sources in the concentration of nutrients such as Ca, Mg, Mn and Zn (Tables 36, 37, 38 and 39, respectively) in black pepper was significant, whereas in the case of N, K, S and Fe (Table 35) significant differences were not obtained.

Among the P sources, superphosphate significantly increased the concentration of Ca in black pepper. This might be because of the presence of Ca in superphosphate, which is chemically $Ca(H_2PO_4)_2 + CaSO_4$. Absorption of larger quantities of Ca following superphosphate applications was also reported in coconut (Anilkumar and Wahid, 1989).

Magnesium concentration in black pepper was significantly higher when nitrophosphate was used as the P source. Superphosphate was on par with nitrophosphate in enhancing the Mg concentration in the leaf (Table 37). Presence of Mg in nitrophosphate and superphosphate is the only probable reason for this trend (Yawalkar et al., 1984).

When amophos was used as the P source, greater accumulation of Mn in stem and leaf was observed. In the case of stem Mn concentration amophos was on par with superphosphate (Table 38). This could be due to the lowering of soil pH, thereby increasing the availability of Mn. Increased availability of Mn in soil following the application of ammonium sulphate was reported (Kamaladevi et al., 1975; Anilkumar and Wahid, 1989). Superphosphate on the other hand enhanced the levels of Zn in the stem whereas the levels of Zn in the leaf was enhanced by nitrophosphate and amophos. Increased Zn concentration may be due to the presence of Zn in the fertilizer. On chemical analysis, the concentrations of Zn were found to be 1460, 878 and 717 ppm in nitrophosphate, amophos and superphosphate, respectively.

On dry matter basis, the concentrations of N, K, Ca, S, Fe and Mn were more in leaf (2.33%, 2.82%, 2.31%, 0.151%, 454.32 ppm and 411.80 ppm, respectively) and those of P and Mg were more in the stem (0.133% and 0.85%, respectively). Not much differences were noticed with regard to the concentrations of Zn in stem and leaf (Fig. 9). These findings are in agreement with the reports of many other workers (De Waard, 1969, Nagarajan and Pillai, 1975, Pillai and Sasikumaran, 1976, Sushama et al., 1984, for macronutrients and Wahid et al., 1982, Sankar, 1985, Nybe, 1986, both for macro and micronutrients). The normal foliar level of N, as reported by De Waard (1969), is much higher (3.40-3.10%) than observed in the present study. However, the results of the present study agree well with the reports from India. Nagarajan and Pillai (1975) obtained similar results for N, P, K and Ca, but in the case of Mg, leaf was found to be better accumulator according to them.

Based on the nutrient removal, all the varieties were on par with respect to N, K, Ca and Mg (Table 40). With regard to P uptake, Karimunda topped the list and was on par with Aimpirian, Kutching, Poonjarmunda and Kottanadan. Kuthiyanikkodi recorded the least value. Uptake of S was the highest in Aimpirian, followed by Poonjarmunda, Kuthiravally, Kottanadan and Panniyur-1 and they were on par, whereas all other varieties, except Neelamundi, were significantly inferior and on par. Fe uptake was the highest in Aimpirian which was on par with Neelamundi, Panniyur-1, Kottanadan, Kuthiravally, Karimunda and Poonjarmunda, whereas Kutching recorded the least and was on par with all varieties tried, except Aimpirian. Regarding the Mn uptake (Table 42) maximum was recorded in Poonjarmunda and was on par with Kottanadan, Aimpirian, Kuthiravally, Neelamundi, Kanjiramundi, Panniyur-1 and Karimunda. Minimum Mn uptake was in Kottakkodi and was significantly inferior to all others, except Kutching and Kuthiyanikkodi. As regards Zn uptake, maximum was recorded by Neelamundi and was on par with all others, except Kottakkodi and Kuthiyanikkodi. Least uptake was recorded by Kuthiyanikkodi.

Influence of P sources on the uptake of Ca, Mg, S, Zn and Mn were significant (Tables 41 and 42). Maximum uptake was recorded by superphosphate receiving plants which was on par with amophos for the uptake of Mn and with nitrophosphate for the uptake of Mg. The increased uptake when supplied with superphosphate is directly related to the increased dry matter production, as already discussed.

Of the nine elements studied, the quantities of nutrients removed by black pepper, in the descending order, were K, N, Ca, Mg, P, S, Fe, Mn and zn. On an average, a nine-month old pepper vine removes 0.18 g N, 12.00 mg P, 0.23 g K, 0.17 g Ca, 0.07 g Mg, 10.45 mg S, 3.42 mg Fe, 2.25 mg Mn and 0.39 mg Zn. The results also show that pepper plant requires more or less equal quantities of N and K whereas P requirement is lower. Calicum is also required in appreciable quantities for proper growth of the plant. Requirement of Mg was less than that of Ca. Black pepper also requires S, the demand for which is less than that of P. These results are in line with the findings of several workers for bearing plants (Huitema, 1941; De Waard, 1964; Sim, 1971; Nagarajan and Pillai, 1975; Pillai and Sasikumaran, 1976 and Sankar, 1985) for macronutrients. The order of micronutrient removal was also in agreement with Sim (1973) and Sankar (1985).

5.3. Soil zone of maximum nutrient absorption

The soil zone of maximum nutrient absorption relates to the zone where maximum feeding roots are concentrated. Identification of this zone is useful for increasing the utilization of applied nutrients by the vine. The present trial laid out in black pepper vines took into consideration two types of standards, viz., a dead standard (teak pole) and a live one (*Erythrina indica*). Three methods of application of ^{32}P were tried in these vines, viz., semicircle area facing the vine, semicircle area opposite the vine and full circle area around the vine.

The recovery of soil-applied ^{32}P in the leaves was considered as the criterion for evaluating the extent of absorption of the radiolabel. Since the trial was conducted during rainy season, absorption of applied ^{32}P was not affected by soil moisture stress. Thus the absorption of ^{32}P gives more or less the correct picture of the extent of active root zone.

In the case of teak pole trailed vines, the method of application did not significantly influence the uptake of ^{32}P on 30th day after application. But the recovery was significantly influenced by the lateral distances tried (Table 43). When ^{32}P was applied in the area of 30 cm from the vine, maximum recovery of ^{32}P (more than 80%) could be obtained, which clearly indicated that the maximum concentration of feeding roots was in this zone (Table 45). This is in confirmity with the finding of Sankar et al. (1988). The data for 60th day of application indicated that the application of radiolabel in full circle around the vine enhanced the uptake of ^{32}P (Table 44). Here too the maximum recovery in the leaves was made when ^{32}P was applied within a lateral distance of 30 cm. A comparison of various treatments revealed that application of ^{32}P in full circle of radius 30 cm around the vine recorded the maximum recovery of radioactivity in the plant.

When Erythrina indica was used as the standard, neither the method of application nor the lateral distance was found to influence ^{32}P uptake by the vine (Tables 46 and 47). Sankar et al. (1988) found more or less uniform distribution of feeder roots when the vines were trailed on *Erythrina indica* standard, as compared to those trailed on teak pole. Competition for nutrients and also the interaction between the standard and the vines might be the probable reasons. When live standard is used it also becomes a component for competition and thus influences the absorption of the nutrient by the vine as is evidenced in the present study.

A comparison of the leaf ^{32}P concentration in the two categories of vines indicates that the total uptake of ^{32}P by the vines on *Erythrina indica* was considerably less than that of the vines on teak pole. The overall means of leaf ^{32}P contents of vines trailed on teak pole and *Erythrina indica* were 193.4 and 38.7 cpm, respectively. This may be due to the increased root production in vines trailed on teak pole and/or the root competition for the applied label between the vine and support tree. The vine trailed on teak pole can be visualised as monoculture and the vines trailed on *Erythrina indica* as mixed culture systems. Differential uptake of nutrients is generally considered as due to competitive interaction between the component species in mixed systems (Willey, 1979). Competitive interaction between two plant species sharing the same space can be expected when the nutrient in question is in short supply and inadequate to meet the demand of both the species. The decreased uptake of ^{32}P atoms by the vines trailed on *Erythrina indica* as compared to vines trailed on teak pole, may be due to the faster rate of depletion of ^{32}P atoms in the mixed system than in the monoculture situation, due to the sharing of the space by the roots of both the vine and the support tree. Consequently the availability of ^{32}P per root of the vine also gets reduced. As a result ^{32}P uptake by the vine trailed on *Erythrina indica* decreases.

The foregoing discussions on the results generated from the present studies indicated that there were consistent differences in the magnitude of response to applied nutrients between bush pepper and vine pepper, especially with regard to N, K, Ca, Mg and S. The vine pepper requires more quantities of these nutrients compared to bush pepper consequent to the greater biomass production. Eventhough the nature of response compares well between the two types, bush pepper is not a good substitute for vine pepper as an experimental material for investigations of nutrient requirement and fertilizer response. Nevertheless, bush pepper can be used as a material in studies of fertility status and nutrient supplying power of the soils in relation to black pepper nutrition. The quantitative nature of response of these two types to applied nutrients points to such a possibility.

Considerable variability among varieties could be noticed in dry matter production, fertilizer P utilization and nutrient concentration and uptake by black pepper. The findings indicated the need for considering micronutrients also in the nutrition of black pepper. In a perennial crop like black pepper, long term fertilizer trials should also be based on variety and fertilizer source.

Irrespective of the type of standard used in black pepper, the application of fertilizers may be restricted to a lateral distance of 30 cm in full circle area around the vine in order to have better absorption and utilization of applied nutrients. It is also imperative to study the root distribution of common live standards of black pepper, in order to understand the crop-standard competitive interaction.

Summary

SUMMARY

Investigations pertaining to the nutritional aspects of black pepper (*Piper nigrum* L.) were carried out at the Centre for Advanced Studies on Humid Tropical Tree Crops, College of Horticulture, Vellanikkara, during the period from May 1986 to May 1988 and from July 1989 to April 1990 and at the Banana Research Station, Kannara, from August 1987 to October 1987. The main objective of the trial was to study the pattern of growth and nutrient uptake in bush pepper and vine pepper. Pot culture studies were undertaken in the hybrid Panniyur-1 employing different levels of N, P, K, Ca, Mg and S. Another objective was to evaluate the relative efficiencies of black pepper varieties in the utilization of applied P. Phosphorus-32 labelled fertilizers, namely, nitrophosphate, amophos and superphosphate were used. In addition, the soil zone of maximum nutrient absorption in pepper vines trailed on dead and live standards were also ascertained. The salient findings of the study are summarised below.

Effect of N on the growth and nutrient uptake in bush pepper as well as vine pepper was evident. In both the types, plants which did not receive application of N produced typical N deficiency symptoms. The absorption of N increased with increasing levels of

applied N. Application of N increased the uptake of not only N but also P, K, Ca, Mg and Mn in bush pepper and that of all the nutrients, ie., N, P, K, Ca, Mg, S, Fe, Mn and Zn, in vine pepper.

Phosphorus also influenced the growth of both the types of pepper. When no P was applied, the growth characters, in general, were significantly reduced. However, the concentrations of nutrients were not significantly affected, except that of Fe. Phosphorus application at higher levels, enhanced the uptake of all the nutrients studied, except that of Mn and Zn, in bush pepper and vine pepper.

Among the growth parameters, total leaf area and dry matter production were markedly improved by the highest level of K, in bush pepper as well as vine pepper. However, K could not influence the nutrient concentrations in different plant parts, either in bush pepper or in vine pepper. As to the uptake of nutrients, the quantities of K and Ca in bush pepper and K, Ca and Mg in vine pepper were appreciably improved at the highest level of applied K.

All the root characters were improved with Ca application to the plants (both bush pepper and vine pepper). The concentrations of nutrients in different plant parts and their uptake were also not influenced by the different levels of Ca used.

Influence of Mg on biomass production was discernible, both in bush pepper and vine pepper. Highest levels of Mg application resulted in remarkably better performance. Effect of Mg on the nutrient concentration in different plant parts was not significant, except in the case of P, in vine pepper. Foliar P concentration was considerably reduced in plants that did not receive Mg application. In bush pepper, highest Mg level resulted in maximum uptake of P, K, Mg and Fe, whereas, in vine pepper, N, P, Ca, Mg and Fe responded well to the above treatment.

Vegetative growth, in general, was reduced both in bush pepper and vine pepper when no S was applied. At the increased levels of S, concentration of S was higher both in the stem and in the leaf while that of P was lower in the stem of bush pepper and leaf of vine pepper. Higher levels of S also increased the uptake of Mg and Fe in bush pepper, N and Ca in vine pepper and K and S in both the types.

In the overall comparison between the two types, vine pepper was found to be more vigorous in terms of height, number of leaves and roots. Bush pepper, however, compensated these parameters to a great extent by producing more number of branches, larger leaves and longer roots. In both the types the total biomass production is a good indicator of the response to applied fertilizers as revealed from the results obtained for N, P, K, Mg and S application. In Ca, no response was registered either for the dry weight of aerial part or for the total dry weight. Although the root characters were significantly influenced by the Ca levels, the trend of variation between bush pepper and vine pepper did not change. As to the uptake of nutrients, the consistencies observed in the response between these two types of plants are more conspicuous and marked. Thus it may be stated that qualitatively the comparison of the response to applied nutrients, namely, N, P, K, Ca, Mg and S, between bush pepper and vine pepper holds good.

Two mathematical models, linear and quadratic, were tried in order to examine whether the responses of bush pepper and vine pepper in relation to applied nutrients, namely, N, P, K, Ca, Mg and S, are quantitatively similar. The responses of bush pepper and vine pepper to N, P, K, Mg and S for dry matter production (aerial as well as total) and nutrient uptake could be better explained by the quadratic model.

Quadratic regression models using dummy variables was fitted to the data to evaluate the differences in response to applied nutrients in bush pepper and vine pepper, in terms of dry matter production and nutrient uptake. The models explained the variability between bush pepper and vine pepper in dry matter production and nutrient uptake. The additional responses of vine pepper over bush pepper were highly significant to all the nutrients applied, in the dry matter production. The differences in uptake between bush pepper and vine pepper were highly significant in respect of N, K, Ca, Mg and S, wherein the additional effect of vine pepper was evident.

Eventhough the nature of response to applied nutrients compares well between the two types, the magnitude of response differs. Hence bush pepper is not a good substitute for vine pepper as an experimental material for investigation of nutrient requirement and fertilizer response. Nevertheless, it can be used in the studies of the fertility status and nutrient supplying power of the soils in relation to black pepper nutrition.

All the eleven black pepper varieties differed significantly with respect to the growth parameters such as length of the vine, number of leaves, total leaf area and dry matter production, the maximum in these characters being recorded by Karimunda, Kutching, Neelamundi and Aimpirian, respectively. The total dry weight of the varieties ranged from 7.14 to 11.16 g/plant. The percentage contribution by the stem and the leaf ranged from 42.51 to 60.12 and 39.88 to 57.49, respectively. Of the three sources of P (nitro-phosphate, amophos and superphosphate), superphosphate was found to be the best and it was significantly superior to the other two sources in the biomass production.

Significant differences in the specific activity of absorbed P in the stem or leaf among black pepper varieties could not be obtained. However, the specific activity in the whole plant differed distinctly, recording the highest value for Aimpirian (933.2 cpm/mg P) and the lowest for Kanjiramundi (186.1 cpm/mg P). The sources of fertilizer P were also found to have influence wherein amophos recorded the maximum specific activity (573.4 cpm/mg P).

Variability among the varieties could be noticed in the fertilizer P uptake and P utilization by black pepper. Maximum quantity of fertilizer P (2.09 mg/plant) was absorbed by Kuthiravally and the lowest (0.37 mg/plant) by Kottakkodi. Utilization of P from the applied P sources ranged from 1.18 per cent for Kottakkodi to 7.05 per cent for Kuthiravally. When the total P absorbed was considered, Kuthiravally derived 40.37 per cent from fertilizer whereas Kutching derived only 11.60 per cent. In general, the varieties met 59.33-88.40 per cent of the P requirement from soil P sources. When fertilizer P sources were compared, superphosphate and amophos were found to be preferred by black pepper.

Varietal differences were not significant with respect to the concentration of macronutrients like N, K and S whereas P, Ca and

Mg differed. Foliar P concentration was the highest in Karimunda (0.191%) and the lowest in Panniyur-1 (0.096%). The concentration of Ca in the stem was the highest in Karimunda (1.67%) and was on par with Kuthiyanikkodi (1.59%) and Kutching (1.52%). In the leaf, Kutching had significantly higher Ca concentration (2.74%). As regards Mg concentration, in the stem, Kottanadan recorded the highest value (0.90%) and Kottakkodi the lowest (0.81%). Leaf Mg concentration was the highest in Kottakkodi (0.73%) and the least in Kottanadan (0.59%). Influence of P sources on the concentration of nutrients such as Ca and Mg in black pepper was significant. But in the case of N, P, K and S the differences were not distinct. Among the P sources, superphosphate was significantly superior to the other sources in influencing the concentration of Ca in the stem and in the leaf of black pepper. Nitrophosphate significantly enhanced the Mg concentration in the stem whereas superphosphate and nitrophosphate, in the leaf, of black pepper.

Among the micronutrients, Mn and Zn concentration in the stem and in the leaf of black pepper varieties varied considerably. Variety Aimpirian had the highest Mn concentration in the stem (69.44 ppm) and Kottanadan in the leaf (507.78 ppm). The concentration of Zn in the stem was significantly more in Panniyur-1 (49.18 ppm) and the lowest in Poonjarmunda (36.29 ppm). In the leaf, the highest concentration of Zn was recorded by Neelamundi (43.12 ppm) and the lowest by Kuthiyanikkodi (34.89 ppm). Among the P sources, amophos and superphosphate were significantly superior to nitrophosphate in the stem concentration of Mn whereas, in the leaf concentration of Mn amophos was significantly superior to the other two sources. The concentration of Zn in the stem was significantly enhanced by superphosphate and that in the leaf by nitrophosphate and amophos.

On dry matter basis, the concentrations of N, K, Ca, S, Fe and Mn were more accumulated in the leaf (2.33%, 2.82%, 2.31%, 0.151%, 454.32 ppm and 411.80 ppm, respectively) and P and Mg in the stem (0.133% and 0.85%, respectively). Not much difference was noticed with regard to the concentration of Zn in the stem and in the leaf.

None of the varieties significantly influenced the uptake of macronutrients like N, K, Ca and Mg, but that of P and S differed significantly. Maximum P uptake was recorded by Karimunda (15.21 mg/plant) and minimum by Kuthiyanikkodi (9.06 mg/plant). As regards the uptake of S, Aimpirian had the maximum value (13.23 mg/plant). Influence of P sources on the uptake of macronutrients, namely, Ca, Mg and S was evident. Of the three sources tried, superphosphate was significantly superior for Ca and S uptake. For Mg uptake superphosphate and nitrophosphate were significantly superior.

Variability in the uptake of micronutrients such as Fe, Mn and Zn was observed among varieties. Aimpirian recorded the maximum uptake of Fe (4.30 mg/plant) and Kottanadan and Poonjarmunda the maximum Mn (3.12 mg/plant, each). Neelamundi recorded the maximum Zn uptake (0.45 mg/plant) and was significantly superior to Kottakkodi (0.32 mg/plant) and Kuthiyanikkodi (0.28 mg/plant). Among the three sources of P, superphosphate was significantly superior for the uptake of Zn, whereas it was amophos for Mn, which was on par with superphosphate.

On an average, a nine month old pepper vine removed 0.18 g N, 12.00 mg P, 0.23 g K, 0.17 g Ca, 0.07 g Mg, 10.45 mg S, 3.42 mg Fe, 2.25 mg Mn and 0.39 mg Zn. Nutrient removal by black pepper was in the order K $>$ N $>$ Ca $>$ Mg $>$ P $>$ S $>$ Fe $>$ Mn $>$ Zn.

Recovery of soil applied ^{32}P in the leaves indicated active absorption of the radiolabel upto a lateral distance of 30 cm in full circle around the vine, in the case of pepper vines trailed on teak pole. When <u>Erythrina indica</u> was used as the standard, neither the methods of application nor the lateral distances contributed any significant differences. It is suggested that, irrespective of the type of standard used, the fertilizer application to black pepper may be restricted to a lateral distance of 30 cm in full circle area around the vine.

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*Original not seen

Appendices

APPENDIX I

Weather data of the experimental sites

Year	Month	Total rainfall (mm)	Number of rainy days	Relative humidity (%)	Mean temperature (°C)	
					Maximum	Minimum
1. College of Horticulture, Vellanikkara						
1986	May	118.6	7	72	34.2	24.7
	June	669.9	20	84	30.0	23.1
	July	381.4	16	84	29.5	23.2
	August	358.7	12	83	29.4	22.7
	September	296.3	10	81	30.5	22.7
	October	421.3	11	80	31.8	22.9
	November	176.2	9	71	31.2	22.0
	December	[illegible]	1	60	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	February	0.0	0	52	35.0	22.4
	March	0.0	0	55	36.4	22.2
	April	13.3	1	64	36.2	25.3
	May	95.5	3	66	36.1	24.3
	June	837.7	21	83	30.7	23.7
	July	336.5	17	84	30.3	23.5
	August	388.4	22	87	29.8	23.5
	September	174.0	8	79	31.5	23.9
	October	280.4	16	79	31.9	23.9
	November	224.4	6	77	31.6	22.8
	December	64.6	6	70	31.6	23.3
1988	January	0.0	0	56	32.4	22.0
	February	7.8	1	56	35.8	23.1
	March	37.9	2	67	35.7	24.4
	April	145.4	9	70	35.1	24.3
	May	242.6	6	76	33.7	25.4
1989	July	562.0	17	86	29.1	23.3
	August	319.9	19	83	29.5	23.1
	September	180.1	15	82	29.9	23.1
	October	116.6	16	80	31.0	23.0
	November	8.1	2	63	32.5	22.7
	December	0.0	0	60	32.7	23.2
1990	January	3.5	0	50	33.5	20.8
	February	0.0	0	58	34.9	21.9
	March	4.4	1	64	36.0	23.8
	April	38.8	2	68	35.8	25.4
2. Banana Research Station, Kannara						
1987	August	408.0	21	89	28.8	22.0
	September	214.8	10	78	31.2	23.4
	October	262.0	13	79	30.8	22.1

Source: Meteorological observatories at Vellanikkara and Kannara, respectively

APPENDIX II

Physical and chemical properties of the soil of the experimental sites

	Vellanikkara	Kannara
A. Physical properties		
Sand (%)	57.50	52.50
Silt (%)	14.50	5.30
Clay (%)	28.00	42.20
B. Chemical properties		
Organic carbon (%)	1.32	1.31
Total Nitrogen (%)	0.18	0.16
Available P (ppm)	14	19
Available K (ppm)	68	61
Exchangeable Ca (ppm)	254	226
Exchangeable Mg (ppm)	20	44
Soil pH	5.8	6.1

APPENDIX III

Analyses of variance for growth parameters in bush pepper and vine pepper as influenced by N, P and K fertilization

Character	Bush pepper		Vine pepper	
	Treatment mean squares	Error mean squares	Treatment mean squares	Error mean squares
(Degrees of freedom	4	15	4	15)
Effect of N				
Plant height	58.60	35.44	30043.19	1271.22**
Number of primary branches	1.69	1.04	-	-
Number of secondary branches	18.69	3.53**	-	-
Number of leaves	166.58	39.65*	1422.24	280.88**
Total leaf area	1857571.98	529222.76**	2047672.03	628120.25*
Number of roots	16.40	7.16	12.43	71.75
Root length	322.70	955.53	2066.32	902.63*
Root dry weight	6.69	7.62	30.83	51.53
Stem dry weight	19.09	5.32*	510.73	24.42**
Leaf dry weight	41.76	7.01**	344.32	52.61**
Spike dry weight	36.00	10.20*	-	-
Dry weight of aerial part	402.13	118.62*	1599.17	95.39**
Total dry weight	398.81	101.22*	1988.77	148.05**
Effect of P				
Plant height	61.81	32.60	17116.31	5140.03*
Number of primary branches	1.56	0.53*	-	-
Number of secondary. branches	4.50	4.08	-	-
Number of leaves	207.43	58.43*	3135.24	840.50*
Total leaf area	1482752.08	424857.30*	8807039.26	2480856.1*
Number of roots	0.52	7.95	134.60	24.54**
Root length	564.48	195.95*	754.64	202.86*
Root dry weight	28.39	7.51*	12.19	12.46
Stem dry weight	16.42	4.61*	360.23	105.33*
Leaf dry weight	94.51	26.47*	333.29	84.37*
Spike dry weight	3.84	22.77	-	-
Dry weight of aerial part	217.92	56.6*	1321.47	355.23*
Total dry weight	396.85	101.50*	1453.44	367.02**
Effect of K				
Plant height	60.10	29.04	10898.00	6227.73
Number of primary branches	1.38	0.95	-	-
Number of secondary branches	7.09	4.70	-	-
Number of leaves	39.30	46.40	751.62	741.58
Total leaf area	2918040.28	297546.65**	2994472.03	878144.28*
Number of roots	19.39	2.15**	29.26	20.16
Root length	7928.25	1825.03	126.43	314.75
Root dry weight	31.07	20.82	16.76	6.15
Stem dry weight	9.62	12.91	129.58	167.28
Leaf dry weight	89.39	92.79	200.71	382.47
Spike dry weight	7.78	7.42	-	-
Dry weight of aerial part	207.59	63.96*	553.56	139.09*
Total dry weight	242.89	58.24**	689.70	212.21*

* Significant at five per cent level
**Significant at one per cent level

APPENDIX IV

Analyses of variance for growth parameters in bush pepper and vine pepper as influenced by Ca, Mg and S fertilization

Character	Bush pepper		Vine pepper	
	Treatment mean squares	Error mean squares	Treatment mean squares	Error mean squares
(Degrees of freedom	4	15	4	15)
Effect of Ca				
Plant height	56.44	31.59	4663.81	12074.89
Number of primary branches	1.00	0.68	-	-
Number of secondary branches	1.54	1.95	-	-
Number of leaves	124.76	27.07*	549.66	808.24
Total leaf area	934136.01	259483.77*	248623.99	4134169.58
Number of roots	3.06	0.49**	13.73	3.83*
Root length	2269.13	632.88*	188.57	47.50*
Root dry weight	46.97	13.26*	14.33	4.86*
Stem dry weight	21.38	27.38	90.68	316.82
Leaf dry weight	47.99	141.77	49.74	62.12
Spike dry weight	18.84	7.88	-	-
Dry weight of aerial part	84.23	359.82	296.31	589.32
Total dry weight	131.49	402.58	209.06	709.89
Effect of Mg				
Plant height	31.88	22.12	11686.13	5679.43
Number of primary branches	0.85	0.42	-	-
Number of secondary branches	10.77	1.42**	-	-
Number of leaves	46.01	27.07	696.72	662.73
Total leaf area	590456.01	556529.05	51432.00	257804.27
Number of roots	12.58	4.28	15.23	13.30
Root length	162.33	479.37	1409.68	371.37*
Root dry weight	13.13	12.30	24.57	6.60*
Stem dry weight	26.54	14.35	209.26	54.49*
Leaf dry weight	104.78	34.65	24.82	75.40
Spike dry weight	13.12	11.54	-	-
Dry weight of aerial part	282.35	86.75*	404.39	108.71*
Total dry weight	254.27	64.86*	410.93	248.45*
Effect of S				
Plant height	23.16	24.61	3175.38	933.94*
Number of primary branches	0.54	0.97	-	-
Number of secondary branches	11.37	2.02**	-	-
Number of leaves	97.24	62.64	831.95	361.56
Total leaf area	1088770.00	285767.95**	192266.00	351404.29
Number of roots	6.89	4.04	2.02	6.17
Root length	750.70	191.80*	332.57	577.75
Root dry weight	53.41	15.10*	17.65	7.54
Stem dry weight	12.54	24.58	243.65	47.58**
Leaf dry weight	63.50	44.02	31.86	232.84
Spike dry weight	32.28	16.55	-	-
Dry weight of aerial part	174.07	52.47*	424.75	108.91*
Total dry weight	392.16	102.31*	584.82	144.04*

* Significant at five per cent level
**Significant at one per cent level

APPENDIX V

Correlation coefficient and regression equation for the biomass production In black pepper

Variables y vs x	Type of plant	Regression equation	R^2
Dry weight of aerial part vs levels of N	Bp	$y = 39.927990+0.14600x$	0.884
		$y = 40.819177+0.086574x+.000495x^2$	0.897
	Vp	$y = 48.948006+0.4167x$	0.977
		$y = 51.015043+0.278895x+0.001148x^2$	0.985
Total dry weight vs levels of N	Bp	$y = 49.979991+0.170334x$	0.890
		$y = 50.519981+0.134336x+0.000300x^2$	0.894
	Vp	$y = 61.189985+0.465200x$	0.979
		$y = 61.955518+0.414160x+0.000425x^2$	0.980
Dry weight of aerial part vs levels of P	Bp	$y = 52.634015+0.280866x$	0.814
		$y = 49.535098+0.694025x-0.006886x^2$	0.968
	Vp	$y = 58.324003+0.72800x$	0.863
		$y = 54.288067+1.250703x+-0.008968x^2$	0.906
Total dry weight vs levels of P	Bp	$y = 63.343992+0.377334x$	0.807
		$y = 59.121198+0.940381x-0.009384x^2$	0.964
	Vp	$y = 68.090004+0.768133x$	0.909
		$y = 64.158143+1.292319x-0.008736x^2$	0.946
Dry weight of aerial part vs levels of K	Bp	$y = 53.745989+0.0505x$	0.132
		$y = 60.055631-0.370162x+0.003506x^2$	0.934
	Vp	$y = 69.530+0.2201x$	0.791
		$y = 75.211157-0.158654x+0.003156x^2$	0.996
Total dry weight vs levels of K	Bp	$y = 62.132+0.103367x$	0.417
		$y = 67.730584-0.269870x+0.003110x^2$	0.893
	Vp	$y = 79.038+0.262733x$	0.881
		$y = 83.877315-0.059927x+0.002689x^2$	0.998
Dry weight of aerial part vs levels of Ca	Bp	$y = 57.247991-0.065266x$	0.820
		$y = 56.222372+0.003114x-0.00057x^2$	0.898
	Vp	$y = 108.340021-0.100134x$	0.333
		$y = 107.879757-0.069079x-0.000259x^2$	0.335
Total dry weight vs levels of Ca	Bp	$y = 69.065990-0.014200x-97.048$	0.029
		$y = 69.787192-0.110377x+0.001603x^2$	0.148
	Vp	$y = 118.799972-0.126799x$	0.183
		$y = 118.982386-0.151166x+0.000406x^2$	0.183
Dry weight of aerial part vs levels of Mg	Bp	$y = 54.2039914+0.126734x$	0.128
		$y = 62.068023-0.921828x+0.017476x^2$	0.895
	Vp	$y = 83.211984+0.318467x$	0.888
		$y = 83.112792+0.331629x-0.000219x^2$	0.889
Total dry weight vs levels of Mg	Bp	$y = 68.791999+0.128267x$	0.146
		$y = 76.603202-0.913251x+0.017359x^2$	0.986
	Vp	$y = 95.514001 + .342133x$	0.909
		$y = 93.939132+0.552059x-0.003498x^2$	0.939
Dry weight of aerial part vs levels of S	Bp	$y = 57.256798-0.130907$	0.820
		$y = 56.227369+0.006326x-0.002287x^2$	0.899
	Vp	$y = 78.456001+0.394867x$	0.824
		$y = 81.503086-0.011415x+0.006771x^2$	0.900
Total dry weight vs levels of S	Bp	$y = 57.324018+0.417466x$	0.863
		$y = 54.598093+0.780899x-0.006057x^2$	0.921
	Vp	$y = 87.676010+0.480267x$	0.886
		$y = 90.912885+0.048656x+0.007194x^2$	0.948

Bp : Bush pepper; Vp : Vine pepper

APPENDIX VI

Analyses of variance for nutrient distribution in bush pepper and vine pepper as influenced by N, P and K fertilization

Nutrient concentration		Effect of N				Effect of P				Effect of K			
		Bush pepper		Vine pepper		Bush pepper		Vine pepper		Bush pepper		Vine pepper	
		Treatment mean squares	Error mean squares	Treatment mean squares	Error mean squares	Treatment mean squares	Error mean squares	Treatment mean squares	Error mean squares	Treatment mean squares	Error mean squares	Treatment mean squares	Error mean squares
(Degree of freedom		4	15	4	15	4	15	4	15	4	15	4	15)
N	Stem	0.009	0.010**	0.067	0.012**	0.042	0.560	0.061	0.146	0.014	0.146	0.132	0.108
	Leaf	0.190	0.018**	0.179	0.051*	0.070	0.150	0.017	0.132	0.077	0.249	0.092	0.152
	Spike	0.049	0.067	-	-	0.086	0.153	-	-	0.030	0.067	-	-
P	Stem	0.0010	0.0003*	0.0005	0.0001*	0.0010	0.0004	0.001	0.001	0.0004	0.0004	0.001	0.001
	Leaf	0.0004	0.0010	0.001	0.001	0.0010	0.0010	0.001	0.0005	0.0004	0.0004	0.0004	0.0003
	Spike	0.0004	0.0004	-	-	0.0003	0.0004	-	-	0.0004	0.0005	-	-
K	Stem	0.073	0.074	0.028	0.082	0.004	0.071	0.014	0.028	0.026	0.073	0.022	0.064
	Leaf	0.046	0.103	0.007	0.058	0.180	0.178	0.085	0.209	0.015	0.072	0.0111	0.073
	Spike	0.023	0.167	-	-	0.014	0.064	-	-	0.112	0.090	-	-
Ca	Stem	0.016	0.020	0.032	0.108	0.050	0.013*	0.009	0.029	0.004	0.036	0.017	0.034
	Leaf	0.003	0.024	0.001	0.025	0.002	0.040	0.004	0.034	0.011	0.087	0.009	0.162
	Spike	0.008	0.023	-	-	0.006	0.018	-	-	0.002	0.010	-	-
Mg	Stem	0.003	0.029	0.013	0.019	0.002	0.011	0.004	0.014	0.002	0.022	0.005	0.024
	Leaf	0.010	0.055	0.004	0.007	0.006	0.049	0.006	0.029	0.006	0.040	0.075	0.075
	Spike	0.016	0.108	-	-	0.007	0.041	-	-	0.070	0.064	-	-
S	Stem	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001
	Leaf	0.001	0.001	0.0004	0.0004	0.001	0.001	0.0004	0.0004	0.001	0.001	0.0004	0.0004
	Spike	0.0004	0.0004	-	-	0.0004	0.0004	-	-	0.001	0.001	-	-
Fe	Stem	11169.438	5789.417	17259.563	24080.851	7143.63	2184.60*	13816.56	3664.90*	2273.437	4367.100	4603.375	32752.020
	Leaf	12703.001	17422.132	7220.000	25454.533	11321.50	3189.15*	5382.13	1582.97*	11603.250	9304.934	11021.249	15334.033
	Spike	709.875	2046.283	-	-	593.187	836.100	-	-	447.812	1569.433	-	-
Mn	Stem	45.730	242.217	18.920	84.883	24.721	297.932	25.184	49.501	14.219	186.812	6.658	80.802
	Leaf	19763.626	14234.049	14321.625	5549.883	3649.000	5986.401	576.375	12003.902	7155.313	13770.233	10745.500	17144.517
	Spike	109.193	84.447	-	-	12.331	41.994	-	-	10.272	50.060	-	-
Zn	Stem	11.098	128.292	69.443	147.118	41.773	149.828	20.982	155.889	40.889	488.042	21.195	610.117
	Leaf	14.623	92.478	11.934	49.689	72.108	42.523	16.667	27.997	110.895	114.427	8.580	54.711
	Spike	5.548	13.644	-	-	24.929	11.179	-	-	16.302	9.068	-	-

* Significant at five per cent level
**Significant at one per cent level

APPENDIX VII

Analayses of variance for nutrient distribution in bush pepper and vine pepper as influenced by Ca, Mg and S fertilization

Nutrient concentration		Effect of Ca				Effect of Mg				Effect of S			
		Bush pepper		Vine pepper		Bush pepper		Vine pepper		Bush pepper		Vine pepper	
		Treatment mean squares	Error mean squares	Treatment mean squares	Error mean squares	Treatment mean squares	Error mean squares	Treatment mean squares	Error mean squares	Treatment mean squares	Error mean squares	Treatment mean squares	Error mean squares
(Degree of freedom		4	15	4	15	4	15	4	15	4	15	4	15)
N	Stem	0.288	0.131	0.029	0.306	0.075	0.368	0.199	0.208	0.116	0.244	0.215	0.319
	Leaf	0.124	0.149	0.006	0.135	0.121	0.070	0.025	0.150	0.025	0.193	0.111	0.201
	Spike	0.030	0.168	-	-	0.027	0.101	-	-	0.020	0.067	-	-
P	Stem	0.0004	0.0010	0.001	0.001	0.0010	0.0010	0.0004	0.0003	0.0003	0.00006*	0.001	0.001
	Leaf	0.0004	0.0010	0.001	0.001	0.0010	0.0010	0.00125	0.00031*	0.0020	0.0010	0.00225	0.0007*
	Spike	0.0004	0.0010	-	-	0.00040	0.0010	-	-	0.0004	0.0010	-	-
K	Stem	0.025	0.093	0.024	0.035	0.014	0.033	0.007	0.085	0.005	0.041	0.048	0.081
	Leaf	0.045	0.069	0.104	0.129	0.020	0.082	0.020	0.058	0.015	0.074	0.029	0.083
	Spike	0.023	0.051	-	-	0.072	0.111	-	-	0.071	0.144	-	-
Ca	Stem	0.030	0.029	0.004	0.030	0.002	0.024	0.003	0.026	0.002	0.026	0.004	0.030
	Leaf	0.011	0.066	0.029	0.088	0.004	0.027	0.003	0.057	0.020	0.135	0.015	0.067
	Spike	0.011	0.012	-	-	0.010	0.015	-	-	0.023	0.017	-	-
Mg	Stem	0.001	0.021	0.005	0.049	0.003	0.017	0.006	0.015	0.003	0.017	0.009	0.027
	Leaf	0.001	0.035	0.002	0.037	0.003	0.119	0.009	0.091	0.012	0.040	0.004	0.039
	Spike	0.006	0.060	-	-	0.118	0.079	-	-	0.029	0.093	-	-
S	Stem	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.0004**	0.003	0.0004**
	Leaf	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.0005*	0.003	0.0006**
	Spike	0.0004	0.0004	-	-	0.0004	0.0004	-	-	0.0004	0.0004	-	-
Fe	Stem	7828.876	3380.817	7957.938	31348.714	19446.311	25874.350	25245.561	17049.083	14505.000	62323.942	654.562	4654.683
	Leaf	3899.501	19053.934	9159.001	22591.664	29857.501	25246.133	6548.876	9688.433	25514.752	32512.004	28046.498	18149.066
	Spike	739.750	371.000	-	-	202.938	670.083	-	-	1088.188	2669.750	-	-
Mn	Stem	129.496	114.531	35.838	53.572	6.586	247.882	8.473	99.898	79.326	89.599	80.574	44.081
	Leaf	2362.000	6758.550	427.813	20048.098	2014.312	2257.067	6830.875	14988.801	6695.000	8833.100	889.665	6045.751
	Spike	29.692	42.113	-	-	22.825	26.085	-	-	15.102	58.419	-	-
Zn	Stem	39.758	94.048	31.688	90.003	45.799	265.379	26.568	332.699	223.586	132.841	44.643	269.081
	Leaf	11.767	23.959	24.288	23.844	17.774	34.381	69.845	113.232	22.900	121.713	9.199	61.218
	Spike	4.415	12.826	-	-	2.210	19.131	-	-	4.608	10.246	-	-

* Significant at five per cent level

**Significant at one per cet level

APPENDIX VIII

Analyses of variance for nutrient uptake by bush pepper and vine pepper as influenced by N, P and K fertilization

Nutrient uptake	Bush pepper Treatment mean squares	Bush pepper Error mean squares	Vine pepper Treatment mean squares	Vine pepper Error mean squares
(Degree of freedom	4	15	4	15)
Effect of N				
N	0.048	0.013*	0.059	0.019**
P	328.000	88.890*	2387.930	628.480*
K	0.218	0.067*	0.280	0.048**
Ca	0.185	0.052*	0.326	0.045**
Mg	0.068	0.016*	0.161	0.026**
S	857.140	494.260	4412.310	1240.100*
Fe	71.270	122.410	753.780	102.570**
Mn	107.030	30.060*	158.160	12.790**
Zn	0.540	0.689	8.130	1.240**
Effect of P				
N	0.234	0.061*	0.376	0.014*
P	217.060	63.370*	635.320	198.530*
K	0.151	0.038*	0.784	0.037**
Ca	0.043	0.012*	0.251	0.054**
Mg	0.058	0.018*	0.133	0.039*
S	887.830	266.600*	3014.420	612.690**
Fe	76.640	23.580*	313.820	71.000**
Mn	59.199	38.912	73.023	74.468
Zn	0.818	0.984	6.437	3.356
Effect of K				
N	0.079	0.078	0.211	0.315
P	467.557	606.167	552.473	747.578
K	0.156	0.036**	0.445	0.117*
Ca	0.110	0.028*	0.095	0.026*
Mg	0.073	0.042	0.032	0.012*
S	403.199	557.060	224.560	1048.042
Fe	77.710	66.750	201.305	242.243
Mn	12.599	33.238	43.453	75.653
Zn	0.335	1.501	3.033	3.707

*Significant at five per cent level
**Significant at one per cent level

APPENDIX IX

Analyses of variance for nutrient uptake by bush pepper and vine pepper as influenced by Ca, Mg and S fertilization

Nutrient uptake	Bush pepper Treatment mean squares	Bush pepper Error mean squares	Vine pepper Treatment mean squares	Vine pepper Error mean squares
(Degrees of freedom	4	15	4	15)
Effect of Ca				
N	0.004	0.146	0.096	0.282
P	56.484	781.945	834.891	1413.525
K	0.113	0.191	0.290	0.430
Ca	0.009	0.065	0.040	0.108
Mg	0.015	0.066	0.021	0.091
S	189.809	731.951	1007.133	1634.912
Fe	11.993	106.231	78.619	197.921
Mn	14.537	19.178	131.834	226.405
Zn	0.066	1.266	1.309	2.654
Effect of Mg				
N	0.179	0.078	0.268	0.077*
P	1123.260	329.400*	2808.610	210.600*
K	0.147	0.047*	0.135	0.147
Ca	0.072	0.038	0.058	0.018*
Mg	0.067	0.020*	0.042	0.011*
S	501.148	286.299	350.711	988.613
Fe	250.840	51.78*	226.030	63.850*
Mn	13.734	9.054	27.922	39.721
Zn	0.845	0.595	1.025	2.648
Effect of S				
N	0.185	0.116	0.246	0.063*
P	42.305	587.647	180.398	1387.902
K	0.281	0.013**	0.154	0.005*
Ca	0.055	0.054	0.079	0.002*
Mg	0.040	0.030	0.035	0.056
S	1554.508	172.480**	3692.735	885.433*
Fe	116.069	36.240**	64.718	190.259
Mn	28.755	15.790	16.193	46.647
Zn	1.233	0.587	2.807	1.887

*Significant at five per cent level
**Significant at one per cent level

APPENDIX X

Correlation coefficients and regression equation for nutrient uptake in black pepper

Variables y vs x	Type of plant	Regression equation	R^2
N uptake vs levels of N	Bp	$y = 0.660+0.0032x$	0.910
		$y = 0.6400+0.004533x-0.00001x^2$	0.924
	Vp	$y = 0.628+0.0081x$	0.976
		$y = 0.649428+0.006671x+0.000012x^2$	0.978
P uptake vs levels of P	Bp	$y = 71.414017+0.328866x$	0.419
		$y = 63.666596+1.361829x-0.017216x^2$	0.779
	Vp	$y = 68.078031+0.873466x$	0.709
		$y = 60.934405+1.825872x-0.015873x^2$	0.860
K uptake vs levels of K	Bp	$y = 1.4200+0.002133x$	0.270
		$y = 1.582846-0.008724x+0.000090x^2$	0.883
	Vp	$y = 1.700001+0.005367x$	0.743
		$y = 1.858561-0.005205x+0.000088x^2$	0.996
Ca uptake vs levels of Ca	Bp	$y = 0.930-0.000933x$	0.505
		$y = 0.884283+0.002114x-0.000025x^2$	0.976
	Vp	$y = 1.5880-0.0011x$	0.285
		$y = 1.563705+0.000519x-0.000013x^2$	0.338
Mg uptake vs levels of Mg	Bp	$y = 0.678000+0.001733$	0.096
		$y = 0.809425-0.015790x+0.000292x^2$	0.952
	Vp	$y = 0.824000+0.003467x$	0.817
		$y = 0.809710+0.005372x-0.000032x^2$	0.839
S uptake vs levels of S	Bp	$y = 59.24002+0.775066x$	0.861
		$y = 55.033845+1.335833x-0.009346x^2$	0.901
	Vp	$y = 90.318012+1.23666x$	0.893
		$y = 83.917951+2.090007x-0.014222x^2$	0.930

Bp : Bush pepper; Vp : Vine pepper

APPENDIX XI

Analyses of variance for growth parameters in black pepper as influenced by variety and P source

Source	df	Mean squares					
		Vine length	Number of leaves	Total leaf area	Dry matter yield		
					Stem	Leaf	Total
Variety	10	1206.250*	78.091**	162804.794**	3.404	6.809**	11.332*
Source	2	954.250	87.344*	22656.002	5.832	4.018	15.676*
Variety x Source	20	334.400	15.454	17187.601	1.919	1.040	3.942
Error	64	556.785	24.384	44204.311	2.372	1.969	4.661

* Significant at five per cent level
**Significant at one per cent level

APPENDIX XII

Analyses of variance for the concentration and uptake of P in black pepper as influenced by variety and P source

Source	df	Mean squares				
		P concentration		P uptake		
		Stem	Leaf	Stem	Leaf	Total
Variety	10	0.003	0.0060**	13.647	6.343*	32.704*
Source	2	0.001	0.0020	20.914	4.306	39.879
Variety x Source	20	0.002	0.0015	10.668	4.083	22.165
Error	64	0.002	0.0010	10.002	3.081	15.617

* Significant at five per cent level
**Significant at one per cent level

APPENDIX XIII

Analyses of variance for the specific activity of absorbed P and fertilizer P uptake by black pepper as influenced by variety and P source

Source	df	Mean squares						
		Specific activity						
		Stem	Leaf	Whole plant	Pdff	Pdfs	Fertilizer P uptake	P utilization
Variety	10	868465.614	394103.841	305273.008*	783.119	778.856	2.376**	25.609**
Source	2	3276556.253*	18364.000	807804.012**	126.742	122.906	1.959**	18.827
Variety x Source	20	733533.811	418223.571	168439.402	482.529	489.444	0.390	4.514
Error	64	927911.281	329238.009	140756.311	408.353	407.676	0.538	6.225

* Significant at five per cent level
**Significant at one per cent level

APPENDIX XIV

Analyses of variance for the concentration of nutrients in black pepper as influenced by variety and P source

Nutrient concentration		Mean squares			
		Variety	Source	Variety x source	Error
(Degree of freedom		10	2	20	64)
N					
	Stem	0.006	0.012	0.004	0.013
	Leaf	0.008	0.002	0.018	0.025
K					
	Stem	0.007	0.001	0.004	0.028
	Leaf	0.012	0.018	0.015	0.023
Ca					
	Stem	0.199**	0.416**	0.263**	0.027
	Leaf	0.224*	0.349*	0.399*	0.111
Mg					
	Stem	0.008**	0.013**	0.019**	0.002
	Leaf	0.018**	0.019**	0.015**	0.002
S					
	Stem	0.0002	0.0005	0.0003	0.0002
	Leaf	0.0002	0.0005	0.0002	0.0003
Fe					
	Stem	1770.950	517.250	1076.525	747.406
	Leaf	11600.999	7091.000	7572.001	6114.813
Mn					
	Stem	663.253**	667.906**	474.798*	196.097
	Leaf	39235.198*	129513.001*	28118.300*	4768.094
Zn					
	Stem	116.950**	788.234**	205.648**	30.616
	Leaf	55.481**	105.695**	145.498**	10.867

* Significant at five per cent level
**Significant at one per cent level

APPENDIX XV

Mean, standard deviation and range of nutrient concentration in stem and leaf of black pepper

Nutrient	Stem	Leaf
N (%)	1.38* ± 0.12** (1.33 - 1.43)***	2.33 ± 0.03 (2.29 - 2.38)
P (%)	0.133 ± 0.022 (0.108 - 0.167)	0.124 ± 0.022 (0.096 - 0.191)
K (%)	1.97 ± 0.32 (1.92 - 2.02)	2.82 ± 0.09 (2.76 - 2.87)
Ca (%)	1.40 ± 0.38 (1.25 - 1.67)	2.31 ± 0.12 (2.20 - 2.74)
Mg (%)	0.85 ± 0.09 (0.81 - 0.90)	0.65 ± 0.06 (0.59 - 0.73)
S (%)	0.066 ± 0.006 (0.058 - 0.072)	0.151 ± 0.017 (0.106 - 0.163)
Fe (ppm)	259.97 ± 13.36 (237.22 - 289.22)	454.32 ± 34.28 (399.89 - 511.78)
Mn (ppm)	54.57 ± 8.17 (41.56 - 65.56)	411.80 ± 62.95 (298.89 - 507.78)
Zn (ppm)	42.51 ± 3.41 (36.29 - 49.18)	38.65 ± 2.44 (34.89 - 43.12)

* Mean
** Standard deviation
*** Range

APPENDIX XVI

Analyses of variance for the nutrient uptake by black pepper as influenced by variety and P source

Nutrient uptake	Mean squares			
	Variety	Source	Variety x Source	Error
(Degrees of freedom	10	2	20	64)
N	0.003	0.005	0.003	0.004
K	0.015	0.035	0.013	0.018
Ca	0.005	0.029*	0.002	0.003
Mg	0.0005	0.0015*	0.0004	0.0004
S	22.396**	26.225*	4.808	7.081
Fe	2.823**	1.600	1.097	0.983
Mn	4.353**	3.893**	1.139**	0.460
Zn	0.026**	0.075**	0.013	0.011

* Significant at five per cent level
**Significant at one per cent level

APPENDIX XVII

Mean, standard deviation and range values of the uptake of nutrients by black pepper

Nutrient	Total uptake/plant
N (g)	0.18 ± 0.04 (0.14 - 0.20)
P (mg)	12.00 ± 1.82 (9.06 - 15.21)
K (g)	0.23 ± 0.01 (0.17 - 0.27)
Ca (g)	0.17 ± 0.03 (0.14 - 0.20)
Mg (g)	0.07 ± 0.01 (0.05 - 0.08)
S (mg)	10.45 ± 1.83 (7.99 - 13.23)
Fe (mg)	3.42 ± 0.53 (2.41 - 4.30)
Mn (mg)	2.25 ± 0.63 (1.24 - 3.12)
Zn (mg)	0.39 ± 0.03 (0.28 - 0.45)

APPENDIX XVIII

Analyses of variance for the recovery of radioactivty in the leaves of pepper vines as influenced by lateral distance and method of application

Source	df	Mean squares			
		Pepper vine trailed on teak pole		Pepper vine trailed on *Erythrina indica*	
		Days after ^{32}P application		Days after ^{32}P application	
		30	60	30	60
Lateral distance	2	2.811**	3.083**	0.048	0.014
Method of application	2	0.577	0.503*	0.073	0.008
Lateral distance x Method of application	4	0.183	0.170	0.225	0.010
Error	16	0.307	0.112	0.253	0.028

* Significant at five per cent level
**Significant at one per cent level

EVALUATION OF NUTRIENT UPTAKE IN BLACK PEPPER (*Piper nigrum* L.)

By

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ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the requirements for the degree

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1990

ABSTRACT

Experiments on the nutritional aspects of black pepper were carried out at the Centre for Advanced Studies on Humid Tropical Tree Crops, College of Horticulture, Vellanikkara and at the Banana Research Station, Kannara, during 1986-1990. The pattern of growth and nutrient uptake in bush pepper and vine pepper, the relative efficiencies of black pepper varieties in the utilization of applied P and the soil zone of maximum nutrient absorption in pepper vines trailed on dead and live standards were investigated.

All the nutrients tried, namely, N, P, K, Ca, Mg and S, had influence on one or more of the growth parameters of bush pepper as well as vine pepper. Application of Ca improved the root characters markedly. Vine pepper had superiority in terms of height, number of leaves and number of roots. Bush pepper produced more number of branches, larger leaves and longer roots. In both the types, the total biomass was a good indicator to applied nutrients.

Among the nutrients applied, only N and S increased their concentrations in the stem and leaf of bush pepper and vine pepper. In both the types, treatment devoid of N produced typical N deficiency symptoms. The nature of response in uptake was more or less similar in all the treatments.

The variability in biomass production and nutrient uptake in bush pepper and vine pepper could be explained by quadratic models for all the nutrients, except Ca. On comparing the quadratic responses in biomass production between the two types of plants, vine pepper revealed an additional response over bush pepper. The differences in nutrient uptake between the two types of pepper were also highly significant, except for P. Hence, bush pepper cannot be used as a suitable substitute for vine pepper, for purpose of investigations on nutrient requirements. However, in the context of studies on fertility status and nutrient supplying power of soils, there is scope for using bush pepper as substitute for vine pepper.

Considerable variability existed among black pepper varieties with respect to growth, fertilizer P utilization and nutrient uptake. Of the eleven varieties evaluated, biomass production was the lowest in Kuthiyanikkodi and the highest in Aimpirian. Superphosphate was found to be the best P source for biomass production. Utilization of P from applied P sources was the lowest in Kuthiyanikkodi and the highest in Kuthiravally. When the total P absorbed was considered, Kuthiravally derived 40.37 per cent of its P requirement from the fertilizer whereas other varieties met 11.60 to 32.27 per cent. Among the fertilizer P sources, superphosphate and amophos were found to be preferred by black pepper.

Varieties differed significantly with respect to the concentrations of P, Ca, Mg, Mn and Zn. Karimunda recorded more P concentration in the leaf and Ca in the stem. Kutching had more foliar Ca concentration. Magnesium concentration in the leaf was higher in Kottakkodi and that in the stem in Kottanadan. Leaf and stem concentrations of Mn was more in Aimpirian and Kottanadan, respectively, whereas those of Zn were more in Panniyur-1 and Neelamundi, respectively. P sources also influenced the concentrations of Ca, Mg, Mn and Zn.

Significant differences were observed in the uptake of P, S, Fe, Mn and Zn among varieties. Influence of P sources was also evident in the uptake of Ca, Mg, S, Mn and Zn in black pepper. Superphosphate exalted the uptake of Ca, S and Zn; but it was on par with nitrophosphate for Mg uptake and amophos for Mn uptake.

Leaf was found to be a better accumulator for N, K, Ca, S, Fe and Mn in black pepper whereas P and Mg were more accumulated in the stem. Concentration of Zn did not differ in both the parts. The order of nutrients removed by black pepper was K $>$ N $>$ Ca $>$ Mg $>$ P $>$ S $>$ Fe $>$ Mn $>$ Zn.

Recovery of soil applied ^{32}P in the leaves of pepper vines indicated that irrespective of the type of standard used, fertilizer application in black pepper is to be restricted to 30 cm wide basin around the vine.