NUTRIENT UPTAKE EFFICIENCY OF CASSAVA (*Manihot esculenta* Crantz) AS INFLUENCED BY VESICULAR ARBUSCULAR MYCORRHIZAL (VAM) ASSOCIATION AND ROCK PHOSPHATE APPLICATION

BY

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THESIS

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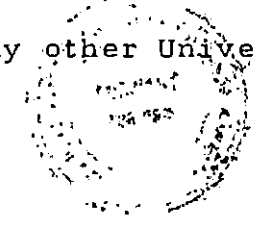
DECLARATION

I hereby declare that this thesis entitled **"Nutrient Uptake Efficiency of Cassava (Manihot esculenta Crantz) as influenced by Vesicular Arbuscular Mycorrhizal (VAM) Association and Rock Phosphate Application"** is a bonafide record of research work done by me during the course of reasearch and that the thesis has not previously formed the basis for the award to me of my degree, diploma, associateship, fellowship or other similar title of any other University or Society.



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S. NARAYANAN

C E R T I F I C A T E

Certified that this thesis entitled **"Nutrient Uptake Efficiency of Cassava (Manihot esculenta Crantz) as influenced by vesicular Arbuscular Mycorrhizal (VAM) Association and Rock Phosphate Application"** is a record of research work done by Shri. Narayanan, S under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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I N T R O D U C T I O N

Cost of inputs in crop production have been growing due to the inherently expensive nature of high oil and power guzzling technology adopted to realise better yields. It must be noted that one percent growth in agricultural sector results in 2.5 percent growth in energy needs. Therefore the main thrust in crop research at present is finding cheap alternatives to costly inputs, expecially chemical fertilisers and also efficient management of fertiliser inputs.

Phosphorus is one of the least effectively utilised nutrient element due to its quick soil fixation and relative immobility. Hence it is of utmost importance to find ways and means for improving the uptake of this element whose natural sources like phosphate rocks in Inaia are nearing depletion due to constant mining.

Healthy soils are abundant in biological life comprising many species of bacteria, fungi and actinomycetes. Over the last two decades, numerous reports have piled up on the beneficial roles of micro organisms in imparting conditions congenial for better utilisation of natural and applied plant nutrients. Of

late, the role of Vesicular Arbuscular Mycorrhizal (VAM) associations in improving crop nutritions gaining attention of scientists as well as farmers. Some of the VAM fungi belonging to the genus Glomus have been found promising in crops including cassava (Potty, 1984). However, the extend of the improvement in nutrient utilisation by these VAM association, has to be delineated.

The greatest opportunity for the use of VAM fungi is in soils in the tropical region and low in available phosphorus. In soils whose native population of VAM is less than the optimum, its inoculation may enable the better use of insoluble rock phosphate instead of costlier super and triple super phosphates. The mechanism involving better utilisation of phosphates must also influence concomitant improvement in the uptake of other nutrients.

Cassava, the test crop in the present study, occupies 15.0 lack ha of agricultural area in Kerala yielding 25.0 lakh tones of tubers. Owing to the high biological yield, this crop demands large supplies of nutrients. A crop of cassava yielding 20.9 T/ha removes about 87.0 kg of N, 37.5 kg of P and 117.0 kg of K per hectare(Kanapathy, 1974).

It has been amply demonstrated that mycorrhizal association is essential for normal growth of cassava in soils of low phosphorus content (Howeler, 1977). A survey conducted by Girija and Nair (1985) in the Instructional Farm of Agricultural College Vellayani elucidated natural associations of VAM in elevan cultivars of cassava. They reported 100% natural association in the M4 cultivar. Meanwhile, artificial inoculation of VAM fungi of cassava was found to be successful in cassava by many workers (Potty, 1984 and Sivaprasad et al., 1990).

The present investigation was thus undertaken to demonstrate the beneficial effects of VAM association in cassava under the following objectives.

1. To partition and quantify the role of Vesicular Arbuscular Mycorrhizal association in cassava (natural and induced) on phosphorus use efficiency and uptake at graded doses of rock phosphate application.

2. To study the effect of VAM and graded doses of rock phosphate on the utilisation and uptake of other nutrients by Cassava.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Commercial Agriculture is facing great set backs due to increasing cost of inputs especially that of mineral fertilizers. Cassava [Manihot esculenta (Crantz)], the tuber crop with very high biological yield (20-39 T/ha) demands relatively higher input of nutrients. The crop removes on an average 180-200 kg nitrogen, 15-22kg phosphorus and 140-160 kg potassium for an yield of 30 T/ha [CTCRI; 1985].

The ever risng cost of fertilizers has made it difficult to supplement the crop removal of nutrients through chemical fertilizers. It is in this context that the significance of integrated fertilizer management through the use of microbes is gaining popularity.

An account of the research work on Vesicular Arbuscular Mycorrhizal (VAM) symbiosis and its role on utilisation of nutrients by plants carried out in India and abroad is presented in this chapter.

2.1 Occurrence and Distribution of Vesicular Arbuscular Mycorrhiza (VAM)

Owing to their wide ecological range and adaptability VAM fungi, have been reported worldwide in cultivated soils, non cultivated soils, forest soils, open woodlands, grass lands, dunes, sediments and beach soils (Mukerji, et al., 1984).

Mycorrohizal associations have also been widely reported from the Indian sub continent (Bagyaraj 1979., and Girija and Nair 1985).

The distribution of VAM is dependent on several factors including seasonal variations, location (Mukerji et al., 1984) and soil conditions (Abbot and Robson, 1977 and Khan, 1975).

The VA Mycorrhizal symbiosis occurs widely throughout the plant kingdom and generally occurs as a rule in cultivated plants excepting a few angiosperms (Gerdeman, 1968).

The fungi, very commonly reported to form VA Mycorrhizal association in field crops generally belongs to

the genera Glomus, Gigaspona, and Acaulopspora. (Mukerji and Kapoor 1986). In general the extent of infection of VAM fungus was found to decrease linearly with increases in P concentration of soil. This was observed by Fernandes et al., (1987) in maize and soybean; Karren (1975) in Solanum, New Zealand Ferns and Leptospermum; and Hicks and Loynachan (1989) in soybean.

2.2 Occurrence of VAM in Tuber Crops

Vesicular Arbuscular Mycorrhizal association in cassava has been reported from Kerala, by Potty in 1978. In his study, the rhizosphere soil yielded a number of spores with different colour shades having various types of peripheral morphology.

Natural association of VAM fungi, with the roots of eleven cultivars of cassava were recorded by Girija and Nair (1985). In their study M4, Pannivella and Kondachu kappan rated 100 per cent infection.

The occurence of VAM association on other tuber crops like colocasia and acorus have also been reported (Selvaraj and Subramonian, 1987) and the fungi involved were

identified as Golmus fasciculatum and Glomus caledonium respectively.

Bhattarai and Mishra (1984) reported VA Mycorrhizal associations in potato. The results of study also showed an increased infection with age of the plants. The infection was effected in 8 to 12 days time.

Sivaprasad et al., (1990) investigated the occurrence of VAM infection in root tissue and its spore count in rhizosphere soil of different cultivars of Manihot esculenta, Ipomoea batatus, Dioscorea alata, D. esculenta and Coleus parviflorus. Their results showed that sweet potato and cassava harbours natural association to the extend of 28-54% and 22-42% respectively. However, the colonization was relatively less in D. alata D. esculenta and Coleus. The rhizosphere spore count was fairly higher in cassava and sweet potato cultivars, whereas the spore count was comparatively less in other tuber crops under test.

2.3 Crop Response To VA Mycorrhizal Inoculation

Mosse (1957) has made the pioneering contribution to VA Mycorrhizal research when she demonstrated the

improved growth of apple due to VAM association. Since then, the favourable effects of VAM in the growth, drymatter production or yield of various crops have been reported. The crops which respond to VAM association include tobacco, tomato and maize (Daft and Nicholson 1969), soyabean (Ross and Harper, 1970; Ross, 1971), Coprosoma and Allium (Hayman and Mosse, 1971), Solanum spp (Karren, 1975), maize and wheat (Khan, 1975) and so on.

Graham et al., (1976) reported the effect of two mycorrhizal fungi ie., Glomus fasciculatum and G. mossae on the growth and tuberisation of potatoes. The mean number of tubers formed on G. fasciculatum inoculated plants over a period of three years were nearly twice than that of non-inoculated control and the dry weights of tops, roots and total plants were also significantly greater.

The response of potatoes to VAM inoculation was studied by Black and Tinker (1977) under field conditions. They found that inoculation with mycorrhiza and added P gave a large increase in yield to the tune of 6.15 to 7.39 kg/plot. The yield increase due to mycorrhizal inoculation was comparable with added P fertilizer treatment. Positive

response of potato to VA Mycorhizal inoculation has been reported from India by Swaminathan and Verma (1979).

More recent works on the crop response to VAM inoculation also revealed a favourable trend in various crops. This was unfailingly observed in soyabean (Diem and Dommergues, 1982; Young et al., 1986) Lucerne (Nielsen and Jensen, 1983), Yellow sweet clover and sudan grass (Rogers and Williams (1986) and subterranian clover (Bolan et al., 1987).

Irene et al., (1987) in a study to evaluate the potency of single and multiple mycorrhizal inoculum on clover and strawberry plants found that, the multiple mycorrhizal inoculum containing four different species of VAM fungus employed, responded well under field conditions than the single species inoculum. This was attributed to wider adaptability of the multiple inoculum as it contained more types of species under field conditions.

Konde et al., (1988) studied the response of Allium under low soil P levels to VA Mycorrhizal infection. He concluded that by employing VA mycorrhizal fungi in crop

production the dossage of phosphatic fertilizers can be reduced by 50 to 25 per cent.

Lin and Hao (1988) also revealed the beneficial role of VAM in the growth and establishment of seedling of different plants. The results showed that the height and fresh weight of all mycorrhizal seedlings and its cuttings were significantly greater than uninoculated seedlings.

The dual inoculation of leguminous plants with VAM and Rhizobium has been studied in a number of plants viz., lucerne, chikpea, cowpea, grams, Cajanus canjan, and alfalfa by Sivaprasad et al., 1983; Subba Rao et al., 1986; Ramaraj and Shanmugham 1986; Sivaprasad and Rai 1987 and Azcon et al. 1988, respectively.

The dual inoculation studies on lucerne showed that, the plants inoculated with VAM fungus and Rhizobium responded well and produced more dry matter and nutrient uptake especially P, N and Mo than their respective controls. Moreover, the plants inoculated with fungus and bacterium singly excelled significantly in dry matter production, nodulation and nutrient uptakes (Sivaprasad et al.,1983 and Manjunath et al., 1984).

Inoculation of tomato with Glomus fasciculatum and Azotobacter vinelandii singly and in combination in the field resulted in significantly increased leaf area, shoot dry weight and yield in relation to uninoculated controls (Mohandas 1987).

2.4 Role of VAM association in nutrient uptake

In general the mycorrhizal plants exhibit significantly increased growth with respect to uninoculated plants owing to the better utilisation of plant nutrients especially of phosphorus from the soil, that too when grown in P deficient or P fixing soils (Hayman and Mosse, 1971; Manjunath and Bagyaraj, 1984 and Sanders and Sheikh, 1983).

Asimi et al., (1980) reported growth and yield increase in nodulated soybeans grown in unamended sterile soil by inoculation with VAM fungus G. mossae. These were accompanied by improved P uptake and better nodulation with high nitrogenase activity. Of the different doses of KH_2PO_4 tried, the dose of 1 g KH_2PO_4/kg of soil and above diminished the infection considerably; in particular fungal spread within the roots.

There are reports of increased plant growth in chillies with decreased dose of P in presence of VAM association. (Bagyaraj and Sreeramulu, 1982). The inoculated plants were found to take up more P and Zn when compared to their controls. The inoculated plants showed significantly higher yields when compared with uninoculated controls and plants which received the recommended full dosage of phosphorus.

Similar increment in shoot growth and nutrient uptake was found in Lucerne, where the response of VAM was pronounced at the lowest soil P level. The inoculation also increased the uptake ratio of fertilizer P in addition to the increased uptake of N and K (Nielsen and Jensen, 1983).

Jensen (1983) elucidated the efficiency of VAMF on increasd nutrient uptake in two Danish soils which are low in available P when tested with Barley.

Rye grass grown in pots with soils of low N and P showed an increased uptake of P, N K and Cu and resulted an increase in shoot growth by 24% when treated with mixed inoculum of VAM fungus (Hall et al., 1984).

Miranda et al.,° (1984) obtained increased P uptake and dry matter production when mycorrhizal sorghum was grown in soils where available P was low.

Kilham (1984) elucidated the incremental effect of mycorrhizal conditions in the uptake of P, Cu, Co and Mg by livestock grasses when treated with Glomus fasciculatum.

Enhanced uptake of Cs and Co by mycorrhizal yellow sweet clover and sudan grass respectively was found to be significantly superior to their respecitve controls at first harvest (Rogers and Williams 1986).

When the effect of VAMF inoculation and phosphorus application was tested on soybeans, mycorrhizal plants recorded higher concentration of Zn and Cu but the P uptake and dry weight the plants were same as that of P applied plants (Pacovsky 1986).

Paulino et al., (1986) showed an increased uptake of phosphorus by mycorrhizal centrosema and macrophilium plants over uninoclated ones when tested with rock phosphate and soluble form of phosphorus.

Soybean plants colonised with G. macrocarpum exhibited higher P absorbtion and utilisation of this element reached a maximum value with 60 and 120 ppm of added P_2O_5 over the uninoculted controls (Siqueira and Paula, 1986).

Gruhn et al., (1987) studied the effect of VAM fungus and P application in two soil types on the uptake of phosphorus by sweet gum. The study showed that in kaolin soils, the non mycorrhizal plants did not respond to P application even at higher rates of application. Under low rates of application mycorrhizal plants grew well and took up significantly higher quantities of P, Mg and Ca.

Santhi et al., (1988) found that VAM inoculation significantly increased the available phosphorus of soil, uptake of phosphorus and other nutrients and grain yield of green gram over the control. In the same study it was found that rock phosphate is more efficiently utilized when applied along with VA mycorrhizal fungus. VAM inoculation with 50 % rock phosphate was as good as full dose of rock phosphate alone.

Subramonian and Dwivedi (1988) elucidated while studying the efficiency of different micro organisms on the utilisation of rock phosphate including VAM, that the P uptake from soil increased in presence of micro organisms in the rhizosphre. Phosphorus content of VAM plants was the highest among other microbes. Bio mass, P content of shoots and chlorophyll content of leaves of VAM inoculated plants were greater than their respective controls.

Bagyaraj (1989) concluded the multifold beneficial effect of VA Mycorrhiza in red soils. He also stated that, in red soils which are generally deficient in phosphorus, VAM inoculation will play a good role in improved uptake of P and thereby increase vigour of the crop plant.

2.5 Mechanism of Improved Uptake of Plant Nutrients by VA Mycorrhizal Roots

The increased uptake of plant nutrients by mycorrhizal roots have been attributed to increased soil explorations of roots having the external hyphae of the VAM fungus ramifying in the soil extending to areas outside the depletion zone around the roots (Sanders and Tinker, 1971).

Sulochana and Manoharachary (1988), after a study in castor and safflower stated that, the increased growth of host plant may be due to adequate availability of moisture, suitable pH, availability of plant nutrients and altered root exudation.

In Bouteloua gracilis, an enhancement of cytokinin activity was observed due to VA mycorrhizal inoculation (Allen et al., 1980).

Azcon et al., (1982) in a study with Glomus mosae on wheat suggested that, the increased P uptake observed in treated plants was due to high affinity of mycorrhizal hyphae for phosphorus.

Dighton (1983) demonstrated in a pure culture of VAM fungi, phosphatase production was generally independent of phosphate concentration. In the presence of Na inositol phosphate, mycorrhizal fungi generally hydrolysed more phosphorus and released a higher proportion into the filterate.

Metachromatic staining of VAM roots of Vaccinium, Erica, and Rhododendron revealed the presence of polyphosphate granules in the endophytes. This was

particularly seen during the lag phase of growth of the endophytic fungi (Starker and Mitchel, 1985).

On the possible beneficial role of nodule initiation in a tripartite symbiosis, Sivaprasad and Rai (1987) effectively proved that the increased nodulation of Cajanus cajan is due to increased cytokinin activity in stem exudates and roots of myorrhizal plants. They hypothesised that, in a tripartite symbiosis VAM fungi enhances the success of nodule initiation through enhanced hormone production and altered host physiological control on nodule initiation.

The adverse effects of soil P on VAM symbiosis has been amply demonstrated (Sanders and Tinker 1971). The effective symbiosis by fungal development under low P conditions on the susceptible host roots has been studied in detail by Elias and Safir (1987). They found that the preference of the fungus to the low P concentration is due to the quantity fo root exudation. The exudates from plants experiencing P deficiency was found to stimulate hyphal elongation of VAM fungus.

A study on the phosphatase activity of Trogonella roots showed that the enhanced enzymatic activities were closely related to the increased growth rates and percentage mycorrhizal infection. This suggested that mycorrhizal root infection probably help in efficient utilisation of P from soil by enveloping the non specific acid and alkaline phosphatases (Kapoor et al 1988).

The micorscopic studies have revealed granules in the sheath and Hartig nets in eucalyptus and pine ectomycorrhizae (Ashford et al., 1975 and Ling Lee et al, 1975) which on the basis and other metachromatic reactions with toluene blue and other histochemical evidence appear to be composed largely of inorganic polyphosphates. Similar granules have also been studied in VA Mycorrhizae (Cox et al., 1975) where various analytical techniques have been added further evidence for the presence of inorganic phosphate aggregation. The granules are located in hyphal vacuoles. It seems likely that, they may be equivalent to the large storage pool of inorganic phosphates as identified in beach mycorrhiza.

Bowen et al., (1985) showed in a radiotracer study that mycorrhizal endophyte neither store appreciable

amounts of absorbed phosphate nor obtain them from plant. They suggested that a consequence of the poor P storage capacity must be a rapid transfer to the host plant, via the relatively large surface area of the arbuscules without a prior need for arbuscule degeneration.

2.6 Cassava nutrition

The nutrient requirement of casava is fairly high due to its greater biological yield. The nutrient removal of the crop has been thoroughly studied by differernt workers in different situations.

Kanapathy (1974) revealed that a crop of cassava yielding 20.9 tonnes per hectare removes about 87 kg N, 36.7 kg P, 117 Kg K and 35.1 kg Mg per hactre.

The studies at CTCRI (1983) showed a greater extend of nutrient removal in laterite soils of Kerala. The nutrient removal was 180-200 kg N, 15-22 kg P and 140-160 kg K per hactre for a crop yeilding 30 tonnes per hactre.

An analysis of the results obtained in a fertiliser trial conducted in Thailand during 1954-67, 1967-72 and 1975-77 revealed that in three consecutive cassava

croppings the quantities of nutrients removed were 103, 69, and 89 kg per hactre of N, P and K respectively in unfertilised plots. When plots were fertilised, the nutrient removal increased to 235, 60, and 250 kg per hactre of N, P and K repsectively (Sittibusaya and Kurmarohita, 1978).

A crop removal to the tune of 164 kg N, 30 kg P and 200 kg K per hactre was reported from a crop of 30 t tuber yield per hactre. (Asher et al.,1980).

Howeler (1981) observed that on an average, nutrients in kilograms per hactre removed per ton of harvested roots were as follows. 2.33, 0.52, 4.11, 0.61 and 0.34 of N, P, K, Ca and Mg respectively.

An FAO survey conducted comprising approximately 2,50,000 fertiliser trials and demonstrations on cassava crop in fourty different countries revealed that, for maximum yield cassava required a nutrient ratio of 1:1:2 N, P_2O_5 and K_2O respectively in West Africa and Asia; an NPK ratio of 1:1.5:1 in Latin America and 2:1:1 in Far East (Richards, 1979).

Mohankumar et al., (1984) worked out the nutrient removal of 30 tonnes per hectre yeilding crop in laterite soils. They found a removal of 180 kg N 22 kg P and 100 kg K per hectre.

It has been seen that, the nutritional requirement of cassava varies greatly depending on the agroclimatic situations.

2.6.1 Phosphorus nutrition

Cassava is found to be inefficient in phosphorus uptake, but still grows well in soils with low P status. The response of cassva to phosphorus application is also very low due to its poor uptake efficiency for this particular nutrient element.

In the experiments conducted at CTCRI (1983) in acid latenite soils of low available P (10-15 Kg P_2O_5), cassava reponded to P application up to 100 Kg P_2O_5/ha, beyond which the yield increase was not significant.

Gomes et al., (1979) showed that yield of cassava increased significantly with P application.

Another experiment conducated in Brazil to determine the effects of sources and levels of phosphorus fertilisation on cassava indicated that the incremental rates of nutrients increased P and Mg contents in the leaf with significant effect on the Harvest Index (Souza ,1979). Gomes et al., (1979) highlighted that, though the P requiremnt of the crop is low it is still limiting the production and suggested that 80 -120 kg P_2O_5 /ha would be applied per hactre..

Howeler (1979) reported that, cassava responded to P application and has fairly high requiremnt of P. In his experiment on the yield response of cassava in three classes of tropical P deficient soils, he got two hundred per cent yield increase by adequate P fertilisation.

Cadavid (1980) obtained a positive response upto 100 kg P_2O_5 /ha and less response at 400 kg/ha in an experiment with four levels of phosphorous (0, 50, 100 and 400 kg P_2O_5 /ha).

Arismendi (1980) found that, P was the most limiting nutrient element for root produciton in cassava followed by N and K.

An experiment conducted on yellow podzolic soil in Australia to evaluate the response of cassava to the band application of different levels of P indicated a low response. But root yields at 100 kg P_2O_5/ha were significantly greater than 0 and 50 KgP_2O_5/ha treatments (Hicks and Fukai, 1981).

The yeild increases obtained due to phosphorus application in cassava had been reported by many other workers (Moraes et al., 1981; Magalhaes, 1981). Yield increase upto 200 kg P_2O_5/ha were also reported from abroad (Cadavid and Howeler, 1982) where as in Kerala the maximum yield was obtained for an application rate of 25 kg P_2O_5/ha (Nair and Prabhakar, 1984).

In the acid laterite soils of south India the response of P fertilisation for cassava is limited to 100 kg P_2O_5/ha (CTCRI, 1983) and the continuous application in high doses of P has resulted in a build up of available P status which lessened the response of P application. Whereas in soils of fairly high P status (100kg/ha) application of 25 Kg P_2O_5/ha was found to be sufficient for maintaining optimum yield of cassava (Gosh et al., 1988).

Trials conducted at CTCRI using P sources such as single and triple super phosphate revealed that citrate soluble basic slag is superior to water soluble super phosphate or other citrate soluble forms like Ultraphos and Ammophos (CTCRI 1983)

Works at CIAT (1985) showed that cassava responded significantly to application of 87 kgP/ha as tripple super phosphate but the crop responded even upto 175 kg P/ha when basic slag or single super phosphate was used as P source.

Cock (1979) reported that in acid infertile soils cassava showed yield response to application of as high as 400 kg/ha of P and levels of 100-150 kg P/ha are commonly recommended.

To increase the availability of P from the sources to the plant, various techniques had been tried. Howeler (1981) reported that mixing of rock phosphate with sulphur or sulphuric acid improved the P availability considerably and cassava responded to application according to citrate solubility of rock phosphate sources. Cock (1979) also reported that partial acidulation of rock phosphate before application to increase P availability, resulted in cassava

yield response comparable to those obtainable from application of Triple Super Phosphate.

2.7 Mycorrhiza in Phosphorus Nutrition of Cassava

It has been observed that cassava grows better in the presence of mycorrhizal fungi in the root zone. Inoculating cassava with an effective strain of mycorrhizal fungi improves the utilisation of native soil phosphorous.

Potty (1978) recorded the association of Vesicular Arbuscular type of Mycorrhizal association in cassava and a survey conducted in Kerala showed that Glomus sp was the predominant VAM forming fungi (Potty 1984).

Another survey conducted by Girija and Nair (1985) also proved that the cassava cultivars M4, Pannnivella and Kondachu Kappan are favourable symbiots for VAM fungi. In their study, these cultivars were found to have a type of natural symbiosis and the scorings were rated as 100 per cent.

Potty (1984) found that the cassava plants inoculated with VAM fungi exhibited increased P uptake even upto seven folds than that of controls.

Kang et al., (1980) after extensive green house and field trials on the effect of phosphate fertilisation and inoculation with VAM fungi performance of cassava revealed that the field grown cassava appears to have a low P requirement. Percentage mycorrhizal infection of cassava roots depend on extractable soil P levels; being low at high soil P and high at low soil P levels. Inoculation with mixed native VAM fungi or with Glomus mossae significantly improved growth, lowered P response and increased P uptake in plant tops of pot grown cassava in sterilised soil. Inoculation with G. mossae reduced plant growth and P uptake in unsterilised soil.

In another study conducted at CIAT, (Howeler, 1982); when cassava grown in a sterilised condition to which eight levels of P had been applied, the uninoculated plants required the application of 3200 kg Pha^{-1} to reach near maximum dry matter at three months stage. Inoculated plants, however, showed only a minor response to applied P at higher levels. Mycorrhizal inoculation in the P check, top growth over 80 fold and total P uptake over 100 fold over the uninoculated P check treatment. In the same study relating dry matter production to available P

concentration in the soil, a critical level of 15 ppm P was obtained for mycorrhizal and 190 ppm for non-mycorrhizal plants. This indicates that the determination of critical levels of P in the soil is highly dependent on the degree of mycorrhizal infection of the root.

This study strongly advocate that, cassava is extremely dependent on an effective myorrhizal association for normal growth in low P soils; but in most natural soils the association is rapidly achieved and inoculation can only be effective in soils with low quantity and quality of active mycorrhiza.

Potty (1988) studied on the response of cassava to VAM inoculation in acid laterite soils and found that, rooted, infected cuttings of cassava responded favaourably to the measured parameters via., growth, dry matter production and tuber production. Significant differences were noted in dry matter production and tuber production in natural soils. Half recommended dose of phosphorus significantly enhanced dry matter production and tuber production in the presence of VAM fungi.

A more recent study on the relative efficiency of VA Mycorrhizal fungi for soil nutrient uptake in cassava showed that on 75th day of growth, the concentration of nutrients in plant tissue as well as the total uptake from soil was higher in plants inoculated with VAM fungi. G. fasciculatum was the most effective in stimulating plant growth and nutrient uptake. The uptake of P, K, Mg, and Ca was highest for plants inoculated with G.fasciculatum. P uptake and dry weights for G. fasciculatum inoculated plants were 28.7 g and 15.75 g Pl^{-1} respectively (Sivaprasad et al., 1990) Experiments carried out at CIAT and CTCRI have amply demonstrated that, under sterile soil conditions inoculation by effective strains of mycorrhizal fungi like Glomus spp improves the utilisation of P in cassava production.

2.8 Response of cassava to other nutrients

2.8.1 Nitrogen

Among different levels of nitrogen applied to cassava 100 kg N/ha was found to be optimum beyond which the yield differences were not significant (CTCRI 1983). Cock (1979), also confirmed that other than in Peaty soils, cassava rarely responds to more than 100 kg/ha of nitrogen.

Split application of nitrogeneous fertilisers, half as basal dose and the other half after one or two months have been recommended by Mandal et al., (1971).

Mohankumar et al., (1984) found that the application of N alone or in combination with P and K had a significant effect on tuber yield.

2.8.2 Pottassium

Cassava is very efficient in extracting K from soil. In a permanent manurial trial conducted at CTCRI, K responded better than N and P even after the sixth year of application of fertiliser doses. (Gosh et al.,1988)

In acid laterite soils, where predominent clay mineral is kaolinite, application of about 100 kg K_2O /ha was found to be sufficient for maximum yield of cassava and further doses resulted in luxury consumption (Ghosh et al., 1988).

N and K at the ratio of 1:1 (@ 100 kg/ha each) was found to be optimum for H-165, H-97 and M-4. (Mohan Kumar et al., 1984).

2.8.3 Micro nutrients

Asher et al., (1980) have presented exhaustive diagnostic information on cassava nutrition including visual symptoms of deficiency.

Howeler, et al., (1982), studied the micronutrient deficiencies and toxicites in cassava plants in nutrients solution. Critical tissue levels for nutrient deficiencies and toxicities were determined, relating dry matter production to the nutrient concentration in the Youngest Fully Expanded Leaf blade (YFEL). For copper the value were 6 µg/g for deficiency and 15 µ g/g for toxicity; for Mn it was 50 and 250, Zn 30 and 120 and for Fe 60 and 200.

Iron deficiency is rare in cassava, but it has been observed in certain calcareous soils in Mexico and in alkaline soils (8.0 pH) of Tamil Nadu (Ghosh et al., 1988).

Manganese content of Youngest Fully Expanded Leaves of normal plant ranges from 50-250 µg/g. The critical level in solution culture in reported to be around 60 µg/g in YFEL (Howeler, 1982).

A significant response to Manganese along with other micro nutrients has been reported from CTCRI (1974).

Zinc concentration in YFEL of healthy plants are normally about 40-100µg/g; Critical level of Zn (35-50 µg/g) have bneen determined for various cultivars (Howeler, 1978). The critical concentration of Zinc in soils, extracted with 0.5 M HCl + 0.0125 M H_2SO_4 is about 0.7 µg/g and extracted with bicarbonate - EDTA was about 0.8 µg/g (Howeler, 1978).

Antagonistic interaction of zinc and phosphorous in acid lateraite soils has been reported (CTCRI, 1986). The zinc concentration in the YFEL decreased with increased application of phosphorous (25kg P_2O_5/ha) to less than Critical levels (35ppm) with resultant yield decrease.

The beneficial effect of Zn application in yield and quality of tubers has been reported by Nair and Kumar (1980).

Normal copper levels range from 7 to 5 µg/g in YFEL and from 2 to 10 µg/g in roots. Chew et al., (1978) reported that copper deficiency reduced yields from 15-4 T/ha in Malaysian Peat soil.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

A pot culture experiment to study the nutrient uptake efficiency of cassava as influenced by Vesicular Arbuscular Mycorrhizal (VAM) association and graded doses of Rock Phospate application was conducted during September-December, 1989 in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani. The pot experiment was located at the enclosed experimental area on the northern side of the Department of Soil Science and Agricultural Chemistry.

The experimental details and methodology for laboratory investigations are explained hereunder.

3.1 Details of experiment

The experiment was designed to study the effect of soil conditions, VAM association and P levels on the growth and nutrient uptake of cassava during the active vegetative phase. Thus the three factors under comparison were employed at different levels as follows:

(1) Soil condition

A) sterilised (S_0)

B) unsterilised (S_1)

(2) VAM fungal population

A) uninoculalted (I_0)

B) inoculalted (I_1)

(3) Phosphorus levels

A) No Phosphorus (P_0)

B) 25.0 kg P_2O_5/ha (50% recommended dose) (P_1)

C) 37.5 kg P_2O_5/ha (75% recommended dose) (P_2)

D) 50.0 kg P_2O_5/ha (100% recommended dose) (P_3)

Treatment combinations

T 1 - S I P 0 0 0	T 5 - S I P 0 1 0	T 9 - S I P 1 0 0	T 13 - S I P 1 1 0
T 2 - S I P 0 0 1	T 6 - S I P 0 1 1	T 10 - S I P 1 0 1	T 14 - S I P 1 1 1
T 3 - S I P 0 0 2	T 7 - S I P 0 1 2	T 11 - S I P 1 0 2	T 15 - S I P 1 1 2
T 4 - S I P 0 0 3	T 8 - S I P 0 1 3	T 12 - S I P 1 0 3	T 16 - S I P 1 1 3

Replications - Six

Design - Completely Randomised Design (CRD)

3.2 The soil

The experimental soil of relatively low P content was selected after determining available P content of Vellalyani soils from different areas in the Instructional Farm.

The fertility of the soil selected for the experiment was subjected to detailed studies on physical and chemical properties. The data are presented in Table No.1

TABLE 1

Physical and chemical characteristics of the soil

Sl.No	Characteristics	Value	Methods followed
1	pH (soil:water 1:2.5)	5.4	pH meter with glass electrode as described by Jackson,(1967)
2	Mechanical composition		
	a) Coarse sand (%)	44.24	Bouyoucos,(1962)
	b) Fine sand (%)	9.26	Hydrometer method
	c) Silt (%)	3.18	
	d) Clay (%)	31.20	
3	Textural class	sandy clay loam	USDA soil survey staff, (1966)
4	P fixing capacity (%)	35.8	Waugh and Fitts,(1966)
5	Total P (%)	0.065	Jackson,(1967)
6	Avail P (kg ha^{-1})	17.5	Olsen et al., (1954)
7	Total N (%)	0.073	Kheldahl procedure as described by Jackson, (1967)
8	Available N (kg ha^{-1})	280.0	Subbiah and Asija, (1956)
9	Total K (%)	0.061	Jackson, (1967)
10	Available K (kg ha-1)	56.0	" "
11	Exchangeable Ca (ppm)	87.52	" "
12	Exchangeable Mg "	42.50	" "
13	Exchangeable Fe "	22.31	" "
14	Exchangeable Cu "	2.50	" "
15	Exchangeable Zn "	2.10	" "
16	Exchangeable Mn "	12.82	" "

The acidic sandy clay loam soil falls under Vellayani series, classified as Fine Loamy Mixed Isohyperthermic family of Khaplic Haplustalfs.

3.2.1 Soil sterilisation

As designed in the experiment eight out of sixteen treatments were replicated six times under sterilised conditions. For this purpose the soil was sterilised using 5% Formaldehyde solution.

The soil to be sterilised was made into a bed of size 5.0 x 1.0 x 0.2 m and the chemical was sprayed @ 5ml/m^{-2} and covered air tight with a thick polythene sheet and plastered with mud on the sides. After 48 hrs, the soil was opened and given a small racking and left open for two days.To ensure complete sterilisation, the process was repeated once again.

3.3 V A Mycorrhizal fungi

One of the very common fungi that forms VAM association in cassava is Glomus fasciculatum. The efficiency of this fungi in cassava was reported earlier by Potty in 1988.

The fungal culture for the experiment was acquired from the stock culture of the Department of Plant Pathology, College of Agriculture, Vellayani.

3.3.1 Mass production of VAM fungus

The VAM fungus G. fasciculatum was mass cultured in the roots of Guinea grass under sterilised condition. This was maintained for three months to attain the required spore density. The inoculation method adopted for the experiment was mixed inoculation. The mixed inoculum was prepared by mixing the soil collected from root zone of the host plant and the roots which were cut into small pieces of about one centimeter length. The 50 ml of such inoculum contained 300 to 400 spores of VAM fungus.

3.4 Conduct of Pot Experiment

3.4.1 Potting

Baked mud pots of uniform dimension were filled with 15 kg each of soil after mixing with urea and muriate of potash @ 50 kg N and 50 kg K_2O/ha respectively. Sterilised soil was handled separately and treated in the same way.

The P treatments were applied as graded doses of Rock Phospate (17.5%) to the soil in different pots as per the experimental design.

3.4.2 Inoculation of VAM fungi

In the case of treatments which required inoculation of VAM fungi, the same was carried out by incorporating 100 ml of mixed inoculum at the centre of each pot. This was to ensure the sprouting roots to pass through the zone of maximum fungal population.

3.4.3 Planting

Cassava cultivar M-4 was the variety used for planting. The setts were prepared at 15 cm length and one sett was planted at the centre of each pot. The potting and planting operations were carried out on the same day.

3.4.4 Crop Management

The crop was managed according to the Package of Practices Recommendations 'Crops - 89' by Kerala Agricultural University (1989). The pots were watered two times daily and maintained for 90 days.

3.5 Observations on treatment effects

3.5.1 Sampling

The soil and plants were sampled at intervels of 30 days for a period of 90 days. The sampling was destructive by removing one replication each of the entire treatments at the first two sampling stages. Three out of the remaining four replications were left for the final detailed laboratory investigations at ninety days after planting.

The soil and plant samples collected periodically were subjected to biometric measurements and various chemical analyses by methods detailed earlier.

3.5.2 Soil analysis

Soil samples collected at monthly intervals were air dried, sieved through a 2 mm sieve and approximately 500 g of sample was finally stored in suitable containers after labelling. The samples were analysed for the following characters.

(i) Soil Reaction - pH was determined in 1:2.5 soil water ratio using a Beckman pH meter, as described by Jackson (1967).

(ii) Available Phosphorus - Available phosphorus was estimated calorimetrically in Bray - I extract using Spectrophotometer, Spectronic 2000.

(iii) Total Phosphorus - Total phosphorus of the soil was estimated using procedure described by Jackson (1967) and expressed as per cent in soil.

(iv) Available Nitrogen - Available Nitrogen of the soil was estimated by the Alkaline Permanganometric titration method and expressed as kg/ha (Subbaiah and Asija, 1956)

(v) Available Pottassium - Available pottassium content was estimated in Neutral Normal Ammonium Acetate Extract (Jackson, 1967); and read with the help of Atomic Absorption Spectrophotometer and expressed in kg/ha.

(vi) Exchangeable Calcium - Exchangeable calcium was estimated in Neutral Normal Ammonium Acetate Extract (Jackson, 1967) and read using Atomic Absorption Spectrophotometer and expressed in ppm.

(vii) Magnesium - The method described for calcium was adopted.

(viii) Micronutrients - The micronutrients (Fe, Cu, Zn, and Mn) were estimated from extractions of the soil with D T P A solution (Jackson, 1967). The extracts were read in a Perkin Elmer Atomic Absorption Spectrophotometer (Model No.3030). The values are expressed in ppm.

3.5.3 Chemical analysis of plant samples

The plant samples collected at monthly intervals were divided into three sections for detailed laboratory investigations.

A: Critical leaf

The Youngest Fully Enlarged Leaf (YFEL) was reported to be the critical leaf of cassava which reflects the nutritional status of the plant (Howeler, 1972). Therefore this leaf was separately processed and analysed.

B: Cassava shoot

The above ground bio-mass of cassava except the

YFEL was grouped under this section and analysed for various constituents.

C: Cassava roots

The complete root portion of the plant was separated and subjected to chemical analysis as well as other observations.

The plant samples collected were cleaned and dried at 70°C in a hot air oven and then powdered. The powdered samples were digested (Jackson, 1967) and digest was used for various estimations except that of Nitrogen.

The methods adopted for the determinations were as follows

(i) Nitrogen - Total Nitrogen was estimated by microkjeldahl method (Jackson, 1967).

(ii) Phosphorus - Total phosphorus was estimated by Ammonium Vanadomolybdate yellow colour method using Spectronic - 2000.

(iii) Potassium - Total potasssium was estimated by direct flame method using a Perkin - Elmer (Model No.3030) Atomic Absorption Spectrophotometer.

(iv) Calcium and Magnesium: Ca and Mg of the plant sample digest were estimated by direct flame method using a Perkin - Elmer (Model No.3030) Atomic Absorption Spectrophotometer.

(v) Microcutrients: The dominant micronutrients viz; Fe Cu, Zn and Mn were determined through Atomic Absorption Spectrophotometry (Perkin - Elmer Model No 3030, AAS).

3.5.4 Biometric Observations

3.5.4.1 Shoot

(i) Plant height - The height of shoots (two shoots were retained) were measured from the point of sprout on the setts to the tip of the apical bud of the shoot and expressed in centimeters.

(ii) Number of leaves per shoot - Total number of fully expanded leaves per shoot was recorded at monthly intervals. The number of leaves were found out for the two shoots maintained per plant. From this average number of leaves per shoot per plant was calculated.

(iii) Dry weight of shoots - The shoots were collected and dried at 70 C in hot air oven to constant weight, after cleaning them to remove soil particles.

3.5.4.2 Root

(i) Number of primary roots - The number of roots arising from the base of the setts was counted and recorded.

(ii) Number of secondary roots per primary root - Ten primary roots were randomly selected to count the secondary roots. Number of secondary roots per primary root was averaged from the ten observations.

(iii) Number of tertiary roots per secondary root - Fifteen secondary roots among the ten selected primary roots were used to count the number of tertiary roots. Thus an average of fifteen observations were recorded as the number of tertiary roots per secondary root.

(iv) Length of longest primary root - The length of the longest three primary roots was measured and the average value was recorded.

(v) Length of the longest secondary root - From the longest three primary roots the length of the three longest secondary roots were measured. Hence an average of nine observations (three secondaries each form three primaries) was recorded as length of the longest secondary root.

(vi) Length of the longest tertiary root - The length of the longest tertiary roots were found out by taking the average of nine observations as in the case of secondary roots.

(vii) Dry weight of roots - After taking biometric observations of the roots, they were cleaned and dried under shade for one day. Afterwards dried in a hot air oven at 70° C to a constant weight and then weighed and expressed in grams.

3.5.5 Rating of mycorrhizal infection

Percentage of mycorrhizal infection was estimated by the method recommended by Phillips and Hayman (1970). The feeder roots of the plants were washed gently and simmered at 90°C for 1-2 hours in 10% KOH solution. The simmered root samples were washed free of KOH and acidified

by immersing in 2% HCl for one to two minutes. The acidified samples were stained with 0.05% trypan blue in lactophenol after thorough washing of HCl. Boiled the root samples along with stain for three minutes. Then to destain the host cells of the samples, excess stain was poured off and added lactophenol and kept overnight. This was examined under a microscope and rated the infection percentages as denoted by the presence of vesicles of the fungus.

3.6 Statistical analysis of the data

The data were analysed statistically by applying the technique of analysis of varience for Completely Randomised Design. Stastical analysis was performed for all data except the soil and crop composition, and uptake during first two months. This was since the observations were made only for one replications of treatments during these periods.

4. R E S U L T S

Effects of VAM inoculation, soil sterilisation and graded doses of rock phosphate application on the soil (Vellayani Series) and the test crop (Cassava) was monitored through various observations at monthly intervals for three months. While the first two sets of observations were intended to record the trends in treatment variations, the final set of data was subjected to detailed statistical tests to arrive at definite conclusions. The data presented in the ensuing pages are arranged parameter wise. Wherever statistical analysis was undertaken th data denotes mean values.

4.1. Impact of treatments on soil characters

4.1.1. Soil reaction

There was no significant variation in soil reaction as a result of treatments. The initial soil pH was 5.4 . One month after planting (MAP) the soil pH in individual pots varied form 5.2 to 6.0. and even after three months it varied only from 5.4 to 6.2 (Table 1).

4.1.2. Nutrient status of soil

Data presented in Tables 2, 3, and 4 represent soil fertility variations during the period of study. Table 2 contains data on major nutrients at three stages of sampling. The main effects of soil condition, VAM population, and phosphorus levels at three MAP on the content of major nutrients are provided in Table 4.

4.1.2.1. Major nutrients

During the first stage of sampling (1 MAP), the available phosphorus status of the soil was found to increase with increase in levels of rock phosphate application. The treatment $S_0 I_0 P_3$ recorded the highest available P content during this time. The effect of treatments was not prominent at two MAP. Here also the treatment $S_0 I_0 P_3$ recorded the highest available P content (32.54 Kg/ha).

The statistical analysis of the data on available P content at three MAP showed no significant effect for this treatment. However, there was an increase in trend in the available P content due to incremental doses of rock

TABLE - 2

EFFECTS OF TREATMENTS ON MAJOR NUTRIENTS IN SOIL AT MONTHLY INTERVALS

Sl. No.	Treatments	Available P (kg/ha)			Total P (%)		
		1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)
1.	S I P 0 0 0	20.75	21.65	16.02	0.033	0.031	0.031
2.	S I P 0 0 1	21.00	21.65	17.88	0.026	0.029	0.031
3.	S I P 0 0 2	22.25	20.75	18.89	0.027	0.030	0.029
4.	S I P 0 0 3	32.35	32.54	19.70	0.032	0.033	0.033
5.	S I P 0 1 0	19.84	21.75	20.09	0.027	0.026	0.028
6.	S I P 0 1 1	25.75	22.63	19.69	0.029	0.029	0.029
7.	S I P 0 1 2	18.75	20.97	20.25	0.029	0.028	0.031
8.	S I P 0 1 3	28.25	25.75	21.16	0.033	0.031	0.032
9.	S I P 1 0 0	15.75	21.30	18.89	0.025	0.029	0.029
10	S I P 1 0 1	18.75	17.89	19.06	0.027	0.028	0.031
11.	S I P 1 0 2	17.45	20.75	17.23	0.027	0.029	0.031
12.	S I P 1 0 3	15.75	18.75	18.37	0.029	0.031	0.032
13.	S I P 1 1 0	20.00	19.50	21.36	0.028	0.029	0.029
14.	S I P 1 1 1	26.25	21.75	21.79	0.007	0.026	0.03
15.	S I P 1 1 2	20.25	28.75	27.34	0.029	0.032	0.032
16.	S I P 1 1 3	26.16	28.50	20.52	0.033	0.033	0.033
CD		--	--	N S	--	--	N S
SE		--	--	3.47	--	--	0.01

(n=3) - mean of three values N S - variation is not significant

TABLE 2 (Cont..)

EFFECT OF TREATMENTS ON MAJOR NUTRIENTS IN SOIL AT MONTHLY INTERVALS

Sl. No.	Treatments	Available N (kg/ha)			Available K (kg/ha)		
		1MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)
1.	S I P 0 0 0	175.56	117.04	81.98	38.0	37.13	46.02
2.	S I P 0 0 1	117.04	93.72	103.84	41.61	38.89	51.89
3.	S I P 0 0 2	105.38	105.38	101.42	39.22	36.85	51.80
4.	S I P 0 0 3	128.70	93.72	97.60	38.88	33.83	60.20
5.	S I P 0 1 0	93.72	140.36	70.18	43.39	39.60	56.19
6.	S I P 0 1 1	105.38	120.70	62.41	44.77	46.03	36.78
7.	S I P 0 1 2	93.72	93.72	85.87	42.78	41.53	53.67
8.	S I P 0 1 3	117.04	155.38	85.87	40.37	34.54	35.28
9.	S I P 1 0 0	93.72	140.36	54.56	49.78	37.02	46.58
10	S I P 1 0 1	93.72	128.70	109.26	34.85	37.40	62.44
11.	S I P 1 0 2	105.38	117.00	89.76	42.24	38.45	67.11
12.	S I P 1 0 3	81.84	93.72	93.65	40.98	48.26	46.26
13.	S I P 1 1 0	117.04	117.40	54.63	43.75	33.61	44.39
14.	S I P 1 1 1	105.38	105.38	105.38	38.97	36.69	49.45
15.	S I P 1 1 2	105.38	105.38	50.74	40.59	35.92	50.87
16.	S I P 1 1 3	81.84	105.38	128.70	41.20	37.02	46.76
CD		--	--	N S	--	--	N S
SE		--	--	15.29	--	--	11.6

(n=3) - mean of three values N S - variation is not significant

TABLE - 3

phosphate application. The highest value for available P in soil was recorded for the treatment $S_1 I_1 P_2$, where the fungus was inoculated without sterilisation of the soil. In the case of main effects also non sterile condition and inoculation of fungus resulted in higher available P content compared to sterile inoculated conditions (20.57 and 21.53 against 19.21 and 18.26 Kg/ha respectively). The available P content increased from 19.09 Kg/ha in the control (P_0) to 20.193 Kg/ha at P_2 level which then decreased slightly to 19.94 Kg/ha in the P_3 treatment (Table - 4).

Data on the soil composition on total phosphorus available nitrogen and available potassium were also recorded at three stages of sampling (Tables 2 and 4). Statistical analysis of the date yielded no significant variations.

4.1.2.2. Exchangeable bases and micro nutrients

The data pertaining to the status of exchangeable cations (Ca and Mg) and micronutrients (Fe, Cu, Zn and Mn) are presented in Table 3 and the main effects of treatments on these parameters are included in Table 4. Eventhough, there were remarkable variations no definite

TABLE - 3

EFFECT OF TREATMENTS ON THE EXCHANGABLE BASES AND MICRO NUTRIENTS IN SOIL AT MONTHLY INTERVALS

Sl. No.	Treatments	Ca(ppm)			Mg(ppm)		
		1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)
1.	S I P 0 0 0	475.25	594.5	743.08	77.66	45.75	92.01
2.	S I P 0 0 1	400.75	359.0	592.75	85.87	46.03	75.99
3.	S I P 0 0 2	450.25	494.0	785.08	73.18	46.88	82.84
4.	S I P 0 0 3	425.75	359.75	886.92	55.93	36.63	85.27
5.	S I P 0 1 0	467.20	442.75	749.58	51.43	45.50	63.49
6.	S I P 0 1 1	590.50	657.00	702.00	116.74	105.43	51.04
7.	S I P 0 1 2	585.25	691.75	792.33	66.72	87.75	77.44
8.	S I P 0 1 3	550.25	779.25	484.00	49.78	43.50	63.45
9.	S I P 1 0 0	462.20	442.25	770.75	80.88	42.35	53.65
10.	S I P 1 0 1	450.75	434.25	892.42	48.81	49.05	60.61
11.	S I P 1 0 2	505.75	420.50	765.40	48.84	50.15	69.38
12.	S I P 1 0 3	490.75	482.00	622.42	50.16	39.78	61.87
13.	S I P 1 1 0	395.00	419.75	549.00	96.88	49.05	56.02
14.	S I P 1 1 1	350.75	390.75	533.50	81.89	57.13	46.35
15.	S I P 1 1 2	475.20	1037.00	597.58	64.52	47.38	49.66
16.	S I P 1 1 3	540.50	623.25	690.92	52.61	71.40	64.33
CD 5%		--	--	N S	--	--	N S
S.E.		--	--	42.50	--	--	13.73

(n=3) - mean of three values N S - variation is not significant

TABLE - 3 (Cont...)

EFFECT OF TREATMENTS ON THE EXCHANGABLE BASES AND MICRO NUTRIENTS IN SOIL AT MONTHLY INTERVALS

Sl. No.	Treatments	Fe(ppm)			Cu(ppm)		
		1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)
1.	S I P 0 0 0	19.44	10.90	19.36	2.22	1.38	1.90
2.	S I P 0 0 1	20.70	10.11	20.24	1.99	1.27	1.58
3.	S I P 0 0 2	22.06	18.44	20.84	2.05	1.16	1.69
4.	S I P 0 0 3	22.10	10.41	16.28	4.12	2.06	1.81
5.	S I P 0 1 0	20.08	11.11	19.19	1.86	2.31	1.68
6.	S I P 0 1 1	21.62	10.63	18.13	1.67	1.89	1.43
7.	S I P 0 1 2	21.84	10.94	17.35	1.45	2.04	1.24
8.	S I P 0 1 3	23.40	10.41	19.44	2.64	2.52	1.34
9.	S I P 1 0 0	20.92	10.06	25.81	1.56	1.02	1.50
10.	S I P 1 0 1	19.74	10.08	20.29	1.94	1.26	1.47
11.	S I P 1 0 2	19.42	10.12	19.83	1.46	1.61	1.49
12.	S I P 1 0 3	18.16	10.01	18.55	3.10	1.62	1.37
13.	S I P 1 1 0	21.96	11.11	26.85	2.11	1.26	1.27
14.	S I P 1 1 1	21.38	10.34	18.26	2.56	1.35	1.29
15.	S I P 1 1 2	21.36	11.09	16.35	1.43	1.64	1.36
16.	S I P 1 1 3	18.16	10.02	20.03	1.15	1.09	1.37
CD 5%		--	--	N S	--	--	N S
S.E.		--	--	5.95	--	--	0.76

(n=3) - mean of three values N S - variation is not significant

TABLE - 3 (Cont...)

EFFECT OF TREATMENTS ON THE EXCHANGABLE BASES AND MICRO NUTRIENTS IN SOIL AT MONTHLY INTERVALS

Sl. No.	Treatments	Zn(ppm)			Mn(ppm)		
		1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)
1.	S I P 0 0 0	1.90	2.38	1.97	10.42	9.07	15.29
2.	S I P 0 0 1	2.38	2.60	1.94	13.32	10.15	15.50
3.	S I P 0 0 2	4.31	1.05	1.75	12.85	10.26	13.94
4.	S I P 0 0 3	6.38	2.01	1.44	12.64	11.45	14.61
5.	S I P 0 1 0	4.63	3.05	1.97	12.96	10.73	15.25
6.	S I P 0 1 1	3.38	3.30	1.12	12.41	9.67	14.27
7.	S I P 0 1 2	2.06	2.63	1.11	13.11	11.11	11.74
8.	S I P 0 1 3	2.92	5.63	1.49	12.83	10.78	13.47
9.	S I P 1 0 0	2.50	2.92	1.10	12.04	10.84	13.72
10.	S I P 1 0 1	4.86	4.07	1.48	13.56	11.23	13.09
11.	S I P 1 0 2	1.51	2.17	1.08	13.33	11.52	13.37
12.	S I P 1 0 3	4.05	2.19	0.89	13.53	10.97	13.94
13.	S I P 1 1 0	4.90	1.88	1.35	14.91	11.75	12.80
14.	S I P 1 1 1	5.38	1.81	1.16	13.96	12.05	12.91
15.	S I P 1 1 2	2.03	2.01	1.56	12.24	11.65	13.20
16.	S I P 1 1 3	3.96	1.02	0.98	11.82	12.82	12.86
CD 5%		--	--	N S	--	--	N S
S.E.		--	--	0.85	--	--	4.84

(n=3) - mean of three values . N S - variation is not significant

TABLE - 4

MAIN EFFECTS OF TREATMENTS ON SOIL NUTRIENTS AT THREE MAP

Main effects	Avail.P (Kg/ha)	Total P (%)	Avail.N (Kg/ha)	Avail.K (Kg/ha)	Ca (ppm)	Mg (ppm)	Fe (ppm)	Cu (ppm)	Mn (ppm)	Zn (ppm)
Sterilised	19.21	0.031	86.15	48.98	715.96	73.94	18.85	1.58	14.25	1.60
Unsterilised	20.57	0.031	85.84	52.15	677.75	57.73	20.77	1.39	13.24	1.20
CD 5%	N S	N S	N S	N S	N S	12.86	N S	0.1	0.83	0.3
SE	3.47	0.01	15.29	11.6	84.79	12.63	2.49	0.1	0.82	0.29
Uninoculated	18.26	0.031	91.54	45.67	757.35	72.70	20.15	1.60	14.19	1.46
Inoculated	21.53	0.031	80.47	46.70	637.36	58.97	19.47	1.37	13.31	1.34
CD 5 %	N S	N S	N S	N S	86.31	12.86	N S	0.1	N S	N S
SE	3.47	0.01	15.29	11.6	84.79	12.63	2.49	0.1	0.82	0.29
0 P	19.09	0.029	65.34	48.35	703.10	66.29	22.80	1.59	14.28	1.60
50% P	19.61	0.030	95.22	50.14	680.16	58.49	19.23	1.44	13.94	1.43
75% P	20.93	0.031	81.95	55.86	735.10	69.82	18.64	1.44	13.06	1.38
100% P	19.94	0.032	101.46	47.16	671.06	68.73	18.57	1.47	13.71	1.20
CD	N S	N S	N S	N S	N S	N S	N S	N S	N S	N S
SE	3.47	0.01	15.29	11.6	84.79	12.63	2.49	0.1	0.82	0.29

N S - variation is not significant

pattern was observed in the nutrient composition of soil with respect to exchangeable bases and micronutrients.

At the last sampling period (3 MAP), it was observed that the content of exchangeable Ca and Mg were significantly lower in the inoculated pots than the uninoculated ones. Magnesium content ;was significantly higher in sterile soil when compared with unsterilized soil. So was the case with Cu, Mn and Zn concentrations. The copper content was also higher in uninoculated soil than in inoculated soil and the variation was statistically significant. The main effects of phosphorus treatments could influence the contents of none of the base and micronutrients significantly.

4.2. Growth of cassava under treatment effect

Data pertaining to the effect of treatment combinations and the main effects on the biometric parameters of the crop are provided in Tables 5, 6, 7 and 8. The number of leaves per shoot ranged from 5 to 7 in the first month, which increased from 9 to 13 at the third month after planting. Increasing levels of phosphorus application resulted in better leaf production. So also was the effect of VAM inoculation (Tables 5 and 6).

TABLE - 5

EFFECT OF TREATMENTS ON SHOOT CHARACTERS AT MONTHLY INTERVALS

Sl. No.	Treatments	Number of leaves per shoot			Average shoot height (cm)		
		1 MAP (a)	2 MAP (b)	3 MAP (c)	1 MAP (a)	2 MAP (b)	3 MAP (c)
1	S I P 0 0 0	5.22	8.50	9.75	9.47	13.30	18.63
2.	S I P 0 0 1	5.58	9.10	9.62	11.00	15.90	19.63
3.	S I P 0 0 2	5.26	9.30	11.00	11.30	15.80	22.63
4.	S I P 0 0 3	5.61	10.63	10.88	11.36	18.10	19.38
5.	S I P 0 1 0	5.33	9.83	10.17	10.58	16.50	20.63
6.	S I P 0 1 1	5.67	9.70	12.12	11.33	16.30	22.75
7.	S I P 0 1 2	6.00	9.60	10.90	11.83	17.30	20.50
8.	S I P 0 1 3	5.42	10.40	12.50	10.95	18.50	22.87
9.	S I P 1 0 0	5.22	10.23	12.90	11.63	16.90	22.50
10.	S I P 1 0 1	5.86	9.63	11.12	11.58	16.96	22.63
11.	S I P 1 0 2	5.86	9.40	11.12	11.63	17.40	22.38
12.	S I P 1 0 3	5.17	9.90	9.50	11.29	16.00	19.04
13.	S I P 1 1 0	5.50	10.00	11.00	10.13	17.86	20.38
14.	S I P 1 1 1	5.28	10.10	11.87	11.16	18.40	22.38
15.	S I P 1 1 2	6.75	10.90	11.75	10.91	18.20	21.13
16.	S I P 1 1 3	4.86	10.70	11.88	11.08	16.83	21.75
CD 5%		N S	N S	1.4	N S	N S	1.5
S E		0.35	0.70	0.79	0.73	1.17	1.57

a= mean of 6 replications b=mean of 5 replications
c= mean of 4 replications

TABLE - 6

MAIN EFFECT OF TREATMENTS ON SHOOT CHARACTERS AT MONTHLY INTERVALS

Main Effects	Number of leaves per shoot			Average shoot height (cm)		
	1 MAP (a)	2 MAP (b)	3 MAP (c)	1 MAP (a)	2 MAP (b)	3 MAP (c)
Sterilised	5.51	9.63	10.86	10.98	16.46	20.87
Unsterilised	5.56	10.22	11.14	11.18	17.32	21.48
CD - 5%	N S	N S	N S	N S	N S	N S
SE	0.35	0.7	0.79	0.73	1.17	1.57
Uninoculated	5.47	9.58	10.48	11.16	16.29	20.81
Inoculated	5.60	10.27	11.52	11.00	17.49	21.54
CD - 5%	N S	N S	0.70	N S	1.17	N S
SE	0.35	0.7	0.79	0.73	1.17	1.57
0 - P	5.31	9.89	10.44	10.45	16.14	20.46
50% - P	5.59	9.63	11.18	11.27	16.89	21.84
75% - P	5.96	9.80	11.18	11.42	17.17	21.65
100% - P	5.26	10.40	11.18	11.17	17.35	20.76
CD - 5%	0.49	N S	N S	N S	N S	N S
SE	0.35	0.7	0.79	0.73	1.17	1.57

a - Mean of 6 values ; b - Mean of 5 values ; c - Mean of 4 values

Fig. No - 1

EFFECT OF STERILISATION ON NUMBER OF LEAVES PER SHOOT AT MONTHLY INTERVALS

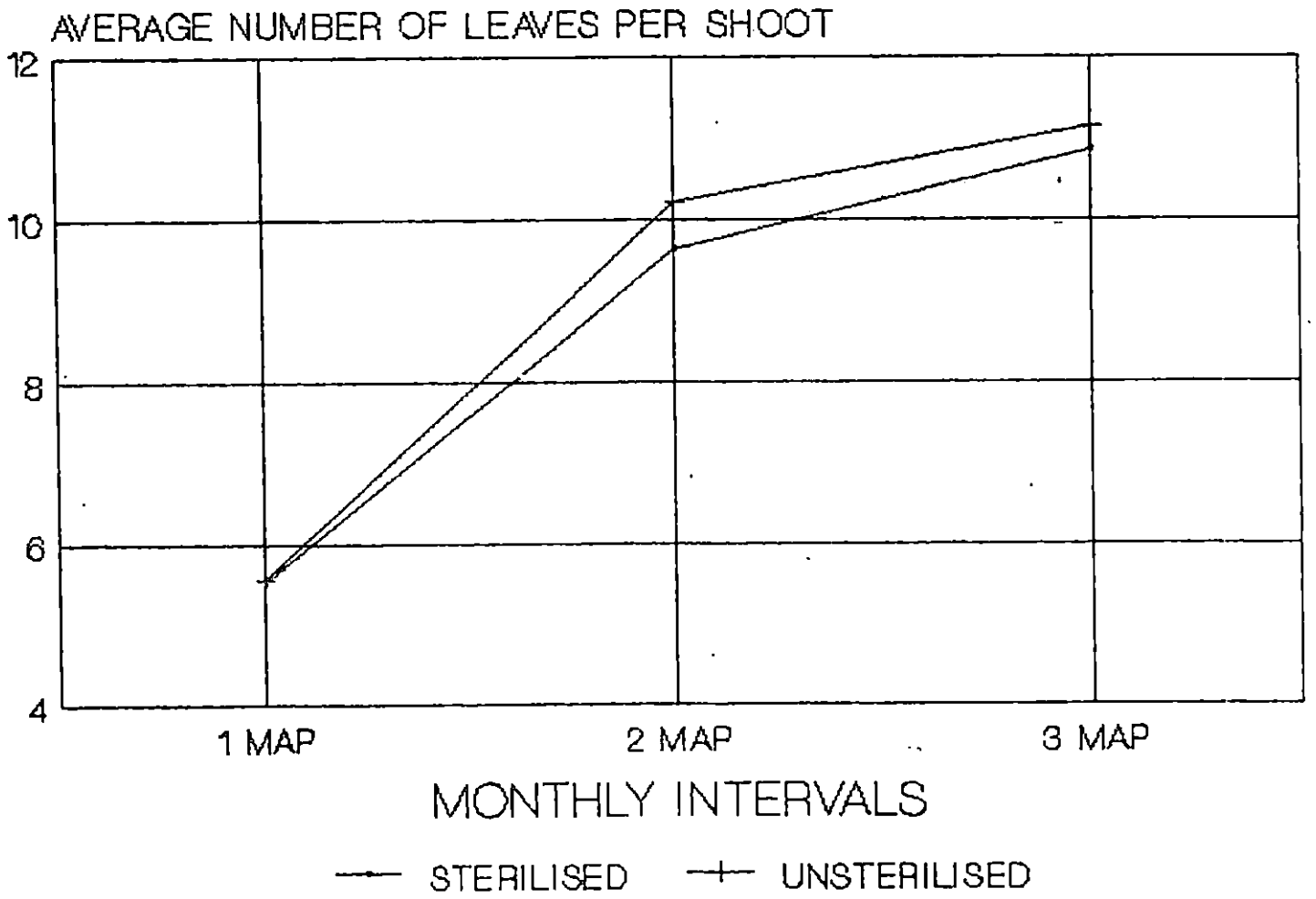


Fig- 2

EFFECT OF INOCULATION ON NUMBER OF LEAVES PER SHOOT AT MONTHLY INTERVALS

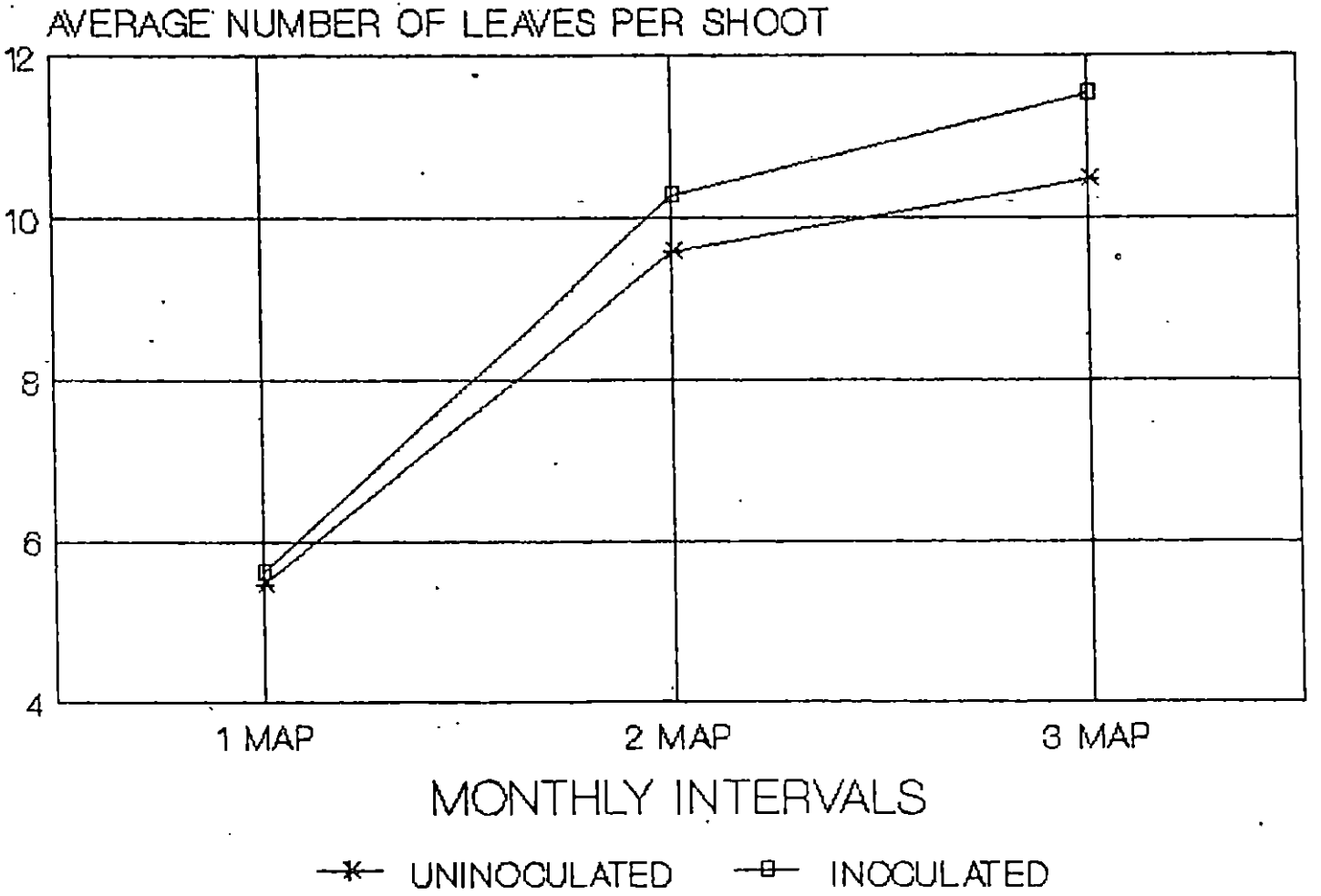
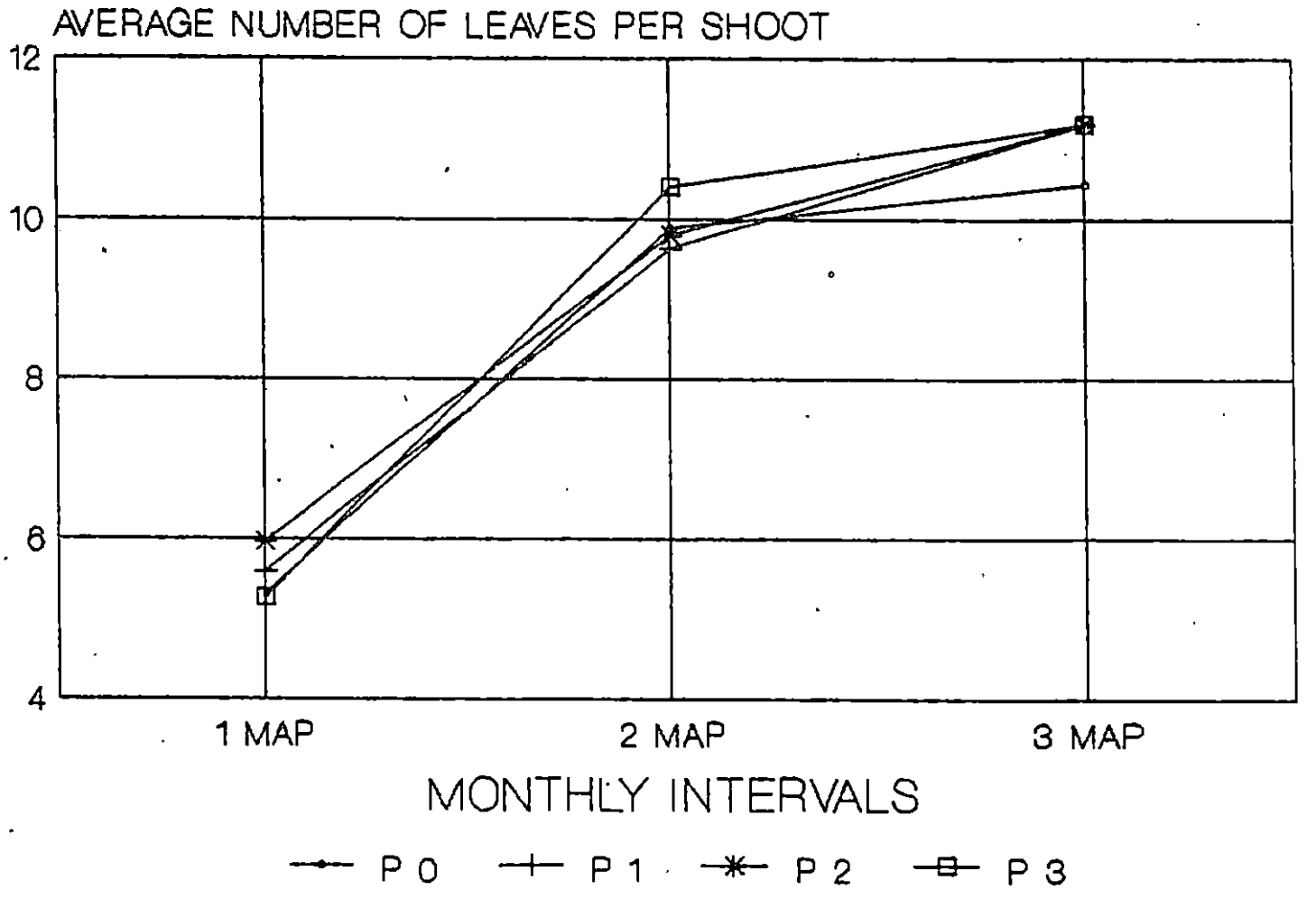


Fig-3

EFFECT OF DOSES OF P ON NUMBER OF LEAVES PER SHOOT AT MONTHLY INTERVALS



Inoculation of VAM fungus increased the height of the plant significantly as recorded at two months after planting. The trend was similar at other sampling periods also eventhough the data were not statistically significant. Rock phosphate application at graded levels could not influence the shoot height significantly.

The average number of primary roots of cassava at three months after planting was between 40 and 60. The number of secondary roots and tertiary roots ranged from 140 to 212 and one to three respectively. One remarkable observation was the significant variation in branching of roots between levels of inoculation and sterilisation (Tables 7 and 8).

With respect to the length of primary, secondary and tertiary roots, it was seen that the treatments could not significantly influence these parameters.

Increasing levels of phosphorus application has resulted in higher number of primary roots. The mean values ranged from 51.33 at P_0 level to 56.83 at P_2 level (Table 8).

Fig-4

EFFECT OF STERILISATION ON AVERAGE SHOOT HEIGHT (cm) AT MONTHLY INTERVALS

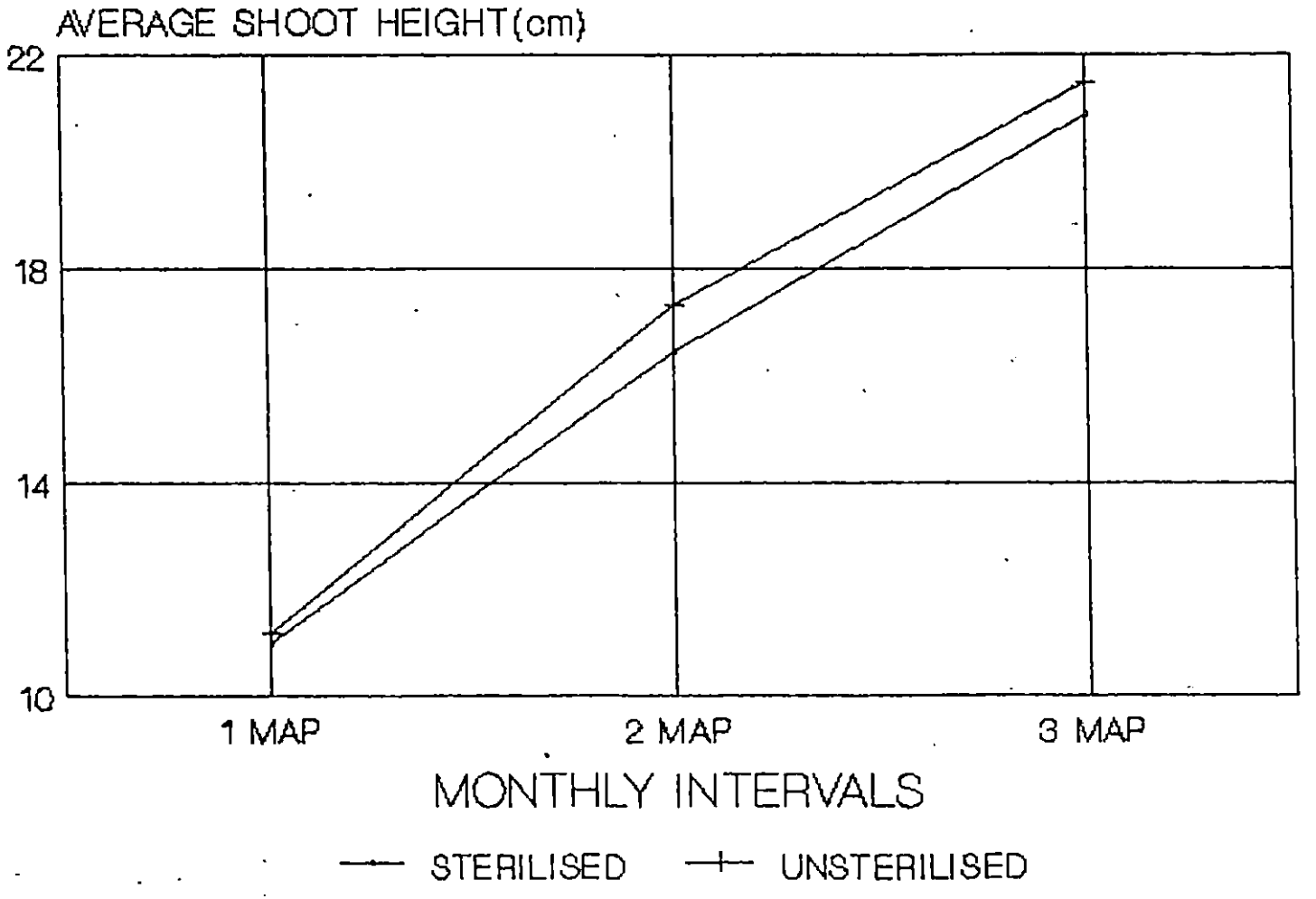


Fig-5

EFFECT OF INOCULATION ON AVERAGE SHOOT HEIGHT(cm) AT MONTHLY INTERVALS

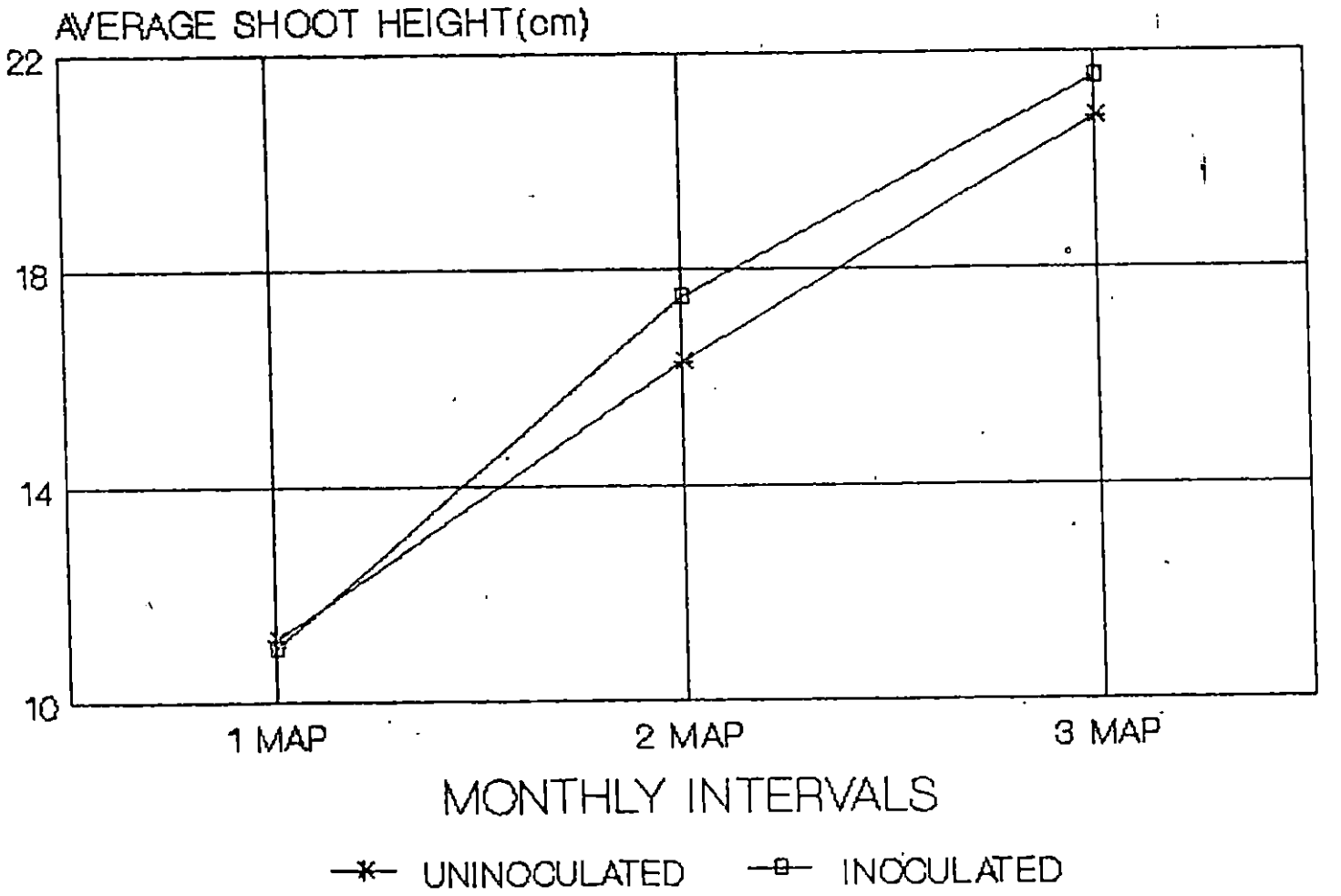


Fig-6

EFFECT OF DOSES OF P ON AVERAGE SHOOT HEIGHT (cm) AT MONTHLY INTERVALS

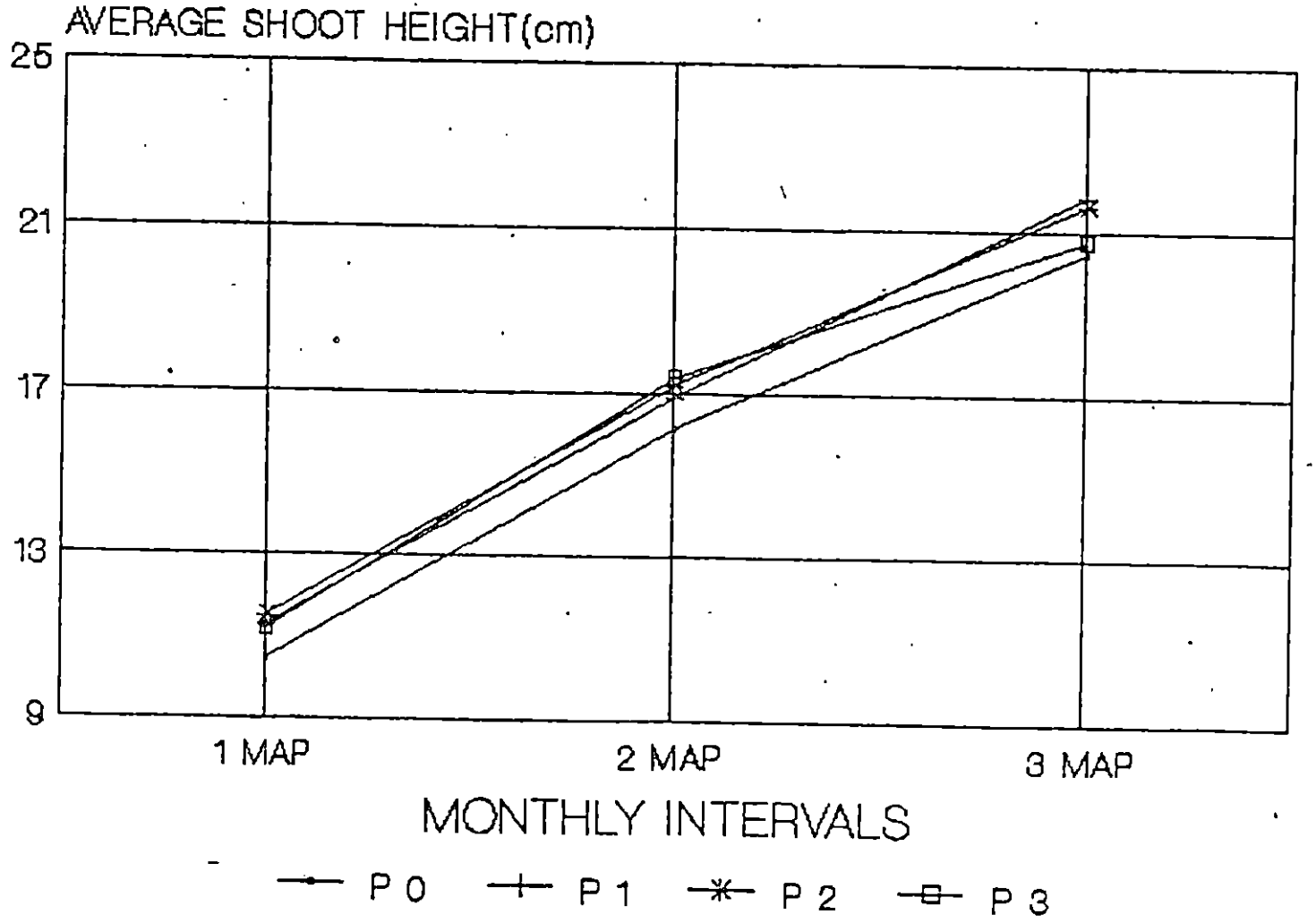


TABLE - 7

EFFECT OF TREATMENTS ON ROOT CHARACTERS AT THREE MAP

Sl. No.	Treatments	Av.No primary roots per plant	Av.No Secondary roots per plant	Av.No. tertiary roots per plant	Av.length Primary roots(cm)	Av.length secondary roots(cm)	Av.length tertiary roots(cm)
1.	S I P 0 0 0	53.00	188.33	2.51	36.55	7.16	1.53
2.	S I P 0 0 1	51.00	165.33	1.86	35.11	5.86	1.85
3.	S I P 0 0 2	59.33	184.0	1.74	39.55	6.08	1.37
4.	S I P 0 0 3	47.00	212.33	4.4	39.55	7.58	1.81
5.	S I P 0 1 0	41.33	168.00	1.73	35.55	6.44	1.96
6.	S I P 0 1 1	57.00	164.00	1.18	65.33	5.44	1.00
7.	S I P 0 1 2	56.33	156.77	1.50	33.55	4.78	1.03
8.	S I P 0 1 3	52.67	177.00	1.20	35.11	5.11	0.95
9.	S I P 1 0 0	55.67	170.33	1.56	30.77	5.48	1.36
10	S I P 1 0 1	54.0	168.66	2.66	37.00	6.07	1.37
11	S I P 1 0 2	55.33	164.00	3.13	36.00	5.37	1.14
12	S I P 1 0 3	52.67	162.00	2.70	34.55	6.22	1.66
13	S I P 1 1 0	55.33	164.00	1.96	33.89	6.59	1.03
14	S I P 1 1 1	59.33	151.66	1.40	38.00	5.48	0.56
15	S I P 1 1 2	56.33	168.33	1.80	34.77	6.43	1.14
16	S I P 1 1 3	55.33	139.00	1.37	36.11	7.44	1.44
CD 5%		N S	N S	N S	N S	N S	N S
S E		4.36	13.74	0.69	2.84	0.75	0.33

N S - variation is not significant

TABLE - 8

MAIN EFFECT OF TREATMENTS ON ROOTS CHARACTERS AT THREE MAP

Main Effects	Av.No. Primary Roots per plant	Av.No. Secondary Roots per Prim.Root	Av.No Tertiary Roots per Sec.Root	Av.Length of Prim. Roots (cm)	Av.Length of Sec. Roots (cm)	Av.Length of Ter. Roots (cm)
Sterilised	52.20	176.95	2.01	36.29	6.05	1.44
Unsterilised	55.54	161.00	2.07	35.13	6.13	1.21
CD - 5%	N S	13.98	N S	N S	N S	N S
SE	4.36	13.47	0.69	2.84	0.75	0.33
Uninoculated	53.50	176.95	2.57	36.13	6.23	1.51
Inoculated	54.25	161.08	1.51	35.29	5.96	1.14
CD - 5%	N S	13.98	0.70	N S	N S	0.33
SE	4.36	13.47	0.69	2.84	0.75	0.33
0 - P	51.33	172.66	1.94	34.19	6.42	1.47
50% - P	55.33	162.41	1.77	36.36	5.71	1.19
75% - P	56.83	168.25	2.04	36.97	5.66	1.17
100% -P	52.00	172.58	2.41	36.33	6.59	1.47
CD - 5%	N S	N S	N S	N S	N S	N S
SE	4.36	13.47	0.69	2.84	0.75	0.33

N S - variation is not significant

4.3. Mycorrhizal colonisation

Data on the percentage of mycorrhizal infection is provided in Table 9. Since the observation warranted destructive sampling data were collected for one replication each at the two stages of sampling and three replications at three months after planting.

Little infection was noticed in the sterile uninoculated soils during the three months period of crop growth. However, in the non sterile, uninoculated soils infection was noted only from two months after planting. The rates of infection was nil at 1 AP, it was 10% at 2 MAP and 35 to 40% at 3 MAP. In contrast, the infection rates in the plants where VAM fungus was inoculated was much higher than the uninoculated plants. Here the infection could be observed the first month (13 to 15%) which increased steadily to more than 90% in many cases at third month after planting. There was no remarkable variation among the treatment combinations in the rates of infection.

4.4. Nutritional status of cassava during the experimental period (composition of YFEL)

The composition of Youngest Fully Emerged Leaf (YFEL) was in forms of major and minor nutrient elements was

TABLE - 9

EFFECTS OF TREATMENTS ON RATE OF VAM ASSOCIATION

AT MONTHLY INTERVALS (PERCENTAGE INFECTION)

Sl. No.	Treatments	1 MAP	2 MAP	3 MAP			
				R1	R2	R3	Mean
1.	S I P 0 0 0	NIL	NIL	NIL	NIL	NIL	NIL
2.	S I P 0 0 1	"	"	"	"	"	"
3.	S I P 0 0 2	"	"	"	"	"	"
4.	S I P 0 0 3	"	"	"	"	"	
5.	S I P 0 1 0	14.50	52.50	88.25	82.75	88.00	86.33
6.	S I P 0 1 1	13.50	60.50	92.50	89.25	90.00	90.58
7.	S I P 0 1 2	15.50	65.25	90.50	88.75	92.50	90.58
8.	S I P 0 1 3	7.50	51.50	85.00	84.75	85.25	85.00
9.	S I P 1 0 0	NIL	10.25	38.25	30.50	36.75	35.17
10.	S I P 1 0 1	"	11.50	40.50	42.00	36.50	39.67
11.	S I P 1 0 2	"	10.50	35.00	37.00	37.25	36.42
12.	S I P 1 0 3	"	10.00	34.25	35.75	33.50	34.50
13.	S I P 1 1 0	15.50	40.50	85.00	87.00	86.75	86.25
14.	S I P 1 1 1	15.00	38.25	82.50	83.75	80.50	82.25
15.	S I P 1 1 2	14.75	38.50	80.25	82.50	80.50	81.08
16.	S I P 1 1 3	14.00	36.25	75.50	80.75	77.50	77.92

R - replications

monitored over the three sampling periods. Data are presented on Tables 10, 11 and 12.

(i) Nitrogen :- Among the different major treatments, levels of inoculation of fungus and doses of rock phosphate application produced statistically significant variation at 3 MAP. The mean values for inoculated condition is statistically superior to uninoculated conditions. Similarly the doses of phosphorus also produced satistically significant variation. The incremental addition of phosphorus to the soil resulted in an increase in the concentration of nitrogen in YFEL and the effect was prominent upto P_2 level and decreased afterwards.

(ii) Phosphorus :- The concentration of phosphorus in the YFEL at monthly intervals are recorded and the data are presented in Table 10. The main effects on the phosphorus content of the YFEL are given in Table 12.

The inoculated pots recorded higher concentration of phosphorus in YFEL. During the third sampling period ie., 3 MAP, percent of phosphorus in YFEL showed significant variation among various treatments after statistical analysis. $S_1 I_3 P_3$ treatment combination ie.,

TABLE - 10

EFFECT OF TREATMENTS ON THE CONTENT OF MAJOR AND SECONDARY NUTRIENTS IN Y.F.E.L. AT MONTHLY INTERVALS

Sl. No.	Treatments	N(%)			P(%)		
		1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)
1.	S I P 0 0 0	0.922	0.479	0.603	0.96	0.667	0.362
2.	S I P 0 0 1	0.694	0.625	0.559	0.86	1.163	0.548
3.	S I P 0 0 2	0.559	0.572	0.514	0.59	1.614	0.532
4.	S I P 0 0 3	0.412	0.849	0.425	0.59	0.850	0.437
5.	S I P 0 1 0	0.559	0.250	0.588	0.86	0.638	0.515
6.	S I P 0 1 1	0.585	0.612	0.550	1.03	0.902	0.467
7.	S I P 0 1 2	0.589	0.625	0.563	1.50	1.113	0.467
8.	S I P 0 1 3	0.569	0.638	0.548	1.50	0.868	0.613
9.	S I P 1 0 0	0.333	0.665	0.505	0.85	0.850	0.443
10	S I P 1 0 1	0.466	0.878	0.545	0.77	0.798	0.55
11	S I P 1 0 2	0.652	0.665	0.528	0.76	1.023	0.504
12	S I P 1 0 3	0.559	0.638	0.501	1.07	0.625	0.535
13	S I P 1 1 0	0.603	0.625	0.452	1.90	1.075	0.432
14	S I P 1 1 1	0.599	0.572	0.554	0.93	1.213	0.467
15	S I P 1 1 2	0.816	0.639	0.563	1.18	1.129	0.592
16	S I P 1 1 3	0.692	0.625	0.576	1.50	0.900	0.588
CD 5%		--	--	0.053	--	--	0.083
SE		--	--	0.18	--	--	0.029

(n=3) - mean of three values N S = variation is not significant

TABLE - 10 (Cont...)

EFFECT OF TREATMENTS ON THE CONTENT OF MAJOR

AND SECONDARY NUTRIENTS IN Y.F.E.L. AT MONTHLY INTERVALS

Sl. No.	Treatments	K (%)			Ca(%)			Mg(%)		
		1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)
1.	S I P 0 0 0	1.34	0.81	1.04	18.03	1.58	1.37	0.88	0.53	0.57
2.	S I P 0 0 1	2.18	1.34	1.00	12.36	1.39	1.65	0.48	0.51	0.56
3.	S I P 0 0 2	0.92	0.72	0.75	15.56	1.58	1.19	0.23	0.64	0.46
4.	S I P 0 0 3	1.02	1.01	1.47	10.79	0.85	1.39	0.45	0.56	0.45
5.	S I P 0 1 0	2.16	0.75	0.47	8.53	2.60	1.35	0.40	0.75	0.43
6.	S I P 0 1 1	1.50	1.47	0.60	13.43	1.25	1.22	0.34	0.46	0.40
7.	S I P 0 1 2	1.80	0.89	1.26	13.21	1.32	1.10	0.39	0.42	0.52
8.	S I P 0 1 3	1.50	0.72	1.03	12.23	0.72	1.02	0.48	0.49	0.48
9.	S I P 1 0 0	2.04	0.67	0.55	4.58	1.35	1.75	0.58	0.56	0.74
10	S I P 1 0 1	1.98	0.87	1.02	13.78	1.17	1.63	0.50	0.53	0.39
11	S I P 1 0 2	1.94	0.58	0.63	17.51	1.16	1.88	0.66	0.60	0.78
12	S I P 1 0 3	2.25	0.79	0.77	5.59	1.22	1.59	0.62	0.47	0.82
13	S I P 1 1 0	2.01	0.69	1.33	13.12	1.23	1.47	0.90	0.49	0.76
14	S I P 1 1 1	2.32	0.83	1.29	15.29	1.36	1.63	0.59	0.55	0.86
15	S I P 1 1 2	1.27	0.55	1.56	10.27	1.44	1.62	0.98	0.53	0.70
16	S I P 1 1 3	3.80	0.79	1.06	9.59	1.22	1.60	0.57	0.41	0.89
CD 5%		--	--	0.48	--	--	N S	--	--	N S
SE		--	--	0.17	--	--	0.27	--	--	0.22

(n=3) - mean of three values N S = variation is not significant

100% recommended dose of phosphorus with inoculation of fungus in sterile soil recorded the highest mean value for this parameter (0.613).

The major treatment effects viz, sterilisation, inoculation and P levels produced statistically significant variations in the percent of phosphorus in YFEL. The mean value for the inoculated condition (0.51) was found to be statistically superior to uninoculated condition (0.47).

The variation caused by the doses of phosphorus applied also differed significantly. The incremental increase in the dose of phosphorus caused a similar increase in the concentration of phosphorus in YFEL. The lowest of mean values was recorded for P_0 level (0.43) and the highest for P_3 level (0.54).

(iii) Potassium :- During the first two sampling periods the concentration of potassium in YFEL ranged from 0.92 to 3.8 at 1 MAP, and 0.55 to 1.47 at 2 MAP. The treatments did not show any variations between themselves. At 3 MAP the treatment $S_1 I_1 P_2$ recorded the highest mean value (1.56) and $S_0 I_1 P_0$ recorded the lowest mean value

(0.47). None of the mean effects produced a significant variation in the mean values.

(iv) Calcium :- The concentration of calcium expressed as percent in YFEL at 1 MAP varied from 0.46 to 1.8 and at 2 MAP the values varied from 0.72 to 2.6. These variations however were not statistically significant.

At 3 MAP the treatment $S_1 I_0 P_2$ was found to be superior (1.88) but statistically on par with other treatment combinations.

The effect of sterilisation (1.29) caused a significant difference in the concentration of Ca in YFEL with unsterilised condition (1.65), the later excelled in the mean value. As the dosage of P was increased from P_0 to P_1, the concentration of Ca in YFEL increased to the maximum level and the further addition of P decreased the concentration of Ca in YFEL. However, these variations were not statistically significant.

(v) Magnesium :- The magnesium content of YFEL ranged from 0.23 ($S_0 I_0 P_0$ to 0.98 ($S_1 I_1 P_2$ at 1 MAP and at 2 MAP the values varied from 0.41 to 0.64. At 3 MAP the

TABLE - 11

EFFECT OF TREATMENTS ON THE CONTENT OF MICRO NUTRIENTS IN Y.F.E.L. AT MONTHLY INTERVALS

Treatments	Fe(ppm)			Cu(ppm)		
	1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)
1. S I P 0 0 0	792.2	750.5	212.50	441.7	100.6	76.43
2. S I P 0 0 1	383.5	1616.7	181.60	193.8	83.3	25.63
3. S I P 0 0 2	376.8	462.5	316.00	168.8	113.7	30.57
4. S I P 0 0 3	331.8	506.3	54.43	68.8	63.8	61.87
5. S I P 0 1 0	447.0	731.3	198.83	125.0	48.1	52.73
6. S I P 0 1 1	335.0	429.7	63.27	181.3	56.8	24.73
7. S I P 0 1 2	245.3	425.0	193.93	68.7	43.8	45.83
8. S I P 0 1 3	385.3	600.0	105.97	125.0	50.0	28.83
9. S I P 1 0 0	380.0	925.0	262.93	62.5	26.5	102.98
10 S I P 1 0 1	305.0	581.3	120.43	62.5	40.6	58.97
11. S I P 1 0 2	294.8	481.3	147.10	75.0	33.1	31.62
12. S I P 1 0 3	563.5	500.0	225.23	112.5	46.2	92.93
13. S I P 1 1 0	474.7	631.3	181.07	108.3	30.6	63.97
14. S I P 1 1 1	386.5	331.3	98.00	43.8	28.7	71.37
15. S I P 1 1 2	693.3	318.7	169.37	50.0	31.3	94.17
16. S I P 1 1 3	479.8	650.0	157.10	62.5	63.7	85.00
CD 5%	--	--	71.5	--	--	40.41
S E	--	--	24.98	--	--	14.12

(n=3) - means of three variations. N S - variations is not significant

TABLE - 11 (Cont...)

EFFECT OF TREATMENTS ON THE CONTENT OF MICRO NUTRIENTS IN Y.F.E.L. AT MONTHLY INTERVALS

Treatments	Zn (ppm)			Mn (ppm)		
	1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)
1. S I P 0 0 0	291.6	137.5	448.0	449.9	256.3	262.33
2. S I P 0 0 1	262.5	208.3	224.69	237.5	266.7	278.66
3. S I P 0 0 2	193.8	187.5	192.43	187.5	187.5	282.67
4. S I P 0 0 3	593.8	106.7	158.67	206.3	175.0	183.33
5. S I P 0 1 0	387.5	118.7	135.43	200.0	443.7	152.10
6. S I P 0 1 1	575.0	170.3	124.23	225.0	171.8	245.00
7. S I P 0 1 2	256.3	118.7	173.27	525.0	118.7	316.67
8. S I P 0 1 3	131.3	181.2	219.33	368.7	156.2	243.67
9. S I P 1 0 0	287.5	168.7	325.43	312.5	162.5	560.00
10 S I P 1 0 1	576.8	150.0	881.17	268.8	162.5	373.00
11. S I P 1 0 2	543.8	187.5	101.67	368.8	200.0	427.00
12. S I P 1 0 3	725.0	156.2	112.93	200.0	118.7	508.33
13. S I P 1 1 0	274.9	187.5	122.70	383.3	156.3	387.67
14. S I P 1 1 1	125.0	175.0	111.63	400.0	112.5	472.67
15. S I P 1 1 2	149.9	112.5	126.86	441.6	75.0	456.67
16. S I P 1 1 3	462.5	175.0	134.94	475.0	112.5	585.00
CD 5%	--	--	N S	--	--	189.19
S E	--	--	48.15	--	--	66.09

(n=3) - means of three variations.
N S - variations is not significant

treatment combination $S_{1}I_{1}P_{3}$ recorded the highest mean value (0.89) and the lowest mean value (0.39) was recorded for the treatment $S_{1}I_{0}P_{1}$. The difference was not statistically significant.

Among the main effects computed, the mean value for unsterilised soil was found to be significantly higher (0.73) than that of sterilised soil (0.48).

Though the inoculation recorded a higher mean value for Mg in YFEL (0.63) over uninoculated condition (0.58) the difference is not statistically significant. The incremental addition of phosphorus though resulted in an increased concentration of Mg in YFEL.

(vi) Iron :- The concentration of Fe in YFEL during the lst two sampling did not show much variation statistically. AT 3 MAP the concentrations of Fe in YFEL were found to differ statistically. The treatment mean $S_{0}I_{0}P_{2}$ was found to be statistically superiors to others and registered highest concentration in YFEL (316.0 ppm).

Among the main effects, the inoculation and doses of phosphorus produced significant variations . As the dose

of phosphorus was increased from P0 to P3 level a decrease in the concentration of Fe in YFEL was observed.

(vii) Copper :- The concentration of copper (ppm) at 1MAP and 2 MAP did not show any significant variation among the treatment means whereas at 3 MAP the data varied significantly. Treatment number 9 ($S_{100}IP$) recorded the highest mean value (102.98) whereas treatment 16 ($S_{113}IP$) recorded the least mean value (85.00).

But the levels of inoculation could not produce any significant difference in the concentration of Cu in YFEL. However, the uninoculated plants carried a higher concentration of Cu in YFEL over the inoculated ones.

(viii) Zinc :- The concentration of Zn (ppm) in YFEL at 1 MAP, 2 MAP and 3 MAP did not vary significantly. Among the major effects only sterilisation caused a significant variation and the variations caused by inoculation and graded doses of P application are not statistically significant.

The effect of unsterilisation recorded a significant higher mean value (105.18) over the mean value

recorded for sterilisation (20.95) Though the levels of inoculation did not produce any significant variation, means of inoculated treatments recorded higher values (70.17) than similar untreated conditions (55.95). Similarly, as the dosage of P application were increased, the concentration of Zn in the YFEL also increased. This increase was maximum at P_3 level (71.42) and the lowest at P_0 level (53.39). The differences were not significant statistically.

(ix) Manganese :- During the first two sampling periods ie., at 1 MAP and 2 MAP the treatments do not show any significant variation. Whereas, at 3 MAP the mean values were found to vary significantly. The treatment combination $S_1 I_1 P_3$ recorded a significantly superior mean value (585.0) which was on par with $S_1 I_1 P_1$ (421.67) and $S_1 I_1 P_2$ (456.67). The lowest of mean value was recorded for $S_0 I_1 P_0$ (152.1).

Sterilisation caused a significantly lower mean value for the concentration of Mn in YFEL (245.55). The incremental addition of P level from P_0 to P_3 resulted in an increased concentrations of Mn in YFEL. The mean values were 340.53, 342.33, 370.75 and 380.08 for P_0, P_1 P_2 and

TABLE - 12

MAIN EFFECTS ON NUTRIENT CONTENT IN Y.F.E.L. AT THREE MAP

Main effects	N	P	K	Ca	Mg	Fe	Cu	Mn	Zn
Sterilised	5.44	0.48	0.95	1.29	0.48	165.82	43.32	245.55	209.50
Unsterilised	5.28	0.51	1.03	1.65	0.73	170.15	75.12	471.29	1051.75
CD 5%	N S	2.95	N S	0.27	0.22	N S	14.37	N S	415.5
SE	0.18	0.03	0.17	0.27	0.22	24.98	14.12	66.04	408.15
Uninoculated	5.22	0.47	0.91	1.56	0.58	190.03	60.12	359.41	559.55
Inoculated	5.49	0.51	1.07	1.38	0.63	145.94	58.32	357.43	701.71
CD 5%	0.13	0.03	N S	N S	N S	25.43	N S	N S	N S
S E	0.18	0.03	0.17	0.27	0.22	24.98	14.12	66.04	408.15
0% P	5.37	0.43	0.85	1.48	0.62	213.83	74.02	340.53	533.97
50% P	5.51	0.50	0.98	1.53	0.53	115.83	45.17	342.33	586.60
75% P	5.42	0.48	1.05	1.45	0.61	206.6	50.54	370.75	687.76
100% P	5.12	0.54	1.08	1.40	0.66	135.68	67.15	380.08	714.19
CD 5%	0.2	0.04	N S	N S	N S	35.68	20.32	N S	N S
SE	0.18	0.03	0.17	0.27	0.22	24.98	14.12	66.04	408.15

N S - variation is not significant

P_3 levels respectively. The increase in concentrations of Mn in YFEL when the level of P dose increase from P_0 to P_3 is about 11% . However this difference is not statistically significant.

4.5. Mineral constituents of plant parts

4.5.1. Mineral constituents of the shoot

The data of the effects of treatments on the content of major and secondary nutrients in shoots are provided in Table 13 and that of micronutrients in Table 14. The main effects of the treatment at 3 MAP are given in Table 15.

(i) Nitrogen :- The content of nitrogen in the shoot ranged from 0.25 ($S_0 I_1 P_1$) to 0.43 ($S_1 I_1 P_1$) at 1 MAP and 0.35 ($S_1 I_0 O_0$) to 0.45 ($S_1 I_1 I_3$) at 2 MAP, however this are not statistically significant. At 3 MAP the treatment means varied significantly. The treatment combinations $S_1 I_1 P_1$ and $S_0 I_1 I_3$ recorded the highest of mean values (0.408) and the lowest value was registered for $S_0 I_0 P_0$ (0.337). In the case of main effects, unsterilised soil condition, inoculation of VAM fungus and increased levels of phosphate

TABLE - 13

EFFECT OF TREATMENTS ON THE CONTENT OF MAJOR AND SECONDARY NUTRIENT IN SHOOTS AT MONTHLY INTERVALS

Sl. No.	Treatments	N(%)			P(%)		
		1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)
1.	S I P 0 0 0	0.399	0.37	0.337	0.88	0.64	0.248
2.	S I P 0 0 1	0.306	0.39	0.346	0.69	0.97	0.271
3.	S I P 0 0 2	0.266	0.41	0.355	1.56	0.87	0.305
4.	S I P 0 0 3	0.266	0.41	0.368	0.59	0.83	0.335
5.	S I P 0 1 0	0.360	0.39	0.372	0.65	0.73	0.272
6.	S I P 0 1 1	0.253	0.41	0.390	1.28	0.54	0.297
7.	S I P 0 1 2	0.306	0.43	0.390	0.75	0.72	0.318
8.	S I P 0 1 3	0.386	0.43	0.408	0.11	0.39	0.335
9.	S I P 1 0 0	06330	0.35	0.341	0.50	0.72	0.219
10	S I P 1 0 1	0.330	0.41	0.364	0.52	0.85	0.256
11.	S I P 1 0 2	0.346	0.37	0.337	0.78	0.72	0.258
12.	S I P 1 0 3	0.372	0.43	0.373	0.69	0.64	0.265
13.	S I P 1 1 0	0.399	0.39	0.390	0.59	0.85	0.293
14.	S I P 1 1 1	0.426	0.43	0.408	0.64	0.85	0.316
15.	S I P 1 1 2	0.399	0.43	0.403	0.71	0.75	0.316
16.	S I P 1 1 3	0.412	0.45	0.395	0.84	0.83	0.344
CD 5%		--	--	0.04	--	--	0.02
S E		--	--	0.16	--	--	0.007

(n=3) - mean of three values N S - variables is not significant

TABLE - 13 (Cont...)

EFFECT OF TREATMENTS ON THE CONTENT OF MAJOR AND SECONDARY NUTRIENT IN SHOOTS AT MONTHLY INTERVALS

Sl. No.	Treatments	K (%)			Ca(%)			Mg(%)		
		1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)
1.	S I P 0 0 0	0.99	0.63	0.765	1.54	2.22	1.89	0.803	0.462	0.502
2.	S I P 0 0 1	1.27	0.57	0.524	1.94	2.72	1.79	0.699	0.522	0.625
3.	S I P 0 0 2	0.81	0.5	0.554	1.21	2.02	1.73	0.55	0.608	0.651
4.	S I P 0 0 3	0.94	0.66	0.683	1.51	2.59	2.06	0.823	0.521	0.632
5.	S I P 0 1 0	1.80	0.66	0.578	1.76	1.87	1.27	0.672	0.420	0.612
6.	S I P 0 1 1	2.03	0.94	0.787	1.98	1.73	1.61	0.578	0.551	0.625
7.	S I P 0 1 2	1.89	0.70	0.686	1.19	1.66	1.55	0.584	0.468	0.655
8.	S I P 0 1 3	1.56	0.62	0.831	2.1	1.70	1.85	0.75	0.510	0.659
9.	S I P 1 0 0	1.07	0.56	0.714	1.09	1.75	1.60	0.651	0.48	0.500
10	S I P 1 0 1	1.36	0.50	0.545	1.37	2.20	2.31	0.563	0.571	0.542
11.	S I P 1 0 2	1.26	0.73	0.672	1.76	1.74	2.05	0.66	0.546	0.518
12.	S I P 1 0 3	1.62	0.54	0.453	1.19	2.38	2.09	0.559	0.469	0.536
13.	S I P 1 1 0	0.94	0.41	0.682	1.29	1.32	2.213	0.713	0.493	0.672
14.	S I P 1 1 1	2.05	0.42	0.694	1.93	3.01	1.57	1.24	0.681	0.750
15.	S I P 1 1 2	1.47	0.39	0.497	1.12	2.09	2.18	0.48	0.628	0.987
16.	S I P 1 1 3	1.20	0.59	0.544	1.31	1.58	1.64	0.78	0.373	0.850
CD 5%		--	--	N S	--	--	N S	--	--	0.23
S E		--	--	0.16	--	--	0.25	--	--	0.05

(n=3) - mean of three values N S - variables is not significant

imparted significant improvement in the nitrogen content of shoot, over the respective control treatment (Table 15).

(ii) Phosphorus :- During the first two samplings the data on the concentration of phosphorus in the shoot ranged between 0.5 ($S_{1}I_{0}P_{0}$) to 1.56 ($S_{0}I_{0}P_{2}$) and 0.39 ($S_{0}I_{1}P_{3}$) to 0.97 ($S_{0}I_{0}P_{1}$) at 1 MAP and 2 MAP respectively. The statistically differing values at 3 MAP ranged from 0.219 ($S_{1}I_{0}P_{0}$) to 0.344 ($S_{1}I_{1}P_{3}$).

The plants grown in sterilised soil rcorded higher percent of this element in shoots (0.29) than those of unsterilised medium. The inoculated plants also recorded higher mean value (0.31) than uninoculated counterparts (0.27). As the dosage of phosphorus was increased from P_{0} level to P_{3} level the percent of phosphorus in shoot showed a increase form 0.25 to 0.32. The P levels P_{1} and P_{2} recorded 0.28 and 0.29 percentages respectively.

(iii) Potassium :- The concentrations of this element in the above ground portions of the test crop is not at all influenced by any of the treatment combinations at all stages of the crop growth period of this experiment.

However, the percent of this nutrient in the shoot portion at 1MAP, 2MAP and 3 MAP ranged from 0.81 ($S_{0\,0\,2}^{I\,P}$) to 2.05 ($S_{1\,1\,1}^{I\,P}$); 0.39 ($S_{1\,1\,2}^{I\,P}$) to 0.94 ($S_{0\,1\,1}^{I\,P}$) and 0.49 ($S_{1\,1\,2}^{I\,P}$) to 0.83 ($S_{0\,1\,3}^{I\,P}$) respectively. Similarly none of the main effects could produce any significantly variation among their means.

(iv) Calcium :- The concentrations of calcium in the shoots of the test crop was not influenced by any of the treatment combinations tested at all stages of sampling. However, the per cent of this nutrient element at 1 MAP, 2 MAP and 3 MAP ranged from 1.09 ($S_{1\,0\,0}^{I\,P}$) to 2.1 ($S_{0\,1\,3}^{I\,P}$) 1.32 ($S_{1\,1\,0}^{I\,P}$) to 3.01 ($S_{1\,1\,1}^{I\,P}$) and 1.27 ($S_{0\,1\,0}^{I\,P}$) to 2.31 ($S_{1\,0\,2}^{I\,P}$) respectively. None of the main effects could influence the parameter in a significant way (Table 15).

(v) Magnesium :- The concentration of magnesium in the shoots of the crop plant at 1 MAP and 2 MAP did not show any statistical significance. The percent of magnesium in the analysed part ranged from 0.48 ($S_{1\,1\,2}^{I\,P}$) to 1.24 ($S_{1\,1\,1}^{I\,P}$) and 0.37 ($S_{1\,1\,3}^{I\,P}$) to 0.68 ($S_{1\,1\,1}^{I\,P}$) at 1 MAP and 2 MAP respectively. On the other hand, at 3 MAP the mean values showed significant variations among them. The treatment $S_{1\,1\,2}^{I\,P}$ (0.987) recorded a significantly higher

TABLE - 14

EFFECT OF TREATMENTS ON THE CONTENT OF MICRONUTRIENTS IN SHOOTS AT MONTHLY INTERVALS

Sl. No.	Treatments	Fe(%)			Cu(%)		
		1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)
1.	S I P 0 0 0	0.484	0.071	0.239	0.154	0.051	0.055
2.	S I P 0 0 1	0.251	0.078	0.117	0.149	0.039	0.043
3.	S I P 0 0 2	0.286	0.094	0.135	0.149	0.039	0.038
4.	S I P 0 0 3	0.303	0.040	0.144	0.156	0.051	0.038
5.	S I P 0 1 0	0.140	0.109	0.434	0.146	0.051	0.042
6.	S I P 0 1 1	0.230	0.150	0.275	0.151	0.022	0.045
7.	S I P 0 1 2	0.420	0.157	0.255	0.155	0.044	0.041
8.	S I P 0 1 3	0.199	0.150	0.411	0.151	0.054	0.039
9.	S I P 1 0 0	0.239	0.067	0.112	0.154	0.030	0.045
10.	S I P 1 0 1	0.259	0.062	0.449	0.157	0.054	0.050
11.	S I P 1 0 2	0.254	0.109	0.666	0.157	0.04	0.057
12.	S I P 1 0 3	0.100	0.055	0.913	0.150	0.038	0.038
13.	S I P 1 1 0	0.268	0.270	0.533	0.157	0.030	0.035
14.	S I P 1 1 1	0.369	0.061	0.850	0.154	0.050	0.047
15.	S I P 1 1 2	0.283	0.020	0.110	0.150	0.040	0.028
16.	S I P 1 1 3	0.523	0.062	0.252	0.150	0.060	0.034
CD 5%		--	--	N S	--	--	N S
S E		--	--	0.08	--	--	0.01

(n=3) - mean of three values. N S - variations is not significant

TABLE - 14 (Cont...)

EFFECT OF TREATMENTS ON THE CONTENT OF MICRONUTRIENTS IN SHOOTS AT MONTHLY INTERVALS

Sl. No.	Treatments	Mn(%)			Zn(%)		
		1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)
1.	S I P 0 0 0	0.025	0.014	0.027	0.192	0.006	0.084
2.	S I P 0 0 1	0.018	0.020	0.025	0.175	0.004	0.098
3.	S I P 0 0 2	0.013	0.016	0.026	0.183	0.014	0.067
4.	S I P 0 0 3	0.011	0.022	0.024	0.318	0.011	0.058
5.	S I P 0 1 0	0.010	0.023	0.024	0.019	0.011	0.058
6.	S I P 0 1 1	0.013	0.009	0.021	0.102	0.008	0.057
7.	S I P 0 1 2	0.012	0.010	0.022	0.133	0.007	0.055
8.	S I P 0 1 3	0.019	0.020	0.025	0.098	0.018	0.059
9.	S I P 1 0 0	0.003	0.010	0.028	0.145	0.007	0.056
10.	S I P 1 0 1	0.023	0.010	0.026	0.122	0.017	0.072
11.	S I P 1 0 2	0.009	0.019	0.026	0.563	0.004	0.056
12.	S I P 1 0 3	0.005	0.015	0.026	0.259	0.006	0.058
13.	S I P 1 1 0	0.009	0.008	0.031	0.149	0.008	0.055
14.	S I P 1 1 1	0.014	0.013	0.016	0.284	0.008	0.047
15.	S I P 1 1 2	0.004	0.012	0.030	0.109	0.003	0.059
16.	S I P 1 1 3	0.005	0.098	0.025	0.133	0.002	0.065
CD 5%		--	--	N S	--	--	N S
S E		--	--	0.003	--	--	0.04

(n=3) - mean of three values. N S - variations is not significant

TABLE 15

MAIN EFFECTS ON NUTRIENTS CONTENTS IN SHOOTS AT THREE MAP

Main effects	N	P	K	Ca	Mg	Fe	Cu	Mn	Zn
Sterilised	3.70	0.29	0.67	1.72	0.62	0.25	0.04	0.024	0.06
Unsterilised	3.76	0.28	0.60	1.96	0.63	0.09	0.04	0.026	0.05
CD 5%	N S	N S	N S	N S	N S	N S	N S	N S	N S
SE	0.16	0.07	0.16	0.25	0.05	0.08	0.01	0.003	0.04
Uninoculated	3.52	0.27	0.61	1.94	0.65	0.11	0.04	0.026	0.06
Inoculated	3.94	0.31	0.65	1.73	0.66	0.23	0.03	0.024	0.05
CD 5%	0.05	N S	N S	N S	N S	N S	N S	N S	N S
SE	0.16	0.07	0.16	0.25	0.05	0.08	0.01	0.003	0.04
0% P	3.60	0.25	0.68	1.74	0.52	0.20	0.04	0.028	0.063
50% P	3.70	0.08	0.66	7.75	0.52	0.13	0.04	0.022	0.068
75% P	3.77	0.29	0.66	1.94	0.62	0.13	0.04	0.026	0.059
100% P	3.85	0.32	0.62	1.91	0.62	0.22	0.03	0.025	0.060
CD 5%	N S	N S	N S	N S	N S	N S	N S	N S	N S
SE	0.16	0.07	0.16	0.25	0.05	0.08	0.01	0.003	0.04

N S - variation is not significant

mean value and the treatment $S_{1}I_{0}P_{0}$ (0.5) recorded the lowest mean value. The inoculated plans recorded significantly higher concentrations of Mg in shoot (0.66) when compared with uninoculated plants (0.65).

(vi) Micronutrients :- Neither the treatment combinations, nor the main effects showed statistically significant influence on the contents of iron, copper, zinc and manganese in the cassava shoot at the three stages of observation. Data presented in Tables 14 and 15 shows the trends observed during the investigation.

4.5.2. Mineral constituents of root

The concentration of essential plant nutrients in the root portions are estimated and expressed as percentages in Tables 16, 17 and 18.

(i) Nitrogen :- The per cent of N_{2} at 1 MAP and at 2 MAP did not show any significant variation among the treatments tested. At 3 MAP the treatment $S_{1}I_{1}P_{1}$ (0.44) recorded the highest mean value which is statistically on par with $S_{1}I_{1}P_{3}$ (0.41); $S_{1}I_{1}P_{0}$ (0.42) and $S_{0}I_{0}P_{3}$ (0.41) and these are significantly superior to all other treatment combinations. In contrast, $S_{0}I_{0}P_{0}$ recorded

the lowest mean value (0.31). The mean values of the main effects did not vary significantly (Tables 18).

(ii) Phosphorus :- The percent of this element at first two sampling stages were not remarkably influenced by the different treatment combinations tried. AT 3 MAP $S_{0\,0\,1}$ recorded the highest (0.875) mean value and this treatment is statistically on par with T_{13}, T_{14}, T_{12} and T_{1}; and statistically superior to other treatments. The lowest mean value was recorded for $S_{0\,1\,0}$ (0.52).

None of the main effects could produce any significant variation in the mean values, eventhough the root phosphorus concentration was enhanced by soil sterilisation, VAM inoculation and phosphate addition.

(iii) Potassium :- The concentration of this element in the below ground portion of the crop was not significantly influenced by any of the treatment combinations, at all stages of observation. However, the percent of this nutrient in the root portion at 1 MAP, 2 MAP and 3 MAP ranged from 0.29 ($S_{0\,1\,3}$) to 1.08 ($S_{0\,1\,0}$); 0.38 ($S_{1\,1\,2}$) to 0.97 ($S_{0\,1\,2}$) and 0.85 ($S_{0\,1\,2}$) to 1.68 ($S_{1\,1\,0}$) respectively.

TABLE - 16

EFFECT OF TREATMENTS ON THE CONTENT OF

MAJOR AND SECONDARY NUTRIENTS IN ROOTS AT MONTHLY INTERVALS

Sl. No.	Treatments	N (%)			P (%)		
		1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)
1.	S I P 0 0 0	0.17	0.39	0.31	0.90	1.15	0.82
2.	S I P 0 0 1	0.16	0.41	0.36	0.72	0.88	0.88
3.	S I P 0 0 2	0.11	0.37	0.39	0.83	1.06	0.77
4.	S I P 0 0 3	0.17	0.45	0.41	0.86	0.78	0.79
5.	S I P 0 1 0	0.12	0.37	0.35	0.88	1.11	0.52
6.	S I P 0 1 1	0.13	0.39	0.39	0.85	1.09	0.50
7.	S I P 0 1 2	0.14	0.41	0.37	0.73	1.09	0.71
8.	S I P 0 1 3	0.15	0.44	0.40	0.72	0.90	0.69
9.	S I P 1 0 0	0.14	0.39	0.40	0.71	1.06	0.54
10.	S I P 1 0 1	0.12	0.45	0.39	0.71	0.08	0.55
11.	S I P 1 0 2	0.10	0.45	0.38	0.13	0.97	0.58
12.	S I P 1 0 3	0.10	0.44	0.36	0.06	0.01	0.81
13.	S I P 1 1 0	0.10	0.39	0.42	0.06	1.09	0.86
14.	S I P 1 1 1	0.10	0.41	0.44	0.09	1.08	0.76
15.	S I P 1 1 2	0.11	0.44	0.39	0.06	1.32	0.69
16.	S I P 1 1 3	0.11	0.47	0.41	0.07	0.71	0.75
CD 5%		--	--	0.03	--	--	0.11
S E		--	--	0.037	--	--	0.27

(n=3) - mean of three values. N S - variation is not significant

TABLE - 16 (Cont....)

EFFECT OF TREATMENTS ON THE CONTENT OF

MAJOR AND SECONDARY NUTRIENTS IN ROOTS AT MONTHLY INTERVALS

Sl. No.	Treatments	K (%)			Ca (%)			Mg (%)		
		1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)
1.	S I P 0 0 0	0.44	0.64	1.07	1.55	1.06	1.04	0.12	0.40	0.68
2.	S I P 0 0 1	0.38	0.51	0.86	1.89	1.25	1.20	0.28	0.39	0.71
3.	S I P 0 0 2	0.34	0.68	0.92	2.87	1.25	0.95	0.14	0.35	0.68
4.	S I P 0 0 3	0.34	0.57	1.03	1.47	1.12	0.99	0.21	0.46	0.68
5.	S I P 0 1 0	1.08	0.79	0.98	2.29	1.52	1.10	0.20	0.39	0.83
6.	S I P 0 1 1	0.77	0.88	0.86	1.79	1.05	1.22	0.12	0.39	0.83
7.	S I P 0 1 2	0.76	0.97	0.85	1.68	1.10	0.07	0.33	0.32	0.76
8.	S I P 0 1 3	0.29	0.92	1.01	2.41	1.45	0.93	0.26	0.41	0.82
9.	S I P 1 0 0	0.43	0.69	1.07	0.95	1.36	1.40	0.24	0.49	0.70
10.	S I P 1 0 1	0.34	0.56	1.01	1.33	1.38	1.21	0.25	0.53	0.68
11.	S I P 1 0 2	0.73	0.46	0.93	1.54	1.26	1.03	0.21	0.43	0.75
12.	S I P 1 0 3	0.98	0.82	0.92	1.52	1.34	1.19	0.17	0.44	0.78
13.	S I P 1 1 0	0.74	0.44	1.68	1.55	1.38	1.12	0.24	0.38	0.84
14.	S I P 1 1 1	0.77	0.45	0.98	1.56	1.32	1.18	0.22	0.38	0.83
15.	S I P 1 1 2	0.71	0.38	0.93	1.55	1.35	1.26	0.20	0.42	0.99
16.	S I P 1 1 3	0.42	0.57	0.92	1.61	1.42	1.19	0.22	0.34	0.01
CD 5%		--	--	N S	--	--	N S	--	--	N S
S E		--	--	0.24	--	--	0.45	--	--	0.26

(n=3) - mean of three values N S - variation is not significant

(iv) Calcium :- The content of Ca in the root of the test crop was not influenced by any of the treatment combinations tested at all stages of sampling. The mean values on the content of Ca in root varied form 0.95 ($S_{1}I_{0}P_{0}$) to 2.87 ($S_{0}I_{0}P_{2}$) at 1 MAP, 1.05 ($S_{0}I_{1}P_{1}$) to 1.52 ($S_{0}I_{1}P_{0}$) at 2 MAP and 0.93 ($S_{0}I_{1}P_{3}$) to 1.26 ($S_{1}I_{1}P_{2}$) at 3 MAP. None of the main effects could influence the mean values (Table 18).

(v) Magnesium :- The percentage content of this element in the cassava root was not significantly influenced by any of the sixteen treatment combinations tested at all stages of the crop growth period. In the case of main effects, inoculated plants contained more percent of magnesium in their roots (0.88) than their uninoculated counterparts (0.71). The difference was not statistically significant.

(iv) Micronutrients :- Data on the micronutrient concentration of cassava roots are presented in Tables 17 and 18. Though there was wide variation among the observations, the results did not reveal any definite trends in response to applied treatments.

TABLE - 17

EFFECT OF TREATMENTS ON THE CONTENT OF MICRONUTRIENTS IN ROOTS AT MONTHLY INTERVALS

Sl. No.	Treatments	Fe(%)			Cu(%)		
		1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)
1.	S I P 0 0 0	0.472	0.561	0.563	0.043	0.060	0.043
2.	S I P 0 0 1	0.740	0.670	0.637	0.088	0.060	0.049
3.	S I P 0 0 2	0.500	0.481	0.792	0.088	0.090	0.038
4.	S I P 0 0 3	0.721	0.858	0.671	0.045	0.090	0.049
5.	S I P 0 1 0	0.685	0.540	0.787	0.050	0.012	0.043
6.	S I P 0 1 1	0.455	0.891	0.724	0.050	0.070	0.051
7.	S I P 0 1 2	1.125	0.642	0.886	0.016	0.080	0.047
8.	S I P 0 1 3	0.757	0.912	0.771	0.040	0.040	0.049
9.	S I P 1 0 0	0.560	0.073	0.740	0.038	0.013	0.043
10.	S I P 1 0 1	0.582	0.621	0.652	0.038	0.011	0.043
11.	S I P 1 0 2	0.648	0.658	0.663	0.053	0.015	0.044
12.	S I P 1 0 3	0.521	0.583	0.679	0.038	0.044	0.024
13.	S I P 1 1 0	0.576	0.592	0.799	0.043	0.040	0.054
14.	S I P 1 1 1	0.539	0.550	0.602	0.050	0.060	0.054
15.	S I P 1 1 2	0.542	0.520	0.847	0.040	0.090	0.056
16.	S I P 1 1 3	0.563	0.716	0.794	0.018	0.040	0.070
CD 5%		--	--	N S	--	--	N S
S E		--	--	0.096	--	--	0.024

(n=3) - mean of three values. N S - variation is not significant

TABLE - 17 (Cont...)

EFFECT OF TREATMENTS ON THE CONTENT OF MICRONUTRIENTS IN ROOTS AT MONTHLY INTERVALS

Sl. No.	Treatments	Mn(%)			Zn(%)		
		1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)
1.	S I P 0 0 0	0.013	0.046	0.045	0.013	0.020	0.095
2.	S I P 0 0 1	0.023	0.060	0.048	0.028	0.021	0.098
3.	S I P 0 0 2	0.013	0.033	0.047	0.098	0.019	0.098
4.	S I P 0 0 3	0.021	0.059	0.039	0.011	0.043	0.105
5.	S I P 0 1 0	0.019	0.063	0.048	0.024	0.025	0.115
6.	S I P 0 1 1	0.011	0.052	0.041	0.018	0.018	0.103
7.	S I P 0 1 2	0.014	0.044	0.043	0.080	0.021	0.113
8.	S I P 0 1 3	0.019	0.054	0.049	0.073	0.016	0.115
9.	S I P 1 0 0	0.023	0.097	0.045	0.070	0.053	0.092
10.	S I P 1 0 1	0.029	0.329	0.086	0.014	0.026	0.096
11.	S I P 1 0 2	0.029	0.086	0.041	0.039	0.018	0.099
12.	S I P 1 0 3	0.064	0.059	0.030	0.022	0.022	0.107
13.	S I P 1 1 0	0.020	0.061	0.061	0.011	0.016	0.112
14.	S I P 1 1 1	0.026	0.063	0.046	0.016	0.012	0.115
15.	S I P 1 1 2	0.018	0.093	0.067	0.033	0.027	0.112
16.	S I P 1 1 3	0.022	0.049	0.057	0.018	0.019	0.019
CD 5%		--	--	N S	--	--	N S
S E		--	--	0.009	--	--	0.073

(n=3) - mean of three values. N S - variation is not significant

TABLE 18

MAIN EFFECTS ON NUTRIENT CONTENTS IN ROOTS AT THREE MAP

Main effects	N	P	K	Ca	Mg	Fe	Cu	Mn	Zn
Sterilised	3.77	0.72	0.95	1.06	0.74	0.72	0.04	0.04	0.10
Unsterilised	3.97	0.69	0.98	1.20	0.82	0.72	0.05	0.05	0.13
CD 5%	N S	N S	N S	N S	N S	N S	N S	N S	N S
SE	0.1	0.037	0.24	0.45	0.26	0.09	0.02	0.009	0.07
Uninoculated	3.78	0.69	0.97	1.12	0.71	0.67	0.04	0.04	0.12
Inoculated	3.95	0.70	0.95	1.14	0.86	0.77	0.05	0.05	0.11
CD 5%	N S	N S	N S	N S	N S	N S	N S	N S	N S
S E	0.1	0.037	0.24	0.45	0.26	0.09	0.02	0.009	0.07
0% P	3.78	0.65	1.05	1.16	0.75	0.72	0.04	0.04	0.15
50% P	3.95	0.71	0.93	1.20	0.76	0.65	0.04	0.04	0.10
75% P	3.80	0.68	0.91	1.08	0.80	0.79	0.04	0.04	0.10
100% P	3.95	0.75	0.97	1.08	0.82	0.72	0.05	0.05	0.11
CD 5%	N S	N S	N S	N S	N S	N S	N S	N S	N S
SE	0.1	0.037	0.24	0.45	0.26	0.09	0.02	0.009	0.07

N S - variation is not significant

4.6. Dry matter production

The dry matter production of crop was monitored at monthly intervals. The dry weights of shoots and roots were recorded in grams.

The treatment means at monthly intervals are provided in Table 19. The main effect of treatments are given in Table 20.

4.6.1. Dry matter production of shoot

The treatment means at 1 MAP ranged range from 1.04 ($S_{0}I_{0}P_{0}$) to 1.88 ($S_{0}I_{1}P_{3}$) where as at 2 MAP the range was 5.08 ($S_{0}I_{0}P_{0}$) to 13.41 ($S_{1}I_{1}P_{0}$).

The treatment means at 3 MAP after statistical analysis were found to vary significantly. The treatment combination $S_{1}I_{1}P_{3}$ recorded the highest mean value (16.79) which was statistically superior the rest except for $S_{1}I_{1}P_{2}$ (15.56) and $S_{1}I_{1}P_{1}$ (15.59). The lowest of mean value was registered for $S_{0}I_{0}P_{0}$ (12.94).

Sterilisation, levels of inoculation and doses of P application influenced the dry matter production

TABLE 19

EFFECT OF TREATMENTS ON DRY MATTER PRODUCTION AT MONTHLY INTERVALS

Sl. No.	Treatments	Shoot (g)			Root(g)			Total (g)		
		1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)
1.	S I P 0 0 0	1.04	5.08	12.94	0.22	2.49	3.93	1.26	7.57	16.87
2.	S I P 0 0 1	1.84	8.39	13.39	0.55	2.76	4.16	2.39	11.15	17.55
3.	S I P 0 0 2	1.28	7.68	15.02	0.55	2.40	5.93	1.83	10.08	20.95
4.	S I P 0 0 3	1.00	5.14	14.59	0.52	2.41	6.15	1.52	7.55	20.74
5.	S I P 0 1 0	1.65	6.03	13.56	0.70	3.23	7.08	2.35	6.73	20.64
6.	S I P 0 1 1	1.92	8.65	15.30	0.61	2.76	6.52	2.53	11.41	21.82
7.	S I P 0 1 2	1.25	7.78	14.05	0.30	3.49	6.32	1.55	11.27	20.89
8.	S I P 0 1 3	1.88	6.15	15.37	0.32	3.09	7.52	2.20	9.24	22.89
9.	S I P 1 0 0	1.35	6.84	14.10	0.21	2.79	5.69	1.56	9.63	19.79
10.	S I P 1 0 1	1.42	6.60	14.65	0.53	3.04	6.96	1.95	9.64	21.61
11.	S I P 1 0 2	1.05	8.55	14.59	0.56	3.79	6.46	1.61	12.34	21.05
12.	S I P 1 0 3	1.26	7.66	14.84	0.73	4.06	4.83	1.99	11.72	19.67
13.	S I P 1 1 0	1.43	13.41	14.89	0.18	3.00	5.11	1.61	16.41	20.00
14.	S I P 1 1 1	1.45	7.26	15.59	0.63	3.51	6.44	2.08	10.77	22.03
15.	S I P 1 1 2	1.54	7.88	15.56	0.17	3.14	7.08	1.71	11.02	22.64
16.	S I P 1 1 3	1.41	7.30	16.79	0.43	3.95	7.72	1.84	11.25	24.51
CD 5%		--	--	1.4	--	--	1.5	--	--	--
S E		--	--	0.47	--	--	0.53	--	--	--

(n=3) - mean of three values N S - variation is not significant

significantly at 3 MAP. The effect of sterilisation significantly lowered the dry matter production, whereas inoculated plants (15.24) produced significantly higher dry matter of shoots over the uninoculated counterpart (14.27).

As the level of phosphorus was increased from P_0 to P_3 the dry matter production was also increased from 13.87 g to 15.39 g through 14.73 g and 14.81 g for P_1 and P_2 levels. The treatments P_3 and P_2 are statistically superior to P_0, whereas P_0 is on par with P_1.

4.6.2. Dry matter production of root

The dry weight of roots at 1 MAP ranged from 0.17 ($S_1I_1P_2$) to 0.73 ($S_1I_0P_3$). During the 2 MAP it ranged from 2.40 ($S_0I_0P_2$) to 4.06 ($S_1I_0P_3$). At 3 MAP the data after statistical analysis were found to be varying significantly. The treatment combination $S_1I_1P_3$ recorded the highest mean value (7.72) followed by $S_0I_1P_3$ (7.52) and the lowest was recorded by $S_0I_0P_3$ (3.93).

The main effects of treatments on the root dry matter production was found to be vary significantly except for sterilisation. The inoculated plants recorded

TABLE 20

MAIN EFFECT OF TREATMENTS ON DRY MATTER PRODUCTION (g)

Main effects	Shoot	Root
Sterilised	14.28	5.91
Unsterilised	15.13	6.29
CD 5%	0.48	N S
S.E	0.47	0.53
Uninoculated	14.27	5.52
Inoculated	15.14	6.68
CD 5%	0.48	0.54
SE	0.47	0.53
0% P	13.87	5.45
50% P	14.73	5.93
75% P	14.81	6.45
100% P	15.39	6.55
CD 5%	0.91	0.77
SE	0.47	0.53

N S - variation is not significant

significantly higher mean value (6.68) than the uninoculated plants (5.52) The levels of phosphorus applied also brought about increased responses in root dry matter production over the P_0 treatment. As the level of phosphorus was increased from P_0 to P_3 the dry matter production of roots also increased from 5.45 to 6.55; a statistically significant variation. The mean of P_3 level is statistically on par with the mean of P_1 (5.93) and P_2 levels (6.45).

4.6.3. Total dry matter production

The total dry matter production ranged from 1.26 ($S_0I_0P_0$) to 2.53 ($S_1I_1P_1$) at 1 MAP and the range was 6.73 ($S_0I_0P_0$) to 12.34 ($S_1I_1P_1$) at 2 MAP. At 3 MAP, the treatment $S_0I_1P_0$ recorded the highest mean value (24.51) followed by $S_1I_1P_2$ (22.64) and $S_1I_1P_1$ (22.03). The lowest mean value was recorded for $S_0I_0P_0$ (16.87). However, these differences are not statistically significant.

4.7 Nutrient removal

The removal of major and minor plant nutrient from the experimental soil by the test crop were measured in

grams at monthly intervals. The crop removal has been calculated separately for shoot and root. The results are given separately.

4.7.1. Nutrient removal by shoot

The removal of major and minor nutrients from the experimental soil by the shoots alone of the crop have been worked out at monthly intervals. The data on the effects of treatment means are included in Tables 21 and 22 while the data on the main effects of treatments are provided in Table 23.

(1) Nitrogen :- The quantities of nitrogen removed by the crop ranged from 0.27 to 0.725 at 1 MAP. The removal at 2 MAP ranged from 1.88 ($S_0I_0P_0$) to 5.23 ($S_1I_1P_0$).

During the third sampling period ie., at 3 MAP, the treatment combination $S_1I_1P_3$ recorded the highest of mean value (6.60) which was statistically superior to other treatment combinations except for $S_1I_1P_2$ (6.29); $S_1I_1P_1$ (6.36); $S_0I_1P_3$ (6.27) and $S_0I_1P_1$ (5.97). The lowest mean value was recorded for $S_0I_0P_0$ (4.43).

TABLE - 21

EFFECT OF TREATMENTS ON THE REMOVAL OF MAJOR AND SECONDARY NUTRIENTS BY SHOOT AT MONTHLY INTERVALS (g Pot^{-1})

Sl. No.	Treatments	N (g)			P (g)		
		1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)
1.	S I P 0 0 0	0.415	1.88	4.43	0.91	3.25	3.20
2.	S I P 0 0 1	0.563	3.27	4.62	1.26	8.14	3.64
3.	S I P 0 0 2	0.34	3.15	5.32	1.99	7.45	4.59
4.	S I P 0 0 3	0.27	2.10	5.37	0.59	4.26	4.89
5.	S I P 0 1 0	0.593	2.35	5.05	1.07	3.97	3.69
6.	S I P 0 1 1	0.485	3.54	5.97	2.45	6.31	4.55
7.	S I P 0 1 2	0.382	3.34	5.48	0.93	4.20	4.47
8.	S I P 0 1 3	0.725	2.64	6.27	0.20	4.42	5.13
9.	S I P 1 0 0	0.449	2.39	4.79	0.67	2.67	3.10
10.	S I P 1 0 1	0.491	2.44	4.93	1.10	4.75	3.79
11.	S I P 1 0 2	0.349	3.51	5.31	0.54	6.16	3.74
12.	S I P 1 0 3	0.469	3.29	5.53	0.86	6.51	3.93
13.	S I P 1 1 0	0.571	5.23	5.81	0.82	8.58	4.38
14.	S I P 1 1 1	0.617	3.12	6.36	0.92	6.17	4.92
15.	S I P 1 1 2	2.615	3.39	6.29	1.09	5.91	4.91
16.	S I P 1 1 3	0.581	3.29	6.6	1.84	6.06	5.78
CD 5%		--	--	0.74	--	--	N S
S E		--	--	2.57	--	--	0.17

(n=3) - mean of three values. N S - variations is not significant

TABLE - 21 (Cont...)

EFFECT OF TREATMENTS ON THE REMOVAL OF MAJOR AND SECONDARY NUTRIENTS BY SHOOT AT MONTHLY INTERVALS (g Pot^{-1})

Sl. No.	Treatments	K (g)			Ca (g)			Mg (g)		
		1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)
1.	S I P 0 0 0	1.03	3.20	10.59	1.60	11.25	25.06	0.83	2.34	11.50
2.	S I P 0 0 1	2.33	4.78	7.02	3.56	22.85	24.20	1.28	4.37	10.97
3.	S I P 0 0 2	1.03	3.84	8.27	1.54	15.53	24.90	0.70	4.67	12.60
4.	S I P 0 0 3	0.93	3.39	10.04	1.51	13.32	30.11	0.82	2.68	11.98
5.	S I P 0 1 0	2.97	3.97	7.87	2.90	11.27	17.35	1.10	2.53	10.08
6.	S I P 0 1 1	3.89	8.13	12.07	3.80	14.95	24.68	1.10	4.77	12.22
7.	S I P 0 1 2	2.37	5.4	8.86	1.48	12.88	21.58	0.73	3.40	11.20
8.	S I P 0 1 3	2.93	3.81	12.81	3.94	10.46	28.55	1.41	3.13	12.79
9.	S I P 1 0 0	1.44	3.83	10.06	1.47	11.94	22.55	0.87	3.28	10.72
10.	S I P 1 0 1	1.78	4.81	9.86	2.49	11.49	30.13	0.93	3.60	12.34
11.	S I P 1 0 2	1.45	4.28	7.89	1.43	18.84	33.79	0.59	4.88	12.54
12.	S I P 1 0 3	2.04	4.13	6.82	1.49	18.29	31.19	0.70	3.59	12.77
13.	S I P 1 1 0	1.34	5.49	10.16	2.41	17.70	32.91	1.01	6.60	13.18
14.	S I P 1 1 1	2.97	3.05	10.89	2.79	21.87	24.74	1.79	4.95	11.89
15.	S I P 1 1 2	2.26	3.07	7.74	1.72	16.48	34.01	0.73	4.95	13.42
16.	S I P 1 1 3	1.69	4.31	9.05	1.84	11.55	27.51	1.09	5.64	13.22
CD 5%		--	--	N S	--	--	N S	--	--	N S
S E		--	--	2.42	--	--	3.91	--	--	3.07

(n=3) - mean of three values N S - variations is not significant

The variations caused by the main effects are also statistically significant (Table 23). The mean of unsterilisation recorded a higher value (57.03) than the effect of sterilisation (53.02). Inoculated plants removed significantly higher amounts of nitrogen from soil (59.77) than the uninoculated plants (50.28). This increase in nitrogen uptake is about 18.8%.

The graded doses of phosphorus application was found to increase the uptake of nitrogen significantly. The maximum mean value was recorded for 100% P application (59.43) and this statistically superior to the mean values recorded for P_1 (54.68); and P_0 (49.98) and was on par with P_2 (56.01). P_0 recorded the lowest mean value and this was statistically inferior to other treatments.

(ii) Phosphorus :- At 1 MAP the quantity of phosphorus removed by the crop ranged from 0.2 to 7.09 g. The treatment $S_1 I_1 P_2$ registered the maximum mean value (7.09). During the second sampling period ie., 2 MAP, the range narrowed between 2.67 ($S_1 I_0 P_0$) and 8.58 ($S_1 I_1 P_0$). The maximum mean values was recorded for $S_1 I_1 P_0$ (5.78) and the lowest value was recorded for $S_1 I_1 P_3$ (3.10). The treatment $S_1 I_0 P_0$ was statistically superior to other treatments.
$S_1 I_1 P_3$

Among the means of the main effects levels of inoculation and doses of phosphorus application produced statistically significant variation in P uptake.

Inoculation of fungus resulted in significantly higher removal of phosphorus by shoots (4.73) over the uninoculated plants (3.86). It was seen that, as the level of phosphorus application increased, the removal of phosphorus from the soil by the shoots also increased to a significant level. The maximum p uptake was recorded by P_3 levels (4.94) which was found to be statistically superior to other levels of P application. The lowest mean value was recorded for P_0 level (3.59).

(iii) Potassium :- The removal of potassium ranged from 0.93 ($S_{0\,0\,3}$ I P) to 3.89 ($S_{0\,1\,1}$ I P) at 1 MAP; 3.05 ($S_{1\,1\,1}$ I P) to 8.13 ($S_{0\,1\,1}$ I P)' at 2 MAP and 7.02 ($S_{0\,0\,1}$ I P) to 12.81 ($S_{0\,1\,3}$ I P) at 3 MAP. However, these variations were not statistically significant.

Among the means of main effects; sterilisation of soil, levels of inoculation and doses of phosphorus did not show significant variation. Inoculated plants recorded a

TABLE - 22

EFFECT OF TREATMENTS ON THE REMOVAL OF MICRONUTRIENTS BY SHOOTS AT MONTHLY INTERVALS

Sl. No.	Treatments	Fe(g)			Cu(g)		
		1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)
1.	S I P 0 0 0	0.503	0.360	3.51	0.160	0.257	0.712
2.	S I P 0 0 1	0.396	0.650	1.57	0.274	0.330	0.582
3.	S I P 0 0 2	0.366	0.720	2.07	0.191	0.303	0.558
4.	S I P 0 0 3	0.303	0.205	2.12	0.156	0.264	0.563
5.	S I P 0 1 0	0.231	0.657	5.88	0.241	0.275	0.576
6.	S I P 0 1 1	0.442	1.29	4.21	0.289	0.146	0.694
7.	S I P 0 1 2	0.525	1.22	3.57	0.194	0.341	0.575
8.	S I P 0 1 3	0.374	0.923	2.38	0.284	0.334	0.612
9.	S I P 1 0 0	0.322	0.438	1.60	0.207	0.205	0.645
10.	S I P 1 0 1	0.367	0.409	0.66	0.222	0.359	0.739
11.	S I P 1 0 2	0.266	0.932	0.68	0.165	0.342	0.839
12.	S I P 1 0 3	0.126	0.421	1.36	0.189	0.292	0.569
13.	S I P 1 1 0	0.383	3.62	0.79	0.224	0.394	0.520
14.	S I P 1 1 1	0.535	0.443	1.32	0.231	0.339	0.541
15.	S I P 1 1 2	0.435	0.158	1.71	0.223	0.276	0.437
16.	S I P 1 1 3	0.737	0.452	4.24	0.215	0.434	0.566
CD 5%		--	--	N S	--	--	N S
S E		--	--	1.26	--	--	0.22

(n=3) - mean of three values. N S - variation is not significant

TABLE - 22 (Cont...)

EFFECT OF TREATMENTS ON THE REMOVAL OF MICRONUTRIENTS BY SHOOTS AT MONTHLY INTERVALS

Sl. No.	Treatments	Mn(g)			Zn(g)		
		1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)
1.	S I P 0 0 0	0.026	0.710	0.347	0.199	0.330	1.18
2.	S I P 0 0 1	0.033	1.07	0.332	0.322	0.34	1.324
3.	S I P 0 0 2	0.017	0.122	0.385	0.234	0.108	0.994
4.	S I P 0 0 3	0.011	0.113	0.345	0.318	0.057	0.868
5.	S I P 0 1 0	0.017	0.139	0.333	0.313	0.066	0.798
6.	S I P 0 1 1	0.058	0.078	0.324	0.196	0.069	0.883
7.	S I P 0 1 2	0.015	0.078	0.313	0.166	0.054	0.767
8.	S I P 0 1 3	0.038	0.098	0.382	0.273	0.111	0.930
9.	S I P 1 0 0	0.041	0.068	0.403	0.195	0.048	0.804
10.	S I P 1 0 1	0.033	0.060	0.379	0.173	0.112	1.060
11.	S I P 1 0 2	0.095	0.162	0.377	0.591	0.034	0.827
12.	S I P 1 0 3	0.063	0.115	0.379	0.326	0.046	0.828
13.	S I P 1 1 0	0.013	0.107	0.457	0.213	0.107	0.800
14.	S I P 1 1 1	0.021	0.094	0.242	0.411	0.058	0.730
15.	S I P 1 1 2	0.058	0.095	0.469	0.168	0.024	0.927
16.	S I P 1 1 3	0.071	0.015	0.424	0.188	0.088	1.050
CD 5%		--	--	N S	--	--	N S
S E		--	--	0.004	--	--	0.69

(n=3) - mean of three values. N S - variation is not significant

higher uptake of potassium (9.93) than the uninoculated (8.83), the variation is not statistically significant.

(iv) Other nutrients:- The removal of calcium, magnesium, iron, copper, manganese and zinc by the shoot portion of cassava are presented in Table 21, 22 and 23. The data showed varying trends which are inconclusive. Statistical analysis at 3 MAP revealed no significant influence of applied treatments on these parameters except for the following.

(1) The shoots of plants grown in unsterile soils took up greater quantities of Ca (29.61) as against the shoots of the plants grown in sterile media (24.68).

(2) Plants which are grown in sterile media took up significantly higher amounts of Fe (3.66) in contrast to the plants of unsterile media (1.55). Similarly, the inoculated plants also took up significantly higher quantities (3.51) of Fe, whereas the shoots of uninoculated plants removed a lesser quantity of Fe from the soil (1.69).

Fig-10

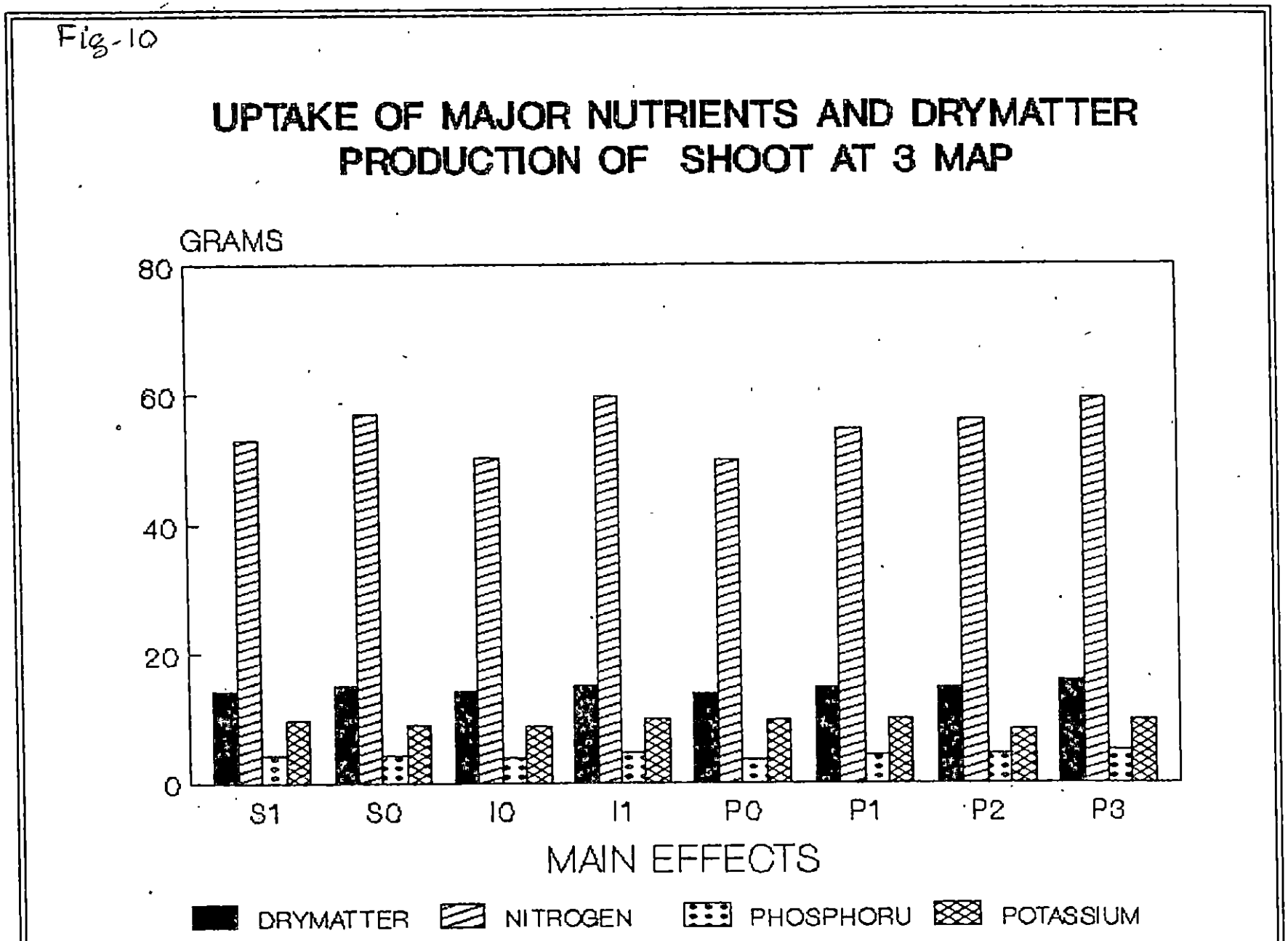

UPTAKE OF MAJOR NUTRIENTS AND DRYMATTER PRODUCTION OF SHOOT AT 3 MAP
GRAMS
80
60
40
20
0
S1
S0
I0
I1
P0
P1
P2
P3
MAIN EFFECTS
DRYMATTER
NITROGEN
PHOSPHORU
POTASSIUM

TABLE 23

MAIN EFFECTS OF TREATMENTS ON THE REMOVAL OF NUTRIENTS BY SHOOTS AT THREE MAP

Main effects	N	P	K	Ca	Mg	Fe	Cu	Mn	Zn
Sterilised	53.02	4.28	9.69	24.68	11.67	3.66	0.609	0.345	0.968
Unsterilised	57.03	4.32	9.07	29.61	12.47	1.55	0.607	0.391	0.887
CD 5%	2.61	N S	N S	3.98	N S	1.28	N S	N S	N S
SE	2.57	0.17	2.42	3.91	3.07	1.26	0.22	0.04	0.69
Uninoculated	50.28	3.86	8.83	27.87	11.93	1.69	0.651	0.368	0.994
Inoculated	59.77	4.73	9.93	26.42	12.21	3.51	0.565	0.368	0.862
CD 5%	2.61	0.17	N S	N S	N S	1.28	N S	N S	N S
SE	2.57	0.17	2.42	3.91	3.07	1.26	0.22	0.04	0.69
0% P	49.98	3.59	9.67	24.47	11.37	2.95	0.613	0.384	0.897
50% P	54.68	4.23	9.96	25.94	11.85	1.94	0.693	0.319	0.999
75% P	56.01	4.43	8.72	28.82	12.36	2.01	0.692	0.386	0.878
100% P	59.43	4.94	9.68	29.34	12.69	3.52	0.577	0.382	0.936
CD 5%	3.69	0.25	N S	N S	N S	N S	N S	N S	N S
SE	2.57	0.17	2.42	3.91	3.07	1.26	0.22	0.04	0.69

N S - variation is not significant

4.7.2. Nutrient removal by roots

The removal of major, secondary and micro nutrients by roots of the test crop from the experimental soil at monthly intervals as influenced by the sixteen treatment combinations and main effects were found out. The data pertaining to them are presented in Tables 24, 25 and 26.

(i) Nitrogen :- The amounts of this major nutrient removed by the roots of the crop from the soil ranged from 0.021 g ($S_{1\,0\,3}$ I P) to 0.88g ($S_{0\,0\,3}$ I P) at 1 MAP. At 2 MAP the range was 0.89g ($S_{0\,0\,2}$ I P) to 1.84 g ($S_{1\,1\,3}$ I P).

The data at 3 MAP after statistical analysis were found to vary significantly. The treatment combination $S_{1\,1\,3}$ I P recorded a significantly superior mean value (3.59) which was statistically on par with $S_{0\,1\,3}$ I P (3.02), $S_{1\,1\,2}$ I P (2.73) and $S_{1\,1\,1}$ I P (2.82). The treatment $S_{0\,0\,0}$ I P recorded the lowest of mean value (1.34).

The plants grown in unsterile soil recorded a significantly superior nitrogen removal by the roots (25.01) compared to the plants grown in sterile medium (22.40).

Inoculated plants took up a significantly higher amounts of nitrogen from the soil (26.35) over the uninoculated counterparts (21.0). The graded increments of phosphorus application also resulted in an increased uptake of the element and the same was statistically differing. The P_3 level recorded the highest mean value (26.60) and the lowest by P_0 (20.68).

(ii) Phosphorus :- The root uptake of this element from the soil at monthly intervals as influenced by the treatment combinations were monitored. The treatment means at 1 MAP and 2 MAP did not show any definite trend. At 3 MAP, the treatment means varied significantly. The treatment combinations $S_1 I_1 P_3$ recorded the highest mean value (4.3) which was statistically superior to other treatment combinations except for $S_1 I_1 P_2$ (3.64), $S_1 I_1 P_3$ (3.63) and $S_1 I_1 P_1$ (3.78) for which it is statistically on par. The treatment $S_0 I_0 P_0$ (1.53) recorded the lowest of mean value and was found to be statistically inferior to T_{16}, T_{15} and T_8.

Of the main effects, the influence of sterilisation was not remarkable, whereas inoculation levels produced significant difference among the mean values.

TABLE - 24

EFFECT OF TREATMENTS ON THE REMOVAL OF MAJOR AND SECONDARY NUTRIENTS BY ROOTS AT MONTHLY INTERVALS ($g\ Pot^{-1}$)

Sl. No.	Treatments	N (g)			P (g)		
		1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)
1.	S I P 0 0 0	0.037	0.99	1.34	0.021	2.85	1.53
2.	S I P 0 0 1	0.088	1.37	1.52	0.181	2.45	2.18
3.	S I P 0 0 2	0.049	0.98	2.31	0.019	2.54	3.10
4.	S I P 0 0 3	0.088	1.08	2.52	0.317	1.92	2.82
5.	S I P 0 1 0	0.084	1.20	2.51	0.056	3.58	2.85
6.	S I P 0 1 1	0.079	1.10	2.39	0.032	3.01	3.07
7.	S I P 0 1 2	0.042	1.43	2.33	0.040	3.80	3.12
8.	S I P 0 1 3	0.048	1.35	3.02	0.038	2.78	3.64
9.	S I P 1 0 0	0.029	1.11	2.29	0.023	2.96	2.63
10.	S I P 1 0 1	0.063	1.37	2.7	0.058	3.28	3.27
11.	S I P 1 0 2	0.056	1.61	2.44	0.072	3.67	3.23
12.	S I P 1 0 3	0.021	1.78	1.74	0.043	4.10	2.04
13.	S I P 1 1 0	0.054	1.19	2.12	0.011	3.27	2.68
14.	S I P 1 1 1	0.019	1.44	2.82	0.057	3.79	3.63
15.	S I P 1 1 2	0.027	1.37	2.73	0.010	4.14	3.78
16.	S I P 1 1 3.	0.03	1.84	3.59	0.03	2.81.	4.30
CD 5%		--	--	0.6	--	--	0.05
S E		--	--	2.11	--	--	0.34

(n=3) - mean of three values N S - variation is not significant

TABLE - 24 (Cont...)

EFFECT OF TREATMENTS ON THE REMOVAL OF MAJOR AND SECONDARY NUTRIENTS BY ROOTS AT MONTHLY INTERVALS (g Pot^{-1})

Sl. No.	Treatments	K (g)			Ca (g)			Mg (g)		
		1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)
1.	S I P 0 0 0	0.031	1.59	4.20	0.34	1.32	3.99	0.027	0.99	2.04
2.	S I P 0 0 1	0.214	1.40	3.67	1.04	1.10	5.02	0.156	1.08	2.97
3.	S I P 0 0 2	0.19	1.58	5.62	1.58	1.11	5.79	0.079	0.85	4.13
4.	S I P 0 0 3	0.17	1.37	6.48	0.76	0.84	0.49	0.111	1.11	4.46
5.	S I P 0 1 0	0.758	2.55	6.99	1.60	1.14	7.80	0.14	1.22	5.02
6.	S I P 0 1 1	0.104	2.46	5.40	1.09	0.61	7.47	0.074	1.08	5.15
7.	S I P 0 1 2	0.230	3.38	5.16	0.50	0.87	6.24	0.10	1.15	4.55
8.	S I P 0 1 3	0.095	2.84	7.58	0.05	0.50	6.97	0.085	1.27	7.17
9.	S I P 1 0 0	0.090	1.93	5.98	0.119	0.87	8.14	0.05	1.38	4.15
10.	S I P 1 0 1	0.181	1.70	6.99	0.70	1.63	8.50	0.137	1.62	4.77
11.	S I P 1 0 2	0.412	1.78	6.14	0.86	2.20	6.93	0.119	1.64	5.05
12.	S I P 1 0 3	0.717	3.32	4.49	1.11	1.85	5.84	0.124	1.79	3.78
13.	S I P 1 1 0	0.026	1.32	5.40	0.27	1.60	5.67	0.044	1.45	4.22
14.	S I P 1 1 1	0.491	1.57	6.67	0.10	1.75	8.55	0.139	1.68	5.99
15.	S I P 1 1 2	0.019	1.50	6.53	0.26	1.79	8.97	0.034	1.32	7.01
16.	S I P 1 1 3	0.181	2.25	6.72	0.69	1.00	9.12	0.097	1.34	7.72
CD 5%		--	--	N S	--	--	N S	--	--	N S
S E		--	--	1.49	--	--	2.84	--	--	1.66

(n=3) - mean of three values N S - variation is not significant

Inoculated plants took up significantly higher amounts (3.37) of phosphorus into their roots whereas the uninoculated roots were poor in the removal of this nutrient from the soil (2.60).

With the increase in dosage of phosphorus to soil, the uptake of the same also increased. The P_0 level registered the lowest of mean value (2.41). The increase in the crop removal of phosphorus was linear with added P upto P_2 level (3.30) and decreased afterwards (P_3 - 3.20). The P_2 level was found to be statistically superior to P_1 and P_0 and was on par with P_3 level.

(iii) Potassium :- The uptake of potassium by roots were observed at monthly intervals and the data showed that, the variations caused by different treatments were not significant. At 3 MAP the treatment $S_0 I_1 P_3$ recorded highest mean value (7.58) as against $S_0 I_0 P_1$ (3.67) which recorded the lowest of mean value.

The effect of sterilisation reduced the uptake of potassium by the roots (5.63) when compared to the effect of unsterilisation (6.11). Though inoculation caused a slight increase in the uptake of this element (6.30) than that of

TABLE - 25

EFFECT OF TREATMENTS ON THE REMOVAL OF MICRONUTRIENTS BY ROOTS AT MONTHLY INTERVALS

Sl. No.	Treatments	Fe(g)			Cu(g)		
		1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)
1.	S I P 0 0 0	0.104	1.39	2.21	0.095	0.015	0.164
2.	S I P 0 0 1	0.407	1.85	2.15	0.048	0.016	0.205
3.	S I P 0 0 2	0.275	1.15	4.65	0.004	0.022	0.228
4.	S I P 0 0 3	0.375	2.06	4.11	0.002	0.026	0.327
5.	S I P 0 1 0	0.479	1.74	5.57	0.004	0.039	0.303
6.	S I P 0 1 1	0.279	2.46	4.47	0.007	0.019	0.312
7.	S I P 0 1 2	0.337	2.24	5.66	0.072	0.028	0.275
8.	S I P 0 1 3	0.242	2.81	5.78	0.006	0.012	0.377
9.	S I P 1 0 0	0.118	1.96	4.09	0.008	0.036	0.247
10.	S I P 1 0 1	0.308	1.88	4.55	0.002	0.833	0.301
11.	S I P 1 0 2	0.363	2.49	4.26	0.003	0.057	0.295
12.	S I P 1 0 3	0.380	2.36	3.27	0.004	0.015	0.215
13.	S I P 1 1 0	0.104	1.77	4.09	0.008	0.012	0.270
14.	S I P 1 1 1	0.339	1.93	3.93	0.004	0.021	0.396
15.	S I P 1 1 2	0.192	1.63	5.91	0.007	0.028	0.392
16.	S I P 1 1 3	0.242	2.83	6.06	0.008	0.016	0.543
CD 5%		--	--	N S	--	--	N S
S E		--	--	0.78	--	--	0.16

(n=3) - mean of three values N S - variation is not significant

TABLE - 25 (Cont...)

EFFECT OF TREATMENTS ON THE REMOVAL OF MICRONUTRIENTS BY ROOTS AT MONTHLY INTERVALS

Sl. No.	Treatments	Mn(g)			Zn(g)		
		1 MAP	2 MAP	3 MAP (n=3)	1 MAP	2 MAP	3 MAP (n=3)
1.	S I P 0 0 0	0.029	0.115	0.175	0.003	0.049	0.350
2.	S I P 0 0 1	0.127	0.166	0.20	0.016	0.058	0.412
3.	S I P 0 0 2	0.007	0.079	0.277	0.054	0.046	0.593
4.	S I P 0 0 3	0.002	0.142	0.245	0.006	0.104	0.705
5.	S I P 0 1 0	0.014	0.203	0.342	0.017	0.081	0.817
6.	S I P 0 1 1	0.069	0.144	0.246	0.011	0.049	0.601
7.	S I P 0 1 2	0.072	0.154	0.264	0.024	0.073	0.672
8.	S I P 0 1 3	0.061	0.167	0.37	0.042	0.049	0.873
9.	S I P 1 0 0	0.005	0.271	0.253	0.015	0.148	0.979
10.	S I P 1 0 1	0.016	0.368	0.299	0.073	0.079	0.673
11.	S I P 1 0 2	0.016	0.326	0.261	0.022	0.068	0.669
12.	S I P 1 0 3	0.017	0.259	0.285	0.022	0.089	0.519
13.	S I P 1 1 0	0.004	0.183	0.313	0.002	0.048	0.562
14.	S I P 1 1 1	0.016	0.211	0.305	0.011	0.042	0.844
15.	S I P 1 1 2	0.003	0.29	0.489	0.057	0.085	0.818
16.	S I P 1 1 3	0.010	0.019	0.435	0.075	0.075	0.936
CD 5%		--	--	N S	--	--	N S
S E		--	--	0.07	--	--	0.51

(n=3) - mean of three values N S - variation is not significant

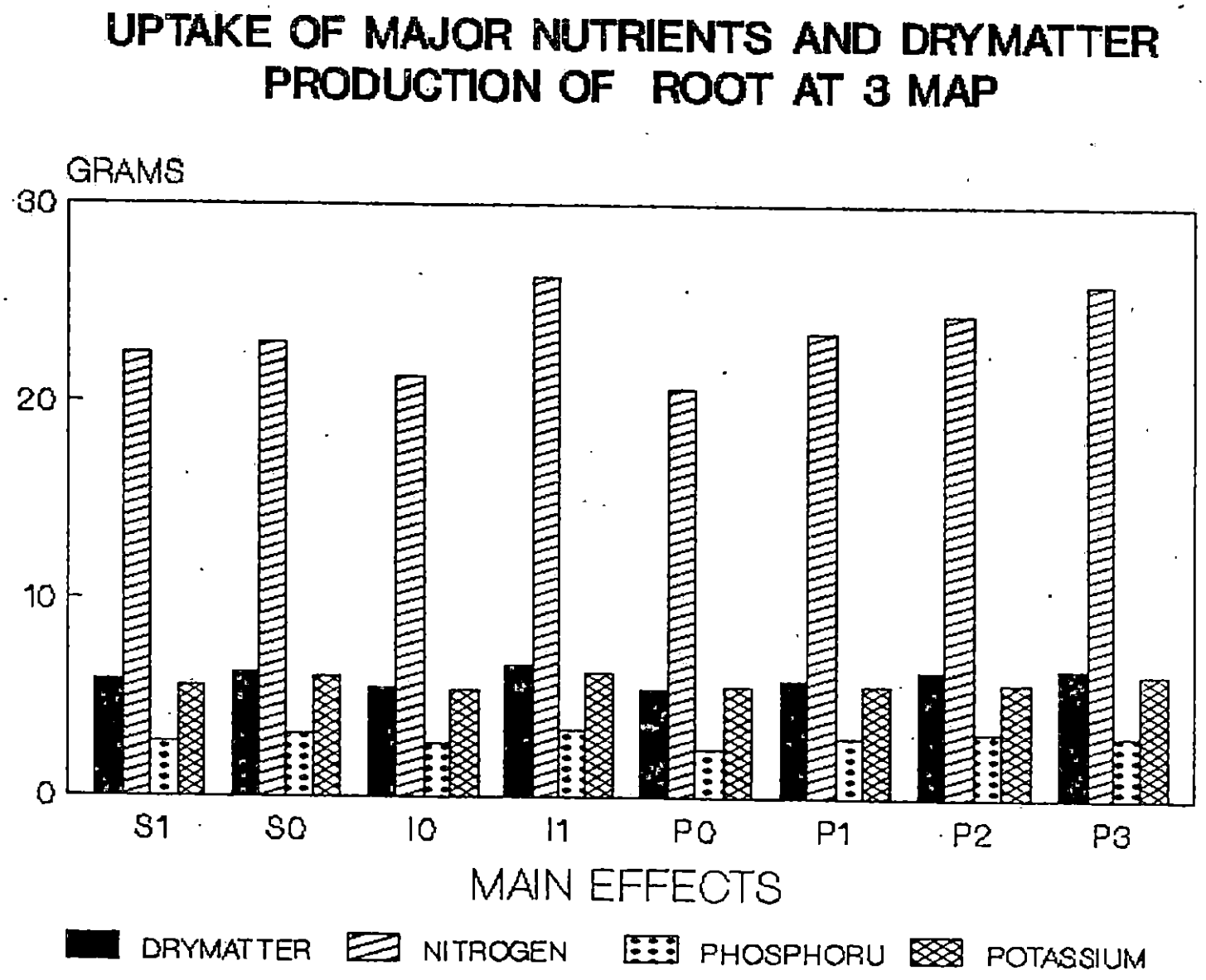
TABLE 26

MAIN EFFECTS OF TREATMENTS ON NUTRIENTS REMOVAL BY ROOTS AT THREE MAP (g)

Main effects	N	P	K	Ca	Mg	Fe	Cu	Mn	Zn
Sterilised	22.40	2.78	5.63	6.23	4.46	4.38	0.274	0.265	0.630
Unsterilsied	25.01	3.19	6.11	7.71	5.33	4.52	0.333	0.330	0.888
CD 5%	2.15	N S	N S	N S	N S	N S	N S	N S	N S
S E	2.11	0.34	1.49	2.84	1.66	0.78	0.16	0.07	0.51
Uninoculated	21.00	2.60	5.44	6.33	3.99	3.72	0.24	0.250	0.752
Inoculated	26.35	3.37	6.30	7.60	5.80	5.08	0.358	0.356	0.766
CD 5%	2.15	0.15	N S	N S	1.69	0.79	N S	N S	N S
S E	2.11	0.34	1.49	2.84	1.66	0.78	0.16	0.07	0.51
0% P	20.68	2.41	5.64	6.41	4.15	3.99	0.246	0.270	0.955
50% P	23.50	3.03	5.68	7.38	4.72	3.90	0.304	0.263	0.633
75% P	24.49	3.30	5.80	6.98	5.18	5.12	0.298	0.323	0.689
100% P	26.06	0.20	6.31	7.10	5.53	4.80	0.367	0.334	0.759
CD 5%	3.04	N S	N S	N S	N S	N S	N S	N S	N S
SE	2.11	0.34	1.49	2.84	1.66	0.78	0.16	0.07	0.51

N S - variation is not significant

Fig-11


UPTAKE OF MAJOR NUTRIENTS AND DRYMATTER PRODUCTION OF ROOT AT 3 MAP
GRAMS
30
20
10
0
S1
S0
I0
I1
P0
P1
P2
P3
MAIN EFFECTS
DRYMATTER
NITROGEN
PHOSPHORU
POTASSIUM

uninoculated plants (5.44), the difference was not statistically significant.

The incremental addition of phosphorus also caused an increase in the uptake of potassium by the roots. P_3 level recorded the maximum mean value (6.31) followed by P_2 (5.8) and P_1 (5.64). P_0 (5.64) recorded the lowest of mean values. However, these differences are statistically not significant.

(iv) Other nutrients :- The Tables 24, 25 and 26 contain the data on root removal of calcium, magnesium, iron, copper, manganese and zinc; as well as major nutrients. These observations, though varied markedly, did not reveal any conclusive results. However, the data are presented to augment discussion on other aspects.

DISCUSSION

5. D I S C U S S I O N

5.1 Growth of cassava under VAM association and differential phosphate application.

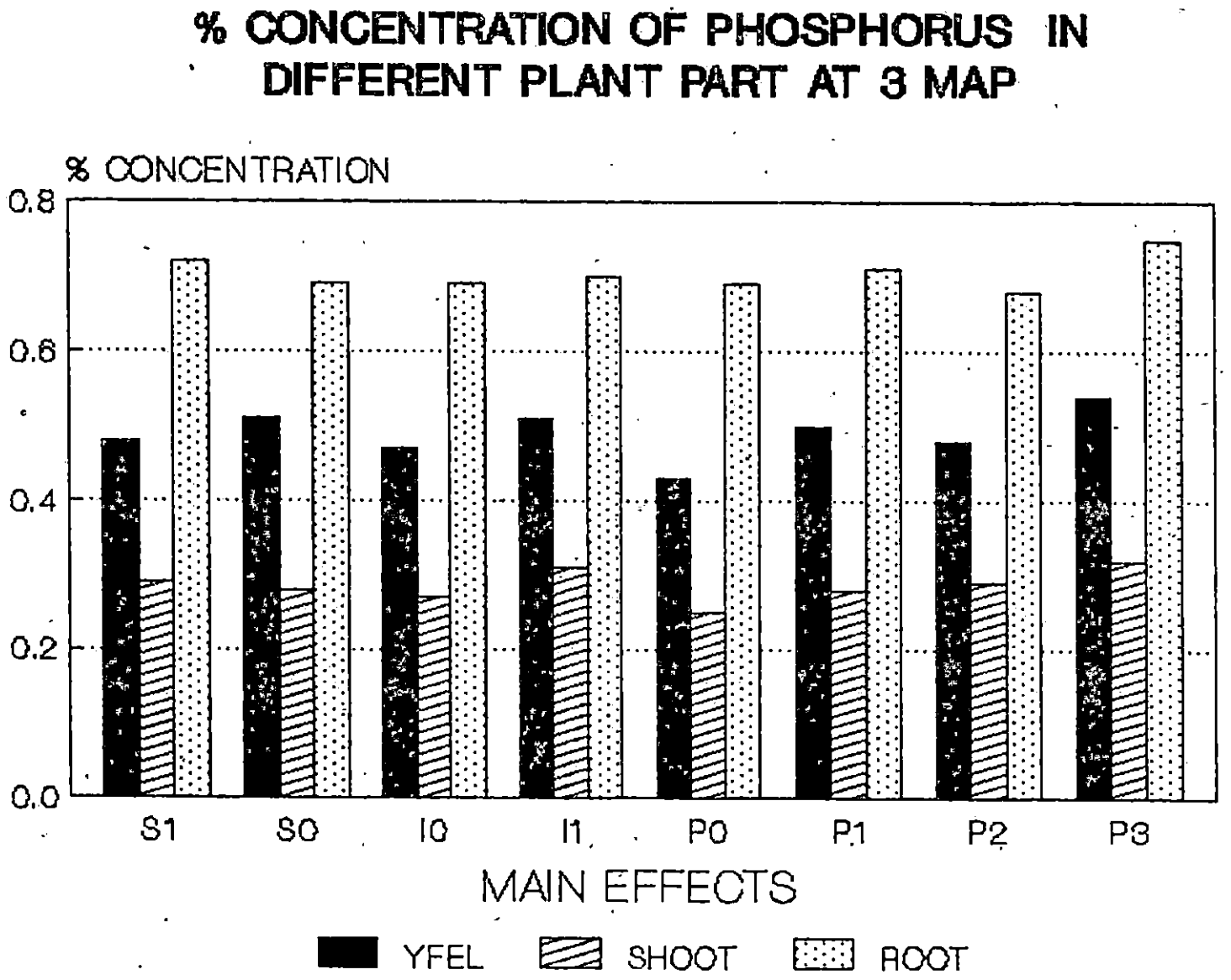
The investigation was intended to assess the beneficial effect of VAM association on the growth and phosphate utilisation in cassava. The biometric observations recorded during the initial growth period of the crop ie., first three months of planting, however, did not establish the possible beneficial effects which might result in an enhanced tuberisation and the final tuber yield. The data on the number of leaves per shoot and average shoot height at monthly intervals did not produce any statistical evidence on the beneficial effects of VAM association under varying soil conditions and graded P levels.

However, the average number of leaves per shoot at three months after planting was substantially higher for the inoculated treatments (Table 6). Evidently this may be due to an increased uptake of nutrients, facilitated by an increased number of secondary and tertiary roots and the increased length of tertiary roots resulted by inoculation (Table 8). Kapoor et al., (1988) showed a close relationship

between increased growth rate of roots and percentage mycorrhizal infection. The higher number of leaves per shoot at this stage may be thus attributed to the improved absorption of nutrients from the soil which this is evident from the presence of significantly higher concentrations of N, p and K in YFEL of VAM inoculated plants (N = 5.49; P = 0.51 and K = 1.07).

The higher number of leaves per shoot recorded for the inoculated plants contributed to an increased dry matter production (Table 20). This increased dry matter production was mainly due to inoculation which caused an overall increment in the number of secondary and tertiary roots, length of tertiary roots and enhanced number of leaves per shoot. The variation due to soil sterilisation and graded doses of phosphorus application was not statistically significant in the case of D.matter production of shoots and roots. These treatments did not produce any significant variation with respect to the number of leaves per shoot or average shoot height at three months after planting and other root characteristics studied (Table 8).

Fig-8


% CONCENTRATION OF PHOSPHORUS IN DIFFERENT PLANT PART AT 3 MAP
% CONCENTRATION
0.8
0.6
0.4
0.2
0.0
S1
S0
I0
I1
P0
P1
P2
P3
MAIN EFFECTS
YFEL
SHOOT
ROOT

On the whole it may viewed that the favourable trends obtained for the above parameters were undoubtedly due to the inoculation with VA Mycorrhizal fungus. Such effect of VAM on cassava has been recorded by many other workers (Kang et al., 1980, Howeler, 1982, Potty 1988 and Sivaprasad et al., 1990) also.

5.2 Phosphorus nutrition of cassava

Kang et al., (1980) has clearly demonstrated that pot cultured cassava plants require higher doses of phosphorus than field grown cassava. The phosphorus nutrition of cassava in the present study was found to be favourably affected by the inoculation of VAM fungus and has helped to absorb a higher amount of phosphorus by the shoot (4.73 g) and root (3.37 g). This is further supported by the root characteristics where the inoculated plants, recorded a significantly higher value for the length and number of tertiary roots as well as the number of secondary roots.

This increased uptake of plant nutrients including phosphorus by mycorrhizal roots have been attributed to increased soil explorations of roots having the external

hyphae of the fungus ramifying in the soil extending to areas outside the depletion zone around the roots (Sanders and Tinker, 1971). Such a possibility can not be overruled in this experiment also. Since the root observations reveal that under the influence of VAM inoculation the number of secondary and tertiary roots and the length of tertiary roots have been increased significantly. This increased number and length of root value helped the plants to absorb more water and nutrient, mainly phosphorus.

Similar responses under the influence of VAM fungus has been amply demonstrated by many workers in several crops like Sorghum, (Miranda et al., 1984), Soybeans (Pacovksy, 1986) Green gram (Santhi et al., 1988) as well as Cassava (Howeler, 1982, Potty 1984 and Sivaprasad et al., 1990).

It may be seen that, cassava grown under nonsterilised soil conditions resulted in a higher absorption of phosphorus by the shoots and roots compared to the plants grown in sterilised soil, though the difference between the two was not significant. The reason for the higher uptake of phosphorus may be attributed to

the root number which was higher in the plants grown in the non sterile soil. Hence, the plants grown in non sterile soil have a higher activity of the fungi in their roots both by inoculation and by native infection which has caused a favourable effect on root number and length. The low activity of the VAM fungus in the sterile soil has caused a lesser uptake of phosphorus by the plants grown in sterile medium. The report that cassava is dependent on VAM fungus for its effective phosphorus nutrition (Howeler, 1982) is corroborated by the present results also.

Graded doses of phosphorus application also had a favourable influence in the uptake of phosphorus by shoot (P_0 - 3.59, P_1 - 4.23, P_2 - 4.43 and P_3 - 4.94) as well as by roots (P_0 - 2.41, P_1 - 3.03, P_2 - 3.30 and P_3 - 3.20). The incremental addition of P has caused a corresponding increase in the uptake of this nutrient by the shoots and roots.

In the case of root uptake of P, P_2 level ie., 37.5 kg P_2O_5/ha recorded the highest mean value (3.3 g) and this may be attributed to the higher number of primary roots developed under the influence of P application (Table 8).

Many of the trials conducted to study the phosphorus nutrition of cassava have revealed that the crop responded to P application even up to 100 Kg P_2O_5/ha in acid laterite soils (CTCRI, 1983). Cadavid (1980) also obtained a positive linear response with the incremental addition of P upto 100 Kg P_2O_5/ha and suggested that, above 100 Kg P_2O_5/ha is not profitable.

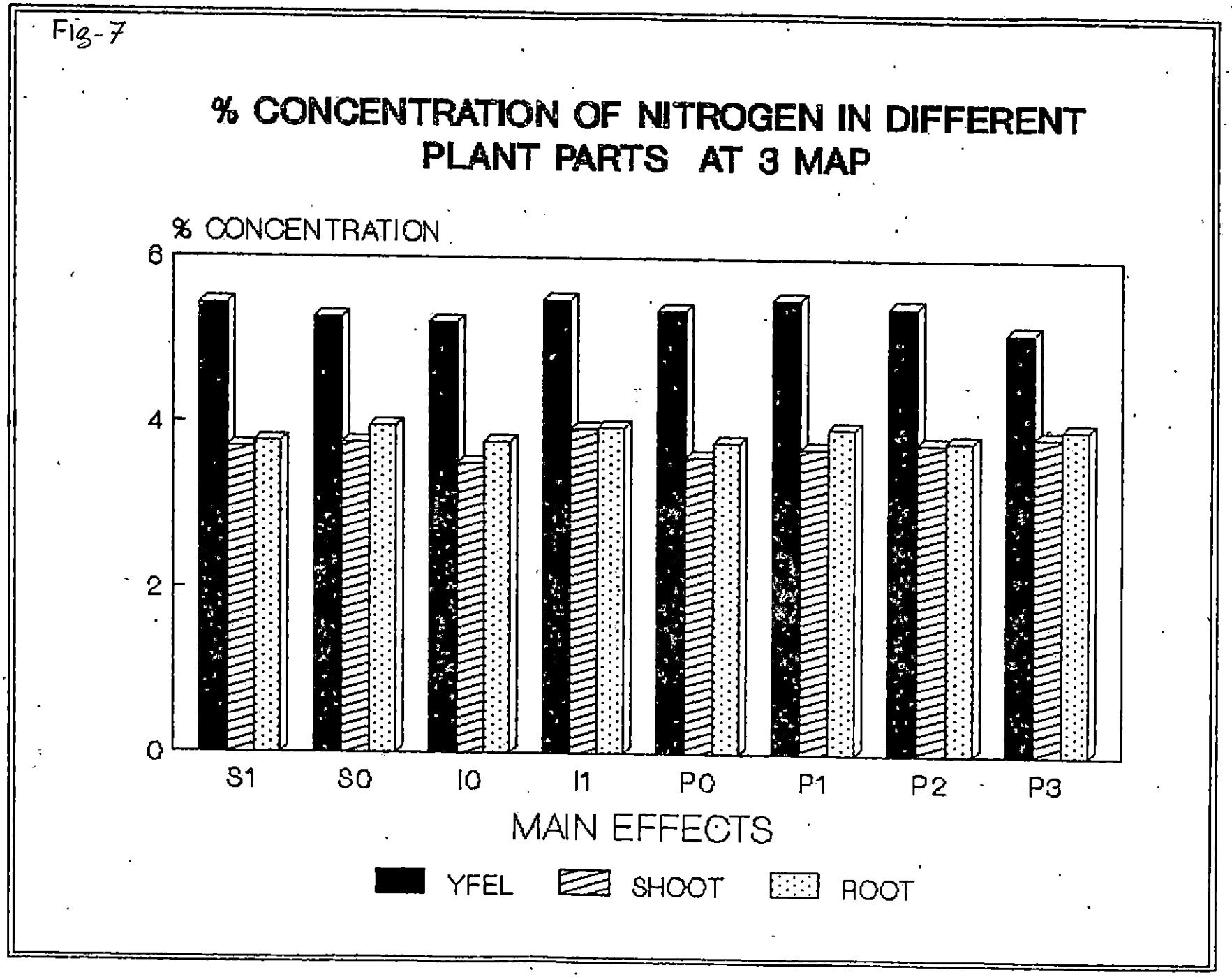
The content of P in YFEL was also favourably influenced by the graded doses of P application as seen from the significantly higher level of P uptake in plants treated with graded P levels (P_0 - 0.43, P_1 - 0.50, P_2 - 0.48 and P_3 - 0.54). The amount of P present in the YFEL is an indication of the favourable effects of P application.

5.3 Nutrition of cassava with respect to other nutrients

5.3.1 Nitrogen

The inoculated plants recorded significantly higher amounts of nitrogen in YFEL (5.49). This higher uptake of nitrogen may be attributed to the favourable root characteristics observed in the inoculated plants. This

Fig-7


% CONCENTRATION OF NITROGEN IN DIFFERENT PLANT PARTS AT 3 MAP
% CONCENTRATION
6
4
2
0
S1
S0
I0
I1
P0
P1
P2
P3
MAIN EFFECTS
YFEL
SHOOT
ROOT

enhanced uptake of nitrogen has also caused a higher dry matter content in the above ground portion (15.14). This increase being statistically superior to uninoculated counter parts.

Similar is the case with the under ground portions also. The roots of the VAM inoculated plants recorded a significantly higher concentration of nitrogen as well as dry matter content.

This enhanced uptake and assimilation of nutrient elements as a result of inoculation of VAM fungus was reported maize and wheat (Khan, 1975) and soybeans (Asimi et al., 1980). In lucerne the inoculation increased the uptake of N and K in addition to P when grown in P deficient soil. (Nielson and Jensen, 1983).

The concentration of nitrogen as influenced by soil sterilisation was not prominent in YFEL though sterilisation caused a little increase in its concentrations. The plants grown in nonsterilised soil recorded a higher concentration of nitrogen in their roots (3.9.7) and this may be due o the activity of native strains of VAM in the soil. A significant difference could

not be obtained, probably due to inefficiency of the native strains of VAM. But in the case of dry matter production, the activity of the native population has resulted in a substantial increase. It may be suggested that upon sterilisation of the soil, the native population both efficient and inefficient were suppressed and it might take a long period to build up the population. Hence the native population present in the non sterile soil excelled in building up of the population when the cutting started sprouting and resulted in a natural association during late period of study. This might have caused a better absorption of nutrients by the plants grown in non-sterile soil by improved root characteristics resulting in a higher dry matter production.

The results of the study suggested that cassava positively requires a natural symbiotic association with VAM for greater efficiency in dry matter production and nutrient uptake. Natural association of VAM with cassava roots has been reported by Potty (1978), Girija and Nair (1985) and Howeler (1982).

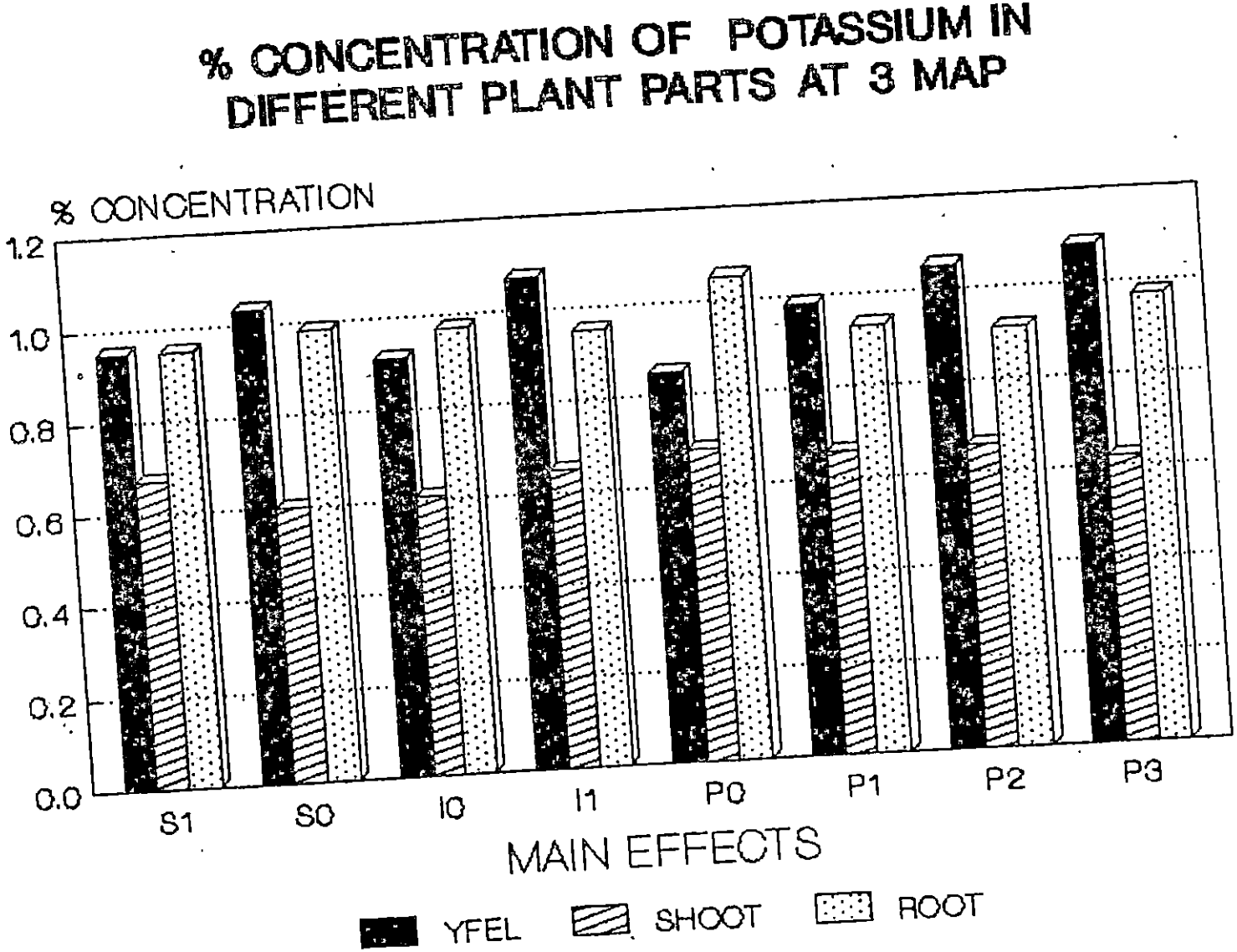
Application of graded doses of phosphorus has also resulted in a significant variation in the mean values of

the concentration of N in YFEL. The treatment P_1 (25 kg P_2O_5 /ha) recorded the maximum value (5.51) which was significantly superior to P_3 level (5.12). Similarly the concentration of nitrogen in the shoot was higher in the treatments which received 50 kg P_2O_5 /ha. In the case of roots also P_1 and P_3 recorded highest mean value. The higher concentration of nitrogen in the shoots and roots significantly increased their dry matter content also. This has ultimately resulted in the higher uptake of nitrogen from the soil by shoot and roots. Similar findings are reported from various trials where phosphorus application is found to increase the yield of the crop by effective utilisation of plant nutrients. Howeler (1979) obtained 200 percent yield increase due to adequate application of phosphorus. Cadavid, (1980) and CTCRI (1983) have corroborates these results.

5.3.2 Potassium

The inoculated plants were found to remove a higher quantity of potassium from the soil than the uninoculated plants and this was reflected in the concentration of K in YFEL. In the case of shoots also, inoculated plants maintained a higher concentration (0.65) when compared to its uninoculated counterparts. In

Fig-9


% CONCENTRATION OF POTASSIUM IN DIFFERENT PLANT PARTS AT 3 MAP
% CONCENTRATION
1.2
1.0
0.8
0.6
0.4
0.2
0.0
S1
S0
I0
I1
P0
P1
P2
P3
MAIN EFFECTS
YFEL
SHOOT
ROOT

contrast, the concentration of this element in the roots was significantly lower for inoculated plants (0.95). Hence the final removal of this element; though was mediated by mycorrhizal roots in treated plants, was not statistically superior to that of uninoculated plants. This was true for both shoot (Table 23) and root (Table 26) uptakes.

Phosphate application to cassava has produced a remarkable effect on the absorption and assimilation of potassium. Graded levels of phosphorus application produced corresponding variations in the uptake of potassium by shoots as well as by roots. Eventhough this variation was not statistically significant. A definite trend, warranting a discussion was not observed in the potassium absorption pattern due to the effect of VAM inoculation, P application as well as soil sterilisation.

5.3.3 Secondary nutrients

Of the secondary nutrients, VAM inoculation has significantly increased the uptake of Mg by roots (5.88) though this treatment increased the root uptake of Ca, it was not statistically significant (Table 26). The reason for this is also due to the dilution effect. The

concentration of Ca in shoots (Table 23) and roots (Table 26) as influenced by inoculation was not so pronounced as that of dry matter production. Hence, measure on the uptake of this element was lessened, still maintained a higher level than in uninoculated plants.

Effect of sterilisation was not pronounced on the root uptake of Ca, and Mg. The plants grown in natural soil recorded higher quantities of Ca and Mg in their roots and shoots. The non sterile soil with a native population of mycorrhiza has helped the plants to absorb more nutrients than those plants grown in sterile soil. This is supported by the data on the concentration on Ca and Mg in roots and shoots. The concentration of Ca and Mg of shoots of plants grown in non sterile soil was 1.96 and 0.63 respectively; similarly, for their roots, it was 1.2 and 0.82.

The drymatter content of roots as influenced by the effect of sterilisation also confirms this. The plants grown in nonsterile soil recorded a significantly higher mean values (15.13 g) for the dry matter content in roots. In the case of shoots, although a variation was evident, it was not statistically significant. Application of

phosphorus did not produce any significant effect on the uptake Ca and Mg by roots. The failure to bring about a significant increase in the uptake of these elements may be due to dilution effect. A similar findig was reported by Buwalda et al., (1983) where in, though a positive response was noted for the uptake of anions the cation uptake was lessened and P application singly and in combination.

5.3.4 Micro nutrients

The root uptake of micronutrients viz., Cu, Zn and Mn, as influenced by the population of VAM in the pots was not significantly varying as seen from the results eventhough an increasing trend in the mean value was recorded by the inoculated plants. The root uptake of Fe by inoculated plants, however, showed a favourable variation. A similar trend was obtained for Fe in the shoot portions also.

The variation in the concentration of micronutrients in root as well as shoot caused by VAM inoculation was not significant. In the case of their concentration in YFEL also there was no significant

variation except in the uninoculated plants which recorded a significantly higher amounts of Fe in the YFEL.

The plants grown in non sterile medium also recorded a higher level of these nutrients. However, variations in Cu and Zn only were statistically significant.

The variations in the uptake of these nutrients as influenced by soil sterilisation was not significant in the case of root and shoot except for Fe. The amount uptake of Fe caused in sterile soil was statistically higher than that plants gown in nonsterile soil.

The content and uptake of micronutrients as in the root and shoot influenced by graded doses of P application was not significantly different. It may be seen that as the level of applied P increased from P_0 and P_3 the concentration of Fe, Cu and Zn has shown a decrease.

An increased uptake of Ca, Mg and Cu in VAM inoculated perennial grass has been reported by Kilham (1984). In the present study, however, a similar trend was not found for Cu, Zn and Mn. A comparatively increase uptake of Fe alone was noticed in VAM treated plants.

SUMMARY

6. SUMMARY

Agricultural scientists all over the world would testify that chemical fertlisation of crops though aimed at realisation of better yields is not economically as well as ecologically feasible due to price rise and environmental disasters. The present investigation was aimed at increasing rock phosphate use efficiency through inoculation of VAM fungi in the soil. This technology of inducing artificial VAM associations in field crops will go a long way in economisisng crop production through realistion of better yields under low resource situations.

The pot culture experiment was conducted at college of Agriculture, Vellayani during Sept - Dec, 1989, with Casaava [Manihot esculenta Crantz] as the test crop. Four levels of rock phosphate application (0%, 50%, 75% and 100% recommended dose) was tried under VAM inoculated and uninoculated conditions as well as sterlised and unsterlised soil conditins were recorded at one month interval, for the first three months of crop growth. The results were stastically analysed and inferences drawn.

6.1 Soil characters

The experiment was conducted in Fine Loamy Mixed Isohyperthermic Khaplic Haplustalf soil of Vellayani series. A crop of cassava for three months under graded phosphate application, fungal association and soil sterlisation did not influence the soil rection remarkably with respect to the plant nutrient contents in the soil. Eventhough there were variations among tratements there was no definite trend observed. This was true since a crop of three months with whatever soil manipulation can not bring about significant changes in soil conditios even though the soil responds the treatement application with respect to availability of nutrients to the growing crop.

6.2 Growth and nutrition of cassava

The dry matter production of cassava was increased due to VAM association established at early stages of crop growth. This was reflected in the growth indices namely number of leaves per shoot, height of plant, root number and its spread etc., Better intake of essential nutrients including the difficultly absorbed elements like Phosphorus enabled the crop to flourish during the initial vegetative phase. This was facilitated by the fast rates of infection

of VAM fungi which ranged from 13 to 15 per cent in the first month to more than 90 percent in many cases at third month. Higher levels of phosphorus application resulted in corresponding increse of dry matter production.

The concentration of nitrogen phosphorus and potassium in YFEL was significantly increased due to VAM inoculation of fungus. So was the case when phosphorus supplywas increased.

Soil sterilisation had a marked influence in reducing the major, secondary and micro nutrients in YFEL, presumably due to low soil fungal population and resultant lack of association with the crop.

In the case of micronutrients inoculation of VAM fungus inreased the content of Zn in YFEL while it decreased the contents of Cu, Mn and Fe.

Inoculation of VAM and graded doses of phosphate application resulted in better concentrations of mineral nutrients in shoots as well as in roots. This together with higher dry matter production resulted in better uptake of

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the nutrients under study. However, the results in many instances were not statistically significant. Moreover the beneficial effect of VAM association in cassava was not pronounced in the uptake of mineral nutrients under study except N, P and Fe in the case of shoots and N, Mg and Fe in the case of roots.

The present investigation confined to the active vegetative phase of cassava and the results highlight the significance of VAM inoculation in improving the nutritional status of the crop.

The salient conclusions drawn from the experiment are the following:

1. Inoculation of VAM fungi in the soil at planting time of the cassava (Cultivar M-4) will help in better root production and concomitant increse in essential nutrient uptake especially phosphorus.

2. Effect of soil sterilisaions on the association of VAM in cassava and the resultant uptake of different nutrients was fluctuating and therefore not conclusive.

3. Incremental addition of phosphate to the cassava crop resulted in better uptake of the element as well as N and K with respect to secondary and micronutrients the effect was not remarkable.

Field experiments are recommended to establish the influence of VAM association in increasing the tuber yield of the crop and thereby reducing the cost of cultivation.

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NUTRIENT UPTAKE EFFICIENCY OF CASSAVA *(Manihot esculenta* Crantz*)* AS INFLUENCED BY VESICULAR ARBUSCULAR MYCORRHIZAL (VAM) ASSOCIATION AND ROCK PHOSPHATE APPLICATION

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ABSTRACT OF THESIS

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A B S T R A C T

An experiment was conducted under pot culture in Fine Loamy Mixed Isohyperthermic Khaplic Haplustalfs soil of Vellayani series at College of Agriculture, Vellayani, Trivandrum; during Sep. to Dec. 1989. Sixteen treatment combinations with four levels of Rock phospahate (0, 50%, 75% and 100% recommended dose), VAM inoculation and control, and soil sterlisation and non-sterlisation was applied to cassava (cultvair M-4). Biometric observation and chemical analysis of plant parts were undertaken for three mouths of thirty days interval.

The results indicated no significant variation in soil nutrient status due to the effect of applied treatments during the three months. Dry matter production of cassava was increased by inoculation of VAM and phosphate nutrition. Application of 37.5 Kg P_2O_5 /ha in non-sterlised soil along with VAM inoculation was found to be the best treatement combination.

Inocualation of VAM fungi resulted in better uptake of major, secondary & micro nutrients during the active vegetative phase of the crop. Effect of soil sterilisation was not conclusive. Phosphate nutrition of

the crop resulted in better uptake of all major nutrients. Field experiments are suggested to establish the present findings and to relate the effects of treatements with tuber yield.