STUDIES ON THE VESICULAR–ARBUSCULAR MYCORRHIZA OF CERTAIN CROP PLANTS OF MEGHALAYA

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SUPERVISOR'S CERTIFICATE

I certify that the thesis entitled "STUDIES ON THE VESICULAR-ARBUSCULAR MYCORRHIZA OF CERTAIN CROP PLANTS OF MEGHALAYA" submitted by Mrs. Indira Devi Bhattarai for the Degree of Doctor of Philosophy of the North-Eastern Hill University, Shillong, embodies the record of original investigation carried out by her under my supervision. She has been duly registered and the thesis presented is worthy of being considered for the award of Ph.D. degree. This work has not been submitted for any degree of any other university.

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C O N T E N T S

INTRODUCTION

Extensive investigations have revealed that vesicular-arbuscular mycorrhiza (VAM) is the most widespread, being found in association with the roots of about 95% plants of the world (Gerdemann, 1968). This type of mycorrhiza is not restricted to specific group of plants as they occur in angiosperms, in most gymnosperms, in many pteridophytes and bryophytes. Its ubiquitous occurrence in nature provide its importance from ecological and physiological stand point.

The importance of VAM in the agricultural crops have been widely recognised (Mosse, 1973, 1978; Gerdemann, 1975; Hayman, 1978, Khan, 1972; Powell and Daniel, 1978). The beneficial effect was attributed to increased phosphorus uptake by the endophyte. Phosphorus (P) absorption was thought to be enhanced by the extension of hyphae to the zone where P had been depleted by diffusion to roots (Tinker, 1975). Besides P, the mycorrhizal fungi help in the absorption of microelements in some way or other (Gerdemann, 1964).

There are reports that mycorrhizal infection and Endogone spore population were influenced by soil treatments. The addition of soluble phosphate decreased root infection (Mosse, 1973; Abbott and Robson, 1977) and spore-population in the field (Khan, 1972) whereas the addition of nitrogen-fertilizer greatly decreased spore-population (Hayman, 1970). Some workers have found an inverse relationship between mycorrhizal infection and the nutrient status of the soil (Hayman et al., 1975; Csinos, 1981).

There is relatively little systematic work on the morphogenesis of host and their associated VAM fungi in natural habitats. Most workers have restricted their sampling to a few times throughout a growing season (Khan, 1974; Daft and Nicolson, 1974). Studies during a single growing season have also been carried out by some workers (Hayman, 1970; Sutton and Barron, 1972; Sutton, 1973; Saif and Khan, 1975; Saif, 1977).

Though much work has been done on different aspects of VAM fungi yet it has not been fully demonstrated whether varieties of a species differ in response to VAM. There are, however, some suggestions indicating that this does occur in Trifolium repens and maize (Hall, Scott and Johnstone, 1977; Hall, 1978), citrus cultivars (Menge, Johnson and Platt, 1978), citrus rootstock (Nemec, 1978) and wheat cultivars (Azcon and Ocampo, 1981) but no difference was observed in the degree of mycorrhizal development between the different species of Festuca (Molina, Trappe and Strickler, 1978).

In north-eastern part of India where most of the people do not use the fertilizers due to the lack of transportation and their socio-economic conditions, the VAM fungi could be utilized to increase the yield of the crop plants. The spores of the mycorrhizal fungi may be preinoculated for the enhancement of fertility level. Taking this point into view, it was planned to study the different aspects of VAM fungi in the three important crop plants of this region viz. paddy, maize

and potato. These crops are widely cultivated in this region of the country and they also constitute the staple food of the people. In each crop type, different cultivars were selected to study the mycorrhizal status of the crop plants at the varietal level. The field study was carried out for two growing seasons to estimate systematically the mycorrhizal status in the different cultivars of the above mentioned crop plants with respect to age. In general, the whole work was categorized into the following five heads :

1. Mycorrhizal status in crop plants
2. Soil fertility level and the mycorrhizal development
3. Mycorrhiza and nutrient uptake
4. Mycorrhiza and crop productivity
5. Survey of crops from different agricultural fields for vesicular-arbuscular mycorrhiza and Endogonaceous spores.

REVIEW OF LITERATURE

The term 'mycorrhiza' was first coined by the German scientist Frank in 1885 to the nonpathogenic association of root and fungi and later on divided into two types, Ectotrophic, characterized by the presence of a complete sheath but the mycelium does not enter inside the cortical cells and endotrophic, where external sheath is absent but the mycelium penetrates the cortical cells.

The presence of vesicular-arbuscular mycorrhiza (VAM) in the roots of many angiosperms was reported by Gallaud in 1905 and he classified them into two main classes based on the extent and location of arbuscules. However, reports of later authors clarified that the different infection patterns were caused by the same or a closely related group of fungi.

The reports of VA mycorrhizal fungi in the roots of fossil plants like Rhynia and Asteroxylon by Kindston and Lang (1921) and Butler (1932) suggest a very ancient origin of these fungi.

Peyronel (1923) observed the hyphal connections between the fruiting bodies and mycorrhiza in the soil and suggested the inclusion of these endophytes under the genus, Endogone. Peyronel et al. (1969) proposed three terminology for the common types of mycorrhizas, viz., Ectomycorrhiza, Endomycorrhiza and Ectendomycorrhiza which is the most acceptable and is in practice worldwide.

Garrette (1950) remarked that the mycorrhizal fungi have evolved from aggressive parasites by progressive selection of non-lethal varieties so that the symbiotic stage becomes indefinitely prolonged.

The observation of Peyronel was confirmed by Mosse in 1953 by observing the fructifications of Endogone species attached by extramatrical hyphae to the roots of strawberry. Mycorrhizal infection was successfully established by Mosse (1956, 1957) through surface sterilized spores and sporocarps and she observed better growth in the mycorrhizal plants. She (1962) also tested the ability of germinating spores to infect host plants under sterilized conditions and found that VA mycorrhizal fungi failed to infect plant roots unless assisted by a Pseudomonas species. Mosse and Bowen (1968) prepared a Key for the identification of different spore types based on the nature of cytoplasm, wall structure of spores, presence or absence of attached hyphae, nature of hyphal attachment and the colour of spores. Mosse and Phillips (1971) established mycorrhizal infection in Trifolium parviflorum in a culture medium. Mosse and Hayman (1971) and Mosse et al. (1973) further added that the mycorrhizal plants grew much better than nonmycorrhizal ones in P-deficient soils. The interations between VAM, utilization of rock phosphate and nodulation in three legumes was studied by Mosse et al. (1976) in eight P-deficient soils and it was reported that irrespective of the pH, VA endophytes increased P uptake and nodulation in all the

host plants in different soils. Mosse (1977) reported that the inoculum density in the soil rather than its phosphate status seemed to determine the responses to VA inoculation which were greater in the soils containing very few indigenous endophytes.

Gerdemann (1955) observed a large globose to subglobose spore on a bulbous suspensor-like structure which differed in many respects from Chlamydospores. This species produced endomycorrhizae with arbuscules but vesicles were found only on the external hyphae. Gerdemann and Nicolson (1963) successfully isolated Endogonaceous spores from the soil by wet-sieving and decanting technique and described six different types of spores. Gerdemann (1964, 1965) obtained better growth in mycorrhizal maize plants compared to nonmycorrhizal ones. A detailed account of the Endogonaceous spores was published by Gerdemann and Trappe (1974) and two new species of Endogonaceae (Glomus multicaulis and Sclerocystis sinnosa) from India were described by Gerdemann and Bakshi (1976).

That the incidence of root infection and the amount of endophytic mycelium on the root surface and in the rhizosphere differ greatly in different habitats and communities was shown by Nicolson (1958). He further observed compact aggregates of spores resembling Endogone type fruiting bodies on the external mycelium associated with and directly connected to the endophytic mycelium in the roots of Festuca rubra var

aremaria and Ammophila aremaria. Nicolson and Johnston (1979) found Glomus fasciculatus to be the only endophyte in the Maritime Sand dune. They observed an improved growth in Ammophila aremaria and Agropyron junceiform and better growth in maize on dual inoculation with G. fasciculatus and G. macrocarpus var. geosporus than with either alone. Nicolson and Schenck (1979) surveyed the Endogonaceous mycorrhizal endophytes in Florida and found twenty-one species of which eleven made up the Chlamydosporic species and ten the azygosporic species.

Baylis (1959) and Baylis et al. (1963) obtained better growth in mycorrhizal plants compared to nonmycorrhizal ones in nutrient deficient soils. Baylis (1967) in an experiment with Phycomycetous mycorrhizas of the mixed rain forest of New Zealand found that VA mycorrhizae were normally essential for the uptake of P from the forest soils which were deficient in phosphorus. Baylis (1970) found that Coprosma robusta and other woody species which are deficient in root-hair grew well in unsteamed soil but in steamed soil they did not grow unless phosphate was added or were inoculated with mycorrhizal fungi. He (1975) further observed that the primitive angiosperms, like Magnoliales which lacked root hairs were more dependent on VA mycorrhizae for their nutrient uptake even in moderately fertile soils.

Daft and Nicolson (1966) studied the effects of 3 mycorrhizal fungi on the growth of tobacco, tomato and maize and found

that marked stimulation occurred with low phosphate availability and high root infection. Daft and Nicolson (1969 a, b) observed that all the concentrations of the endophyte ranging from 225 to 3 Chlamydospores per plant led to significant stimulation of growth in tomato, and the plants inoculated with high number of spores produced more upper leaves and retained more lower ones whereas the plants inoculated with low number retained lower leaves than uninoculated controls. They further observed that repeated small doses of soluble phosphate over long periods depressed the production of fungus than when given over shorter periods. Daft and Okusanya (1973) reported that the lignification of the xylem was greater in the mycorrhizal tomato and Petunia plants and more vascular bundles were produced in the mycorrhizal maize plants compared to the nonmycorrhizal ones. Daft and El-Giahmi (1976) further observed that infection with Glomus mosseae increased the yields of fruit, plant size and the chemical contents of infected shoot, root and seed in Peanuts, and the dual infection with Glomus and Rhizobium stimulated nodulation and acetylene reduction and contributed greatly to the vigor of the host. The growth of red maple grown in either sand or anthracite waste containing bonemeal was increased when infected with Glomus macrocarpus var. geosporus or Gigaspora gigantia (Daft and Hacskaylo, 1977). Daft and El-Giahmi (1978) further added that defoliation of maize and tomato reduced the mycorrhizal growth response and development of the endophyte estimated as percentage infection, root pigmentation and spore production.

Ali (1969, 1976) observed two types of VAM fungi in Nardus stricta, one broad endophyte having hyphae of .7 cm. diameter; and another fine endophyte having hyphae with a diameter of 0.4 cm. and mycorrhizal inoculation led to increased yield in N. stricta plants.

Hayman (1970) reported that Endogone spore population and mycorrhizal infection in wheat were influenced by season and soil treatment. He obtained high number of spores in July which began to decrease after September but remained unchanged from December to June, maximum number of spores and highest mycorrhizal infection being observed in summer. A marked decrease in spore population was observed with formalin treatment of soil. Hayman and Mosse (1971) observed very large increase of shoot dry weight in Endogone inoculated onion and Coprosma plants grown in phosphate-deficient soils. Hayman (1974) further reported that light and temperature greatly influenced the development of VAM and growth of onion in a P-deficient soil. More arbuscules coupled with better growth was observed with 25,000 lux than with 13,000 lux at 23°C and in a 14° - 23° diurnal cycle. Hayman et al. (1975) studied the effect of phosphate treatments on the number of Endogone spores and the amount of VAM in field soil planted with a rotation of potatoes, barley and swedes. They observed that most spores occured in barley and potato plots given intermediate amounts of phosphate whereas mycorrhizal infection was more in barley and potato roots from plots with least phosphate. Hayman and Mosse (1979)

in field trials in a hill grassland area of mid-Wales (UK) showed that growth of White clover could be improved by inoculation with selected VA-mycorrhizal fungi. Hayman and Stovold (1979) in a survey of New South Wales soils reported more spores in agricultural soil than in native grassland soil.

Phillips and Hayman (1970) suggested a method of clearing the roots by boiling with KOH and then staining with tryphan blue for the rapid assessment of mycorrhizal infection in roots.

Ross and Harper (1970) obtained an increased yield in soybean by artificially inoculating VA mycorrhizal fungi in a fumigated field plot. Ross (1972) further added that mycorrhizal roots of a cultivar of soybean susceptible to Phytophthora were more susceptible to P. megasperma than were nonmycorrhizal ones.

Khan (1971) surveyed West Pakistan soils for Endogone spores and reported that all spore types formed VA-mycorrhizae with red clover seedlings. An increased growth, dry matter production, number of grains per ear along with high phosphate content was observed in mycorrhizal maize plants (Khan, 1972). Khan (1974) further surveyed halophytes, xerophytes and hydrophytes for VA mycorrhizae and reported that except a few, almost all the plants were mycorrhizal. Khan (1975) also reported an increased growth in wheat plants inoculated with

VA-mycorrhizal fungi. He (1978) further added that all the plants except Persoonia and Banksia (Proteaceae) from bituminous coal mines were mycorrhizal. An increased growth of onion on inoculation with VA-mycorrhizal fungi in unsterilized coal waste from coal Cliff Colleries was reported by Khan in 1981.

Sanders and Tinker (1971) observed that mycorrhizal and nonmycorrhizal plants utilized the same source of phosphate and that the external mycelium of endomycorrhizae was responsible for the increased uptake of phosphorus.

Sutton and Barron (1972) described "Floatation adhesive technique" for the recovery of Endogone spores from soil. A three-phase pattern of mycorrhizal development involving sequentially a lag phase, a phase of extensive development and a phase of constancy was observed in the roots of Phaseolus vulgaris and Soybean by Sutton (1973).

Crush (1973) reported Rhizophagus tenuis from high altitude grasses and observed that the fungus stimulated the growth of grasses in their natural soils. He (1974) further reported that VA-mycorrhizal fungi stimulated the growth and nodulation of Centrosema pubescens, Stylosanthes guyanensis, Trifolium repens and Lotus pedunculatus grown in Phosphate-deficient soils. Crush (1975) also recorded very high levels of mycorrhizal infection in legumes sown in fertilized soils.

He (1976) further observed that endophyte host relationship in the symbiosis changed from mutualism to parasitism as phosphorus availability increased. Crush (1978) obtained a rapid increase in the effectiveness of soil endophyte populations as pasture development proceeded.

Bakshi (1974) virtually did a pioneer work in the field of mycorrhizae in India. He surveyed forest trees and also crops for mycorrhizal association, and isolated and identified the Endogonaceous spores in Indian soils and showed their effects on the growth of various plants under different fertilizer treatments.

Hattingh and Gerdemann (1975) successfully established mycorrhizal infection in Brazilian sour orange by pelleting the seed with Glomus fasciculatus in greenhouse and field experiments.

Ho and Trappe (1975) observed that Glomus macrocarpus and G. mosseae possessed nitrate reduction enzyme system which brought about the reduction of nitrate to nitrite.

Iqbal et al. (1975) surveyed the number of Endogone spores in the rhizosphere and occurence of VAM in plants of economic importance. They observed Endogone spores in all the soil samples and heavy VA-mycorrhizal infection in Oryza sativa, Lectuca and Papaver somniferum whereas Parsnip,

Amaryllis, carrots were found to be not infected. Time of transplantation of the preinoculated mycorrhizal seedlings greatly effects the growth of the plant. Iqbal and Malik (1978) observed that transplanting at an early stage results in the better growth in mycorrhizal Helianthus annus, Lactuca sativa and L. scariola plants over nonmycorrhizal ones than transplanting at a later stage. Iqbal et al. (1978) observed that mycorrhizal rice plants produced more tillers, more grain and heavier plants than nonmycorrhizal ones under field conditions. Iqbal and Perveen (1980) isolated and described four species of Endogonaceous genus Sclerocystis including two new ones (Sclerocystis microcarpus sp. nov. and S. pakistan sp. nov.) from the rhizosphere of ferns and cereals.

Powell (1975) reported that preinoculation of VA mycorrhizal fungi to onion and red clover plants helped in the greater uptake of P compared to nonmycorrhizal controls in P-deficient soils. The development of mycorrhizal infections from Endogone spores and infected root segments was studied by Powell (1976) in agar coated glass slides buried in soil, and he found that hyphae from spores first formed fan-like structures of usually septate hyphae and the aseptate hyphae developed later from these fans whereas hyphae from infected root segments were always aseptate and directly infected the roots without forming any such structures. He presumed that the different infection patterns

were due to different nutrient supply in resting spores and mycorrhizal root segments. Powell and Daniel (1978) found that in mycorrhizal clover and ryegrass, the plants grew much better than nonmycorrhizal controls and Glomus tenuis when introduced into the soil already infested with indigenous mycorrhizal fungi greatly stimulated phosphate uptake. Powell (1979) obtained increased growth and dry matter production by pelleting the seeds with introduced endophytes Glomus tenuis and Gigaspora margarita compared to ones pelleted with indigenous endophytes and nonpelleted seeds. Powell et al. (1980) reported increased shoot growth and P uptake in mycorrhizal clover plants over nonmycorrhizal ones at fertilizer rates upto 1.4 g/pot. Powell (1981a) also reported that inoculation with introduced strains of VA mycorrhizal fungi increased seed yield upto 27% with 35% increased phosphate content of the seed in barley compared to inoculation with indigenous strains. He (1981b) in another study further added that the growth response of White clover increased with increasing rates of mycorrhizal inoculum in sterilized soil and in unsterlilized soil the indigenous mycorrhizal fungi greatly stimulated growth of both Clover and onion.

Rhodes and Gerdemann (1975) in an experiment with ^{32}P reported that absorption of phosphate and its translocation to the host plant by hyphae of Glomus fasciculatus extended the phosphate uptake zone of mycorrhizal onions to at least 7 cm from the root surface. They (1978) further observed increased

sulfur uptake in mycorrhizal plants with enhanced P status.

Saif (1975) reported that of the 36 families examined for VAM infection from university campus of Islamabad 26 were found to be mycorrhizal. He (1977) also observed the three phases of mycorrhizal development in several vegetable crops but in musk mellon, tomato and brinjal, constant phase was not observed within the sampling period. Saif and Khan (1977) reported an increased growth of barley seedlings inoculated with VAM fungi over nonmycorrhizal ones grown in P-deficient soils as evident from increased yield and dry matter production.

Temperature has got a marked effect on VAM spore germination. Schenck et al. (1975) reported that at room temperature (20-23°C) poor or low germination of spores occured. Schenck and Kinloch (1980) studied the yearly incidence of root colonization and extramatrical spores of VA mycorrhizal fungi on six agronomic crops grown in monoculture for seven years in a newly cleared woodland site in North-West Florida and found highest number of spores from soybean and lowest from native woodland. They concluded that the changes in the incidence of VA mycorrhizal fungi were primarily due to agricultural system of monoculture.

Becker and Hall (1976) reported six different species of Gigaspora including one new species G. margarita and provided a key based on the size, colour and structure. Becker and Gerdemann (1977) proposed a colorimetric method for estima-

ting the extent of VA-mycorrhizal infection and tested it using onions inoculated with Glomus fasciculatus and obtained a significant correlation of the percent yellow roots by weight with the yellow colour water extracts, chitin content and root/shoot ratios.

Cox and Tinker (1976) put forth their view that digestion of the fungus by the host was not probably a factor in phosphorus transfer but the transfer across the membrane of living fungus and host appeared to be a more probable mechanism. Cox et al. (1980) confirmed the hypothesis that phosphorus is translocated by the fungus by means of the transport of polyphosphate granules by cytoplasmic streaming.

Graham et al. (1976) reported that potato plants inoculated with Glomus fasciculatus showed an increased growth and tuberization over noninoculated controls.

pH and temperature influence greatly the germination of VA-mycorrhizal fungi. Green et al. (1976) observed best germination of Glomus at pH 7, Gigaspora coralloidea at pH 5 and G. heterogama at pH 6. Glomus had maximum germination at 25°C at pH 7 but maximum germination also occured at 15°C at pH 8.

Hall (1976) reported that Coprosma robusta responded differently to different forms of endomycorrhizal inoculum. Rapid and vigorous growth was obtained with root segments than

with spores and with Glomus than with Acaulospora. Hall (1977a) also reported that mycorrhizal fungi stimulated P uptake in Metrosideros umbellata and Leptospermum scoparium but did not always supply host's full P requirements. Hall (1977b) in another study described some species of Endogonaceae including one new combination in Glomus (G. tenuis Rhizophagus tenuis Green 11) and one new species in Gigaspora (G. aurigloba). He (1978) further reported that different cultivars of maize responded differently to VAM fungi. VAM fungi depressed the root dry weight/total dry weight ratios of P X 610 but not of Sweetcorn or W415. Hall and Fish (1979) compiled a key to the Endogonaceae based on the published literature, type material and personal communications, which is certainly the most up-to-date record of Endogone spores.

Read et al. (1976) assessed the intensity of VAM infection in different habitats and found that all the important species of grassland, scrub and woodland were mycorrhizal, heaviest VAM infection being observed in the members of Gramineae. The mycorrhizal status of some alpine plant communities was studied by Read and Haselwandter (1981). They found highest infection levels in herb-rich communities of intermediate altitudes (1900 to 2500 m) and low infection levels in fertilized hay meadows of lower altitudes (1600 m) and in the nival zone (above 3000 m where infection was caused mainly by the fine endophyte, Glomus tenuis).

A positive correlation between the presence of VAM and the amounts of P and N in the cowpea, maize and tomato plants was found by Sanni (1976a). Sanni (1976b) also reported that mycorrhizal rice plants showed better growth over nonmycorrhizal ones.

Ambler and Young (1977) proposed some techniques for determining the root-length infected by VA mycorrhizal fungi.

Ames and Linderman (1977, 1978) studied the VAM of easter Lily from five fields throughout the growing season and found that the infection was sparse and young in March which gradually increased in size and number until September when bulbs were harvested. Inoculation of Easter Lily with pot-culture inoculum containing contaminating fungi and bacteria including pathogens retarded the growth of the plants when compared to control plants due to the greater incidence of Fusarium oxysporum root rot infections.

Backman and Clark (1977) studied the effects of various pesticides on the development of VAM in peanuts and found that only the biocide - Sodium azide and the nematicide - Carbofuran caused significant decrease in VAM development.

Fitter (1977) studied the effect of mycorrhizal infection on competition for P and K by two grasses, Lolium perenne L. and Holcus lanatus L. and observed that both root competition and mycorrhizal infection gave a slight advantage

to H. lanatus, which in turn suppressed the growth of L. perenne.

Furlan and Fortin (1977) reported that under low light intensities (5 and 10 Klx) the rate of mycorrhizal infection was rapid and percentage infection was high as compared to mycorrhizal plants grown under a light intensity of 15 and 20 Klx. The production of spores increased with increase in light intensity and the growth enhancement was observed at all the light levels but was more pronounced under a 10 Klx light regime.

Hepper (1977) proposed a colorimetric method of estimating the extent of VAM infection in roots by measuring the conversion of fungal chitin to glucosamine.

Johnson (1977) reported that most of the vascular plants and some liverworts in a New Zealand coniferous-dicotyledonous forest harboured typical VA endophyte, Rhizophagus tenuis or mixture of the two.

Khrushcheva (1977) reported that vesicle formation was dependent on mineral metabolism and physiological-biochemical processes within the plants. He observed that superphosphate and N decreased the occurrence of vesicles whereas addition of K to NP fertilizer increased its presence in wheat plants, and addition of lime to NPK fertilizer proved beneficial for mycelial growth in roots but decreased the process of vesicle formation.

Kormanik *et al.* (1977) observed that sweetgum seedlings inoculated with *Glomus mosseae* showed low mortality rate and better growth when compared to nonmycorrhizal ones.

Mejstrik (1977) reported that the degree of cultivation and mainly the amount of available food resources in the soil influenced the development of endophyte in the roots of the host plant. He observed that the mycorrhizal development was restricted in more intensively cultivated soils fertilized with high doses of N and P.

Roncadori and Hussey (1977) observed that *Gigaspora margarita* greatly stimulated growth and development of *Gossypium hirsutum* plants grown in low fertility soils and the joint inoculation of VA mycorrhizal fungi and root-knot nematode decreased the stunting caused by the nematode.

Sanders *et al.* (1977) reported that of the four VA endophytes (*Glomus mosseae*, *G. macrocarpus* var. *geosporus*, *G. microcarpus* and *Gigaspora calospora*) inoculated on onion plants, three enhanced the growth whereas one showed no growth response.

Schonbeck and Dehne (1977) observed that nonmycorrhizal cotton seedlings were more severely damaged by *Thielaviopsis basicola* than the mycorrhizal ones. They (1979) further observed that the diseases caused by *Helminthosporium sativum*

and Erysiphe graminis on barley, by Colletotrichum lindemuthianum and Uromyces phaseoli on French bean, by Erysiphe cichoracearum on cucumber, by Botrytis cinerea on lettuce and by TMV on tomato were increased in mycorrhizal plants when compared to nonmycorrhizal ones, but infection by Olpidium brassicae was reduced in mycorrhizal plants.

Smith and Daft (1977) observed extensive nodulation, higher rates of nitrogenase activity and better growth in mycorrhizal Medicago sativa plants. Smith and Bowen (1979) in an experiment with leguminous plants, further observed a positive correlation between increase in root temperature and number of hyphal entry points. Smith and Smith (1981) compared the effectiveness of natural and artificial inoculum and found that the growth responses of plants artificially inoculated were less than those inoculated with natural mycorrhizal inoculum and this was related to the delay in the initiation of mycorrhizal infection. Smith (1982) also reported that the inflow of phosphate from the soil was more into the mycorrhizal roots than to nonmycorrhizal ones and the percent root length infection was little affected by fertilization with phosphate but rapid growth of roots at high levels of phosphate resulted in reductions in percent root length infection.

Swaminathan and Verma (1979) observed that Glomus macrocarpus helped potato plants to assimilate more phosphate from the soil resulting in the large amount of dry matter.

Swaminathan (1979) further reported that the VA mycorrhizal fungi helped in the metabolism of fixed phosphates that are least available to plants thereby resulting in the greater accumulation of phosphate in the mycorrhizal plants.

Trappe (1977) described the morphology, distribution, habitat and mycorrhizal associations of 3 new Endogonaceous spores viz., Glomus contrictus, Sclerocystis clavispora and Acaulospora scrobiculata.

Different VA endophytes differ in their ability to increase the growth of plants. Abbott and Robson (1978) observed greater proportion of dry weight and phosphorus content in the tops of Clover plants inoculated with Glomus monosporus than in the ones inoculated with G. fasciculatus or the control plants. They (1979) further reported that the nutrient status of the soil and the plant influenced the anatomical behaviour of VAM to some extent. They observed that the normal doses of phosphorus has no effect on the formation of arbuscules, the density of hyphae within infected root and the morphology of the branching pattern of the endophyte hyphae, but addition of P above that required for maximum plant yield eliminated vesicle formation. They put forth their view that some features of infection morphology could prove to be helpful for taxonomic purpose.

Azcon et al. (1978) obtained better growth in the plants treated with VAM fungi, Rhizobium, Azotobactor and

Phosphobacteria (Pseudomonas). The whole bacterial culture behaved as the pure plant hormone in improving dry weights and infection levels compared with mycorrhizal control plants. Azcon and Ocampo (1981) further studied the mycorrhizal dependency of wheat cultivars and observed that neither mycorrhizal dependency nor mycorrhizal infection levels were directly affected by N, P, K, Ca and Mg concentrations in plants. They also observed that the nonmycorrhizal varieties of wheat lacked sugar in their root exudation and they presumed that mycorrhizal infection leads to a decrease in reducing as well as total sugars which in turn influences the degree of infection.

Bagyaraj and Menge (1978) observed an increase in the population of bacteria and actinomycetes in the rhizosphere of tomato plants inoculated with the mycorrhizal fungus Glomus fasciculatus and Azotobacter chroococcum compared to the noninoculated controls. Bagyaraj et al. (1979a) for the first time reported the occurrence of VAM infection in some tropical aquatic plants. Bagyaraj et al. (1979b) also studied the interaction between Glomus fasciculatus and Rhizobium japonicum and their effects on soybean in P-deficient soil at pH 5.6, and obtained more dry weight and N content of root nodules in the plants inoculated with both the endophytes than with Rhizobium alone. Bagyaraj and Manjunath (1980) also obtained greater root and shoot weights in cotton, cowpea and finger millet inoculated with Glomus fasciculatus and grown in P-deficient unsterilized soil.

Carling et al. (1978) reported that the dual inoculation of Glomus fasciculatus and Rhizobium japonicum on soybeans increased the total dry weight, nodule weight and also resulted in higher level of nitrogenase and nitrate reduction activities over singly

inoculated or noninoculated plants. Carling et al. (1979) also observed that the number of infection units in young Soybean seedlings increased with the increase in the quantity of Glomus fasciculatus inoculum until a maximum was reached. Carling and Brown (1980) further reported that Soybean inoculated with Glomus isolates showed significantly increased top dry weights and seed yield in low fertility soils as compared to ones inoculated with Gigaspora species.

Cooper and Losel (1978) observed more total lipid in the mycorrhizal roots than nonmycorrhizal ones. Cooper and Tinker (1981) also reported that phosphates are translocated in hyphae by protoplasmic streaming but they did not rule out the possibility of a bulk flow of hyphal content under a water potential gradient.

Davis et al. (1978) reported that mycorrhizal roots of Avocado were more susceptible to Phytophthora cinnamomi than were nonmycorrhizal roots.

Gaunt (1978) compared the growth of plants in sterile soil from seed pelleted with VA mycorrhizal fungi with uninoculated ones and with plants grown in sterile soil to which mycorrhizal fungal spores were added. He found that the dry weight of mycorrhizal onion and tomato plants were greater than the nonmycorrhizal ones and no difference was observed between different methods of mycorrhizal inoculation.

Gianinazzi-Pearson and Gianinazzi (1978) observed a close correlation between the mycorrhiza-specific phosphates activity and development of the infection and the host plant.

The members of the Chenopodiaceae and Cruciferae are reported to be free from mycorrhizal infection. Hirrel et al. (1978) however, observed a sparse vesicular-arbuscular infection by Glomus fasciculatus in 4 species of Chenopodiaceae and 2 species of Cruciferae only when grown in presence of a mycorrhizal companion plant (Citrus or onion). Enhanced Carbon transfer between onions infected with Glomus etunicatus was reported by Hirrel and Gerdemann (1979) and they suggested that two processes viz. cytoplasmic translocation within hyphae and mass flow along hyphal walls, might have been involved in the transfer. They (1980) further observed better growth of mycorrhizal plants in saline soils compared to nonmycorrhizal ones.

Hughes et al. (1978, 1979) reported higher concentration of P in mycorrhizal strawberry and red raspberry plants compared to non-mycorrhizal ones.

Matare and Hattingh (1978) reported that Glomus fasciculatus had no effect on the incidence and subsequent development of root rot disease in avocado seedlings.

Menge et al. (1978) reported that mycorrhizal avocado seedlings had upto 25% greater growth and more water absorption capacity compared to nonmycorrhizal ones. Menge et al. (1978) further stated that the Citrus cultivars exhibited greatest mycorrhizal dependency with the least

fertilization. Menge et al. (1978a) also added that the concentration of phosphorus within the plant and not the soil phosphate status was the regulatory factor in determining colonization, infection and spore production by VAM fungi.

Porter et al. (1978) observed that varying rate of superphosphate affected the number of VA endophyte spores in a pasture soil. By adding 56 kg superphosphate per hectare per year they obtained 40% increase in spore number compared to unfertilized plots. Porter (1979) proposed a most probable number method (MPN) for estimating the number of infective propagules of VA-mycorrhizal fungi in soil.

The various aspects of mycorrhizal infection in Penine grassland have been studied in detail by Sparling and Tinker (1978, a,b,c). They observed that the highest total weight of roots and total weight of infected root occurred in summer although the highest levels of infection was in winter and the top dressing of phosphate fertilizers decreased the mycorrhizal infection. They further noticed that mycorrhizal infection did not significantly increase the plant dry weight in grasses and attributed this to the greater availability of nutrients in irradiated soils upto 20-fold increases in the growth of mycorrhizal clover was noted in soil with little or no phosphate compared to nonmycorrhizal controls.

Timmer and Leyden (1978) observed stunting of some orange seedlings in fumigated seedbeds due to the elimination

of mycorrhizal fungi. They (1980) also observed Cu-deficiency symptoms in mycorrhizal plants fertilized with high doses of phosphorus which was overcome by the application of copper. They assumed that P-induced Cu-deficiency in mycorrhizal seedlings appeared to be P-inhibition of mycorrhizal development.

Allen et al. (1979) obtained growth of mycorrhizal and non-mycorrhizal Bouteloua gracilis in a defined agar medium with no signs of nutrient deficiency. They observed extensive internal hyphae and arbuscular development behind root tips and at the base of the root branches and also internal and external vesicles along the entire root length. Allen et al (1980) also reported 57% and 111% greater Cytokinin activity in leaves and roots of mycorrhizal B. gracilis plants compared to nonmycorrhizal ones. Allen et al. (1982) further observed increased level of gibberellic acid with reduced abscisic acid in the leaves of B. gracilis plants and assumed that this might alter the physiology of the latter.

Black and Tinker (1979) reported that besides some soil factors (clay content and pH), the agricultural practices of the crop rotation greatly influenced the mycorrhizal status of the field. They observed that after the rotation of the crop there was a long delay before an appreciable infection percentage developed in the roots which was followed by a rapid increase and then to constant value.

Bloss (1979, 1980) reported for the first time the occurrence of VAM in jojoba, mariola and guayule and identified

the symbiont as Glomus fasciculatus.

Daniels and Trappe (1979) described a new VA mycorrhizal fungus, Glomus epigaeus sp. nov and reported it to be very useful for VAM research since it produced thousands of clean, uniform, easily harvested spores for experimental inoculum. They (1980) also reported that soil moisture, temperature and to a lesser extent pH influenced the germination of G. epigaeus spores, whereas levels of soil fertility and spore density had little or no effect. Daniels and Menge (1981) further suggested the commercial potentiality of G. epigaeus as it produced more sporocarps in association with Sudangrass and had a better growth response on a number of crops.

Graw (1979) reported that Tagetes minuta and Guizotia abyssinica reacted differently to change in soil pH and to fertilization with various phosphates inspite of the inoculation of the same strain of Glomus macrocarpus. Growth of mycorrhizal Guizotia was severely inhibited at pH 4.3 as it failed to absorb P from all the P-sources whereas mycorrhizal Tagetes grew well at this pH. Graw et al. (1979) further studied the host specificity and effectivity of eight VA mycorrhizal fungi and found that Glomus macrocarpus formed an efficient mycorrhiza with most plant species whereas G. gerdemanni developed mycorrhiza only with Eupatorium odoratum, the other fungi also showed host specificity to some degree.

The formation of mycorrhiza is directly affected by the P-status of plants and not by the soil-P-status. Jasper et al. (1979) observed that P application to soil depressed the mycorrhizal formation in subterranean clover by increasing plant-P-status.

Lambert et al. (1979) observed that mycorrhizal fungi increased the uptake of Zn and Cu for many plants but the mycorrhizal activity was suppressed by P-fertilization. Lambert et al. (1980) also suggested that indigenous strains of mycorrhizal fungi might possess an adaptation to edaphic factors otherwise their performance and persistence might have been limited by lack of adaptation.

Losel and Cooper (1979) in an experiment with labelled ^{14}C in onion reported that VA mycorrhizal fungi also helped to incorporate more carbon from external sources.

Mc Ilvenn and Cole Jr. (1979) reported that percentage root length infection in Glycine max was slightly stimulated by lower rates of added Zinc but the higher rates were inhibitory.

Miller et al. (1979) observed differences in the amount of infection and in spore numbers and types between different forage legumes and grasses in Brazil.

Mishra and Sharma (1979) studied the mycorrhizal status of the forest trees and distribution of Endogone species in the

humid forest of Meghalaya. Mishra et al. (1980) also worked on the mycorrhizal association of the important fern species of north-eastern India and observed VA type of mycorrhizae in all the cases. Mishra et al. (1981) further assessed the inoculum potential of the mycorrhizal fungi and found that 40 or more VAM spores inoculated per plant produced the highest mycorrhizal infection and growth.

Moorman and Reeves (1979) recorded very low infection percentage (2%) in Zea mays plants in disturbed soil compared to the ones planted in undistrubed soil where it was about 77%. They put forth their view that the reduction of active inoculum in disturbed soil might be an important ecological factor in subsequent succession.

Nemec and O'Bannon (1979) reported that different strains of mycorrhizal fungi responded differently in the soil treated with different kinds of soil fumigants. Nemec (1979) further noticed that irrespective of the diseased or healthy conditions of the plants the VA mycorrhizal fungi had stimulatory effect on the host. Nemec et al. (1981) described the VA mycorrhizal fungi associated with Citrus in Florida and also observed that total number of chlamydospores was negatively correlated with soil P and organic matter but were positively correlated with soil Na and pH.

Owusu-Bennoah and Mosse (1979) recorded an increased growth of onions, lucern and barley when some selected VAM

endophytes were introduced to the field soils. Owusu-Bennoah and Wild (1979, 1980) further reported that for the mycorrhizal and nonmycorrhizal roots most P uptake was within 0.2 and 0.1 cm respectively of the root surface, and the inoculation of lettuce, onion and clover with Glomus mosseae increased plant yields and phosphate uptake in P-deficient soils.

Rabatin (1979) measured seasonal differences in the percent length of Gramineae host root infected with Glomus tenuis and recorded highest infection level in spring for P-deficient soils low in moisture.

Rich and Schenck (1979) recorded a low number of VA mycorrhizal fungi on tobacco as compared to other agronomic crops in northern Florida.

Scannerini and Bonfante-Fasolo (1979) by means of combined morphological and cytochemical studies found that the host-arbuscule interfacial matrix was made up of wall material from the host cell (Polysaccharides and Proteins).

Skipper and Smith (1979) reported that the specific cultivar-fungal response was dependent on soil pH. Overall cultivar response in unlimed soil (pH 5.1) was greater for Gigaspora gigantea than Glomus mosseae whereas in limed soil (pH 6.2) the larger responses were obtained with G. mosseae. In general they obtained better growth and nodulation in mycorrhizal soybean plants as compared to nonmycorrhizal ones.

Varma (1979) observed that dual infections of Glycine max with VA endophytes and Rhizobium significantly increased the number and weight of nodules in natural field soil compared to ones inoculated with Rhizobium alone.

Asimi et al. (1980) obtained growth and yield increase in nodulated soybeans in unamended sterile soil by inoculation with the VA mycorrhizal fungus, Glomus mosseae.

Bhattacharjee et al. (1980) described five members of Endogonaceae including one new species, Sclerocystis indicus.

Chambers et al. (1980) observed that addition of combined N decreased VAM development in young plants of Trifolium subterraneum.

Giovannetti and Mosse (1980) proposed different methods for assessing VA mycorrhizal infection. The methods are based on presence or absence of infection at root/grid intersect points, on a visual estimate of percentage cortex occupied by the fungus or on estimates of length, or presence or absence of infection in root pieces mounted on slides.

Heap and Newman (1980, a, b) demonstrated the mycorrhizal fungal connections between the different roots of same plant Lolium perenne and also between the roots of two different species, L. perenne and Plantago lanceolata which were growing together in a permanent pasture.

Jensen and Jakobsen (1980) found that VA mycorrhizal infection was abundant in barley and wheat grown in P-deficient soils and highest in soils with high P. Jensen (1982) reported that Glomus contrictus and the two isolates of G. fasciculatus enhanced the growth rate of barley along with the increased uptake of P, Cu and Zn whereas Gigaspora margarita proved very poor to do so and the effect was not more than the nonmycorrhizal control.

Johnson et al. (1980) observed that high N fertilization reduced percent infection by Glomus species (G. fasciculatus and G. mosseae).

Nagy et al. (1980) suggested that the barriers to mycorrhizal infection in non-hosts are intrinsic and more probably related to characteristics of the root cortex or epidermis than to any infection-inhibiting factors that might be released in root exudates. Ocampo and Hayman (1981) investigated the effect of crop-rotation on mycorrhizal development in pot experiments using sterilized soil inoculated with Glomus fasciculatus, 'E'3 or Gigaspora margarita or unsterile soil containing mainly a type of Glomus macrocarpus var. geosporus. They observed that in the four crop pairs, the amount of VA mycorrhizal infection in a host plant was not depressed in soil previously cropped with a 'non-host' plant, even when roots of the preceding 'non-hosts' were retained intact in the soil. Indeed the early establishment of VAM

infection in barley, lettuce and maize inoculated in sterilized soil was stimulated by the 'non-hosts' oilseed rape, lettuce and sugarbeet respectively.

Pairunan et al. (1980) reported that mycorrhizae markedly increased growth and phosphorus content of tops of subterranean clover at intermediate rates of Phosphorus for all P-sources.

Pope (1980) reported that inoculation of Platanus occidentalis seedlings with Glomus fasciculatus significantly increased plant dry weight and foliar P concentration compared to nonmycorrhizal controls.

Rose and Trappe (1980) described 3 new enomycorrhizal Glomus species (Glomus halonates sp. nov., G. lacteus sp. nov. and G. scintilla sp. nov.) associated with actinorrhizal shrubs. Rose and Youngberg (1981) also established symbiotic associations between nitrogen-fixing nonleguminous snowbrush seedlings and two categories of micro-organisms; VA mycorrhizal fungi and a filamentous actinomycete capable of inducing nodule formation. They observed that the two major nutrients, N and P were made available and supplied to the host by the two symbiotic micro-organisms.

Smith (1980) studied the effect of season and crop rotation (continuous wheat, annual pasture and an alternating crop: Pasture rotation) on the abundance of the spores of VA

mycorrhizal endophytes and observed high spore number in autumn and also found a positive correlation between VA spore abundance and components of Pasture biomass and a negative correlation of VA spore number with wheat biomass.

St. John (1980) observed a strong association between root depth and mycorrhizal condition. Surface roots were much more likely to be infected than deep roots. He (1981) also described a simple method for synthesizing the pure two membrane VAM infections, using simple culture media.

Warner and Mosse (1980) observed that the VAM fungi could spread independently in soil and seemed to play some saprophytic role in soil system.

Biermann and Linderman (1981) proposed different method of evaluating the mycorrhizal status of plants by estimating the percentage of length of the root segments containing VAM fungal structures instead of determing the percentage infection of roots.

Bonfante-Fasolo et al. (1981) observed that the development of the finer arbuscule branches led to the reduction of the primary host wall material which was deposited around hyphae penetrating cells (which seems to contain a glycoprotein complex) whereas host plasmalemma was not structurally or cytochemically modified during arbuscular development.

Bradley et al. (1981) reported that in Calluna vulgaris the mycorrhizal association provided the resistance to heavy metal toxicity and also it led to significant reduction of the heavy metal content of the shoot.

Brown et al. (1981) reported that application of 280 and 560 kg N/ha as ammonium sulfate or ammonium nitrate produced the highest percentages of mycorrhizal roots and highest intensities of infection per infected root segment in Glomus etunicatus inoculated Sweetgum seedlings.

Clarke and Mosse (1981) obtained better yield production when barley crops was inoculated with VA endophyte in field. They further observed that without any addition of phosphate in soil, only mycorrhizal infection doubled the production of ears in terms of fresh weight, but when phosphate was added it increased the ear production more than inoculation with VA endophyte.

Covey et al. (1981) observed that in a fumigated low P soil, Corn was protected from AS toxicity by VA mycorrhizal fungi. They further noted that apple seedlings were more VAM dependent than were corn plants.

Positive responses in growth of Nicotiana tobacum to inoculation with Gigaspora margarita and significantly greater number of spores were observed in soils with lowest fertilization level (Csinos, 1981),

Gould and Liberta (1981) found that the inoculum potential of the mycorrhizal spores decreased due to soil storage and this decrease was proportionate to increase in storage time.

Kariya and Toth (1981) studied the ultrastructure of the mycorrhizal association formed between Zea diploperennis and Glomus fasciculatus. Krishna et al. (1981) studied the anatomical and histochemical differences in the leaves of nonmycorrhizal and mycorrhizal Eleusine coracana. They noticed striking increases in the thickness of leaves, size of midrib vein, major vein, last vein, motor cells, mesophyll cells and number of plastids in the leaves of mycorrhizal plants as compared to nonmycorrhizal ones. The leaves of mycorrhizal plants also contained higher amount of insoluble polysaccharides and insoluble proteins.

Kianmehr (1981) assessed the VAM infection of saffron in the major areas of Korasen (Iran) and found that the Endogone spore population was high in January and low in July and the root infection was heaviest in April.

Koske (1981a) studied the interactions between five species of VA mycorrhizal fungi sporulating in association with the dominant plants on a single barrier sand dune. He concluded that interaction between VA fungi was of less importance in determining species presence and spore density than were

the species of host plant and other environmental factors. Koske (1981b) observed the spore germination of a VA mycorrhizal fungus, Gigaspora gigantea in the absence of a host plant and found no difference between germination of surface-sterilized or nonsuface-sterilized spores incubated at several temperatures on 2% agar and sterile or nonsterile dune sand. He also noticed that spore germination was unaffected by Phosphorus concentrations of upto 500 ppm but water potentials of - 10 bars or glucose in the medium slowed the germination rate and the growth of the germ tube.

Manjunath and Bagyaraj (1981a) studied the intensity of mycorrhizal infection and response of onion at different stages of growth. They observed mycorrhizal infection with internal hyphae and arbuscules in onion roots 15 days after sowing and infection percentage progressively increased upto 35 days whereas plants inoculated with the mycorrhizal fungus weighed less than nonmycorrhizal plants during initial stages upto 35 days but grew faster later after 38 days. Manjunath and Bagyaraj (1981b) further studied the effect of different components of VAM inoculum on the growth of onion and found that the infected root segments and the extramatrical chlamydospores both stimulated the growth but the former was found more efficient as compared to the latter. Whereas the use of only associated micro-organisms of the roots and the sterilized infected segments as inoculum failed to enhance the growth at all. Manjunath et al. (1981a) also reported the

effects of Glomus fasciculatus, Beijerinckia mobilis and Aspergillus niger either singly or in combination on onion plant. They found that except A. niger, the other two inocula had positive growth response and the inoculation with B. mobilis stimulated the spore production by VA mycorrhizal fungus. They concluded that the combined inoculation treatment was much beneficial than alone. Manjunath et al. (1981b) noticed that different cultivars of rice varied in their susceptibility to mycorrhizal infection.

Pugh et al. (1981) studied the influence of inoculum level, soil fertility, soil temperature, and cotton cultivar on VAM development and plant growth. They found that in a Phosphorus deficient soil, inoculum level of either 200 or 400 azygospores of Gigaspora margarita per plant significantly stimulated cotton growth whereas 10, 50 and 100 spores per plant had little or no effect. They further observed that maximum mycorrhizal development by G. margarita and subsequent cotton growth stimulation occurred at 30 and 24°C and was slight or absent at 19 or 14°C. Regarding different cultivars Coker 310 and Stoneville 213 responded best to G. margarita inoculation, Acala 1517-70 and Deltapine 16 were marginally influenced and Paymaster 909 was relatively unaffected.

The VA mycorrhiza inoculum potential was significantly reduced below 30 cm depth and approached zero at less than 1 m depth (Schwab and Reeves, 1981).

Tommerup and Briggs (1981) reported that benomyl which decomposes in soil to give carbendazim and butyl socyanate, significantly reduced the percentage mycorrhizal infection and spore production.

Wallace (1981) observed that both, severe clipping and high N promoted more prostrate shoot growth and inhibited root growth in Panicum coloratum but mycorrhizal infection promoted a prostrate shoot morphology and enhanced root growth. In severe clipping and N regime, the photosynthesis of the mycorrhizal plants was not affected whereas the photosynthesis of nonmycorrhizal plant was largely inhibited. They discussed about the putative roles of mycorrhizae in intensively grazed ecosystems. Wallace et al. (1982) further added that mycorrhizal infection increased green leaf and sheath, nitrogen concentration and had no effect on nitrogen allocation to the various plant components.

Marx et al. (1982) on the basis of ultrastructural studies and the localization of the ATPase activities on arbuscules, proved the earlier hypothesis right, that the nutrient exchange in VA mycorrhizae occurs across the living host fungus interface and also the phosphate transfer from fungus to host is facilitated by the active transport mechanism in the finer branches of arbuscules.

Hays et al. (1982) reported that at high nitrogen low phosphorus levels percentage VAM infection was highest but the infected Bouteloua gracilis plants were significantly smaller

than noninfected ones. At low nitrogen levels infection was moderate and no infection occurred at high N and high P level. They presumed that the parasitic nature of the response to infection represented the early phase of infection.

Howeler et al. (1982) studied the establishment of an effective mycorrhizal association on eight cassava cultivars in flowing solution cultures containing approximately 0.1, 1, 10 or 100 µm phosphate. They observed that cassava plants were heavily infected with VA endophyte at 0.1 and 1 µm phosphate but not at 10 or 100 µm.

Mycorrhiza developed more slowly in barley plants after inoculation in irradiated soils than in untreated soils mainly due to the high concentration of nutrients released by irradiation of the soil (Jakobsen and Andersen, 1982).

Kucey and Paul (1982) determined the biomass of mycorrhizal fungi associated with bean roots by converting the fungal biovolume measurements to biomass using a conversion factor of 0.35 cm^{-3}.

The abundance of endomycorrhizal and root-surface micro-organisms on three grasses (Agrostis tenuis, Dischampsia flexuosa and Festuca ovina) grown separately and in mixtures, was studied by Lawley et al. (1982). They observed that the abundance of bacteria was not affected by the partner species

whereas the fungal abundance was consistently lowest when the partner species was Agrostis and highest when it was Festuca. Mycorrhizal infection was also influenced to a less extent by the partner species. Out of the 31 species of vascular plants from the Boreal Forest region, 15 were found to be endomycorrhizal (Malloch and Malloch, 1982).

Warnock et al. (1982) studied the interactions between mycorrhizal infection with Glomus fasciculatus, soil leachings and the Collembola, Folsomia candida. They observed that the growth of Allium porrum plants was increased by mycorrhizal infection and leachings, the latter having a lesser effect. In presence of F. candida nonmycorrhizal plants grew better than mycorrhizal ones since F. candida grazed on the external hyphae of G. fasciculatus, thereby rendering the infection ineffective.

Whittingham and Read (1982) reported that the nutrients are directly transferred from living source plants to sink plants by means of connecting mycorrhizal hyphae and they assessed the significance of these observations for nutrition and survival of young plants.

MATERIALS AND METHODS

STUDY AREA AND CLIMATE:

The present study was carried out at Shillong, the capital of Meghalaya, which is located at 25°34'N latitude and 91°56'E longitude (Fig. 1). For the general field study, a plot in the Botanical garden in the university campus, which is located at an altitude of 1540 m was selected. Physiographically, the area is hilly covered with pine forest (Pinus **kesiya**). The pot experiments were done in the glass-house and net-house of the Botany Department of the University. Besides the general field study and the pot experiments, a survey work was also conducted at various agricultural fields located at different altitudes viz., Burnihat (100 m), Shillong (1496 m) and Upper Shillong (1890 m).

The soil is red laterite under red loam or brown loam soil type. The sand content of the soil is upto 90% at some places and it is usually acidic in reaction. The soil is rich in nitrogen content. However, the amount of Phosphorus is very low ranging between 20 kg/acre to 50 kg/acre. The soils are poor in available muriate of potash (Zimba, 1978).

The climate of Shillong is very much controlled by the seasonal winds as in the other parts of the country. The seasonal winds are the South-West Monsoons and the North-East Winter Wind. Hence the year may be divided into four seasons:

1. Spring season - March and April
2. Summer (Rainy) season - May to September
3. Autumn season - October and November
4. Winter season - December to February.

During March and April, the atmosphere gradually warms up. From the middle of April to the middle of May, the temperature reaches the maximum. The maximum temperature recorded at Shillong during the period is 26°C. The average maximum temperature is 20.72°C and the average minimum temperature, 12.77°C. The rain starts by the third week of May and continues upto the end of September and sometimes even upto the middle of October after which it gradually diminishes. The average annual rainfall is 173.53 mm. Similarly, the average humidity is very high ranging between 71.38 to 84.21 in a diurnal cycle. October and November are the two months when the climate is cool and temperate. As the month of November approaches the temperature slowly comes down and the climate gradually changes from cool to a cold one. After November, winter season sets in, which continues upto the end of February. During these months the climate is very cold with temperature falling down to 4-5°C. The lower temperature of the winter results into frost which can be seen sometimes early in the morning during December and January.

The data of the temperature and rainfall during the two years field study (1980 and 1981) has been presented in Fig. 2.

Fig. 1: Map of Meghalaya showing the study area.

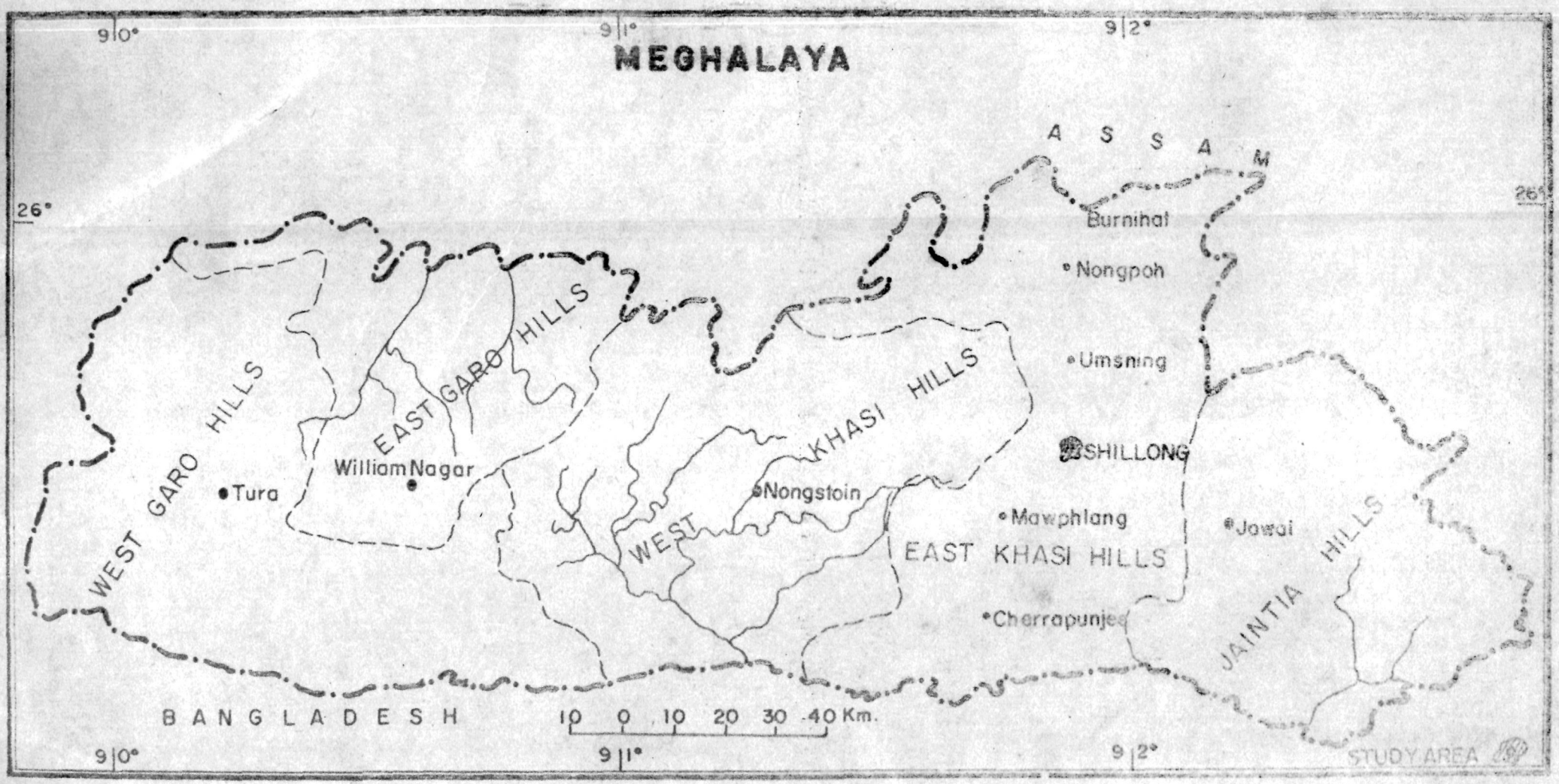

MEGHALAYA
90°
91°
92°
26°
ASSAM
Burnihat
Nongpoh
Umsning
SHILLONG
Nongstoin
Mawphlang
Jowai
Cherrapunjee
WEST GARO HILLS
EAST GARO HILLS
KHASI HILLS
WEST
EAST KHASI HILLS
JAINTIA HILLS
Tura
William Nagar
BANGLADESH
10 0 10 20 30 40 Km.
STUDY AREA

Fig. 1

Fig. 2: Temperature and rainfall during the two years (1980 and 1981) study period.

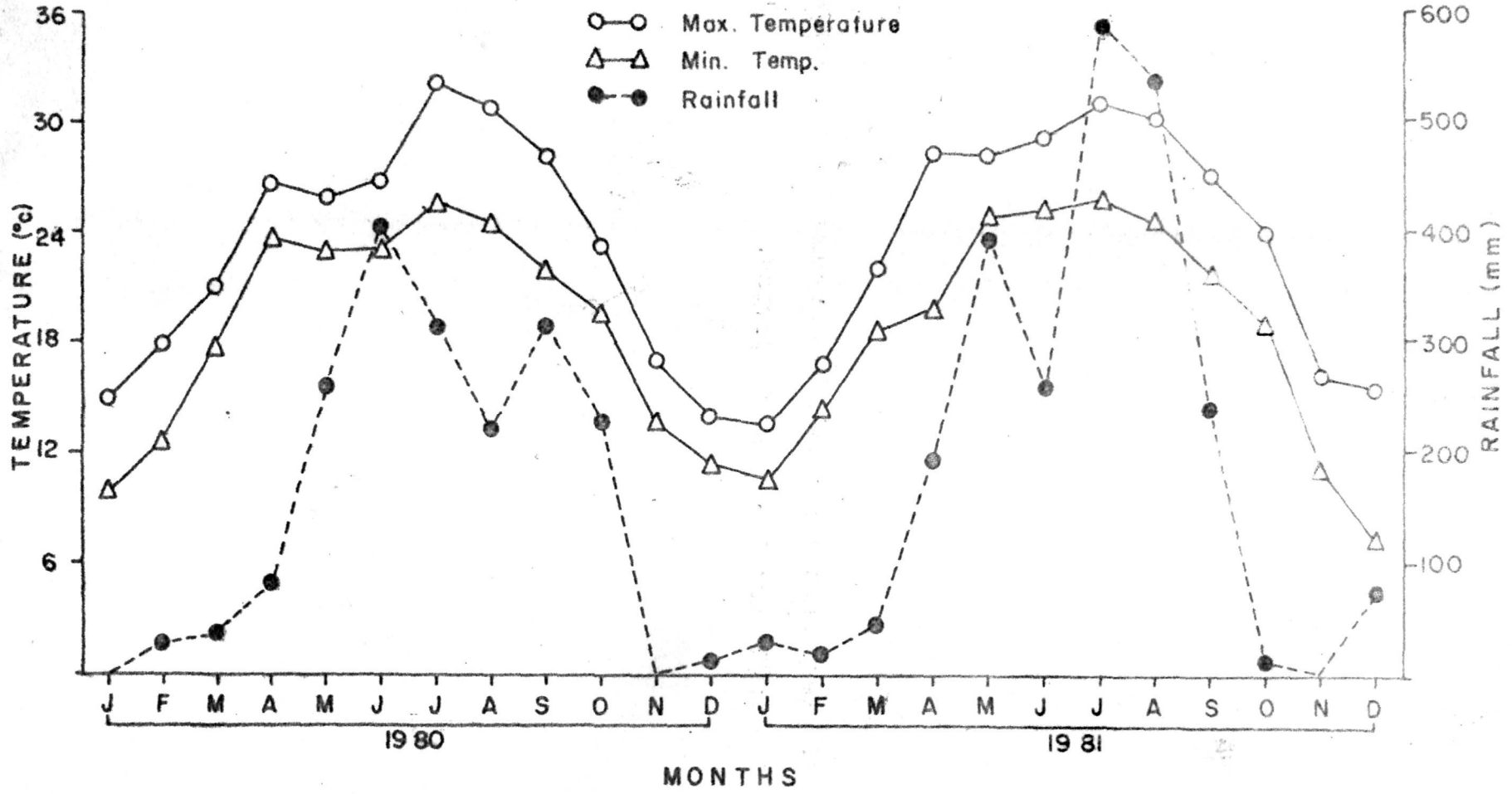

Max. Temperature
Min. Temp.
Rainfall
TEMPERATURE (°c)
RAINFALL (mm)
36
30
24
18
12
6
600
500
400
300
200
100
J F M A M J J A S O N D J F M A M J J A S O N D
1980
1981
MONTHS

Fig. 2

Establishment and development of VA mycorrhizal fungi in different cultivars of three important crops viz., potato, maize and paddy was studied for two growing seasons (1980 and 1981). A site in the university campus was selected for the study. For each cultivar of the three crops mentioned above, plot of the area 15 m x 10 m was prepared.

Potato cultivars : Three different cultivars differing in disease susceptibility ('Late blight' of potato) viz., SSC 1174 (highly resistant), Kufri Jyoti (resistant) and up-to-date locally known as 'Phan Syntiew' (highly susceptible) were selected and plants were raised from the tubers of the same sizes which were planted on 1st March each year and most of the seedlings emerged by 15th March. Plants were sampled at 5, 8, 12, 15 and then after every fifteen days until they were 90 days old. The Endogonaceous spore population in three different fields prior to planting were: Kufri Jyoti field - 48.2/g soil in 1980 and 46.0/g soil in 1981; SSC 1174 field - 48.6/g soil in 1980 and 44.0/g soil in 1981; and in up-to-date field - 45.0/g soil in 1980 and 44.8/g soil in 1981.

Maize cultivars : Three different cultivars viz. Local Yellow, Local White and a composite variety, Vijaya (which was studied in 1980 only) were selected. Seeds were sown by 28th April each year and most of the seedlings emerged on 7th May. Plants were sampled at 5, 9, 12, 15 and then after every fifteen days until they were 150 days old. The Endogonaceous spore population in three different fields prior to planting were:

Local Yellow field - 39.8/g soil in 1980 and 35.0/g soil in 1981; Local White field - 37.6/g soil in 1980 and 33.0/g soil in 1981; and in Vijaya field - 38.4/g soil in 1980.

Paddy cultivars - Again three different cultivars viz., Khonorullu ('Leaf spot' resistant variety), Ngoba and a village paddy (seeds were collected from the village of Mawkhanow) in 1980 and Khonorullu, Ngoba and Mirikrak ('Leaf spot' susceptible variety) in 1981 were selected. Seeds were sown on 19th May each year and most of the seedlings emerged by 28th May. Plants were sampled at 10, 12, 15 and after every fifteen days until they were 150 days old and then a last sampling was done at 180 days. The Endogonaceous spore population prior to planting in different fields were : Khnorullu field - 46.5/g soil in 1980 and 42.5/g soil in 1981; Ngoba field - 44.5/g soil in 1980 and 41.0/g soil in 1981; Village paddy field - 44.0/g soil in 1980; and Mirikrak field - 39.0/g soil in 1981.

Collection of Samples - Five plants of the different cultivars of each crop type were sampled randomly at each sampling period. The intact root system along with the rhizospheric soil was brought to the laboratory where roots were separated from the soil. The separated roots of all the replicates were mixed to form a composite sample for the assessment of mycorrhizal infection and similarly the soils were mixed for the composite sample of soil. The pH and moisture content of the rhizospheric soil were assessed immediately. The mycorrhizal infection was assessed same day or the roots were

preserved in F.A.A. until the completion of examination.

Determination of mycorrhizal infection and isolation of Endogone spores - To prepare the roots for the assessment of mycorrhizal infection, fine root segments 1 cm in length were excised from the sample collected. 100 of them were randomly selected and boiled in 10% KOH for 90 minutes, washed with water, slightly acidified with 5% acetic acid and stained with 0.05% tryphan blue in lactophenol following the procedure of Phillips and Hayman (1970). The root segments were then mounted on microscope slides in clear lactophenol and examined under magnification for endomycorrhizal structures viz. vesicles, arbuscules and hyphae. A root segment was considered infected when one or more of these structures were observed and the percentage root infection was estimated by the root slide technique of Read et al. (1976) and calculated as follows:

$$\% \text{ VAM root infection} = \frac{\text{No. of infected segments}}{\text{Total no. of segments examined}} \times 100$$

Besides percentage VAM infection, number of vesicles, arbuscules and hyphal entry points per cm of root and intensity of mycorrhizal infection were also found out. The measurement of the intensity of infection was based on the visual observation in which the root segments were grouped into following four frequency classes i.e. 0-25% = +, 25-50% = ++, 50-75% = +++ and 75-100% = ++++.

The Endogone spores were isolated by wet-sieving and decanting technique of Gerdemann and Nicolson (1963). 10g airdried soil was stirred in 500 ml water in a beaker, allowed to stand for one minute and decanted to pass through the sieves of the sizes 200 µ, 150 µ, 90 µ and 50 µ. The spores retained on each sieve were washed in tap water to remove the organic debris and collected together and filtered through Whatmann No. 1 filter paper and counted under simple Stereomicroscope in direct light.

The physico-chemical characteristics of the soil was also determined at each sampling.

pH and moisture content determination - 10 g of soil was diluted in 50 ml distilled water, stirred for 15 minutes on mechanical shaker and the pH was read by an electric digital pH meter. Again 20 g soil was dried in a hot air over at 105°C for 24 hours and weighed, and the percentage moisture content was calculated as follows:

$$\% \text{ moisture content} = \frac{\text{Loss in weight on drying (g)}}{\text{Initial sample weight}} \times 100$$

Soil was sieved through 0.2 mm sieve for further determinations. Organic matter determination (Walkely and Black method) - 1 g sieved soil was taken in a 500 ml conical flask and 10 ml IN $K_2Cr_2O_7$ and 20 ml Conc. H_2SO_4 were added and left for 30 minutes. After that, 200 ml distilled water and 10 ml 85% Orthophosphoric acid were added and finally

titrated with IN $FeSO_4$ using diphenylamine as indicator. The percentage organic matter was calculated according to the formula given below:

$$\% \text{ organic matter } \frac{V_I - V_2}{W} \times 0.003 \times 100 \times 1.724$$

Where, V_I = Volume of K_2Cr_2O7

V_2 = Volume of $FeSO_4$

W = Weight of soil (g)

Total nitrogen determination (Micro-Kjeldahl method) - 10 g sieved soil was transferred in a 300 ml digestion flask and moistured with 25 ml of distilled water. After about 20 minutes, 20 g mixed catalyst (20 g Copper sulphate + 3 g Mercuric oxide + 1 g Selanium dioxide) and 35 ml Conc. H_2SO_4 were added. Subsequently digestion was done first by low heating and afterwards at high temperatures in digestion units. The flasks were rotated at intervals and heating was continued until the organic matter was destroyed and the solution got cleared. The whole content was diluted with distilled water in a 800 ml flask and distilled in presence of 40% Sodium hydroxide. The released ammonia was absorbed in 4% boric acid and titrated with N/14 HCl. The percentage nitrogen was then calculated as follows:

$$\% \text{ nitrogen} = (T-B) \times N \times \frac{1.4}{S}$$

Where, T = Sample tiration

B = Blank titration

N = Normality of Acid

S = Sample weight (g)

Determination of available phosphorus (Molybdenum-blue method) - Ammonium fluoride extraction solution which was prepared by mixing 15 ml NH_4F solution (37 g/100 ml) with 25 ml HCl (0.5 N) and 460 ml distilled water, was used for extracting the available phosphorus. 4 g sieved soil was taken in 100 ml conical flask in which 14 ml extraction solution was added and stirred for 15 minutes on mechanical shaker. The extract was filtered through Whatman No. 44 filter paper. 2 ml of the filtrate was taken in a test tube to which 5 ml of distilled water and 1 ml of ammonium molybdate was added. The solution was shaked and 1 ml of Stannous chloride solution was added to develop the blue colour. After 20 minutes the O.D. was read at 660 nm and converted into known units through the standard graph. The available phosphorus (ppm) was calculated as follows:

$$\text{Available P (ppm)} = \frac{\text{ppm of P in solution x combined volume}}{\text{aliquat (ml) x Sample wt. (g)}}$$

Determination of exchangeable potassium - Ammonium acetate solution (which was prepared by mixing 575 ml of glacial acetic acid with 600 ml of ammonia solution and diluted to 10 litres with distilled water) was used for extracting the potassium. The pH was adjusted to 7 $\pm$ 0.05 with the help of acetic acid or ammonia solution. 10 g sieved soil was stirred with 250 ml of extraction solution for one hour and filtered through Whatman No. 44 filter paper. The exchangeable potassium was read in a photoflame meter and converted into known units

through standard graph. The calculation was done as follows:

$$\text{exchangeable K (mg/g)} = \frac{\text{C (ppm) from graph x Solution Volume}}{10^3 \text{ x Sample Wt. (g)}}$$

All the methods followed for soil analyses were as suggested by Jackson (1973) and Allen (1974).

SOIL FERTILITY LEVEL AND THE MYCORRHIZAL DEVELOPMENT :

According to the News Letter, Directorate of Agriculture, Meghalaya (1980), the recommended doses of fertilizers in terms of N, P_2O5 and K_2O kg per hectare were as follows:

N, 60; P_2O5, 30 and K_2O, 25. After calculation the normal doses of NPK for 5 kg soil in terms Ammonium Sulphate (AS), Single Superphosphate (SSP) and Muriate of Potash (MOP, worked out to be 0.75 g AS, 0.47 g SSP and 0.105 g MOP.

The sandy-loam laterite garden soil of the following properties - pH, 6.7; organic matter, 3.33%; P_2O_5, 3.59 kg/ha ; K_2O, 448 kg/ha , and sand of the following property - pH, 5.2; organic matter, 0.27%, P_2O5, 0.59 kg/ha ; K_2O, 22 kg/ha , were autoclaved two times at 15 lb pressure for 3 hours with an interval of 24 hours to kill the mycorrhizal propagules. The autoclaved soil and sand were left in moistened condition for two weeks to overcome any toxic effect of steam sterilization and to regain the microbial activity before setting up the experiment.

To see the effect of soil fertility level on the establishment and development of VA mycorrhizal fungi, the original fertility of the soil was decreased by adding sand in different proportions, and also increased by adding different doses of NPK fertilizer. The following ten treatments were maintained using fifteen 5-kg capacity pots for each treatment:

1. Sand alone; 2. Soil (SO): Sand (Sa), 1:4; 3. SO:Sa, 1:2; 4. SO:Sa, 1:1; 5. Soil alone; 6. SO + ¼ normal dose of NPK fertilizer; 7. SO + ½ normal dose of NPK; 8. SO + 1 normal dose of NPK; 9. SO + 2 normal dose of NPK; and 10. SO + 4 normal dose of NPK.

Using different doses (2 times and 3 times normal dose) of phosphate fertilizer to the normal NK dose and different doses (2 times and 3 times normal dose) of nitrogen fertilizer to the normal PK dose, the following four treatments each consisting of fifteen 5-kg capacity pots were maintained -

1. SO + $(NK)_1P_2$; 2. SO + $(NK)_1P_3$; 3. SO + $(PK)_1N_2$; and 4. SO + $(PK)_1N_3$.

50 g field inoculum (containing mixture of *Glomus* spp. and *Gigaspora* spp.) was supplied at 5 cm below the surface to each pot of the different treatments mentioned above.

Seven numbers of 'Local Yellow' maize seeds were sown in each pot. The seedlings were thinned to five per pot after one week of growth. The pots were watered at every alternate

diluted 2 times by adding acid washed sand in 1:2, soil : sand ratio. This mixture was autoclaved two times at 15 lb pressure for 3 hours with an interval of 24 hours, in order to remove the mycorrhizal propagules from the soil. 5 kg of this soil:sand mixture was put in thirtysix plastic pots and left for fifteen days under moist condition to overcome any toxic effect of steam sterilization and to regain the microbial activity.

Six concentrations of single superphosphate i.e. 0, 0.1, 0.5, 2.0, 5.0 and 10.0 g were mixed thoroughly in separate pots. 6 pots were used for each concentration of phosphate, 3 of which were used as 3 replicates for mycorrhizal treatments and remaining 3 for the nonmycorrhizal treatments.

The local isolate of mycorrhizal fungi Glomus tenuis, isolated and maintained on the host Eupatorium riparium was used as the mycorrhizal inoculum. 25 g of the inoculum containing roots and soil was evenly spread below 3 cm of the soil surface in the pots meant for the experiment of mycorrhizal treatments. The remaining pots to be used for nonmycorrhizal experiment received the twice filtered washings of the same inoculum in order to keep the other microbial characters same in both the sets.

The seeds of the maize cultivar 'Local Yellow' were germinated on moist filter paper in petriplates at 30°C in an incubator and 8 numbers of one week old seedlings were transplanted in each pot, which was finally thinned to 4 per

pot after one week of growth. The pots were watered at every alternate days for 4 weeks and then twice a week till the end of the experiment. The plants were harvested after 9 weeks. The experiment was conducted under glasshouse conditions during the months May - July 1981.

Measurements : The shoot and root length was measured by general scales. The diameter of the 1st internode of stem was measured by slide callipers. The dry weight was obtained after drying the plant materials at 80°C oven and reweighing till constant weight.

Percentage infection : Percentage mycorrhizal infection was estimated in 70 to 100 randomly selected 1 cm length root segments following the method of Phillips and Hayman (1970). Besides percentage root infection, the intensity of mycorrhizal infection was also found out in all the treatments.

Plant material analysis : Root, stem and leaves were powdered separately in small grinder and sieved through 0.2 mm sieve. From the sieved material, the total nitrogen was estimated by the micro-Kjeldahl method. Phosphorus was estimated by molybdenum blue method (after ashing the material with magnesium nitrate).

MYCORRHIZA AND CROP PRODUCTIVITY :

The effect of VA mycorrhizal fungi Glomus fasciculatus

(Thaxter sensu Gerdemann) Gerdemann & Trappe on the growth and productivity of potato and maize, was studied.

Potato : The sandy-loam laterite garden soil of the following properties: pH 5.80, organic matter 3.88%, total nitrogen 0.33% and exchangeable potassium 0.15 mg/g, was outoclaved two times at 15 lb pressure for 3 hours with an interval of 24 hours in order to remove the mycorrhizal propagules from the soil. 10 kg soil was put in 18 plastic pots (26 cm length and 28 cm diameter) and left for fifteen days under moist condition to overcome the toxic effect of steam sterilization and to regain the microbial activity.

The mycorrhizal inoculum used was Glomus fasciculatus (provided by Dr. Menge, U.S.A.) which was maintained in pure culture on the host Allium sativum L. 50 g inoculum containing root and soil was evenly spread below 4 cm of the soil surface in 9 pots. The remaining 9 pots to be used for nonmycorrhizal experiments received the twice filtered washings of the same inoculum in order to keep the other microbial characters similar in both the sets. Four potato tubers (cultivar 'Up-to-date') of the similar sizes were planted in each pot. When the seedlings were one-week old, thinning was done in order to allow only two healthy seedlings per pot to grow further. The plants were watered every alternate days for 4 weeks in the beginning and twice a week afterwards. The experiment was conducted under glasshouse conditions between February-May, 1982. The

temperature during the study period ranged between 14°C to 25°C. Harvesting was done when the plants were 30, 60 and 90 days old and three replicate pots alongwith six replicate plants were sampled at each harvesting time.

Maize : The sandy-loam laterite garden soil of the following properties: pH 6.40, organic matter 3.64%, total nitrogen 0.3%, available phosphorus 3.93 ppm, exchangeable potassium 0.25 mg/g was steam-sterilized as above and 10 kg soil was put in 24 plastic pots (26 cm length and 28 cm diameter) and left for fifteen days in moist condition to overcome any toxic effect of steam-sterilization and to regain the microbial activity.

50 g mycorrhizal inoculum (Glomus fasciculatus inoculum maintained as mentioned above) containing roots and soil was evenly spread below 4 cm of the soil surface in half of the pots. The pots to be used for nonmycorrhizal experiments received the twice filtered washings of the same inoculum in order to keep the other microbial characters similar in both the sets. The Local Yellow maize seeds were germinated in moist filter paper and one-week old seedlings were transferred to each pot. Afterwards the seedlings were thinned to 3 per pot in 18 pots but only one seedling per pot was left in 6 pots (3 in mycorrhizal set and 3 in nonmycorrhizal set, to record the yield at the end of the experiment). The pots were watered at every alternate days for 4 weeks and then twice a week till the end of the

experiment. Harvesting was done when the plants were 30, 60, 90 and 150 days old and 3 replicate pots alongwith 9 replicate plants were sampled at each time (3 plants in the last harvest i.e. at 150 days old). The experiment was conducted under glasshouse conditions during the months March-August 1982. The temperature during the study period ranged between 16°C to 26°C.

Measurements : The shoot and root length was measured by general scales, and the diameter of the 1st internode of stem was measured by slide callipers. The leaf area was calculated on per plant leaf dry weight basis, after determining the total leaf area of a plant by planimeter. The dry weight was calculated after drying the plant materials at 80°C oven and reweighing till constant weight was recorded. In maize for determining yield, number of ears/plant, size of the ear, number of grain /ear and dry weight of grains/100 grains were taken into consideration. Whereas in potato, tuber number/2 plants and tuber weight/10 tubers (dry weight) were considered.

Percentage infection:: The clearing and staining technique of Phillips and Hayman (1970) and root slide technique of Read et al. (1976) were followed to determine the percentage root infection in 70-100 randomly selected root segments of approximately 1 cm length.

Plant material analysis : Root, stem and leaves were powdered separately in small grinder and then sieved through 0.2 mm sieve.

From the sieved material, the total nitrogen was estimated by the micro-Kjeldahl method. Potassium and phosphorus were estimated through dry ashing method. For phosphorus, magnesium nitrate was mixed with plant material before ashing but in case of potassium the ashing was done directly. Molybdenum blue method was used for phosphorus estimation and flame photometer for potassium reading. All these methods were followed as suggested by Allen (1974).

SURVEY OF CROPS FROM DIFFERENT AGRICULTURAL FIELD FOR VESICULAR-ARBUSCULAR MYCORRHIZA AND ENDOGONACEOUS SPORES :

Potato, maize and paddy plants were surveyed for VAM and Endogone spores from different agricultural fields of Meghalaya located at different altitudes viz., Burnihat (100 m), Shillong (1496 m) and Upper Shillong (1890 m).

Root and soil samples were collected from these places for estimating percentage mycorrhizal infection and Endogone spore numbers. The percentage root infection was estimated in 70 to 100 1 cm length root segments, following the methods of Phillips and Hayman (1970) and Read et al. (1976). Endogone spores were extracted from 10 g soil following wet-sieving and decanting technique of Gerdemann and Nicolson (1963). The spores isolated on 200 µ, 150 µ, 90 µ and 50 µ were separately collected and counted under simple stereomicroscope.

pH, moisture content (%), organic matter (%) total nitrogen (%), available phosphorus (ppm) and exchangeable potassium (mg/g) of the soil samples were estimated as described earlier.

RESULTS

A. MYCORRHIZAL STATUS IN CROP PLANTS

1. Mycorrhizal infection:

Potato: Among the three different cultivars of potato, the two disease-resistant cultivars, 'SSC 1174' and 'Kufri Jyoti' showed better mycorrhizal establishment than the disease-susceptible cultivar, 'up-to-date' (Fig. 3). Mycorrhizal establishment in both SSC 1174 and Kufri Jyoti was observed in 12 days and 8 days old plants in the year 1980 and 1981 respectively. The mycorrhizal infection increased with the increase of the age of the plant (except a decrease at 60 days in both the cultivars observed in 1980 and 90 days in case of Kufri Jyoti in 1981) (Fig. 3). In both the cultivars, arbuscules were first observed in 15 days old plants and it increased in number with the increase in the age of plants being maximum in 75 days old plants and then decreased (Fig. 5A). But in 1980, a decrease in the number of arbuscules was observed in 60 days old plants also. Vesicles were first observed in 30 days old plants in both the cultivars and it increased in number with the increase of the age of plants in 1980, but in 1981 its number decreased in 90 days old plants (Fig. 4). The intensity of infection increased with the increase of plant life upto 60 days and then decreased in both SSC 1174 and Kufri Jyoti during both the years (Table 1). The number of hyphal entry points also followed the similar pattern as the intensity of infection in Kufri Jyoti but in SSC 1174 a slight increase was observed in 90 days old plants in 1981 (Table 1).

Unlike the other two cultivars, in up-to-date infection started quite late i.e. in 19 days and 12 days old plants in

Fig. 3: Percentage vesicular-arbuscular mycorrhizal (VAM) infection with respect to different age group in different cultivars of potato during the two years (1980 and 1981) study period.

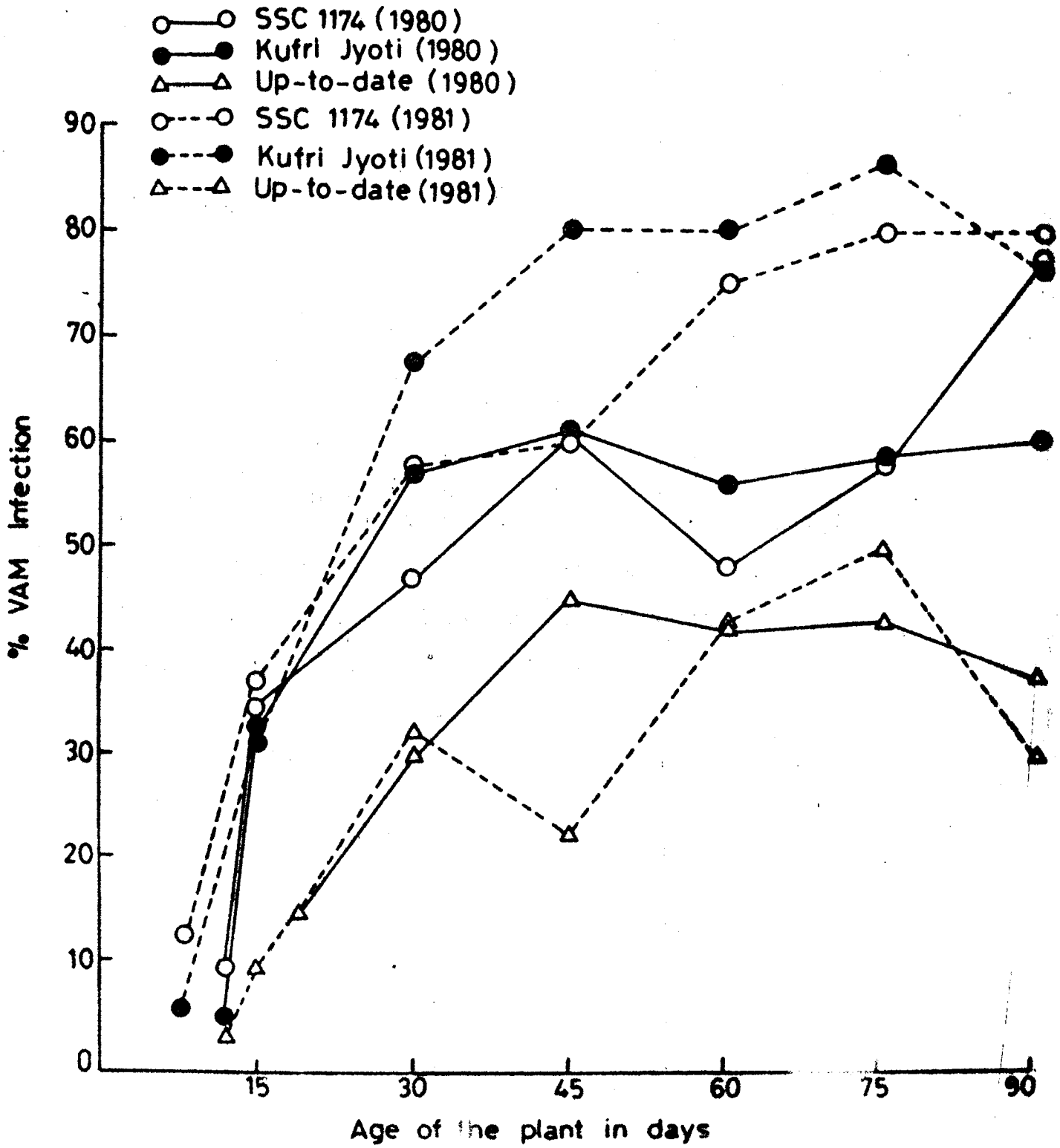

SSC 1174 (1980)
Kufri Jyoti (1980)
Up-to-date (1980)
SSC 1174 (1981)
Kufri Jyoti (1981)
Up-to-date (1981)
% VAM Infection
0
10
20
30
40
50
60
70
80
90
15
30
45
60
75
90
Age of the plant in days

Fig. 3

Fig. 4: Number of vesicles with respect to different age group in different cultivars of potato during the two years (1980 and 1981) study period.

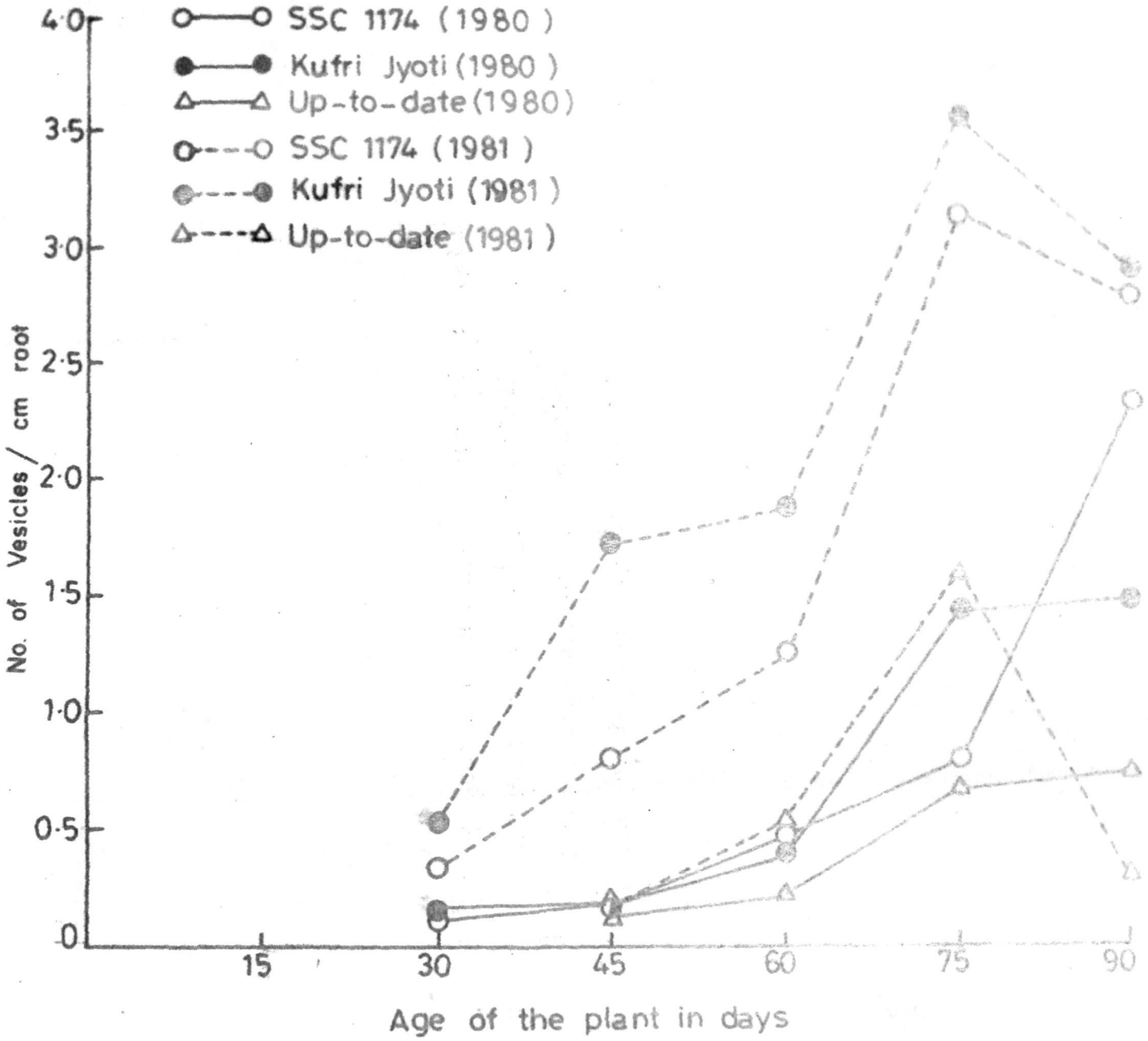

SSC 1174 (1980)
Kufri Jyoti (1980)
Up-to-date (1980)
SSC 1174 (1981)
Kufri Jyoti (1981)
Up-to-date (1981)
No. of Vesicles / cm root
4·0
3·5
3·0
2·5
2·0
1·5
1·0
0·5
0
15
30
45
60
75
90
Age of the plant in days

Fig. 4

1980 and 1981 respectively. The mycorrhizal infection increased with the increase of the age of plant, except a decrease in 60 and 90 days old plants in 1980 and 45 and 90 days old plants in 1981 (Fig. 3). Arbuscules were first observed in 30 days old plants and it increased in number with the increase of plant life upto 75 days followed by a decrease in 90 days old plants (Fig. 5A). However, a decrease was also observed in 60 days old plants in 1981 (Fig. 5A). Vesicles were first observed in 45 days old plants which increased in number with the age of the plants except a decrease at 90 days, in 1981 (Fig. 4). The intensity of infection was more or less the same throughout the age of the plant (Table 1). The number of hyphal entry points increased with the age upto 30 days, then decreased in 45 days old plants and again increased upto 75 days followed by a decrease in 90 days old plants (Table 1).

The analysis of variance showed that in SSC 1174, the percentage of mycorrhizal infection was positively correlated (Significant at 1% level) with pH but negatively correlated (Significant at 5% level) with total nitrogen in 1980. Positive correlation (Significant at 1% level) was also observed with moisture content in 1981 (Table 15). In case of Kufri Jyoti, the percentage mycorrhizal infection showed a negative insignificant correlation with N, P and K, and a positive insignificant correlation with moisture content and organic matter in both the years (Table 14). Whereas, in up-to-date variety the percentage of mycorrhizal infection was positively correlated with pH and

Table 1: Intensity of mycorrhizal infection and number of hyphal entry points/cm root in three different cultivars of potato.

Age of the plant (in days)	Kufri Jyoti			SSC 1174			Up-to-date		
	Intensity		No. of entry points/cm root	Intensity		No. of entry points/cm root	Intensity		No. of entry points/cm root
	I	II	II	I	II	II	I	II	II
15	+	+	0.75	+	+	0.50		+	0.20
30	+	++	1.73	+	++	1.00	+	+	0.50
45	++	++	1.95	++	++	1.25	+	+	0.25
60	++	+++	2.25	++	+++	1.50	+	+	0.75
75	++	++	1.00	++	++	0.95	+	+	0.90
90	+	++	1.00	++	++	0.75	+	+	0.30

I = 1980; II = 1981.

moisture content (Significant at 5% level in 1980) and negatively correlated (Statistically not significant) with phosphorus in both the years. The percentage of mycorrhizal infection showed a significant negative correlation with nitrogen in 1980 but significant positive correlation with the same in 1981 (Table 16).

Maize: The first mycorrhizal infection was observed in 12 days old plants in all the cultivars of maize in 1980 and at the same time in Local White in the following year. In Local Yellow infection could establish in 9 days old seedlings in 1981 (Fig. 6). In Local Yellow, infection increased with the increase in plant life upto 105 days, then decreased which was followed by an increase in 150 days old plants in 1980, whereas in 1981, maximum infection was found in case of 90 days old plants which decreased in 105 and 120 days old plants (Fig. 6). The infection, in Local White, increased with the age of the plant upto 90 days. In 1980, a decrease in infection in 105 days old plants was observed, which was followed by an increase in the subsequent samplings (i.e. 120, 135 and 150 days old plants) (Fig. 6). Whereas, in 1981 after the depression in 105 and 120 days old plants there was a considerable increase in infection reaching the maximum value (100%) in 135 and 150 days old plants (Fig. 6). Like the two other local cultivars, the composite variety i.e. Vijaya showed an increasing trend in mycorrhizal infection with the age upto 60 days which decreased at 75 days and

again increased in 90 days old plants (Fig. 6). Arbuscules were first observed in 15 days old plants in all the three cultivars, which increased in number upto 75 days. Later on an abrupt decrease was noticed (Fig. 5B). Same pattern was observed in 1981. Vesicles were first observed in 30 days old plants in all the three cultivars and it increased in number reaching a peak in 60 days old plants in Local Yellow and Vijaya, and in 105 days in Local White (the increase was much marked after 45 days in all the three cultivars) (Fig. 7). A second vesicular peak was observed in 90 days old plants in Local Yellow which was followed by an abrupt decrease in 120 days old plants and then an increase in the subsequent ages (Fig. 7). Unlike Local Yellow, in Local White the number of vesicles decreased in the 150 days old plants (Fig. 7). In case of Vijaya, the number of vesicles after reaching a peak in 60 days old plants decreased upto 105 days, which was followed by an increase in the subsequent ages (Fig. 7). In 1981, the number of vesicles increased with the increase in plant life upto 120 days and then decreased in the subsequent ages in both Local Yellow and Local White (Fig. 7).

The intensity of infection increased with the age of the plant upto 105 days in Local Yellow and 90 days in Local White and Vijaya in 1980 (Table 2). In Local White the same pattern was observed in 1981 (except some decrease in 60 and 120 days old plants). In Local Yellow, the intensity was maximum in 90 days old plants in 1981, which decreased later

Fig. 5: Number of arbuscules with respect to different age group during the two years study period (1980 and 1981).
A - In different cultivars of potato
B - In different cultivars of maize.

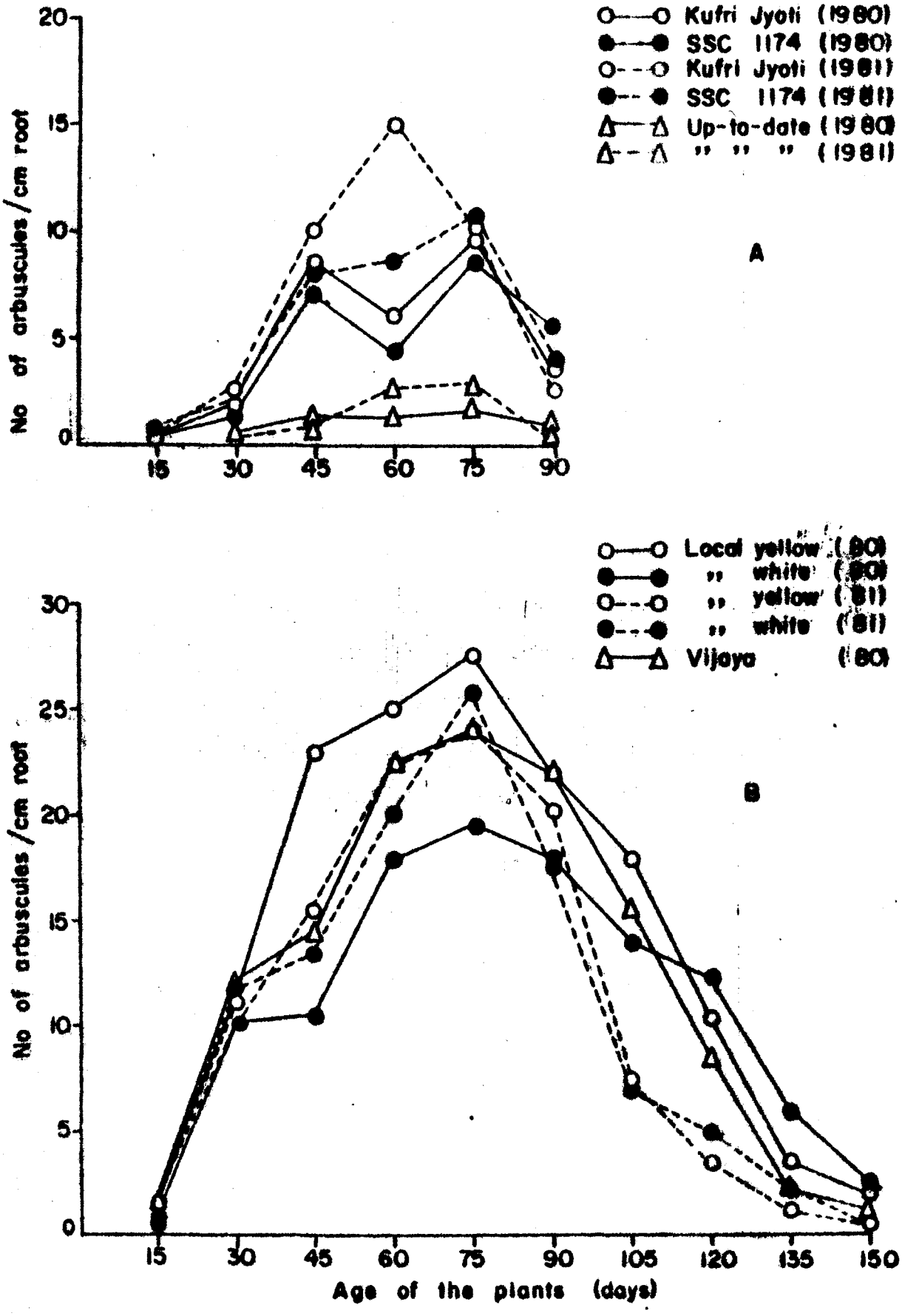

Kufri Jyoti (1980)
SSC 1174 (1980)
Kufri Jyoti (1981)
SSC 1174 (1981)
Up-to-date (1980)
" " " (1981)
A
No of arbuscules/cm root
0
5
10
15
20
15
30
45
60
75
90
Local yellow (80)
" white (80)
" yellow (81)
" white (81)
Vijaya (80)
B
No of arbuscules/cm root
0
5
10
15
20
25
30
15
30
45
60
75
90
105
120
135
150
Age of the plants (days)

Fig. 5

Fig. 6: Percentage vesicular-arbuscular mycorrhizal (VAM) infection with respect to different age goup in different cultivars of maize, during the two years (1980 and 1981) study period.

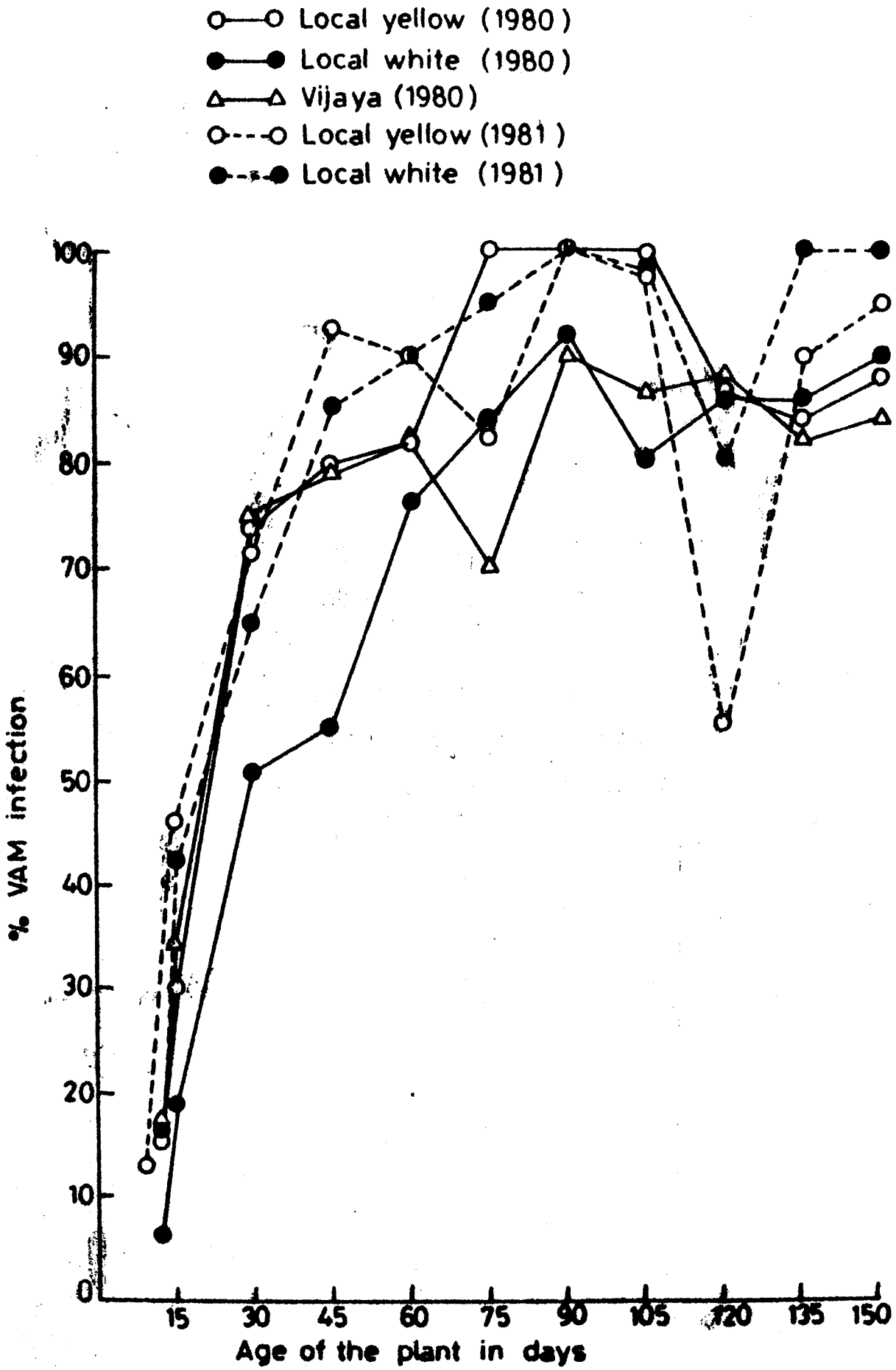

Local yellow (1980)
Local white (1980)
Vijaya (1980)
Local yellow (1981)
Local white (1981)
% VAM infection
0
10
20
30
40
50
60
70
80
90
100
15
30
45
60
75
90
105
120
135
150
Age of the plant in days

Fig. 6

Fig. 7: Number of vesicles with respect to different age group, in different cultivars of maize during the two years (1980 and 1981) study period.

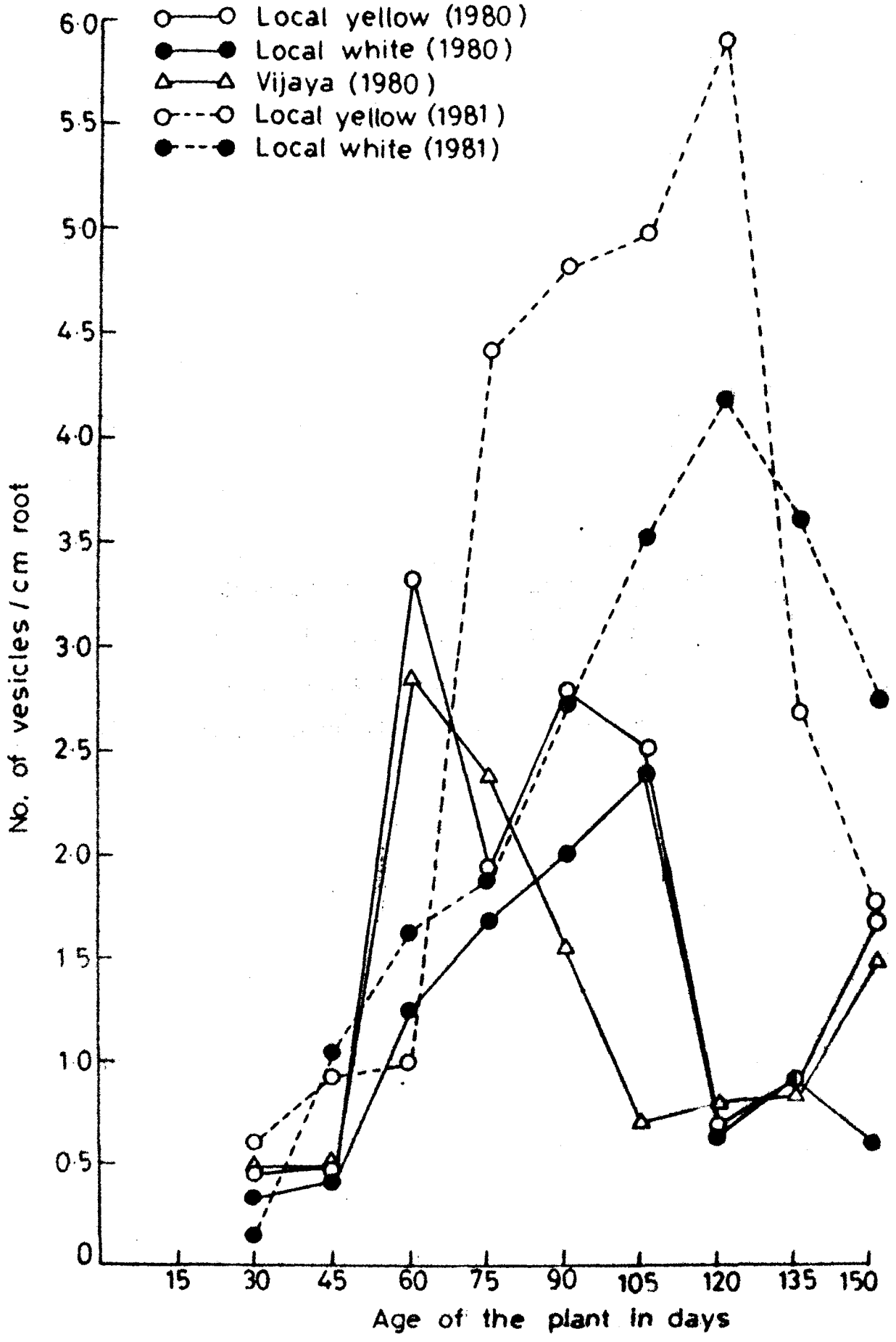

Local yellow (1980)
Local white (1980)
Vijaya (1980)
Local yellow (1981)
Local white (1981)
No. of vesicles / cm root
6·0
5·5
5·0
4·5
4·0
3·5
3·0
2·5
2·0
1·5
1·0
0·5
0
15
30
45
60
75
90
105
120
135
150
Age of the plant in days

Fig. 7

Table 2 : Intensity of mycorrhizal infection and number of hyphal entry points/cm root in different cultivars of maize.

Age of the plant (in days)	Local Yellow			Local White			Vijaya
	Intensity		No. of entry points/ cm root	Intensity		No. of entry points/cm root	Intensity
	I	II	II	I	II	II	I
15	+	+	1.38	+	+	0.68	+
30	+++	++	1.63	++	++	1.83	+++
45	+++	+++	1.75	++	+++	0.95	+++
60	+++	+++	1.74	+++	++	0.73	+++
75	++++	++++	0.43	+++	++++	1.40	+++
90	++++	++++	2.97	++++	++++	0.58	++++
105	++++	++	0.53	+++	+++	0.10	+++
120	+++	++	0.08	+++	++	1.40	+++
135	+++	+++	4.13	+++	+++	2.75	+++
150	+++	+++	4.50	+++	+++	3.25	+++

I = 1980; II = 1981.

on, and again increased in 135 and 150 days old plants (Table 2). In Local Yellow, the number of hyphal entry points increased with the age upto 45 days followed by a decrease at 60 and 75 days. An increase in the number of hyphal entry points was again noticed in 90 days old plants, which decreased upto 120 days followed by an increase in the subsequent ages (Table 2). But in Local White, an increase in the number of hyphal entry points was noticed upto 30 days, which after some fluctuations obtained the maximum value in 150 days old plants (Table 2).

The analysis of variance showed that the percentage mycorrhizal infection was negatively correlated (statistically insignificant) with most of the soil properties, in Local Yellow (Table 17). Whereas, in Local White, it was positively correlated with pH, organic matter and phosphorus (1% level) in 1981, and negatively correlated (statistically not significant) with moisture content (Table 18). In case of Vijaya, the percentage of mycorrhizal infection was negatively correlated with all the soil properties (except pH). The negative correlation with potassium was significant at 1% level (Table 19).

Paddy: Among the different cultivars of paddy, the disease-resistant cultivar 'Khonorullu' and 'Ngoba' showed better mycorrhizal establishment than the disease-susceptible cultivar 'Mirikrak'. The infection started in 12 days old seedlings in Khonorullu in both the years, whereas in Ngoba

it was observed in 15 and 12 days old seedlings in 1980 and 1981 respectively. In village paddy and Mirikrak the infection was noticed in 15 days old seedlings (Fig. 8). The infection in plants increased with the increase of age upto 135 days and then decreased in both Khonorullu and Ngoba. In village paddy, the infection increased with the increase in the plant age upto 75 days, then decreased in 120 days old plants following an increase in the subsequent ages reaching to a maximum level in 150 days and again decreased in 180 days old plants (Fig. 8). In 1981, in Khonorullu, the infection increased with the plant age upto 75 days then decreased abruptly upto 120 days; which was followed by an increase in the subsequent ages (Fig. 8). Whereas, in Ngoba, it increased with the increase in plant life upto 105 days, then decreased abruptly in 135 days old plants following an increase in the subsequent ages (Fig. 8). In Mirikrak, however, the infection which was very mild increased with the plant age upto 75 days, then decreased in 90 and 105 days following a steady increase in the subsequent ages (Fig. 8). The arbuscules were first observed in 15 days old seedlings in all the cultivars of paddy. The number of arbuscules increased with the increase in plant age upto 135 days and then decreased abruptly in the subsequent ages, in Khonorullu and Ngoba (Fig. 9A). In village paddy, the number of arbuscules increased upto 120 days and decreased subsequently (Fig. 9A). However, the number of arbuscules increased upto 90 days in Khonorullu, 105 days in

Fig. 8: Percentage vesicular-arbuscular myoorrhizal (VAM) infection with respect to different age group, in different cultivars of paddy during the two years (1980 and 1981) study period.

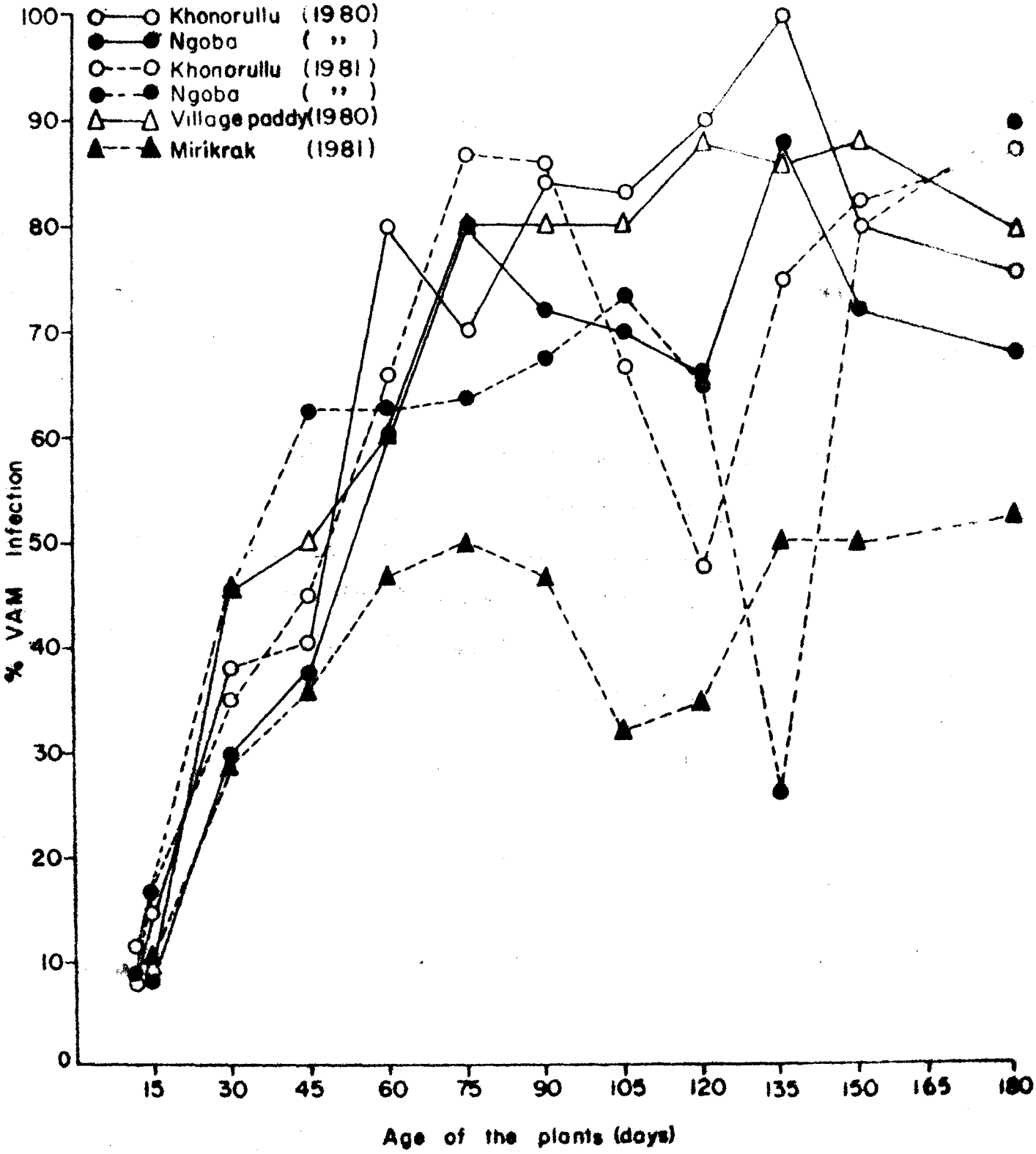

Khonorullu (1980)
Ngoba (")
Khonorullu (1981)
Ngoba (")
Village paddy (1980)
Mirikrak (1981)
% VAM Infection
100
90
80
70
60
50
40
30
20
10
0
15
30
45
60
75
90
105
120
135
150
165
180
Age of the plants (days)

Fig. 8

Ngoba and 75 days in Mirikrak (where the increase was very slow) and then decreased in the subsequent ages in the year 1981 (Fig. 9A).

The first vesicle was observed in 30 days old plants in Khonorullu, Ngoba and village paddy, and in 45 days old plants in Mirikrak (Fig. 9B). In case of Khonorullu and village paddy the number of vesicles increased slowly upto 120 days which was followed by an abrupt increase in the subsequent ages. Whereas, in Ngoba and Mirikrak, a steady increase in the number of vesicles with the increase in plant life, was observed (Fig. 9B). In 1980, the intensity of infection increased with the increase in plant age upto 135 days in all the three cultivars (except a decrease in 105 days old plants in Ngoba), then decreased in the subsequent ages and maintained a consistancy in 180 days old plants (Table 3). However, in the year 1981, the intensity of infection increased upto 75 days in Khonorullu and 105 days in Ngoba, then decreased in the subsequent ages, which was followed by an increase in 150 days old plants (Table 3). Whereas, in Mirikrak variety, the intensity was lowest showing a consistancy upto 120 days, followed by a slight increase in 135 days and then decreased in the subsequent ages (Table 3). The number of hyphal entry points increased with the increase in plant age upto 60 days in Khonorullu 45 days in Ngoba and 30 days in Mirikrak. This was followed by a decrease upto 120 days in Khonorullu and Mirikrak, and 135 days in Ngoba, and then an increase in the subsequent ages (except a decrease

Fig. 9: Arbuscules and vesicles with respect to different age group, in different cultivars of paddy during the two years (1980 and 1981) study period.

A - Number of arbuscules

B - Number of vesicles.

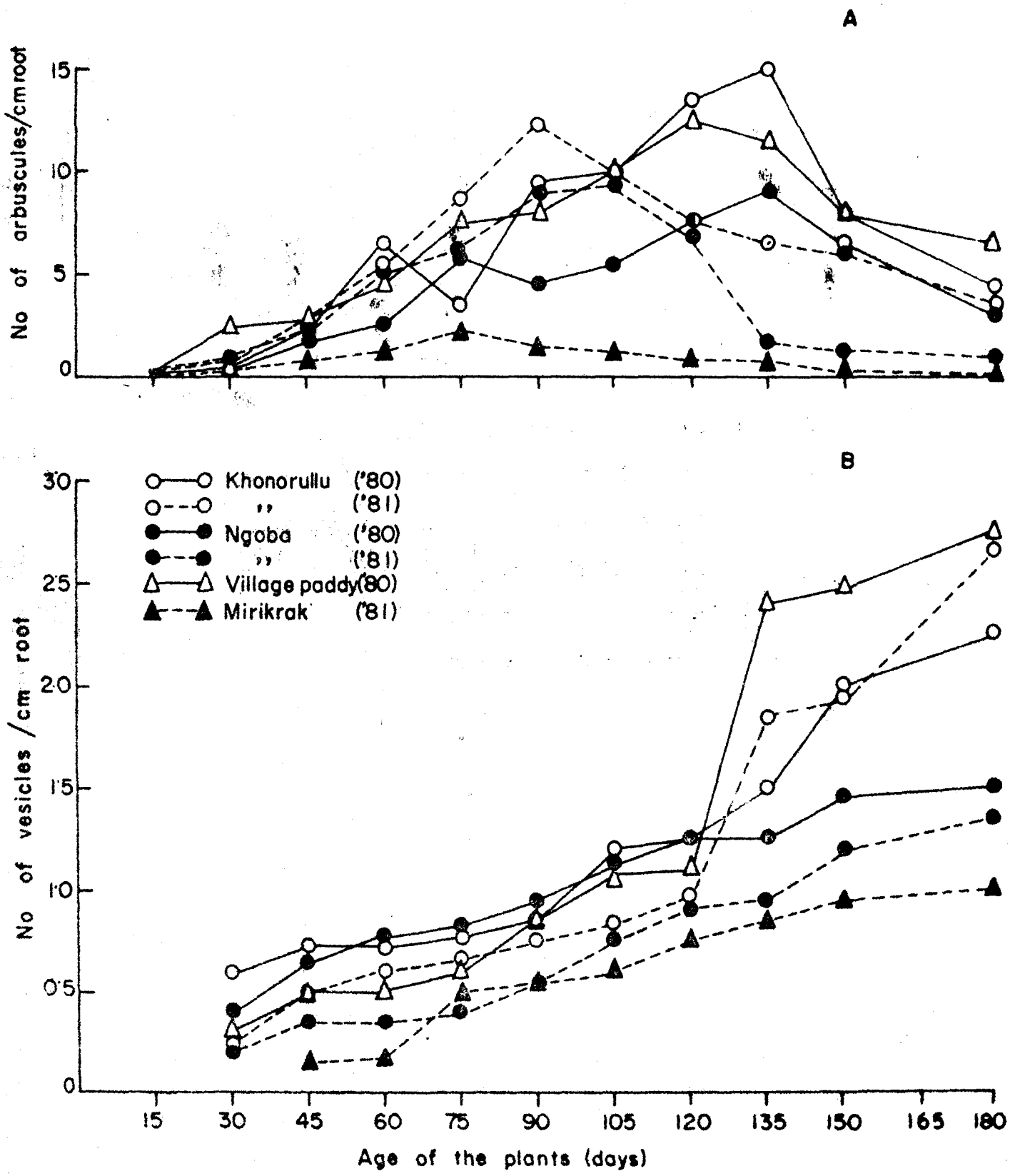

A
No of arbuscules/cm root
15
10
5
0
B
No of vesicles /cm root
30
25
2·0
1·5
1·0
0·5
0
Khonorullu ('80)
,, ('81)
Ngoba ('80)
,, ('81)
Village paddy ('80)
Mirikrak ('81)
15
30
45
60
75
90
105
120
135
150
165
180
Age of the plants (days)

Fig. 9

Table 3: Intensity of mycorrhizal infection and number of hyphal entry points/cm root in different cultivars of paddy.

Age of the plant (in days)	Khonorullu			Ngoba			Village paddy	Mirikrak	
	Intensity		No. of entry points/cm root	Intensity		No. of entry points/cm root	Intensity	Intensity	No. of entry points/cm root
	I	II	II	I	II	II	I	II	II
15	+	+	0.33	+	+	0.30	+	+	0.13
30	+	+	0.95	+	+	0.95	++	+	0.14
45	++	++	1.75	+	++	1.00	++	+	0.40
60	++	+++	1,56	++	++	0.50	++	+	0.30
75	++	++++	0.60	+++	++	0.45	+++	+	0.20
90	+++	+++	0.40	+++	+++	0.40	+++	+	0.20
105	+++	+++	0.33	+++	+++	0.40	+++	+	0.08
120	++++	++	0.20	++	++	0.35	++++	+	0.19
135	++++	++	0.75	+++	+	0.24	++++	++	0.20
150	+++	+++	0.75	++	++	0.75	+++	+	0.20
180	+++	+++	1.00	++	++	1.00	+++	+	0.33

I = 1980; II = 1981.

in 150 days old plants in Mirikrak) (Table 3).

The percentage of mycorrhizal infection showed an insignificant negative correlation with all the rhizosphere soil properties in Khonorullu in the year 1980 (Table 20). It also showed a negative correlation with moisture content (1% level), pH and potassium, in the year 1981 (Table 20). In the case of Ngoba, the percentage of mycorrhizal infection showed an insignificant negative correlation with all the soil properties (except potassium in 1980, and pH and organic matter in 1981) (Table 21). In village paddy too, the percentage of mycorrhizal infection was negatively correlated with most of the soil properties, which was significant at 5% level in the case of pH and phosphorus (Table 22). In Mirikrak, the percentage of mycorrhizal infection was negatively correlated with moisture content (significant at 1% level) and potassium (significant at 5% level (Table 23).

The observation revealed that the mycorrhizal infection in maize may be either dual or triple, which could be distinguished morphologically. The external vesicles (characteristics of Gigaspora sp.) was observed mostly in the first half of the growing period (i.e. mostly in 60 and 75 days old plants) (Plate 3c), the fine endophyte (characteristic of Glomus tenuis) was observed in the second half of the growing period (i.e. mostly in 135 and 150 days old plants) (Plate 3e and f), and the coarse endophyte formed by more than one

Explanation of PLATE-1

Vesicular-arbuscular mycorrhiza in potato (cultivar, Kufri Jyoti)

a. Hyphae penetrating the epidermal cell by forming appressoria x 400, in 15 days old plants.

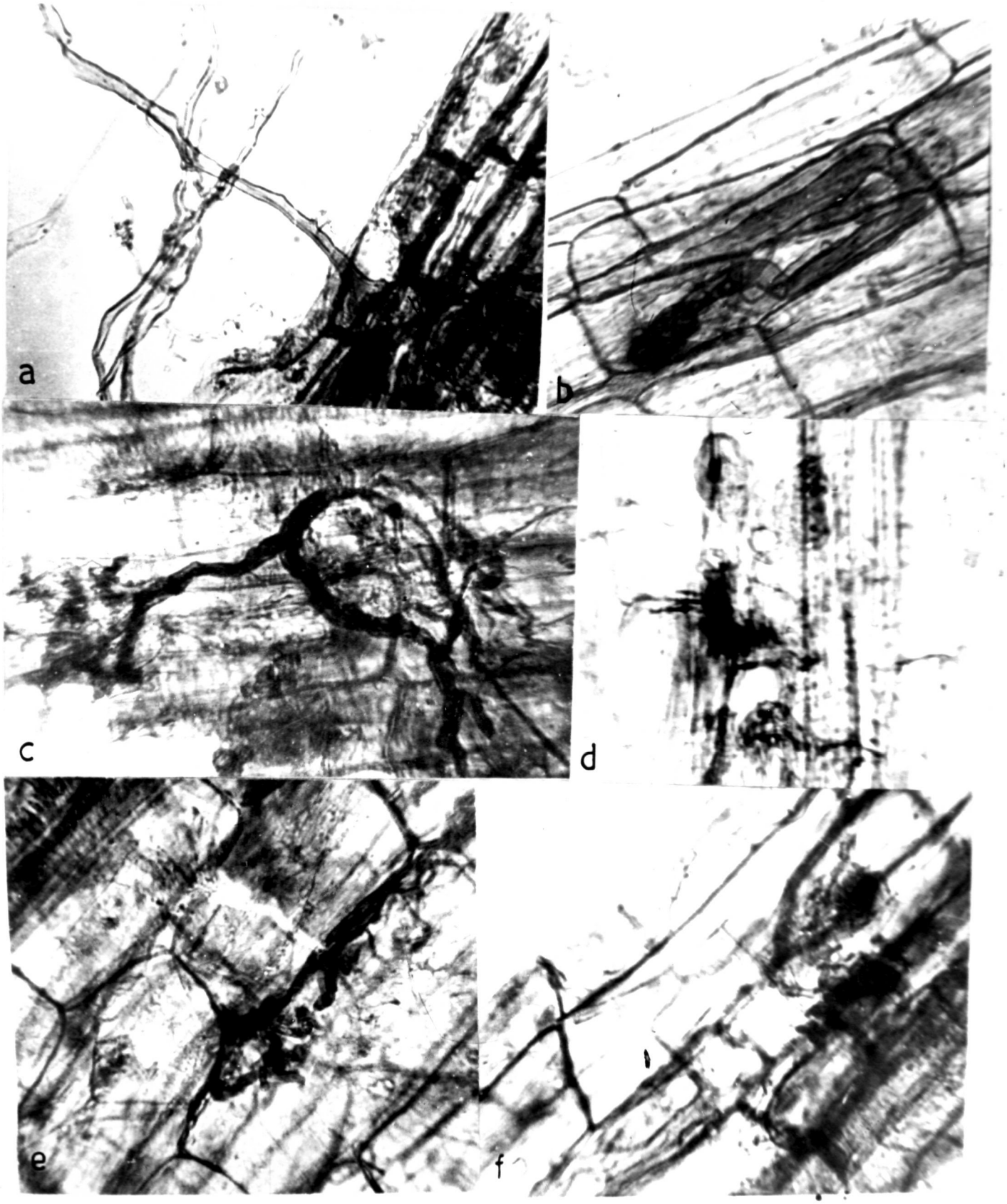
b. Hyphal coil inside the epidermal cell x 400, in 15 days old plants.

c. Initiation of arbuscules x 400, in 15 days old plants.

d. Vesicles x 400, in 30 days old plants.

e and f. Hyphal structure and arbuscules x 400, in 15 days old plants.

PLATE - 1



Explanation of PLATE-2

Vesicular-arbuscular mycorrhiza in potato (cultivar, Kufri Jyoti)

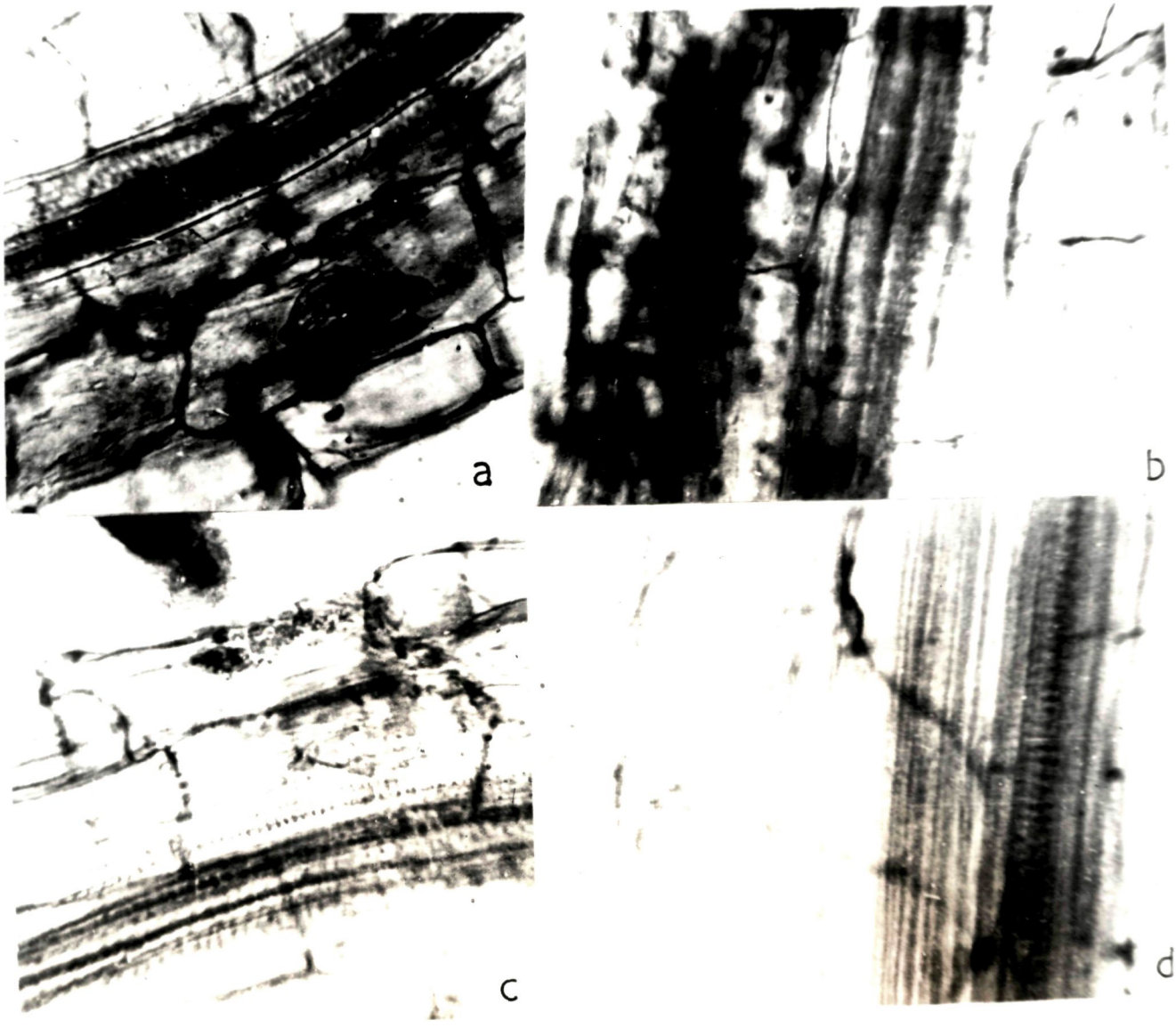
a. Finger-shaped hyphal structure x 400, in 30 days old plants.

b. Arbuscules x 400, in 45 days old plants.

c. Degenerating arbuscules x 400, in 75 days old plants.

d. Degenerating vesicle x 400, in 90 days old plants.

PLATE - 2



Explanation of PLATE-3

Vesicular-arbuscular mycorrhiza in maize (cultivar, Local Yellow)

a. Penetrating hyphae x 100, in 15 days old plants.

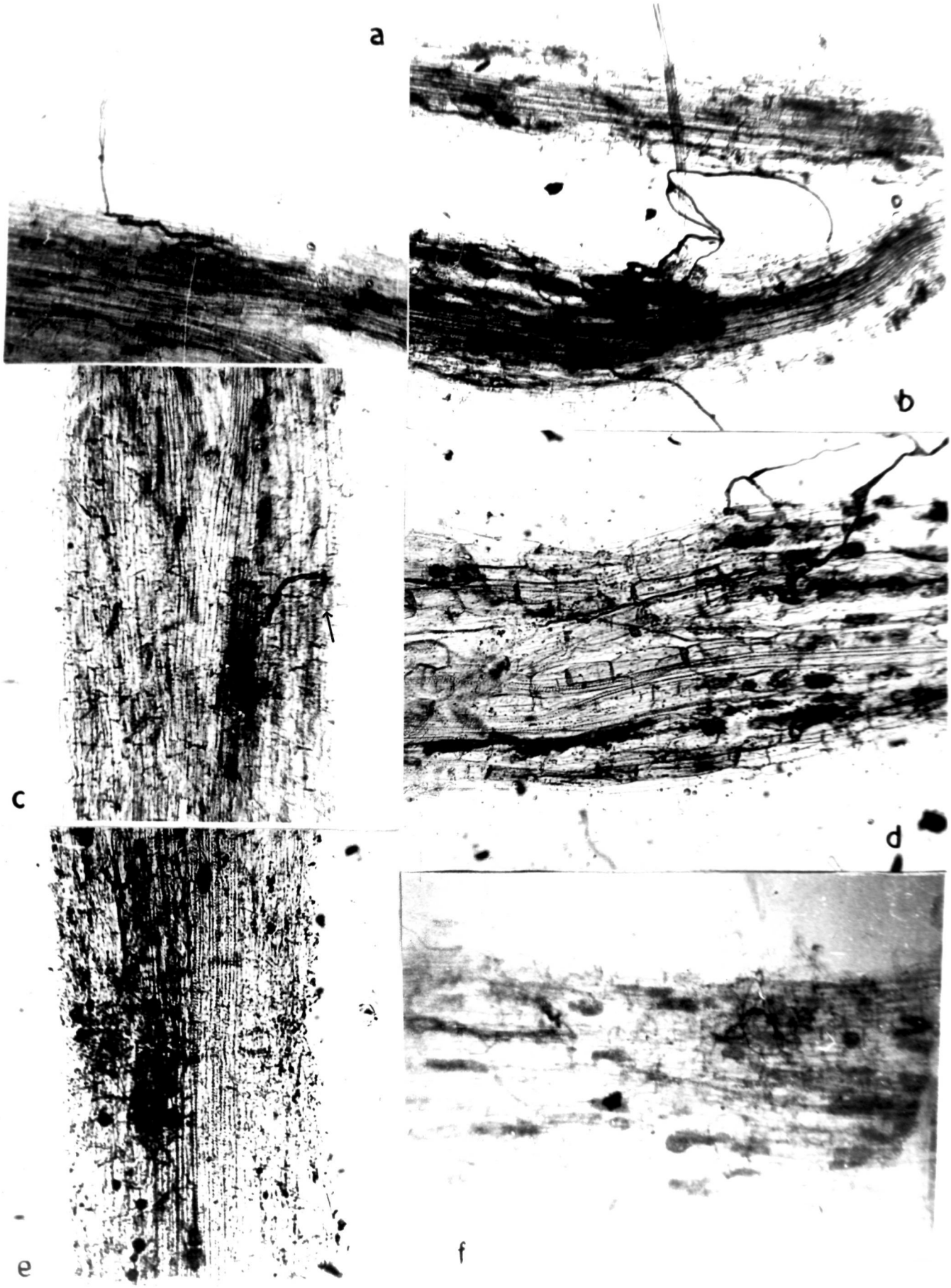
b and d. Penetrating hyphae and abuscules x 100, in 30 days old plants.

c. External vesicles (arrowed) of *Gigaspora* species x 100, in 75 days old plants.

e. Fine hyphae of *Glomus tenuis* x 100, in 135 days old plants.

f. Fine hyphae of *Glomus tenuis* x 400, in 135 days old plants.

PLATE - 3



Explanation of PLATE-4

Vesicular-arbuscular mycorrhiza in maize (cultivar, Local Yellow)

a. Arbuscules x 100, in 75 days old plants.

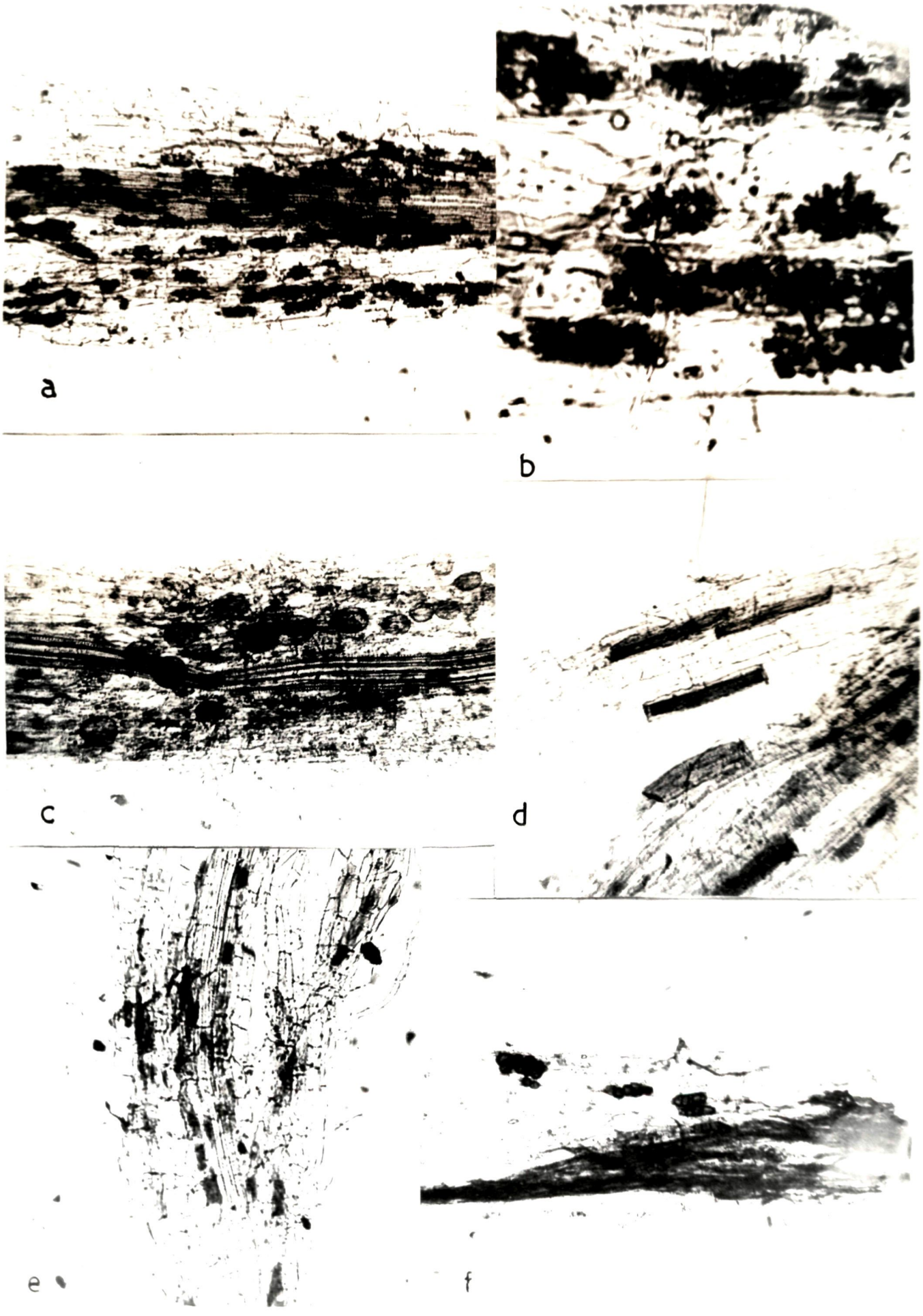
b. Arbuscules x 400, in 75 days old plants.

c. Vesicles x 100, in 105 days old plants.

d and e. Degenerating arbuscules x 100, in 135 and 150 days old plants.

f. Chlamydospore formation on the root surface x 100, in 150 days old plants.

PLATE -4



Explanation of PLATE-5

Vesicular-arbuscular mycorrhiza in paddy (cultivar, Khonorullu)

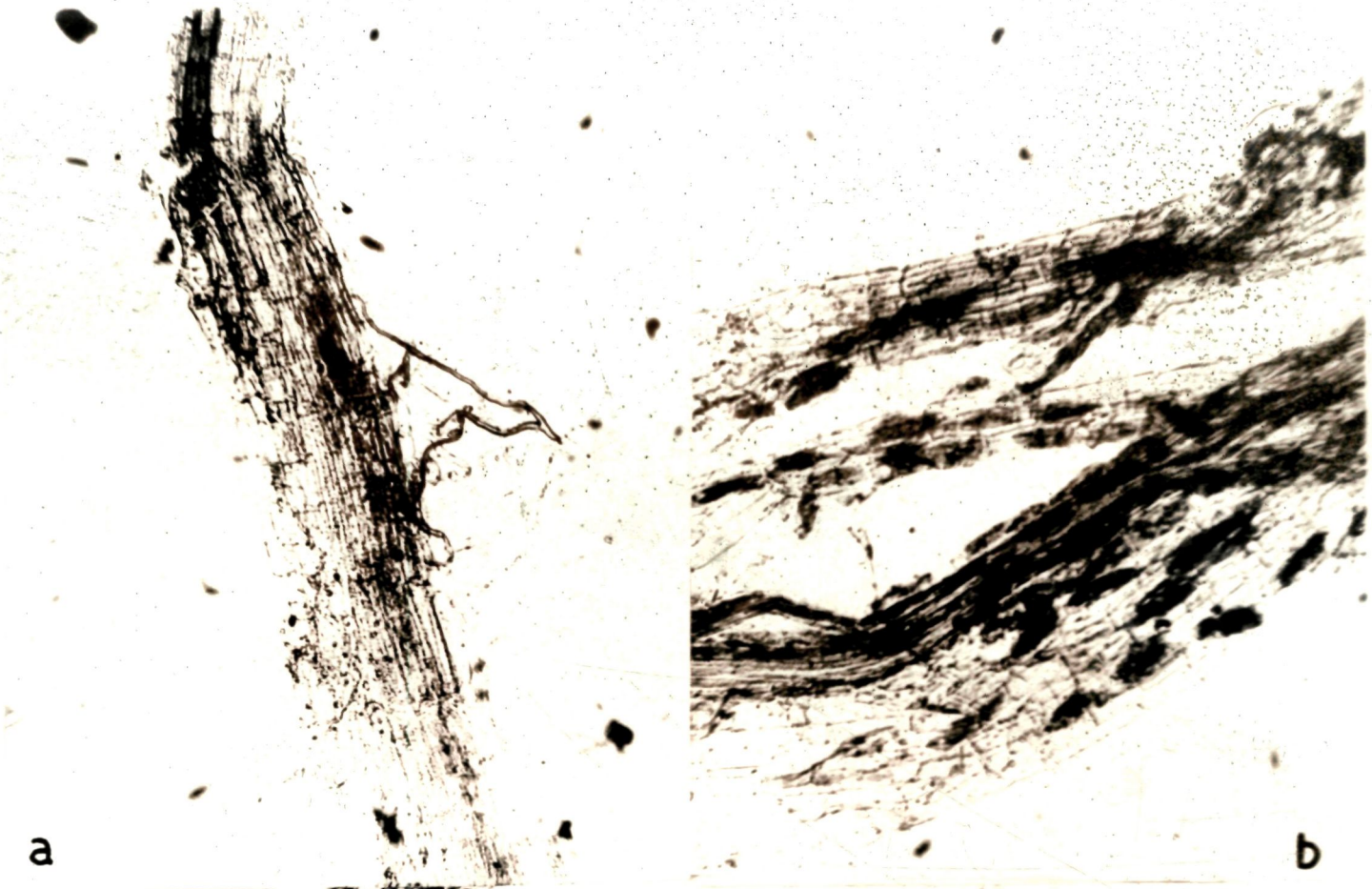
a. Hyphae penetrating through the root hairs x 100, in 30 days old plants.

b. Arbuscules x 100, in 90 days old plants.

c. Arbuscules and vesicles x 100, in 120 days old plants.

d. Degenerating arbuscules x 100, in 180 days old plants.

PLATE - 5



a

b

c

d

Table 4 : Rhizosphere soil properties of the potato cultivar, Kufri Jyoti.

Age of the plant (in days)	pH		Moisture content (%)		Organic matter (%)		Total Nitrogen (%)		Available Phosphorus (ppm)		Exchangeable Potassium (mg/g)	
	I	II	I	II	I	II	I	II	I	II	I	II
15	5.68	6.00	17.50	20.00	2.59	3.67	0.30	0.33	3.50	5.69	0.33	0.25
30	6.64	5.85	19.25	20.50	3.62	3.88	0.32	0.33	3.93	3.50	0.25	0.15
45	6.28	6.15	25.00	22.50	2.84	5.02	0.25	0.23	3.93	2.63	0.28	0.15
60	5.99	5.95	27.50	25.00	2.84	3.72	0.25	0.25	3.06	2.19	0.25	0.13
75	6.35	6.05	25.50	30.00	4.14	4.34	0.18	0.20	3.50	4.81	0.28	0.25
90	6.55	5.60	26.25	27.00	3.36	4.29	0.07	0.17	2.19	4.38	0.20	0.28

I = 1980; II = 1981.

Table 5 : Rhizosphere soil properties of the potato cultivar, SSC 1174.

Age of the plant (in days)	pH		Moisture content (%)		Organic matter (%)		Total Nitrogen (%)		Available Phosphorus (ppm)		Exchangeable Potassium (mg/g)	
	I	II	I	II	I	II	I	II	I	II	I	II
15	5.66	6.05	16.50	18.50	4.14	3.72	0.33	0.30	3.94	3.50	0.40	0.25
30	6.06	5.95	20.65	20.00	3.98	4.40	0.30	0.35	5.69	3.06	0.25	0.15
45	6.28	6.01	25.00	21.50	4.14	4.19	0.28	0.30	3.06	2.63	0.33	0.25
60	6.09	6.20	28.00	26.50	3.88	4.34	0.28	0.32	2.62	2.19	0.25	0.13
75	6.39	6.10	25.75	28.00	3.98	4.76	0.18	0.35	4.81	6.13	0.28	0.25
90	6.54	5.60	26.00	26.50	4.14	4.03	0.10	0.38	3.94	4.81	0.25	0.33

I = 1980; II = 1981.

Table 6 : Rhizosphere soil properties of the potato cultivar, up-to-date.

Age of the plant (in days)	pH		Moisture content (%)		Organic matter (%)		Total Nitrogen (%)		Available Phosphorus (ppm)		Exchangeable Potassium (mg/g)	
	I	II	I	II	I	II	I	II	I	II	I	II
15	5.65	6.10	17.50	20.00	3.62	3.88	0.30	0.31	4.81	6.13	0.40	0.15
30	6.14	6.00	21.50	21.00	3.62	4.24	0.06	0.32	5.25	4.38	0.25	0.15
45	6.27	6.10	24.50	22.00	3.36	3.67	0.06	0.33	3.50	3.50	0.28	0.25
60	6.05	6.15	28.00	25.50	3.62	4.14	0.09	0.33	2.19	2.63	0.28	0.15
75	6.38	6.09	25.50	28.50	3.36	4.24	0.08	0.34	3.06	4.81	0.25	0.25
90	6.51	5.85	26.00	27.00	3.36	4.14	0.04	0.33	5.69	4.38	0.15	0.33

I = 1980; II = 1981.

Table 7 : Rhizosphere soil properties of the maize cultivar, Local Yellow.

Age of the plant (in days)	pH		Moisture content (%)		Organic matter (%)		Total Nitrogen (%)		Available Phosphorus (ppm)		Exchangeable Potassium (mg/g)	
	I	II	I	II	I	II	I	II	I	II	I	II
15	6.69	6.01	27.50	25.50	4.65	4.55	0.29	0.33	3.94	5.25	0.38	0.55
30	6.41	6.04	26.00	30.50	5.02	4.71	0.36	0.33	4.81	5.20	0.38	0.21
45	6.21	6.25	28.00	38.00	5.07	4.91	0.30	0.24	4.38	3.94	0.33	0.33
60	6.69	6.35	25.25	35.50	5.02	3.88	0.30	0.30	3.94	3.31	0.28	0.30
75	6.65	6.50	25.50	25.00	4.71	3.88	0.29	0.34	12.25	3.94	0.38	0.28
90	6.90	6.60	25.75	22.0	4.14	4.71	0.28	0.30	5.69	6.60	0.33	0.28
105	6.98	6.68	21.50	27.50	5.12	4.24	0.25	0.35	3.94	5.25	0.33	0.33
120	6.94	6.68	22.50	25.00	4.40	4.24	0.39	0.35	4.38	10.70	0.28	0.28
135	6.85	6,56	25.50	25.50	4.76	4.71	0.43	0.29	5.25	7.00	0.33	0.24
150	6.77	6.50	24.25	22.50	4.91	5.02	0.41	0.31	2.63	5.99	0.28	0.20

I = 1980; II = 1981.

Table 8 : Rhizosphere soil properties of the maize cultivar, Local White.

Age of the plant (in days)	pH		Moisture content (%)		Organic matter (%)		Total Nitrogen (%)		Available Phosphorus (ppm)		Exchangeable Potassium (mg/g)	
	I	II	I	II	I	II	I	II	I	II	I	II
15	6.60	5.98	27.00	26.50	4.65	3.41	0.21	0.32	3.06	3.06	0.33	0.25
30	6.42	5.95	26.50	32.50	3.88	3.10	0.39	0.25	3.94	3.06	0.40	0.20
45	6.20	5.60	28.00	34.00	3.62	2.93	0.35	0.33	4.81	4.40	0.63	0.20
60	6.70	6.20	25.00	38.20	4.55	4.50	0.30	0.30	4.55	3.94	0.58	0.30
75	6.63	6.58	25.75	27.00	4.81	3.36	0.32	0.38	4.38	3.94	0.33	0.43
90	6.89	6.62	25.50	23.50	4.40	3.88	0.20	0.28	7.88	3.94	0.28	0.23
105	6.99	6.84	21.75	27.25	4.65	4.78	0.34	0.26	4.81	4.81	0.20	0.25
120	6.97	6.24	23.00	26.00	4.14	4.86	0.39	0.41	4.55	7.88	0.20	0.45
135	6.88	6.50	25.75	25.00	4.55	4.98	0.33	0.30	3.94	4.72	0.28	0.31
150	6.81	6.45	24.50	22.50	4.86	4.65	0.36	0.31	3.06	4.33	0.68	0.20

I = 1980; II = 1981.

Table 9 : Rhizosphere soil properties of the maize cultivar, Vijaya (1980).

Age of the plant (in days)	pH	Moisture content (%)	Organic matter (%)	Total Nitrogen (%)	Available Phosphorus (ppm)	Exchangeable Potassium (mg/g)
15	6.68	27.30	5.12	0.40	6.13	0.58
30	6.39	26.50	5.12	0.41	3.94	0.40
45	6.25	27.85	4.86	0.07	3.50	0.43
60	6.63	25.00	4.86	0.11	3.06	0.40
75	6.66	25.50	4.97	0.20	5.69	0.38
90	6.89	25.75	4.55	0.25	4.81	0.38
105	6.99	21.75	5.02	0.11	4.38	0.25
120	6.97	23.00	4.91	0.33	3.36	0.20
135	6.86	25.50	5.07	0.25	7.88	0.28
150	6.80	24.50	5.12	0.07	4.38	0.33

Table 10 : Rhizosphere soil properties of the paddy cultivar, Khonorullu.

Age of the plant (in days)	pH		Moisture content (%)		Organic matter (%)		Total Nitrogen (%)		Available Phosphorus (ppm)		Exchangeable Potassium (mg/g)	
	I	II	I	II	I	II	I	II	I	II	I	II
15	7.09	6.68	28.00	30.00	4.62	4.14	0.28	0.31	3.50	3.06	0.15	0.15
30	7.23	7.01	25.00	35.00	5.03	4.65	0.20	0.25	4.40	3.31	0.14	0.30
45	6.95	7.05	26.50	35.50	3.80	4.55	0.13	0.25	7.88	3.50	0.13	0.28
60	7.05	6.98	26.25	21.40	3.66	4.34	0.17	0.20	3.31	2.21	0.15	0.28
75	7.09	7.33	22.50	21.00	3.52	4.45	0.14	0.43	3.06	2.63	0.15	0.13
90	7.09	6.48	23.50	22.50	4.15	4.40	0.15	0.41	2.21	3.94	0.18	0.15
105	6.89	6.50	25.25	23.00	4.57	4.55	0.17	0.36	5.25	6.56	0.15	0.18
120	6.93	6.85	24.50	24.50	4.77	4.55	0.17	0.30	3.00	4.81	0.12	0.18
135	6.78	6.85	20.75	22.00	4.45	4.86	0.19	0.35	3.62	3.94	0.13	0.15
150	6.92	6.79	17.50	20.50	4.57	4.81	0.21	0.35	3.94	4.40	0.13	0.13
180	6.81	6.76	14.50	18.50	4.90	4.50	0.30	0.32	6.56	4.38	0.15	0.13

I = 1980; II = 1981

Table 11 : Rhizosphere soil properties of the paddy cultivar, Ngoba.

Age of the plant (in days)	pH		Moisture content (%)		Organic matter (%)		Total Nitrogen (%)		Available Phosphorus (ppm)		Exchangeable Potassium (mg/g)	
	I	II	I	II	I	II	I	II	I	II	I	II
15	7.11	6.71	27.90	30.50	4.72	4.40	0.31	0.35	5.25	4.81	0.15	0.15
30	7.21	6.98	25.00	34.50	4.98	4.14	0.25	0.31	5.20	4.40	0.14	0.20
45	6.98	7.03	25.50	35.00	3.90	4.76	0.14	0.31	6.56	7.88	0.15	0.13
60	7.08	7.11	26.25	22.20	3.78	4.55	0.17	0.41	3.62	6.56	0.16	0.20
75	7.11	7.45	22.25	19.90	3.55	4.76	0.18	0.43	3.06	4.81	0.15	0.20
90	7.08	6.83	23.50	22.00	3.90	4.50	0.19	0.41	2.68	3.94	0.18	0.15
105	6.89	6.87	25.25	22.50	4.26	4.50	0.17	0.39	3.94	3.06	0.15	0.1
120	6.92	6.92	24.25	23.00	4.60	4.55	0.17	0.35	3.86	3.94	0.15	0.18
135	6.79	6.91	20.50	21.50	4.47	4.50	0.17	0.35	4.80	6.56	0.15	0.15
150	6.93	6.79	17.00	20.00	4.57	4.65	0.20	0.30	5.20	3.31	0.13	0.15
180	6.83	6.78	15.00	17.50	5.14	4.24	0.29	0.30	6.13	3.06	0.15	0.13

I = 1980; II = 1981

Table 12 : Rhizosphere soil properties of village paddy (1980)

Age of the plant (in days)	pH	Moisture content (%)	Organic matter (%)	Total Nitrogen (%)	Available Phosphorus (ppm)	Exchangeable Potassium (mg/g)
15	7.13	27.90	4.62	0.30	6.13	0.15
30	7.25	25.75	5.03	0.28	5.98	0.15
45	7.01	25.50	3.88	0.33	7.00	0.25
60	7.06	26.00	3.66	0.30	4.40	0.30
75	7.08	22.30	4.67	0.28	5.25	0.25
90	7.08	23.50	4.14	0.25	3.62	0.20
105	6.88	25.25	4.45	0.37	4.38	0.13
120	6.92	24.50	4.60	0.30	2.76	0.15
135	6.79	20.75	4.45	0.20	3.06	0.13
150	6.93	17.25	4.60	0.25	3.94	0.18
180	6.83	14.50	4.90	0.39	6.13	0.25

Table 13 : Rhizosphere soil properties of the paddy cultivar, Mirikrak (1981).

Age of the plant (in days)	pH	Moisture content (%)	Organic matter (%)	Total Nitrogen (%)	Available Phosphorus (ppm)	Exchangeable Potassium (mg/g)
15	6.73	31.50	4.50	0.35	4.81	0.28
30	7.03	35.00	4.24	0.28	5.25	0.28
45	7.05	35.00	4.76	0.28	6.56	0.25
60	7.01	24.00	5.07	0.25	3.94	0.25
75	7.32	18.50	4.24	0.41	3.06	0.15
90	6.44	23.00	4.55	0.41	3.94	0.15
105	6.55	25.00	5.02	0.39	5.99	0.15
120	6.90	26.00	5.07	0.35	5.25	0.18
135	6.88	24.50	4.65	0.35	5.25	0.20
150	6.81	22.00	4.40	0.30	4.40	0.15
180	6.80	19.00	4.15	0.32	3.94	0.15

mycorrhizal strain was observed throughout the growing period. In case of paddy, besides coarse endophyte, fine endophyte was also observed in the later part of the growing period (i.e, mostly in 150 and 180 days old plants) but external vesicles (characteristic of Gigaspora sp.) were rarely observed. Whereas, in potato, fine endophyte was observed only in the young plants (8, 12 and 15 days old plants), and the coarse endophyte was observed throughout the growing period.

2. Endogone spore population :

In all the three cultivars of potato the Endogone spore number decreased first upto 30 days and then increased in the subsequent ages. The spore number was highest in SSC 1174 followed by Kufri Jyoti and up-to-date varieties (Fig. 10). The spore population in Kufri Jyoti was negatively correlated with all the soil properties (except moisture content and organic matter) in 1980, whereas in 1981 the negative correlation was found with only pH and nitrogen (Table 14). The negative correlation with nitrogen was significant at 5% and 1% levels in 1980 and 1981 respectively, and with phosphorus it was significant at 5% level in 1980. In SSC 1174, the spore population was positively correlated with most of the soil properties (except nitrogen and phosphorus in 1980, and pH in 1981). The postive correlation with moisture content was significant at 5% level in 1981 (Table 15). In case of up-to-date, the spore population was positively correlated with

Fig. 10: Endogone spore population with respect to different age group, in different cultivars of potato during the two years (1980 and 1981) study period.

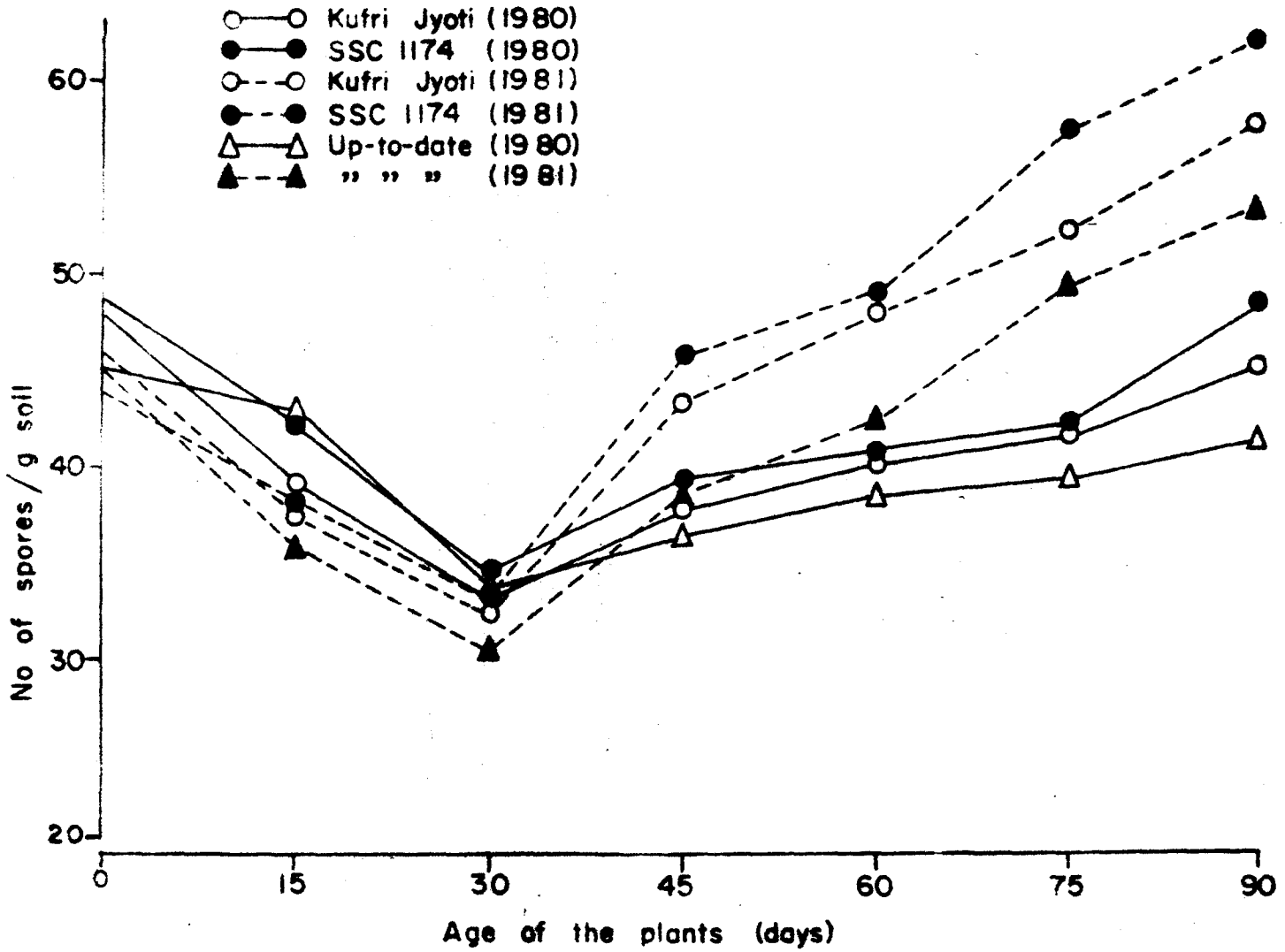

Kufri Jyoti (1980)
SSC 1174 (1980)
Kufri Jyoti (1981)
SSC 1174 (1981)
Up-to-date (1980)
" " " (1981)
No of spores / g soil
60
50
40
30
20
0
15
30
45
60
75
90
Age of the plants (days)

Fig. 10

Table 14 : Relationship (r) of the mycorrhizal infection percentage and the spore population with rhizosphere soil properties in 'Kufri Jyoti'.

	Rhizosphere soil properties					
	pH	Moisture content	Organic matter	Nitrogen	Phosphorus	Potassium
Infection percentage						
1980	0.1658	0.7331	0.4975	-0.4371	-0.3154	-0.6909
1981	-0.0167	0.7066	0.5408	-0.7277	-0.5989	-0.2520
Spore population						
1980	-0.0958	0.5628	0.0534	-0.8951*	-0.8596*	-0.3360
1981	-0.3538	0.8791*	0.3138	-0.9491**	0.0258	0.4964

*Significant at 5% level; **Significant at 1% level.

Table 15 : Relationship (r) of the mycorrhizal infection percentage and the spore population with rhizosphere soil properties in 'SSC 1174'.

	Rhizosphere soil properties					
	pH	Moisture content	Organic matter	Nitrogen	Phosphorus	Potassium
Infection percentage						
1980	0.9255**	0.6236	0.2981	-0.9069*	-0.0761	-0.5113
1981	-0.2061	0.9522**	0.6062	0.7113	0.3758	0.1213
Spore population						
1980	0.4401	0.2866	0.4305	-0.7596	-0.3282	0.0168
1981	-0.3874	0.8788*	0.2599	0.5537	0.6255	0.5951

*Significant at 5% level; **Significant at 1% level.

most of the soil properties (except pH, moisture content and organic matter in 1980; and pH and phosphorus in 1981). The positive correlation with moisture content was significant at 1% level in 1981 (Table 16).

Like potato, in the different cultivars of maize too, the spore population initially decreased upto 30 days (but 15 days in 1981) and then increased continuously with the increase in plant life. The spore population was highest in Vijaya followed by Local Yellow and Local White (Fig. 11). In Local Yellow, the spore population was negatively correlated with most of the soil properties (except pH and nitrogen in both the years and phosphorus in 1981). The positive correlation with pH was significant at 5% and 1% levels in 1980 and 1981 respectively, while the negative correlation with potassium was significant at 5% level in both the years (Table 17). In Local White, the spore population was positively correlated with pH (Significant at 5% level) and organic matter (Significant at 1% level, in 1981) (Table 18). The spore population showed a negative correlation with potassium (significant at 1% level) and a positive correlation (significant at 5% level) with pH (Table 19).

In the different cultivars of paddy, the Endogone spore population initially decreased upto 30 days (but 45 days in Mirikrak) and then increased with the increase of plant age (Fig. 12). In Khonorullu, the spore population was negatively correlated with pH, moisture content (significant at 1% level

Fig. 11: Endogone spore population with respect to different age group, in different cultivars of maize during the two years (1980 and 1981) study period.

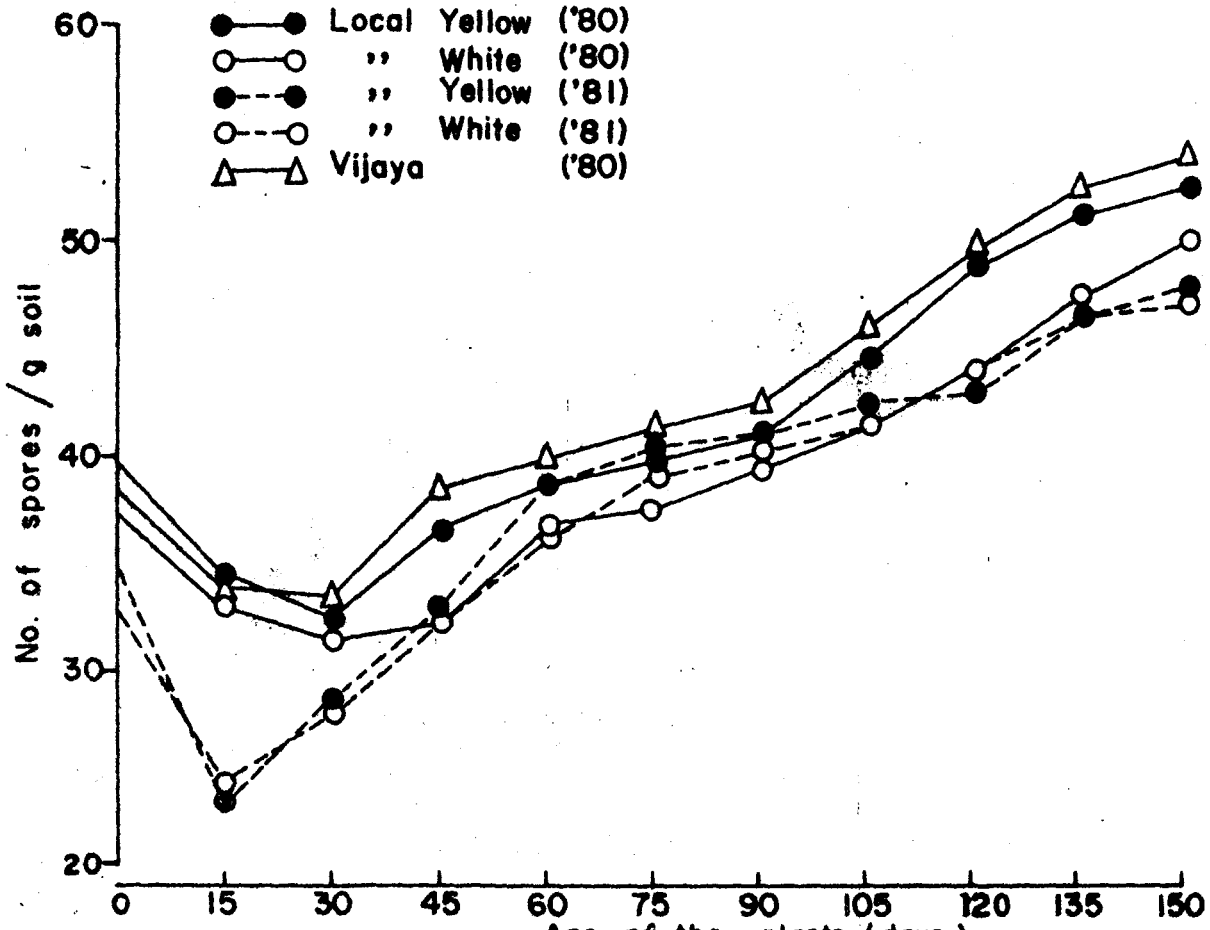

Local Yellow ('80)
" White ('80)
" Yellow ('81)
" White ('81)
Vijaya ('80)
No. of spores / g soil
60
50
40
30
20
0
15
30
45
60
75
90
105
120
135
150
Age of the plants (days)

Fig. 11

Fig. 12: Endogone spore population with respect to different age group, in different cultivars of paddy during the two years (1980 and 1981) study period.

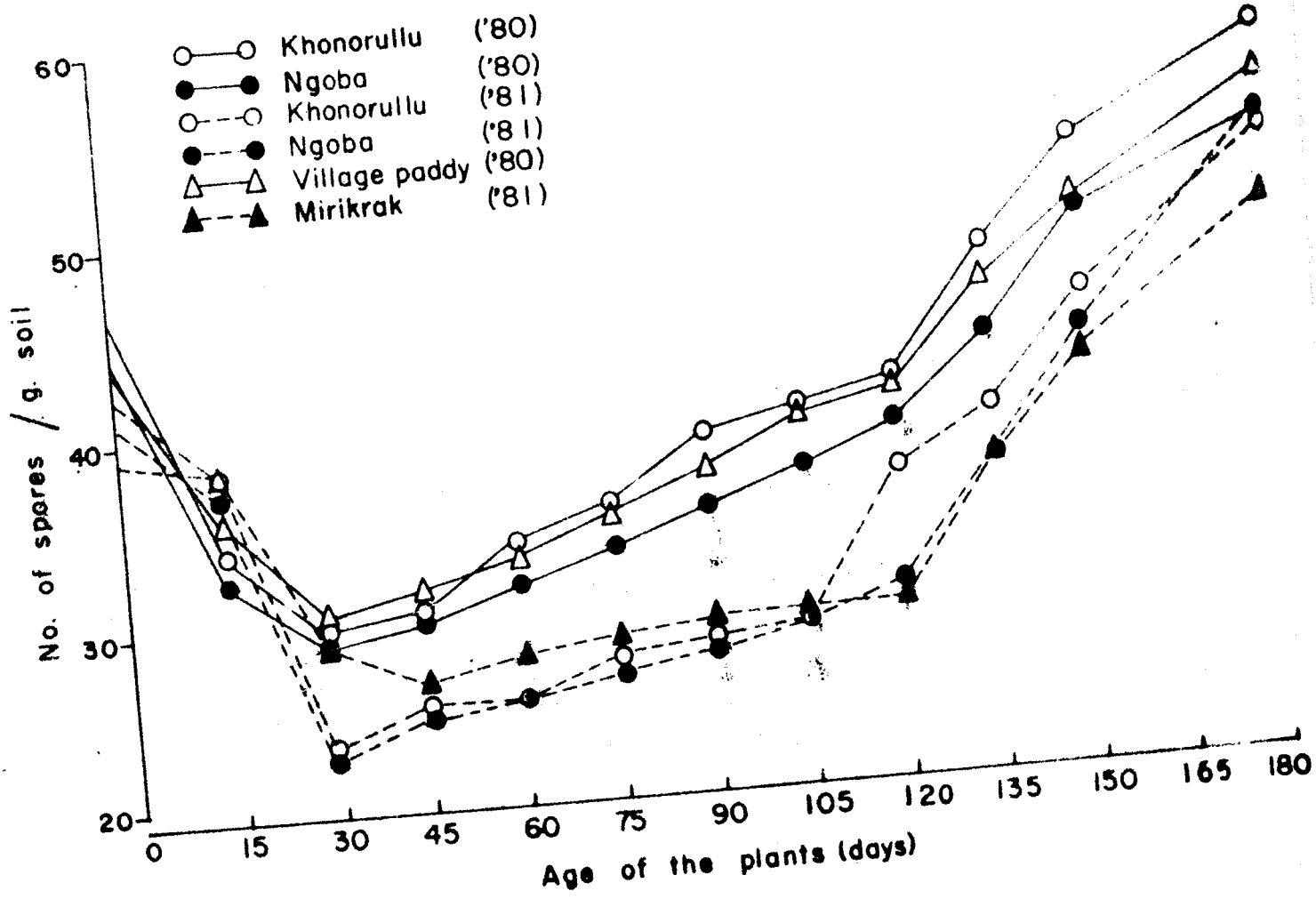

Khonorullu ('80)
Ngoba ('80)
Khonorullu ('81)
Ngoba ('81)
Village paddy ('80)
Mirikrak ('81)
No. of spores / g. soil
60
50
40
30
20
0
15
30
45
60
75
90
105
120
135
150
165
180
Age of the plants (days)

Fig. 12

Table 16 : Relationship (r) of the mycorrhizal infection percentage and the spore population with rhizosphere soil properties in 'up-to-date'.

	Rhizosphere soil properties					
	pH	Moisture content	Organic matter	Nitrogen	Phosphorus	Potassium
Infection percentage						
1980	0.8210*	0.9027*	-0.5738	-0.9093*	-0.4678	-0.7004
1981	0.0728	0.7941	0.6634	0.8177*	-0.4873	0.1449
Spore population						
1980	-0.1813	-0.1122	-0.1652	0.5493	0.0759	0.1746
1981	-0.3816	0.9031*	0.2559	0.7054	-0.1189	0.7994

*Significant at 5% level;

Table 17: Relationship (r) of the mycorrhizal infection percentage and the spore population with rhizosphere soil properties in 'Local Yellow'.

	Rhizosphere soil properties					
	pH	Moisture content	Organic matter	Nitrogen	Phosphorus	Potassium
Infection percentage						
1980	0.2965	-0.5407	-0.0581	-0.0175	0.3367	-0.3489
1981	0.4586	0.1120	-0.0906	-0.4466	-0.3647	-0.5367
Spore population						
1980	0.6525*	-0.6063	-0.1899	0.6095	-0.1790	-0.6434*
1981	0.8913**	-0.3961	-0.0375	0.0381	0.3682	-0.6478*

* Significant at 5% level; ** Significant at 1% level.

Table 18: Relationship (r) of the mycorrhizal infection percentage and the spore population with rhizosphere soil properties in 'Local White'.

	Rhizosphere soil properties					
	pH	Moisture content	Organic matter	Nitrogen	Phosphorus	Potassium
Infection percentage						
1980	0.5895	-0.5730	0.2949	0.2422	0.4191	-0.1022
1981	0.7926**	-0.2456	0.5389	-0.2063	0.2604	0.1362
Spore population						
1980	0.7594*	-0.3424	0.5325	0.2270	-0.0972	-0.0945
1981	0.6763*	-0.5112	0.7967**	0.1998	0.5810	0.3212

* Significant at 5% level; ** Significant at 1% level.

Table 19: Relationship (r) of the mycorrhizal infection percentage and the spore population with rhizosphere soil properties in 'Vijaya'.

	Rhizosphere soil properties					
	pH	Moisture content	Organic matter	Nitrogen	Phosphorus	Potassium
Infection percentage						
1980	0.6632*	-0.5335	-0.4865	-0.4817	-0.3595	-0.8015**
Spore population						
1980	0.6718*	-0.6146	0.0636	-0.3875	0.2011	0.7763**

* Significant at 5% level; ** Significant at 1% level.

in 1980) and potassium (significant at 5% level in 1981) in both the years (Table 20). In Ngoba, the spore population showed a negative correlation (significant at 1% level) with pH and moisture content in 1981 (Table 21). The spore population in village paddy was negatively correlated with pH, moisture content (significant at 1% level), phosphorus and potassium (Table 22). In Mirikrak, the spore population showed an insiginficant negative correlation with all the rhizosphere soil properties (Table 23).

Based on the morphological characters, mainly two types of mycorrhizal fungi could be identified, viz. Glomus spp. (Plate 6a,c) and the Gigaspora sp. (Plate 6b). The Glomus spp. probably formed the bulk of the spore population.

B. SOIL FERTILITY LEVEL AND THE MYCORRHIZAL INFECTION

In the first sampling i.e. in 11 days old plants, mycorrhizal infection showed an increasing trend upto 1:1 level of soil and sand, which decreased in unamended soil. This was followed by an increase in the soil amended with twice normal dose of NPK fertilizer and it again decreased in the soil amended with four normal dose of NPK (highest fertility level in this experiment) (Fig. 13). In 18 days old plants (i.e. in the second sampling) however, the mycorrhizal infection increased with the increase of the fertility level upto one normal dose of NPK, which was followed by a decrease in the higher fertility levels (2 NPK and 4 NPK levels) (Fig. 13).

Explanation of PLATE-6

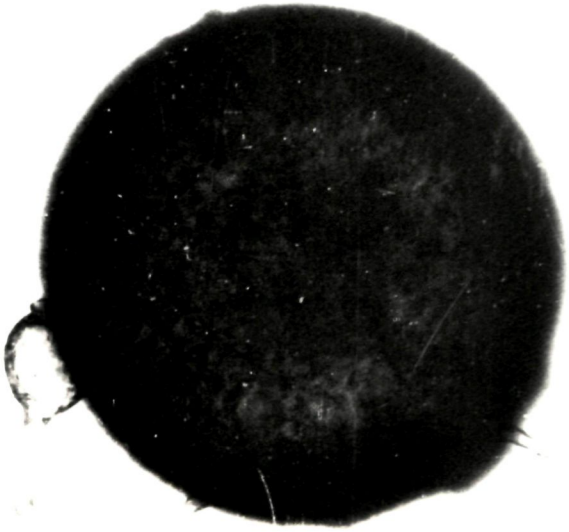
a. Spore of *Glomus* sp. 1 x 400.

b. Spore of *Gigaspora* sp. x 100.

c. Spores of *Glomus* sp. 2 x 100.

PLATE - 6

a



b

c

Table 20: Relationship (r) of the mycorrhizal infection percentage and the spore population with rhizosphere soil properties in 'Khonorullu'.

	Rhizosphere soil properties					
	pH	Moisture content	Organic matter	Nitrogen	Phosphorus	Potassium
Infection percentage						
1980	-0.5733	-0.4828	-0.0768	-0.2862	-0.2884	-0.0364
1981	-0.0312	-0.8137**	0.3557	0.5648	0.1623	-0.4982
Spore population						
1980	-0.7517**	-0.9102**	0.4040	0.5176	0.0917	-0.1346
1981	-0.2889	-0.5076	0.2097	0.1970	0.2787	-0.6746*

* Significant at 5% level; ** Significant at 1% level.

Table 21: Relationship (r) of the mycorrhizal infection percentage and the spore population with rhizosphere soil properties in 'Ngoba'.

	pH	Moisture content	Organic matter	Nitrogen	Phosphorus	Potassium
Infection percentage						
1980	-0.5665	-0.5816	-0.2941	-0.5283	-0.4570	0.1460
1981	0.0753	-0.4968	0.1655	-0.0457	-0.4502	-0.2304
Spore population						
1980	-0.7528**	-0.9088**	0.4985	0.2367	0.2687	-0.2886
1981	-0.5231	-0.5169	-0.2786	-0.3615	-0.4300	-0.5016

** Significant at 1% level.

Table 22: Relationship (r) of the mycorrhizal infection percentage and the spore population with rhizosphere soil properties in 'Village paddy'.

	Rhizosphere soil properties					
	pH	Moisture content	Organic matter	Nitrogen	Phosphorus	Potassium
Infection percentage						
1980	-0.6258*	-0.5760	0.0112	-0.1798	-0.6919*	-0.0183
Spore population						
1980	-0.7879**	-0.8918**	-0.3728	0.1099	-0.2776	-0.1076

* Significant at 5% level; ** Significant at 1% level.

Table 23 : Relationship (r) of the mycorrhizal infection percentage and the spore population with rhizosphere soil properties in 'Mirikrak'.

	Rhizosphere soil properties					
	pH	Moisture content	Organic matter	Nitrogen	Phosphorus	Potassium
Infection percentage						
1981	0.1649	-0.7351**	-0.1660	0.0246	-0.4780	-0.6446*
Spore population						
1981	-0.2133	-0.3743	-0.5226	-0.0878	-0.2536	-0.2495

* Significant at 5% level; ** Significant at 1% level.

Similar pattern was observed in 30, 60 and 100 days old plants (Fig. 13, 14). With the increase of the age of plant, the mycorrhizal infection also increased in all the treatments (except unamended sand, unamended soil, 1NPK, 2 NPK and 4 NPK levels. Where it decreased in 100 days old plants) (Fig. 13 and 14).

In 100 days old plants, the glucosamine content of the root also followed the similar pattern as the vesicular-arbuscular mycorrhizal infection (Fig. 14). The total nitrogen (%) in the root showed much fluctuation at different treatment levels, unlike mycorrhizal infection it was highest in the unamended soil and decreased with the increase in the fertility level upto one normal dose of NPK, The increased nitrogen contents which was observed in the 2 NPK level, was lowered in the highest fertility level i.e. 4 NPK level (Fig. 15). The total phosphorus (%) in the root increased with the increase in the fertility level upto $\frac{1}{4}$ normal dose of NPK and then decrease in the subsequent fertility levels (i.e. $\frac{1}{2}$ and 1 NPK levels). This was followed by an increase in the higher fertility levels i.e. 2 NPK and 4 NPK levels (Fig. 15).

The arbuscules were first observed in the 18 days old plants in all the fertility levels except the highest level, where it was first observed in 60 days old plants. In 30 days old plants, the number of arbuscules increased with the increase in the fertility level upto one normal dose of NPK

Fig. 13: Percentage vesicular-arbuscular mycorrhizal (VAM) infection with respect to different fertility levels (treatments) in maize plants, at different sampling periods (11, 18, 30 and 60 days old plants).
So = Soil, Sa = Sand.

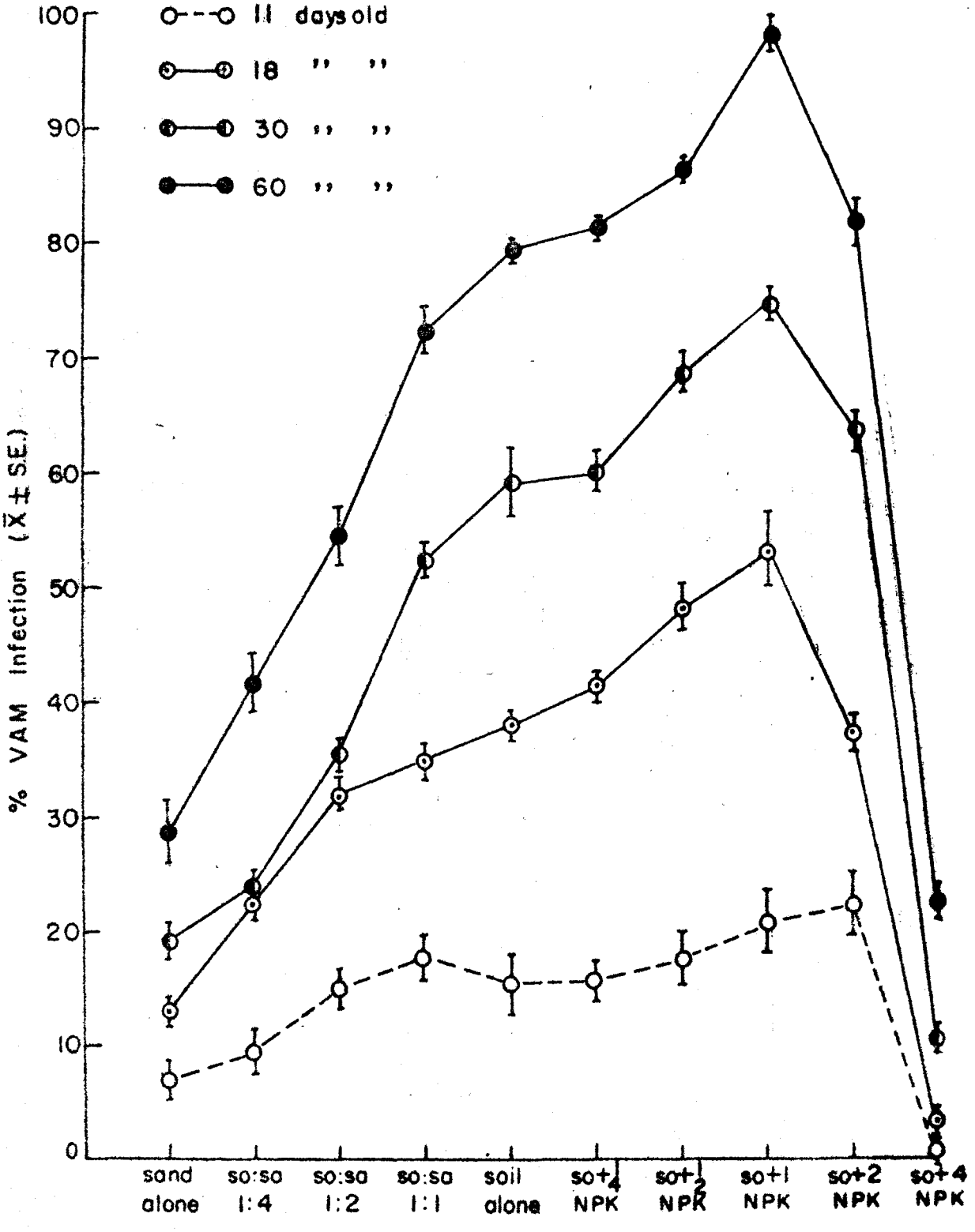

11 days old
18 " "
30 " "
60 " "
% VAM Infection (X̄ ± S.E.)
100
90
80
70
60
50
40
30
20
10
0
sand alone
so:sa 1:4
so:sa 1:2
so:sa 1:1
soil alone
so+¼ NPK
so+½ NPK
so+1 NPK
so+2 NPK
so+4 NPK
Treatments

Fig. 13

Fig. 14: Percentage vesicular-arbuscular mycorrhizal (VAM) infection and Glucosamine content of root with respect to different fertility levels (treatments) in 100 days old maize plants.

So = Soil, Sa = Sand.

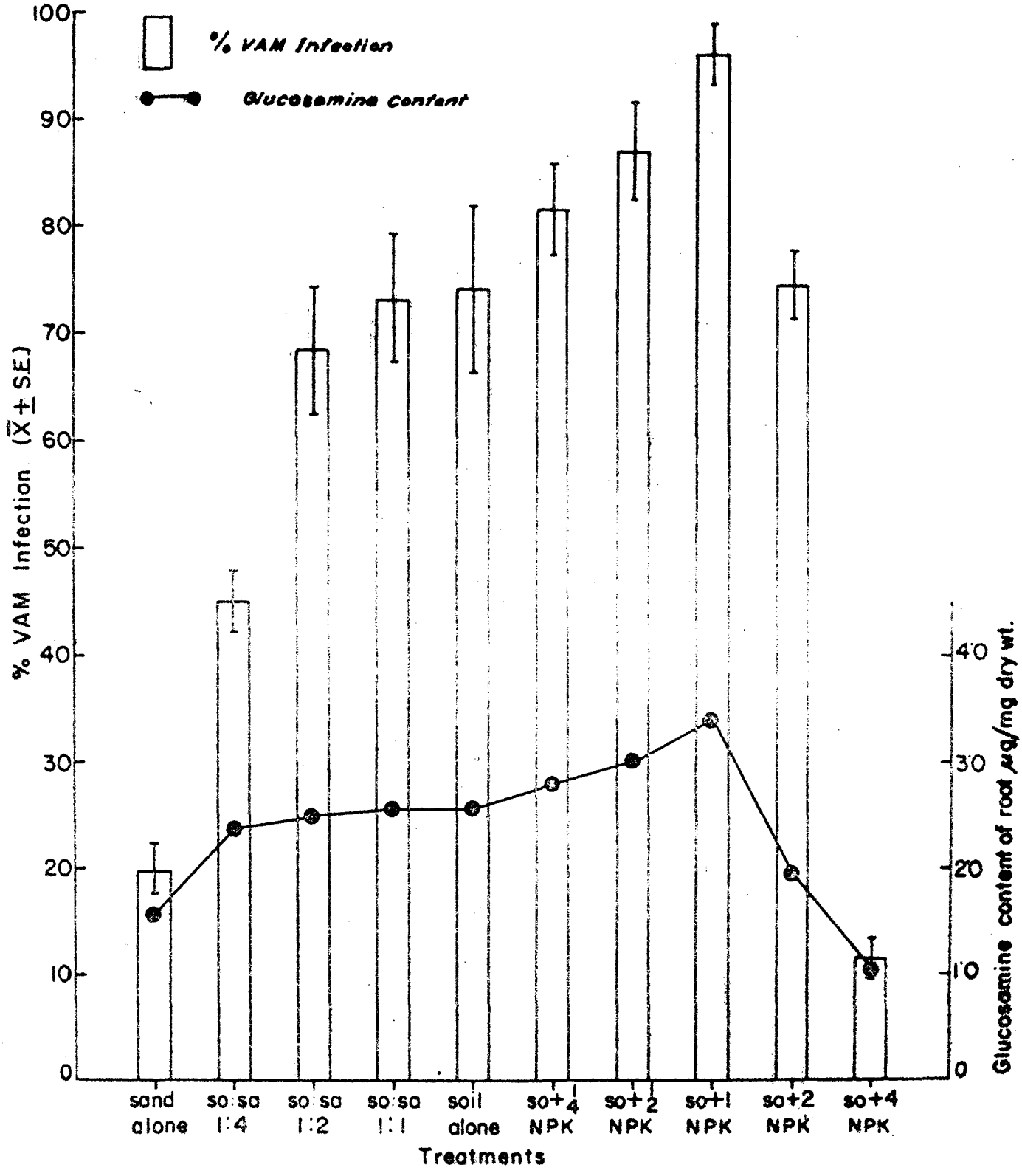

% VAM Infection
Glucosamine content
% VAM Infection (X̄ ± SE)
Glucosamine content of root µg/mg dry wt.
0
10
20
30
40
50
60
70
80
90
100
0
10
20
30
40
sand alone
so:sa 1:4
so:sa 1:2
so:sa 1:1
soil alone
so+¼ NPK
so+½ NPK
so+1 NPK
so+2 NPK
so+4 NPK
Treatments

Fig 14

Fig. 15: Percentage nutrient, i.e. nitrogen (N) and Phosphorus (P), in the root and percentage vesicular-arbuscular mycorrhizal (VAM) infection with respect to different fertility levels (treatments) in 100 days old maize plants.
So = Soil, Sa = Sand.

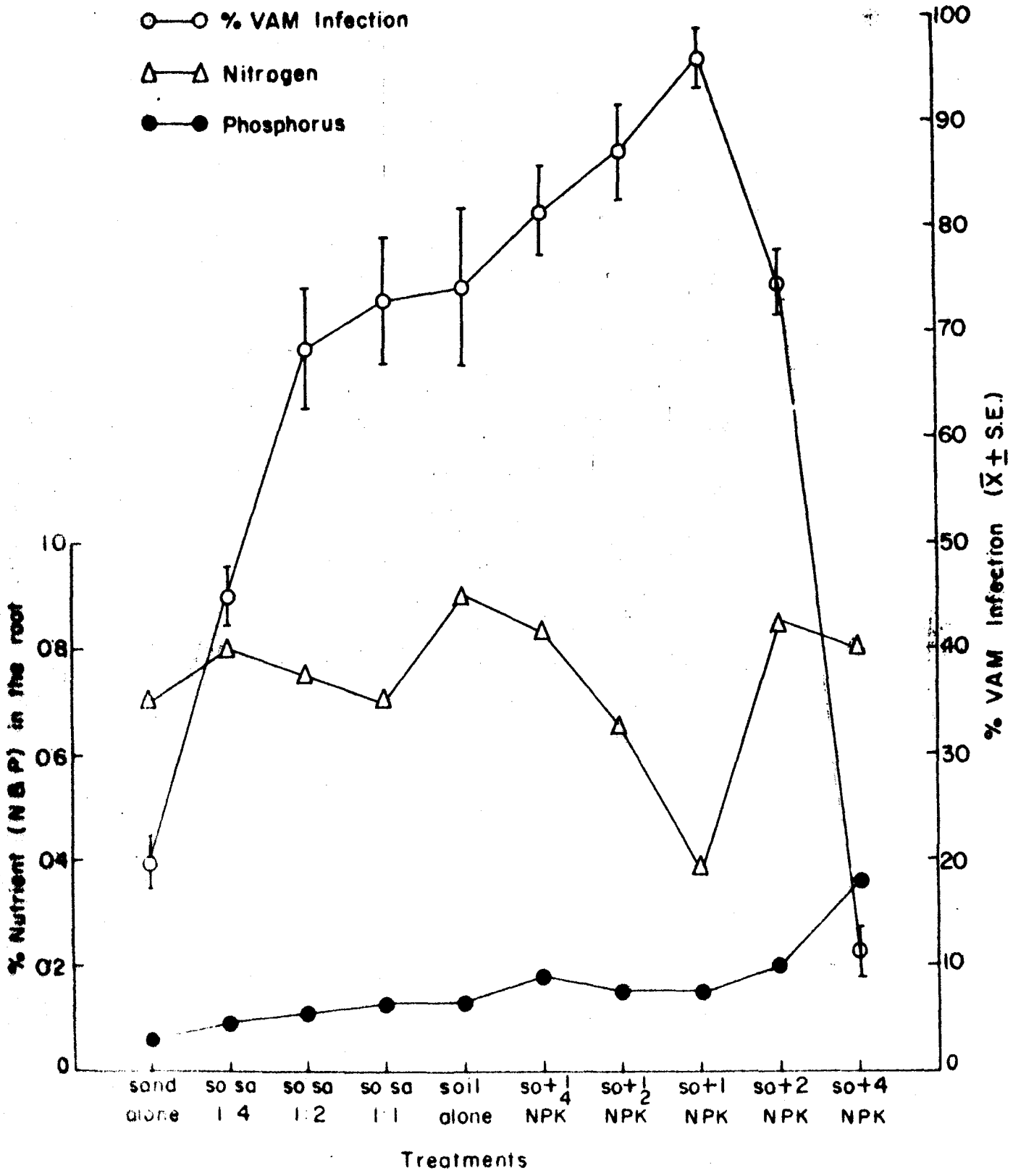

% VAM Infection
Nitrogen
Phosphorus
% Nutrient (N & P) in the root
% VAM Infection (X̄ ± S.E.)
0
02
04
06
08
10
0
10
20
30
40
50
60
70
80
90
100
sand alone
so sa 1 4
so sa 1 2
so sa 1 1
soil alone
so+1/4 NPK
so+1/2 NPK
so+1 NPK
so+2 NPK
so+4 NPK
Treatments

Fig.15

following a decrease in the subsequent fertility levels (Fig. 17 B). Similar pattern was observed in the last two samplings (60 and 100 days old plants). A marked increase in the number of arbuscules was observed in the soil amended with one normal dose of NPK fertilizer in 60 and 100 days old plants, which was followed by an abrupt decrease in the subsequent higher levels (Fig. 17 B).

The vesicles were first observed in 30 days old plants in most of the fertility levels except the two lowest (unamended sand; and soil and sand ratio of 1:4) and the highest (4 NPK level) levels, where it was first observed in 60 days old plants (Fig.16). The number of vesicles also showed the similar trend as the number of arbuscules. The vesicles were very less at the highest fertility level. In all the treatments, the number of both arbuscules and vesicles increased with the increase of age of the plant (Fig. 16).

The number of hyphal entry points also increased with the increase in the fertility level upto one normal dose of NPK in all the five samplings (11, 18, 30, 60 and 100 days old plants). In all the treatments except, in the soil and sand ratio of 1:4, and soils amended with 1, 2 and 4 normal doses of NPK fertilizer, the hyphal entry points increased in number with increase in the age of plant upto 30 days and then decreased in 60 days old plants following an increase in 100 days old plants (Table 24). Whereas, no increase in the number

Fig. 16: Number of vesicles with respect to different fertility levels (treatments) in 30, 60 and 100 days old maize plants.
So = Scil, Sa = Sand.

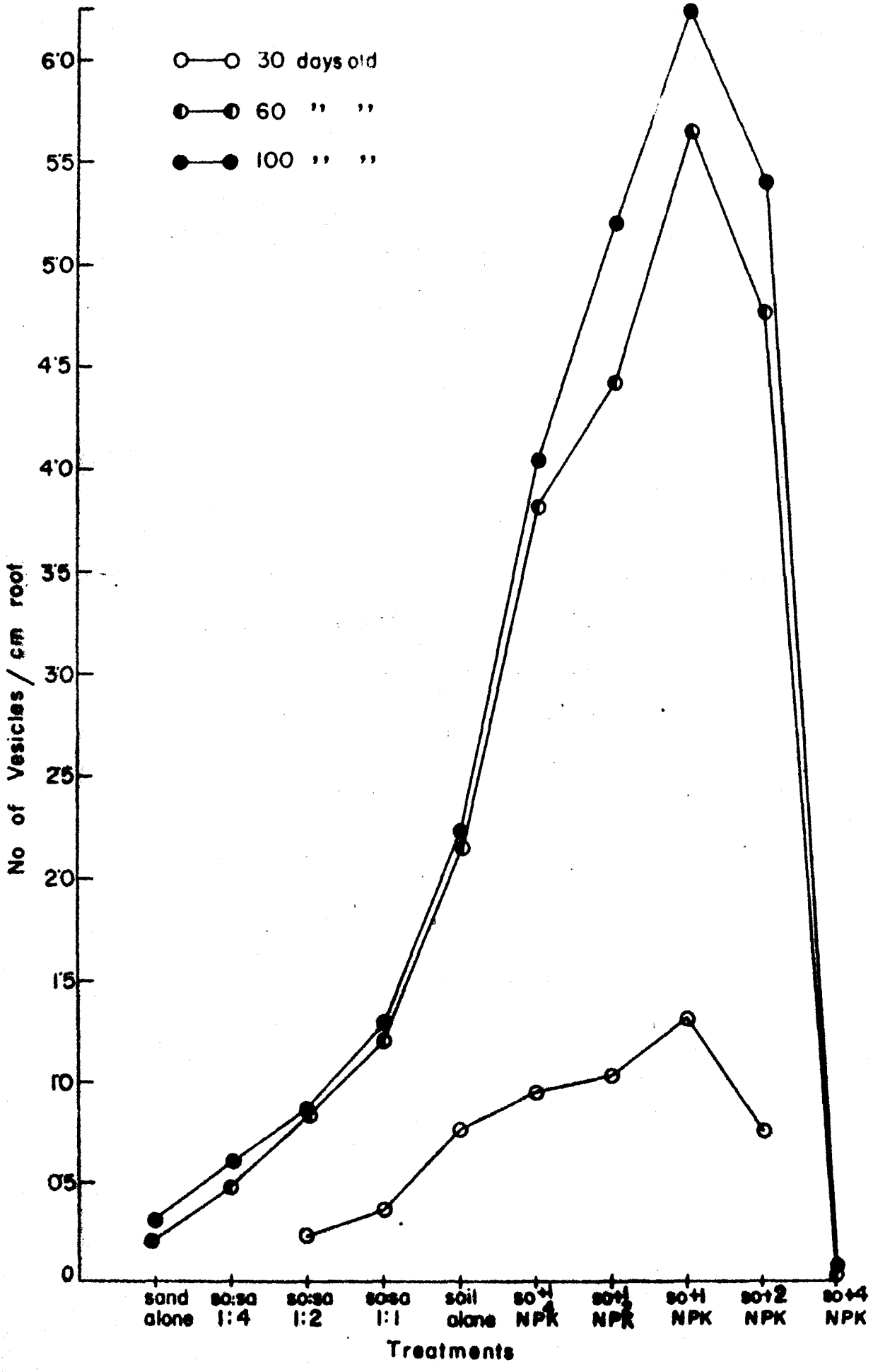

30 days old
60 " "
100 " "
No of Vesicles / cm root
6·0
5·5
5·0
4·5
4·0
3·5
3·0
2·5
2·0
1·5
1·0
0·5
0
sand alone
so:sa 1:4
so:sa 1:2
so:sa 1:1
soil alone
so+1 NPK
so+2 NPK
so+1 NPK
so+2 NPK
so+4 NPK
Treatments

Fig. 16

of hyphal entry points was observed in the soils amended with 1 and 2 normal doses of NPK fertilizer, in 100 days old plants. In the soil and sand ratio of 1:4 and 4 NPK levels, it increased with the increase in plant life upto 60 days and then decreased in the case of former in 100 days old plants (Table 24).

No remarkable change was observed in the intensity of mycorrhizal infection upto the fertility level of ¼ NPK, in 18 days old seedlings. But the intensity increased in the subsequent higher levels (½ NPK and 1 NPK levels) followed by a decrease in the two highest fertility levels (2 NPK and 4 NPK levels). In the subsequent samplings too (30, 60 and 100 days old plants), the intensity was higher in the soil amended with one normal dose of NPK fertilizer than the soil of higher fertility levels (Table 24). The spore population increased with the increase in the fertility level upto one normal dose of NPK and then decreased in the higher fertility levels (Fig. 17 A).

In each of the four different treatments, i.e. Soil + $(NK)_1P_2$, Soil + $(NK)_1P_3$, Soil + $(PK)_1N_2$ and Soil + $(PK)_1N_3$; the percentage of VAM infection increased with the increase in plant life upto 60 days and then decreased in the subsequent age (Table 25). In each sampling the infection was more in the soils fertilized with two normal doses of P and N compared to the ones fertilized with three normal doses of each (Table 25). The number of hyphal entry points increased with the increase of the plant age in all the treatments upto 30 days and then

Fig. 17: Endogone spore population and number of arbuscules with respect to different fertility levels (treatments) in maize plants.

So = Soil, Sa = Sand.

A = Endogone spore population in 100 days old plants.

B = Number of arbuscules in 30, 60 and 100 days old plants.

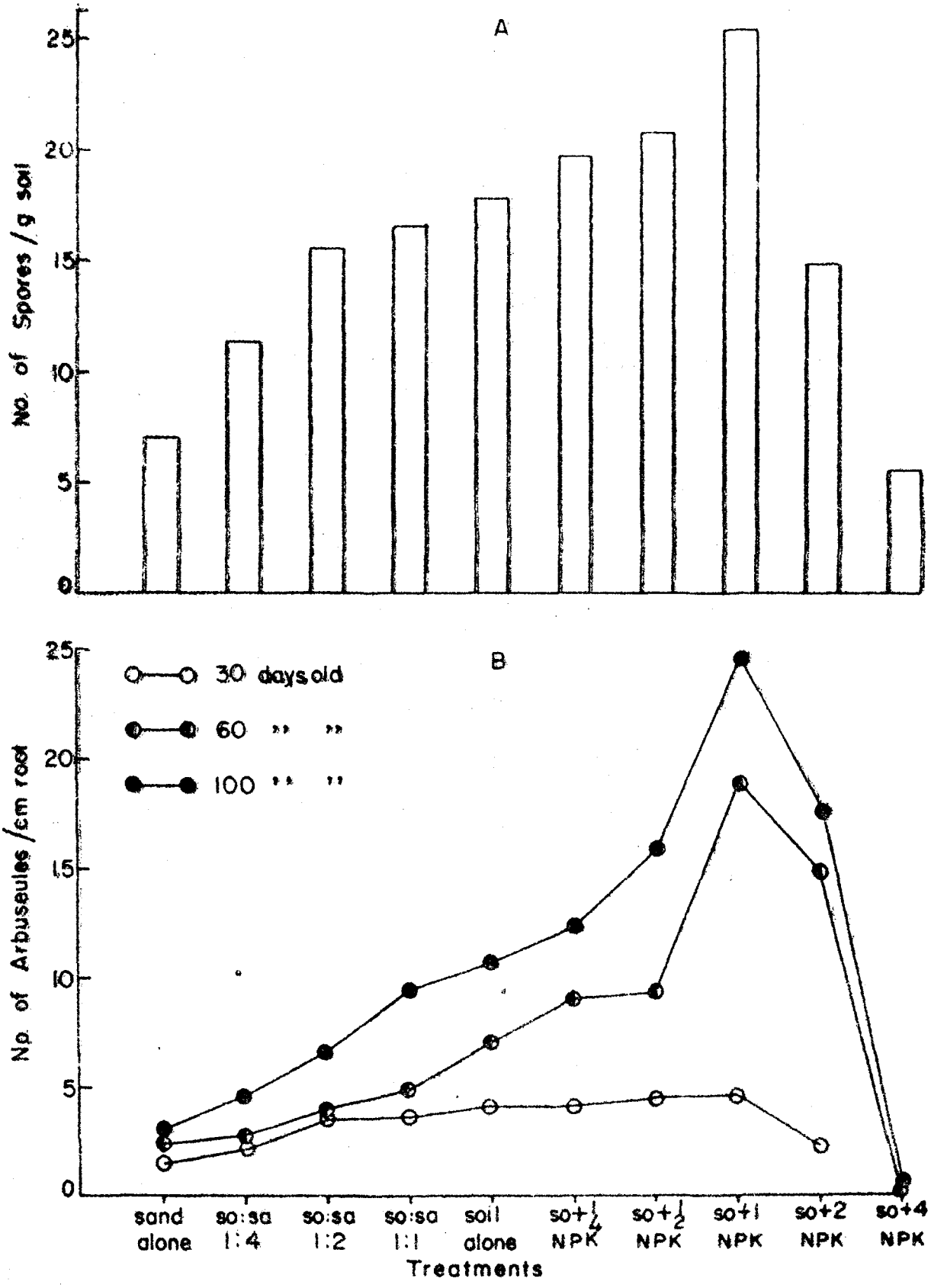

A
No. of Spores / g soil
25
20
15
10
5
0
B
No. of Arbuscules / cm root
30 days old
60 " "
100 " "
25
20
15
10
5
0
sand alone
so:sa 1:4
so:sa 1:2
so:sa 1:1
soil alone
so+¼ NPK
so+½ NPK
so+1 NPK
so+2 NPK
so+4 NPK
Treatments

Fig. 17

Table 24: Number of hyphal entry points/cm root and intensity of mycorrhizal infection in different treatments with respect to the age of the plant (in days).

Treatments	Hyphal entry points/cm root					Intensity of mycorrhizal infection			
	11 days	18 days	30 days	60 days	100 days	18 days	30 days	60 days	100 days
Sand alone	0.06	0.22	0.58	0.55	0.50	+	+	+	+
So:Sa, 1:4	0.06	0.33	0.80	0.92	0.85	+	+	+	+
So:Sa, 1:2	0.09	0.53	1.12	0.92	1.33	+	+	++	+
So:Sa, 1:1	0.09	0.58	1.55	1.23	1.43	+	++	++	++
Soil alone	0.14	0.78	1.67	1.48	1.74	+	++	+++	++
So + ¼ NPK	0.17	0.92	1.80	1.62	1.87	+	++	+++	+++
So + ½ NPK	0.18	0.97	1.88	1.73	1.95	++	++	+++	+++
So + 1 NPK	0.24	1.15	2.38	2.12	2.10	++	+++	++++	++++
So + 2 NPK	0.13	0.63	1.61	1.45	1.22	+	++	++	+++
So + 4 NPK	0.01	0.03	0.06	0.07	0.07	+	+	+	+

So = Soil; Sa = Sand.

Table 25: VAM Infection (%) in the four different treatments; So + $(NK)_1P_2$, So + $(NK)_1P_3$, So + $(PK)_1N_2$ and So + $(PK)_1N_3$.

Age of the plant (in days)	Treatments			
	So + $(NK)_1P_2$	So + $(NK)_1P_3$	So + $(PK)_1N_2$	So + $(PK)_1N_3$
11	28.50±4.81	6.58±0.98	20.67±0.93	10.16±0.73
18	34.75±2.51	12.50±1.23	23.70±0.67	10.25±1.18
30	61.42±1.91	25.00±1.61	56.00±1.26	24.61±1.71
60	74.50±2.37	46.83±4.49	55.33±2.90	40.67±4.05
100	65.17±2.75	33.00±1.26	47.17±1.48	35.83±3.53

Each figure represents mean ± standard error.

decreased at 60 days, followed by an increase at 100 days (except in Soil + $(NK)_1P_2$, where it was same in 60 and 100 days old plants)(Table 26). The arbuscules and the vesicles increased in number with the increase of the age of plant in all the treatments and were found to be more in the soils amended with two normal doses of P and N compared to the ones amended with three normal doses of each. The endogonaceous spore population (in 100 days old plants) also followed the similar pattern (Table 26).

C. MYCORRHIZA AND NUTRIENT UPTAKE :

The mycorrhizal infection increased with the increase of the phosphate application upto 0.5 g/pot and then decreased abruptly with further increase in the phosphate level (Table 27). The intensity of mycorrhizal infection also followed the similar trend.

Better plant growth was observed at lower and medium applied doses of phosphate in the mycorrhizal sets compared to the nonmycorrhizal ones. The shoot and root length of the mycorrhizal plants showed an increasing trend at low doses of phosphate, and then decreased with the increased phosphate levels (in case of shoot length, a little increase was observed at the last two phosphate levels) (Fig. 18 A, B). The leaf number and the diameter of the first internode in mycorrhizal plants increased with the increase in the phosphate level (Fig. 19 A, B). The shoot length, root length, leaf number

Table 26: Number of Hyphal entry points/cm root, number of arbuscules/cm root, number of vesicles/cm root and the number of Endogone spores/g soil in the four different treatments.

Age of the plant (in days)		Treatments			
		So + $(NK)_1P_2$	So + $(NK)_1P_3$	So + $(PK)_1N_2$	So + $(PK)_1N_3$
11	H	0.13	0.03	0.09	0.02
18	H	0.85	0.20	0.21	0.13
30	H	1.70	0.23	1.49	0.83
	A	2.45	2.00	2.25	1.20
	V	0.83	0.27	0.20	0.06
60	H	1.10	0.86	0.73	0.70
	A	14.58	4.75	7.68	2.21
	V	4.32	1.83	2.05	0.83
100	H	1.10	0.95	0.95	0.75
	A	16.20	5.59	9.09	2.15
	V	4.53	2.06	3.36	1.26
	S	21.43	14.43	13.70	7.30

H = Hyphal entry points, A = Arbuscules, V = Vesicles, S = Spores.

Table 27: VAM infection (%) and intensity of mycorrhizal infection in the maize plants grown in different phosphate levels.

Phosphate levels g/pot	VAM infection (%)	Intensity of mycorrhizal infection
0	70.50	+++
0.1	73.33	+++
0.5	100.00	++++
2.0	60.00	++
5.0	26.66	+
10.0	13.33	+

and the diameter of the first internode in nonmycorrhizal plants showed an increasing trend with the increase of phosphate level (Fig, 18, 19).

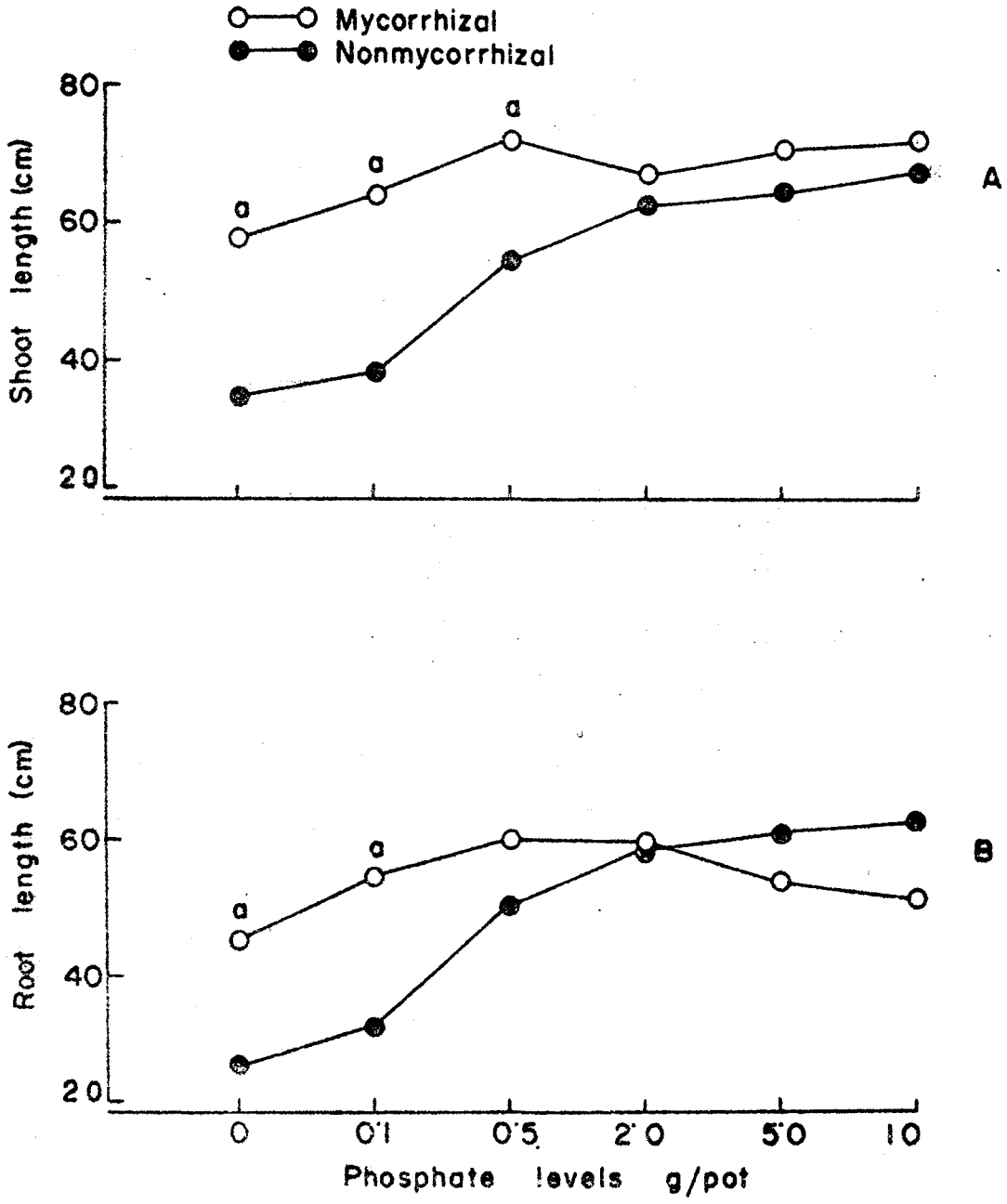
A significant (1% level) increase in shoot length and diameter of first internode of stem was observed in mycorrhizal plants than nonmycorrhizal ones in the phosphate levels upto 0.5 g/pot. The root lenght of the mycorrhizal plants was however significantly (significant at 1% level) greater than the nonmycorrhizal ones in the two lower phosphate levels (Fig. 18 B). Increase in leaf number was not significantly influenced at any phosphate level (Fig. 19 B).

The shoot biomass and the total biomass produced by the mycorrhizal plants were significantly greater upto 0.5 g/pot phosphate level. But no significant variation in shoot biomass and total biomass was observed between mycorrhizal and nonmycorrhizal plants at higher phosphate levels (Table 28). The root biomass of the mycorrhizal plants was significantly higher upto 0.1 g/pot phosphate level. At the high phosphate levels (5.0 and 10.0 g/pot), the nonmycorrhizal plants produced more root biomass (Table 28).

The root/shoot ratio was always lesser in the mycorrhizal plants than the nonmycorrhizal ones. In case of nonmycorrhizal plants, the root/shoot ratio increased with the increase in phosphate application upto 5.0 g/pot phosphate level and then decreased. Whereas, in mycorrhizal plants, it

Fig. 18: Shoot length and root length in mycorrhizal and nonmycorrhizal maize plants with respect to varying phosphate additions in soil (Phosphate levels).

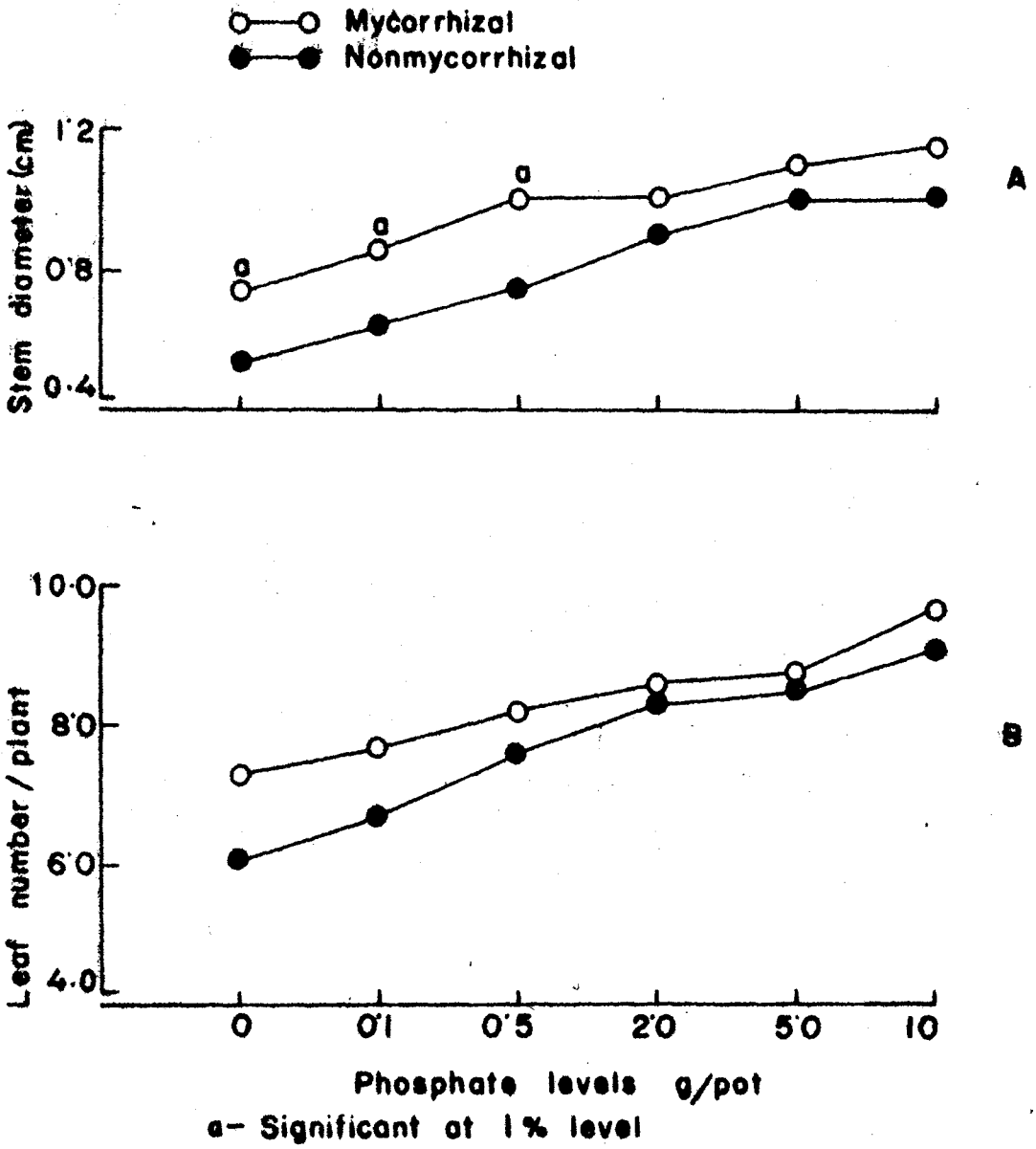
A = Shoot length, B = Root length.



a– Significant at 1% level

Fig. 18

Fig. 19: Diameter of the first internode of stem and number of leaves per plant in mycorrhizal and nonmycorrhizal maize plants with respect to varying phosphate additions in soil (phosphate levels).
A = Stem diameter, B = Leaf number per plant.



a- Significant at 1% level

Fig. 19

decreased with the increase in phosphate level upto 0.5 g/pot, then increased in the subsequent level followed by a decrease in the higher levels (5.0 g and 10.0 g/pot). In the two highest levels the nonmycorrhizal plants produced significantly greater (significant at 5% level in 5.0 g/pot and 1% level in 10.0 g/pot) root/shoot ratios (Table 28).

The phosphorus content was higher in the leaves than in stem and root. Increased phosphate contents in the leaves, stem and root of mycorrhizal plants was observed at the phosphate levels upto 0.5 g/pot which declined at higher phosphate levels. Whereas, in nonmycorrhizal plants the phosphorus content of the leaf increased upto 2.0 g/pot phosphate level and then showed a decreasing trend. But the phosphorus content of stem and root in nonmycorrhizal plants increased with the increase in phosphate level (Fig. 20 A, B, C).

The nitrogen content was also higher in the leaves than in stem and root. The nitrogen content of the leaf in mycorrhizal plants was found to be higher at the lowest phosphate level (0 level) and lowest at the higher phosphate level (5 g/pot). Whereas, in nonmycorrhizal plants it increased with the increase of phosphate level upto 0.5 g/pot, and then decreased abruptly in the subsequent level followed by an increase in higher levels (Fig. 21 A). The significant variation in nitrogen content of the stem was not influenced by the phosphate application in mycorrhizal plants, whereas in

Fig. 20: Percentage phosphorus content in leaf (A), stem (B) and root (C), in mycorrhizal and nonmycorrhizal maize plants with respect to varying phosphate additions in soil (Phosphate levels).

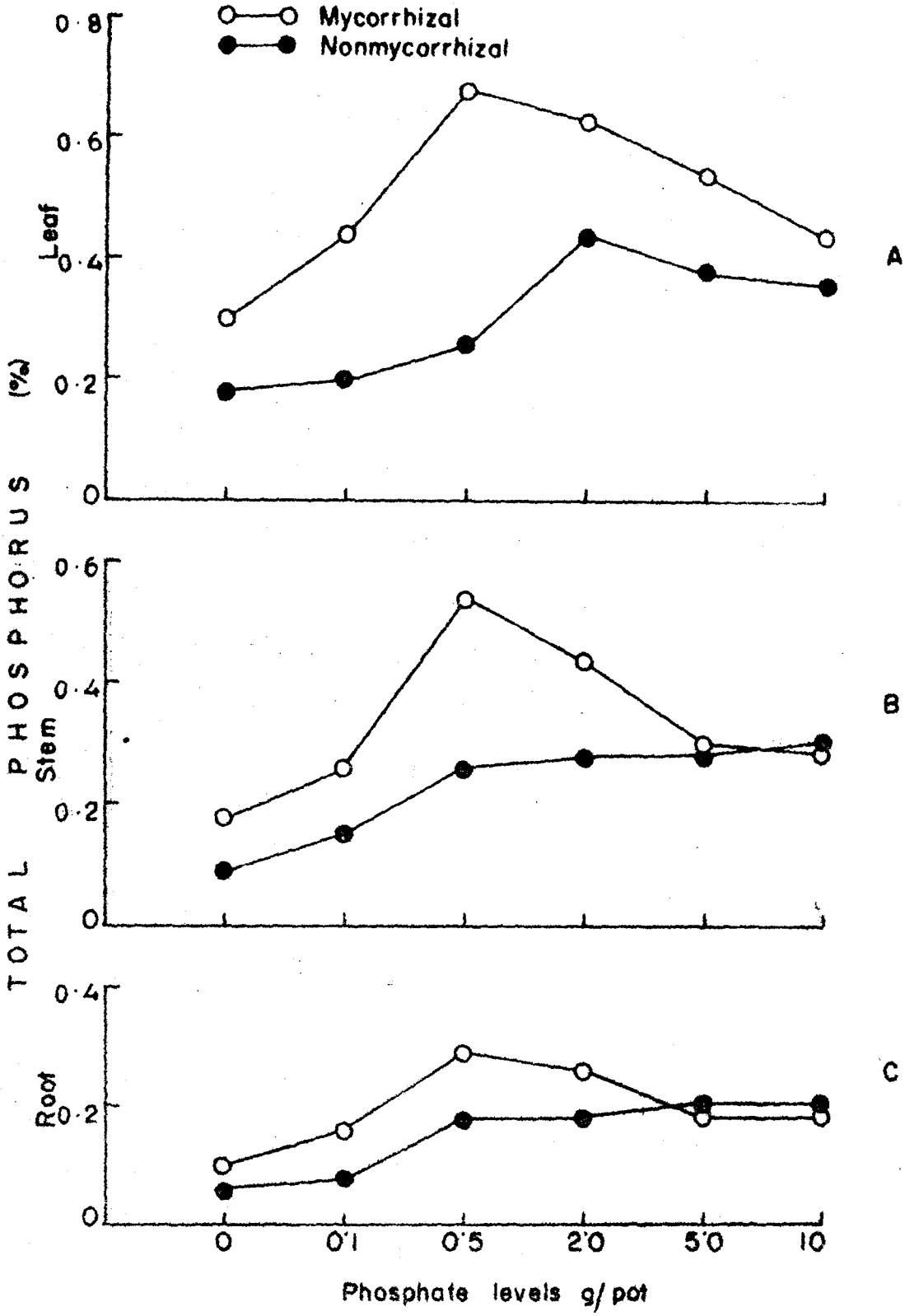

Mycorrhizal
Nonmycorrhizal
TOTAL PHOSPHORUS (%)
Leaf
Stem
Root
A
B
C
0·8
0·6
0·4
0·2
0
0·6
0·4
0·2
0
0·4
0·2
0
0
0·1
0·5
2·0
5·0
10
Phosphate levels g/pot

Fig. 20

Table 28: Root biomass, shoot biomass, total biomass and root/shoot ratio in the mycorrhizal (+M) and nonmycorrhizal (-M) maize plants grown in different phosphate levels.

Phosphate levels g/pot		Root biomass g/plant	Shoot biomass g/plant	Total biomass g/plant	Root/shoot ratio
0	+M	0.97**	1.99**	2.96**	0.78
	-M	0.71	1.15	1.86	0.79
0.1	+M	1.07**	2.38**	3.45**	0.85
	-M	0.78	1.28	2.06	0.87
0.5	+M	1.20	2.85**	4.05**	0.83
	-M	0.99	1.84	2.83	0.92
2.0	+M	1.15	2.56	3.71	0.89
	-M	1.03	2.12	3.15	0.94
5.0	+M	1.25	2.89	4.14	0.76
	-M	1.33	2.41	3.74	0.94*
10.0	+M	1.39	3.24	4.63	0.71
	-M	1.44	2.64	4.07	0.93**

Values are the mean of ten replicate plants.

* Significant at 5% level; ** Significant at 1% level.

nonmycorrhizal plants it was highest at the lowest phosphate level, then decreased upto 0.5 g/pot followed by an increase in the highest phosphate level (Fig. 21 B). The nitrogen content of the root in both mycorrhizal and nonmycorrhizal plants was not influenced by the phosphate application (except an increase in the nonmycorrhizal plants at the highest phosphate level) (Fig. 21 C).

D. MYCORRHIZA AND CROP PRODUCTIVITY :

Potato : Better growth was observed in the mycorrhizal potato plants compared to the nonmycorrhizal ones. The mycorrhizal plants had significantly greater (significant at 1% level) stem diameter than the nonmycorrhizal ones, in the first harvest (Table 29). In the second harvest, the mycorrhizal plants had significantly greater shoot length, leaf number, leaf area (significant at 1% level) and root length (significant at 5% level) than the nonmycorrhizal plants (Table 29). Besides, they also had higher shoot biomass and root biomass (significant at 1% level) (Table 30). In the last harvest, shoot length, leaf area and shoot biomass were found to be significantly higher (significant at 1% level) in the mycorrhizal plants compared to the nonmycorrhizal ones (Tables 29, 30). In addition, the mycorrhizal plants had higher tuber weight (significant at 5% level) than the nonmycorrhizal ones (Table 30). The mycorrhizal infection increased with the increase in the age of plant.

Fig. 21: Percentage nitrogen content in leaf (A), Stem (B) and root (C), in mycorrhizal and nonmycorrhizal maize plants with respect to varying phosphate additions in soil (Phosphate levels).

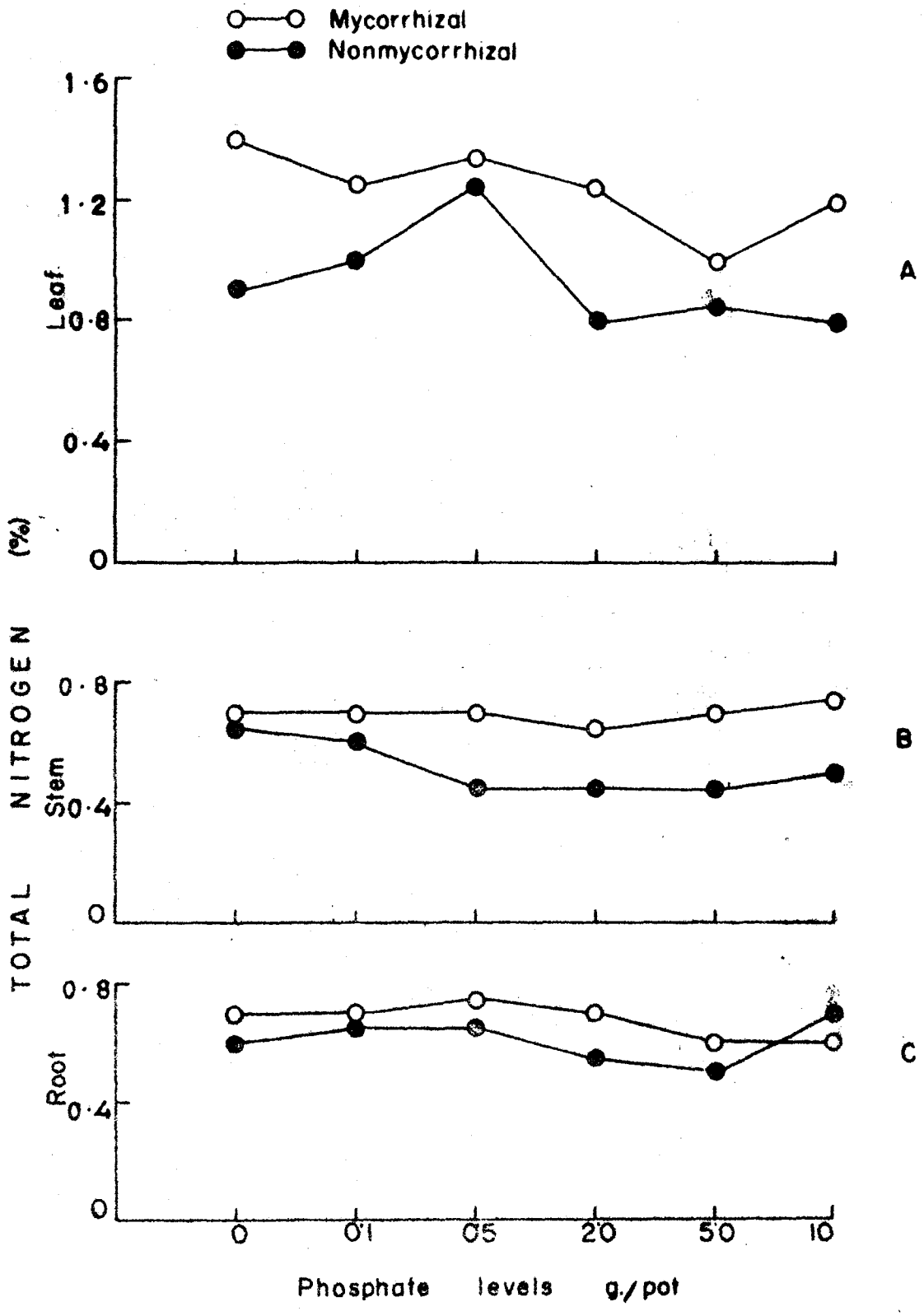

Mycorrhizal
Nonmycorrhizal
TOTAL NITROGEN (%)
Leaf
1·6
1·2
0·8
0·4
0
A
Stem
0·8
0·4
0
B
Root
0·8
0·4
0
C
0
01
05
20
50
10
Phosphate levels g./pot

Fig. 21

Table 29: Shoot length, root length, stem diameter, leaf number and leaf area in mycorrhizal and nonmycorrhizal potato plants, at different harvests.

Harvests		Shoot length (cm)	Root length (cm)	Stem diameter (cm)	Leaf number/ plant	Leaf area/plant (cm^2)
I (30 days old)	+M	20.75±0.79	26.50±2.43	0.50±0.48*	42.50±2.59	261.83±13.45
	-M	17.66±1.41	21.33±0.54	0.34±0.02	37.66±1.43	192.00±6.68
II (60 days old)	+M	33.58±1.66**	32.00±1.63*	0.60±0.00	109.17±10.03**	380.33±38.17**
	-M	18.58±0.33	21.75±0.63	0.43±0.01	52.83±5.19	340.33±16.37
III (90 days old)	+M	44.75±1.58**	34.17±0.87	0.80±0.03	140.67±1.52	848.00±9.63**
	-M	26.00±1.06	25.67±0.60	0.58±0.02	107.33±3.08	536.67±15.42

Each figure represent mean ± standard error.

+M = Mycorrhizal; -M = Nonmycorrhizal.

* Significant at 5% level; ** Significant at 1% level.

Table 30: Percentage mycorrhizal infection, shoot biomass, root biomass, tuber number and tuber weight in mycorrhizal and nonmycorrhizal potato plants at different harvests.

Harvests		Mycorrhizal infection (%)	Shoot biomass g/plant	Root biomass g/plant	Tuber No./ 2 plants	Dry weight g/10 tubers
I (30 days old)	+M	45.00±1.73	1.29±0.09*	0.37±0.05	2.00±0	-
	-M	0.	0.75±0.06	0.29±0.004	2.00±0	-
II (60 days old)	+M	72.50±2.31	3.62±0.19**	1.93±0.06**	4.00±0.	-
	-M	0	1.46±0.09	0.72±0.08	3.00±0	-
III (90 days old)	+M	98.00±1.15	4.81±0.12**	2.31±0.04**	16.67±1.77	54.00±2.89*
	-M	0	2.22±0.07	1.20±0.02	10.00±1.16	18.33±0.44

The figures represent mean ± standard error.

+M = Mycorrhizal; -M = Nonmycorrhizal.

* Significant at 5% level; ** Significant at 1% level.

In all the harvests, the mycorrhizal plants had higher phosphorus content than the nonmycorrhizal ones, being maximum in the leaf followed by stem and root (Fig. 22 A, B, C). The nitrogen content was also more in the treated plants than the untreated ones (Fig. 23 A, B, C). Though the potassium content in the leaf, stem and root, was more in the mycorrhizal plants than the nonmycorrhizal ones, the difference was not much (Fig. 24 A, B, C).

Maize : Like potato, better growth was observed in the mycorrhizal maize plants compared to the nonmycorrhizal ones. In the first harvest, the mycorrhizal plants had greater shoot length, root length, stem diameter and leaf area (significant at 1% level) than the nonmycorrhizal ones (Table 31). In the second and third harvests, significant difference was found in all the above growth parameters (significant at 1% level) except root length between mycorrhizal and nonmycorrhizal plants (Table 31). Besides this, in the third harvest the mycorrhizal plants had higher (significant at 5% level) leaf number than the nonmycorrhizal ones (Table 31). The shoot biomass was significantly greater ($P < 0.01$) in mycorrhizal plants compared to the nonmycorrhizal ones, in all the harvests (Table 32). Whereas, the root biomass was significantly greater in the former group in the first and third harvests (Table 32). The mycorrhizal plants had greater number of grain per ear (significant at 5% level) and higher dry weight of the grains, compared to the nonmycorrhizal ones (Table 33). The mycorrhizal

Fig. 22: Percentage phosphorus content in leaf (A), Stem (B) and root (C), in mycorrhizal and nonmycorrhizal potato plants at different harvesting periods.

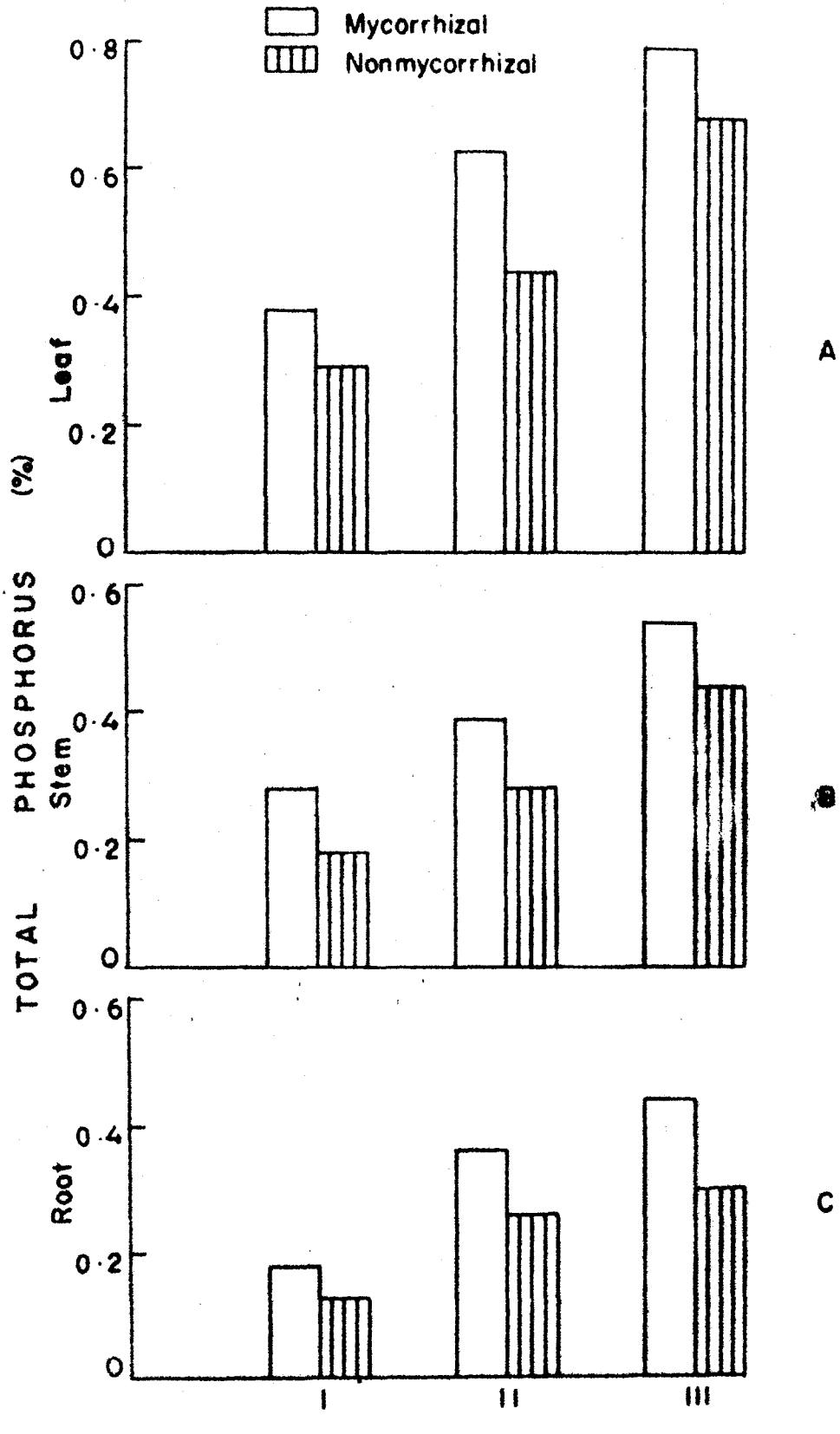

Mycorrhizal
Nonmycorrhizal
TOTAL PHOSPHORUS (%)
Leaf
Stem
Root
0·8
0·6
0·4
0·2
0
A
B
C
I
II
III
Harvests

Fig. 22

Fig. 23: Percentage nitrogen content in leaf (A), stem (B) and root (C), in mycorrhizal and nonmycorrhizal potato plants at different harvesting periods.

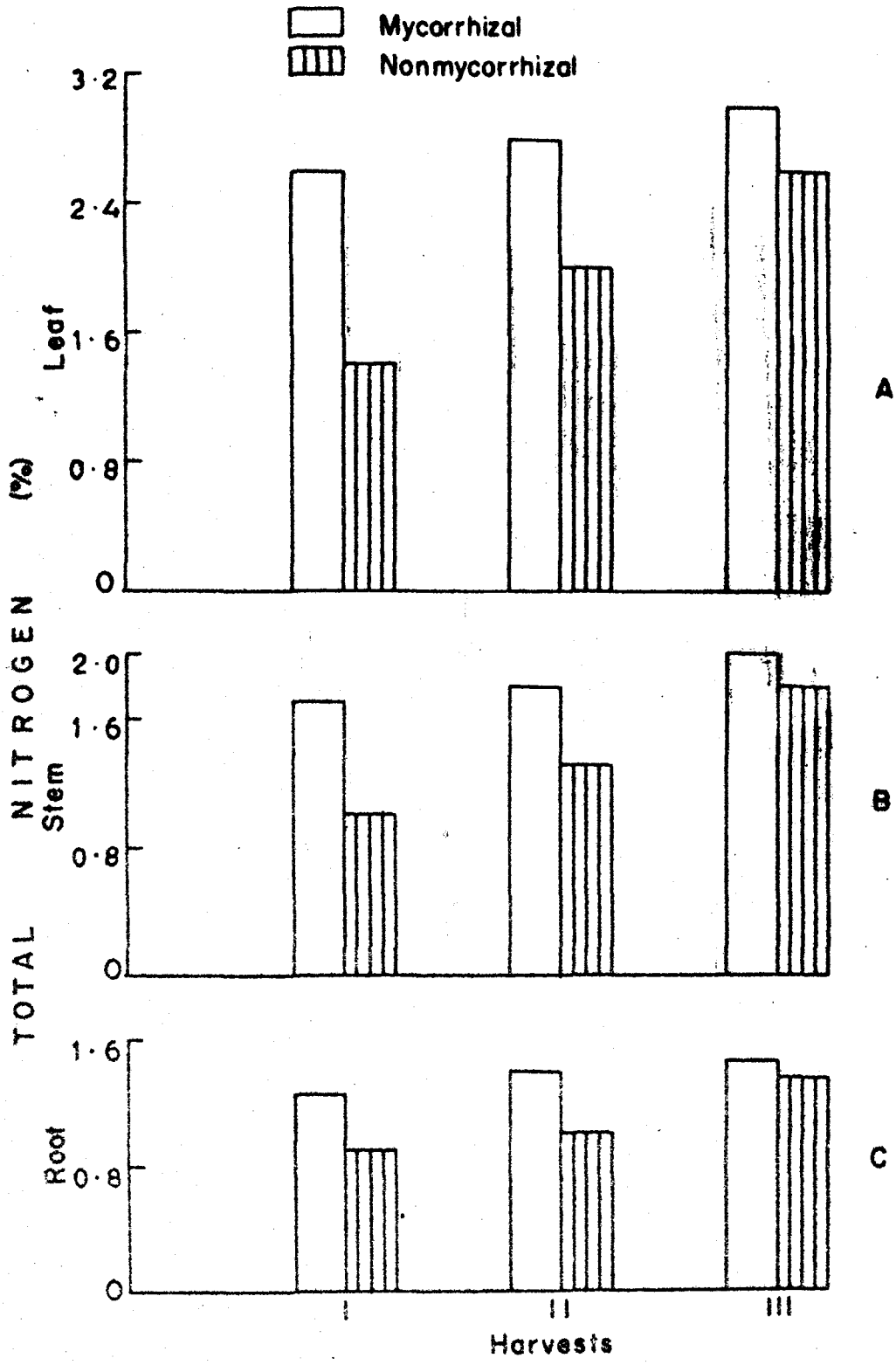

Mycorrhizal
Nonmycorrhizal
TOTAL NITROGEN (%)
Leaf
Stem
Root
3·2
2·4
1·6
0·8
0
2·0
1·6
0·8
0
1·6
0·8
0
A
B
C
I
II
III
Harvests

Fig. 23

Explanation of PLATE-7

Effect of *Glomus fasciculatus* on the growth of potato plants.

Inoculated plants (INO.) and noninoculated plants (NON.).

PLATE - 7

Explanation of PLATE-8

Effect of *Glomus fasciculatus* on the growth of maize plants.

Noninoculated plants (NON. MAIZE) and inoculated plants (INO. MAIZE).

PLATE - 8

Table 31: Shoot length, root length, stem diameter, leaf number and leaf area in mycorrhizal and nonmycorrhizal maize plants, at different harvests.

Harvests		Shoot length (cm)	Root length (cm)	Stem diameter (cm)	Leaf number/ plant	Leaf area/plant (cm^2)
I (30 days old)	+M	57.80±3.36**	47.67±1.22**	0.79±0.01**	6.33±0.17	396.14±4.51**
	-M	45.16±1.52	31.92±1.85	0.52±0.01	5.22±0.15	282.11±7.35
II (60 days old)	+M	88.08±1.65**	67.42±1.59	1.39±0.06**	8.78±0.15	657.38±8.08**
	-M	52.15±2.61	53.91±2.32	0.68±0.05	7.44±0.18	386.66±10.54
III (90 days old)	+M	145.78±3.39**	92.00±1.56	2.40±0.09**	14.44±0.18*	1608.33±13.18**
	-M	94.12±1.99	77.61±1.75	1.47±0.09	11.00±0.24	1161.66±15.55

Each figure represents mean ± standard error.
+M = Mycorrhizal; -M = Nonmycorrhizal.
* Significant at 5% level; ** Significant at 1% level.

Table 32 : Percentage mycorrhizal infection, shoot biomass and root biomass in mycorrhizal and nonmycorrhizal maize plants at different harvests.

Harvests		Mycorrhizal infection (%)	Shoot biomass g/plant	Root biomass g/plant
I (30 days old)	+M	60.00±2.31	2.58±0.12**	1.03±0.02**
	-M	0	1.63±0.06	0.42±0.05
II (60 days old)	+M	85.00±1.15	3.89±0.06**	2.27±0.05
	-M	0	2.30±0.19	2.01±0.16
III (90 days old)	+M	100.00±0	18.04±0.66*	7.44±0.15*
	-M	0	10.95±0.31	5.71±0.15

The figures represent mean ± standard error.

+M = Mycorrhizal; -M = Nonmycorrhizal.

* Significant at 5% level; ** Significant at 1% level.

Table 33: Number of ear, size of the ear, number of grain and dry weight of the grains in mycorrhizal and nonmycorrhizal maize plants at the last harvest (150 days old plants)

	Mycorrhizal	Nonmycorrhizal
Number of ears/plant	1.00±0	1.00±0
Length of the ear (cm)	27.67±0.33	20.33±0.88
Diameter of the ear (cm)	7.67±0.88	4.50±0.29
Number of grains/ear	544.00±35.59*	242.67±12.36
Dry weight, g/100 grains	37.67±1.45	18.67±0.60

Each figure represents mean ± standard error.

* Significant at 5% level.

infection increased with the increase in the age of plant.

The mycorrhizal plants had higher phosphorus and nitrogen contents than the nonmycorrhizal ones, being highest in the leaf followed by stem and root (Fig. 25, 26). But the difference in the potassium content between mycorrhizal and nonmycorrhizal plants was very less (Fig. 27).

E. SURVEY OF CROPS FROM DIFFERENT AGRICULTURAL FIELDS FOR VESICULAR-ARBUSCULAR MYCORRHIZA AND ENDOGONACEOUS SPORES :

The mycorrhizal infection was more in the potato plants from Shillong than those from Upper Shillong (Fig. 28 A). The number of Endogone spores also followed the similar pattern. Spores more than 90 μ in size represented the highest number (Fig. 28 B).

The percentage of root infection was more in maize and paddy at lower altitude i.e. Burnihat and lower at the higher altitude i.e. Shillong and Upper Shillong (Fig. 29 A, B). The Endogone spores were more in the maize and paddy fields of Burnihat followed by Shillong and Upper Shillong (Fig. 30, 31). Like potato field, in maize and paddy fields also spores more than 90 u in size formed the bulk of the total population. Besides, in Burnihat the spores of the higher sizes (more than 200 u and 150 u) were more in comparison to Shillong and Upper Shillong (Fig. 30, 31).

Fig. 24: Percentage potassium content in leaf (A), stem (B) and root (C), in mycorrhizal and nonmycorrhizal potato plants at different harvesting periods.

Fig. 25 : Percentage phosphorus content in leaf (A), stem (B) and root (C), in mycorrhizal and nonmycorrhizal maize plants at different harvesting periods.

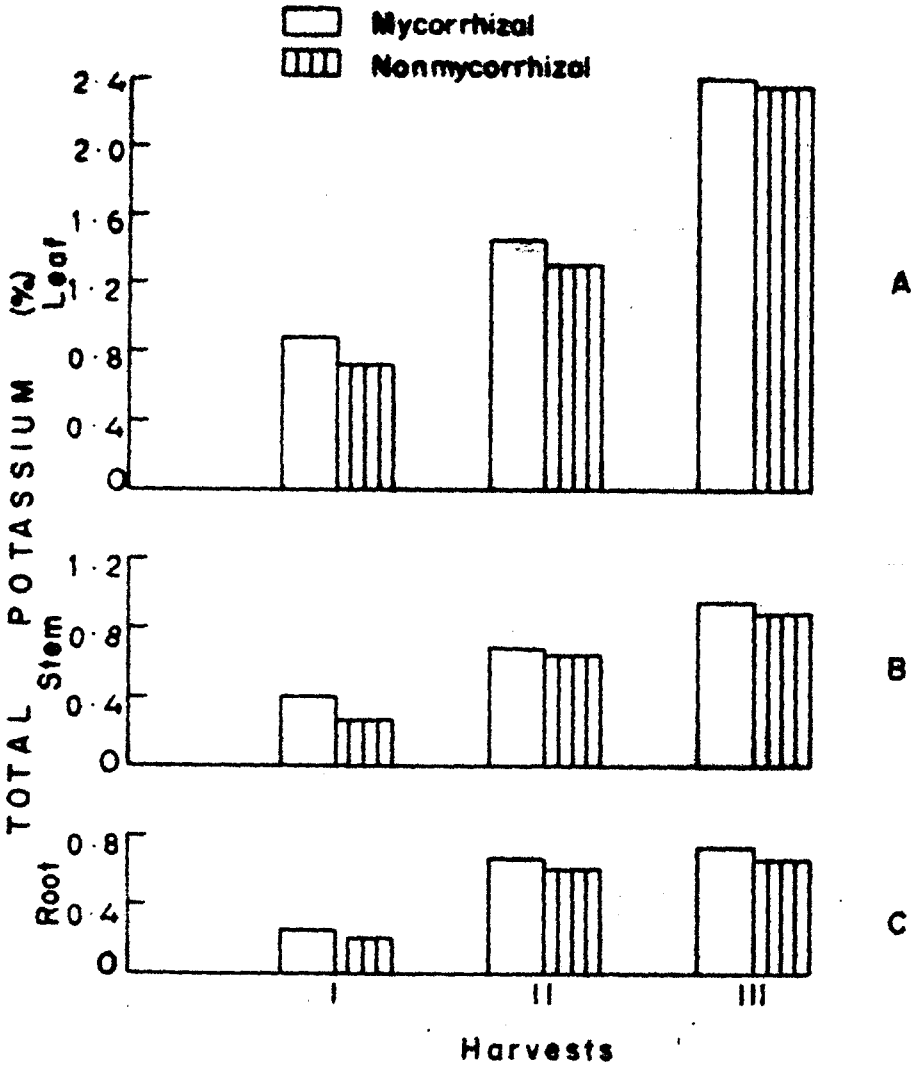

Mycorrhizal
Non mycorrhizal
TOTAL POTASSIUM (%)
Leaf
Stem
Root
A
B
C
2·4
2·0
1·6
1·2
0·8
0·4
0
I
II
III
Harvests

Fig. 24

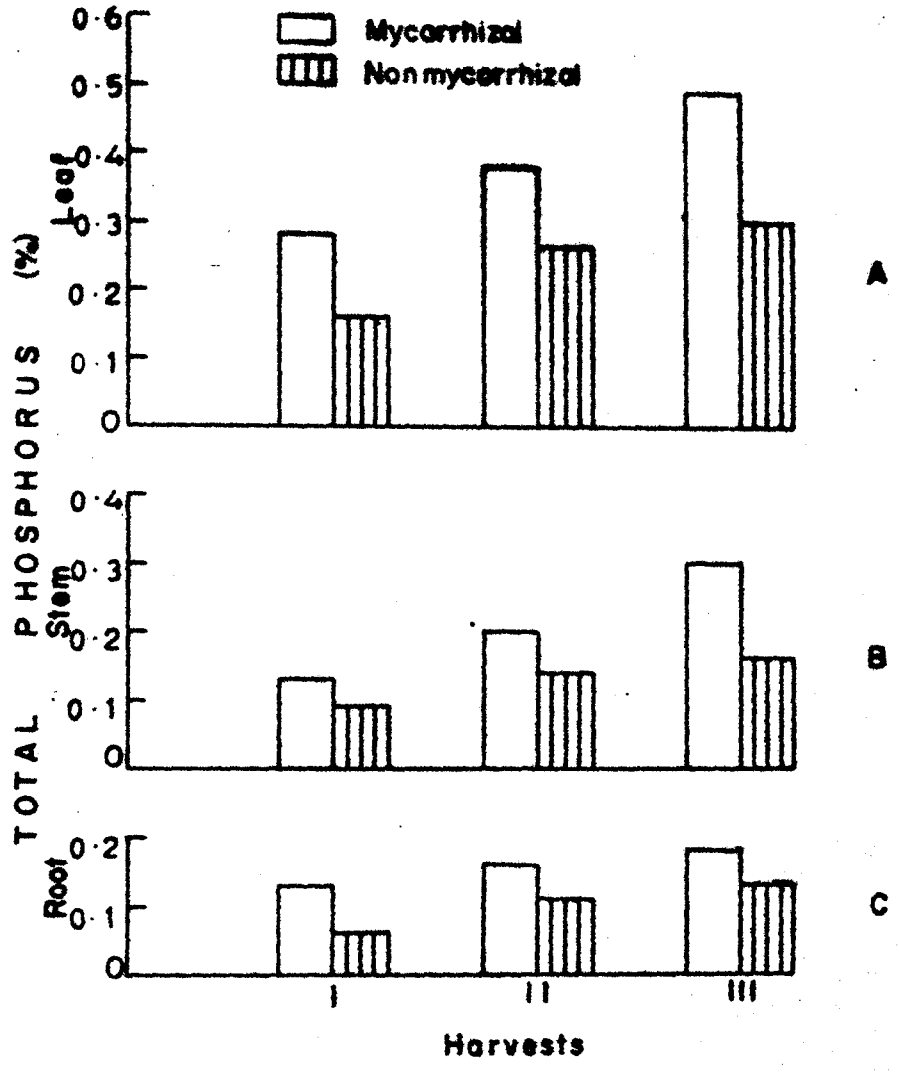

Mycorrhizal
Non mycorrhizal
TOTAL PHOSPHORUS (%)
Leaf
Stem
Root
A
B
C
0·6
0·5
0·4
0·3
0·2
0·1
0
I
II
III
Harvests

Fig. 25

Fig. 26: Percentage nitrogen content in leaf (A), stem (B) and root (C), in mycorrhizal and nonmycorrhizal maize plants at different harvesting periods.

Fig. 27: Percentage potassium content in leaf (A), stem (B) and root (C), in mycorrhizal and nonmycorrhizal maize plants at different harvesting periods.

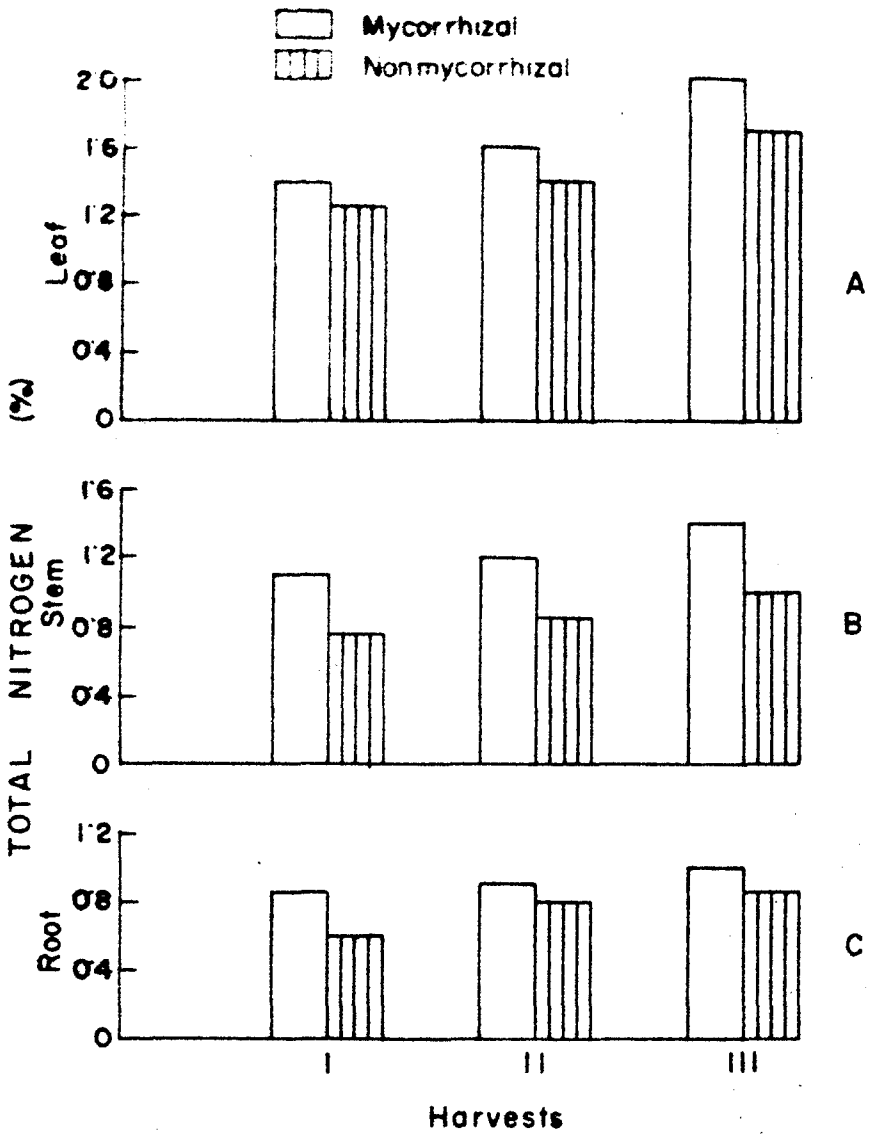

Mycorrhizal
Non mycorrhizal
TOTAL NITROGEN (%)
Leaf
Stem
Root
A
B
C
2·0
1·6
1·2
0·8
0·4
0
I
II
III
Harvests

Fig.26

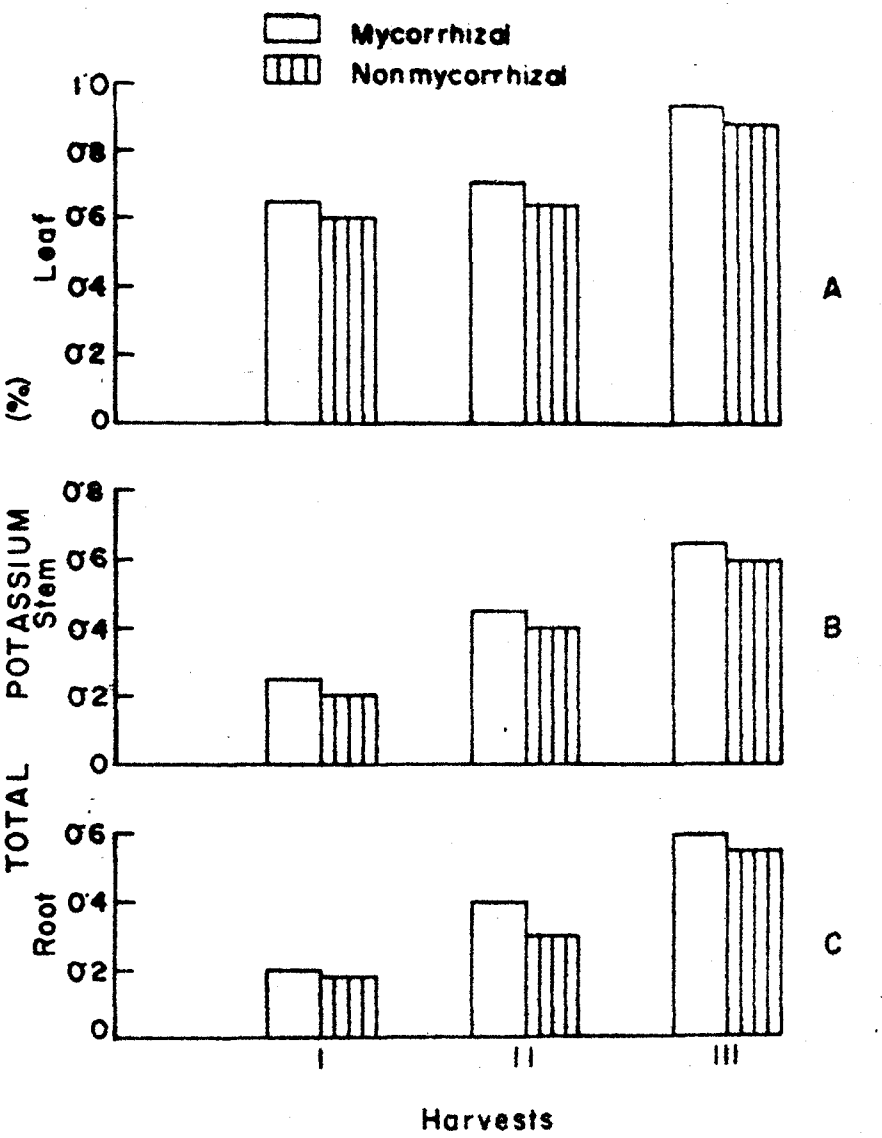

Mycorrhizal
Non mycorrhizal
TOTAL POTASSIUM (%)
Leaf
Stem
Root
A
B
C
1·0
0·8
0·6
0·4
0·2
0
I
II
III
Harvests

Fig. 27

Fig. 28: Percentage vesicular-arbuscular mycorrhizal (VAM) infection and Endogone spore population in potato plants and soil collected from two different potato fields, one located at Shillong and another at Upper Shillong, in April, May and June.

A = Percentage VAM infection
B = Endogone spore population

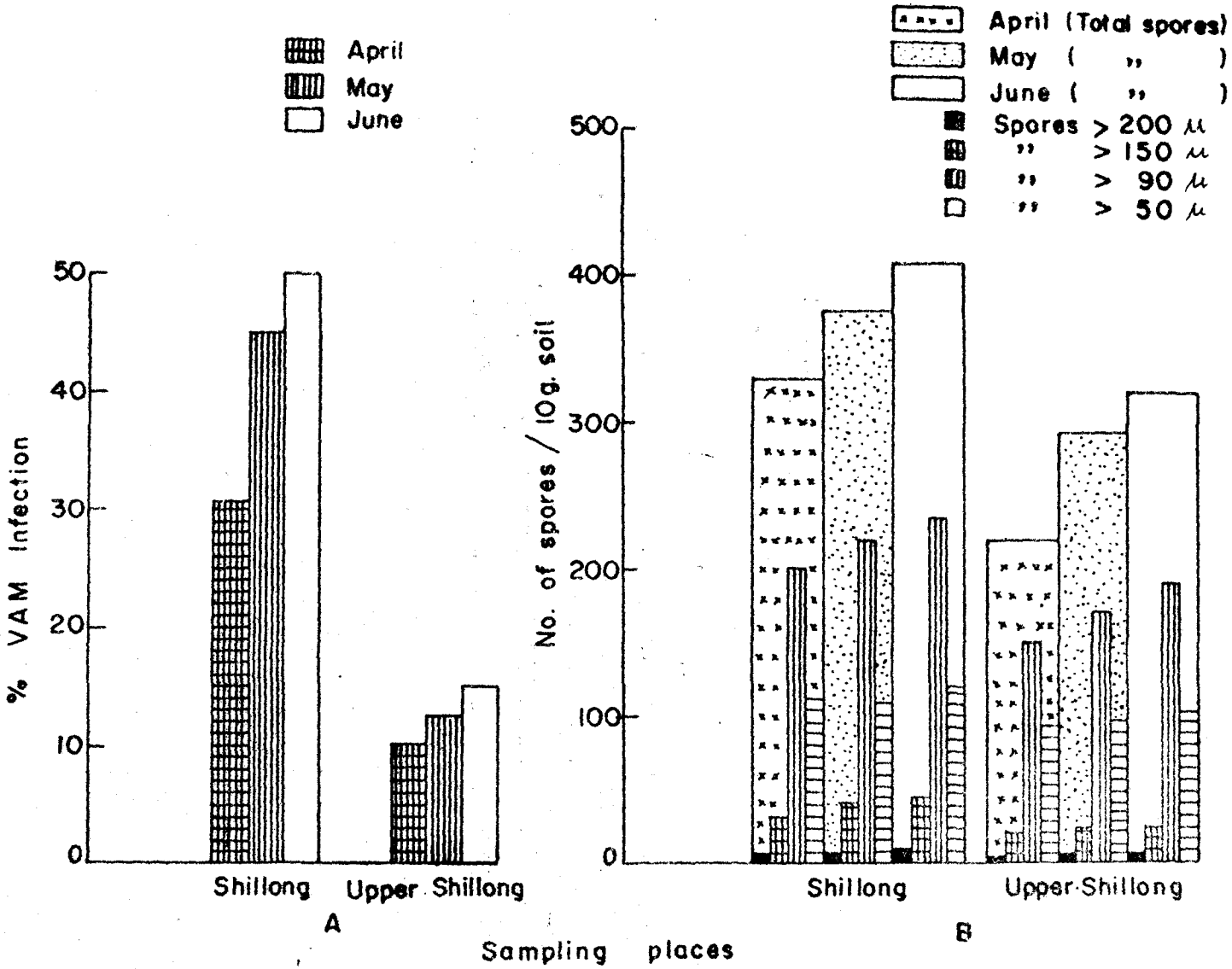

April
May
June
% VAM Infection
50
40
30
20
10
0
Shillong
Upper Shillong
A
April (Total spores)
May (,,)
June (,,)
Spores > 200 μ
,, > 150 μ
,, > 90 μ
,, > 50 μ
No. of spores / 10g. soil
500
400
300
200
100
0
Shillong
Upper Shillong
B
Sampling places

Fig. 28

Fig. 29: Percentage vesicular-arbuscular mycorrhizal (VAM) infection in maize and paddy plants collected from three different fields, each located at Burnihat, Shillong and Upper Shillong, in July and October.

A = Percentage VAM infection in maize plants.

B = Percentage VAM infection in paddy plants.

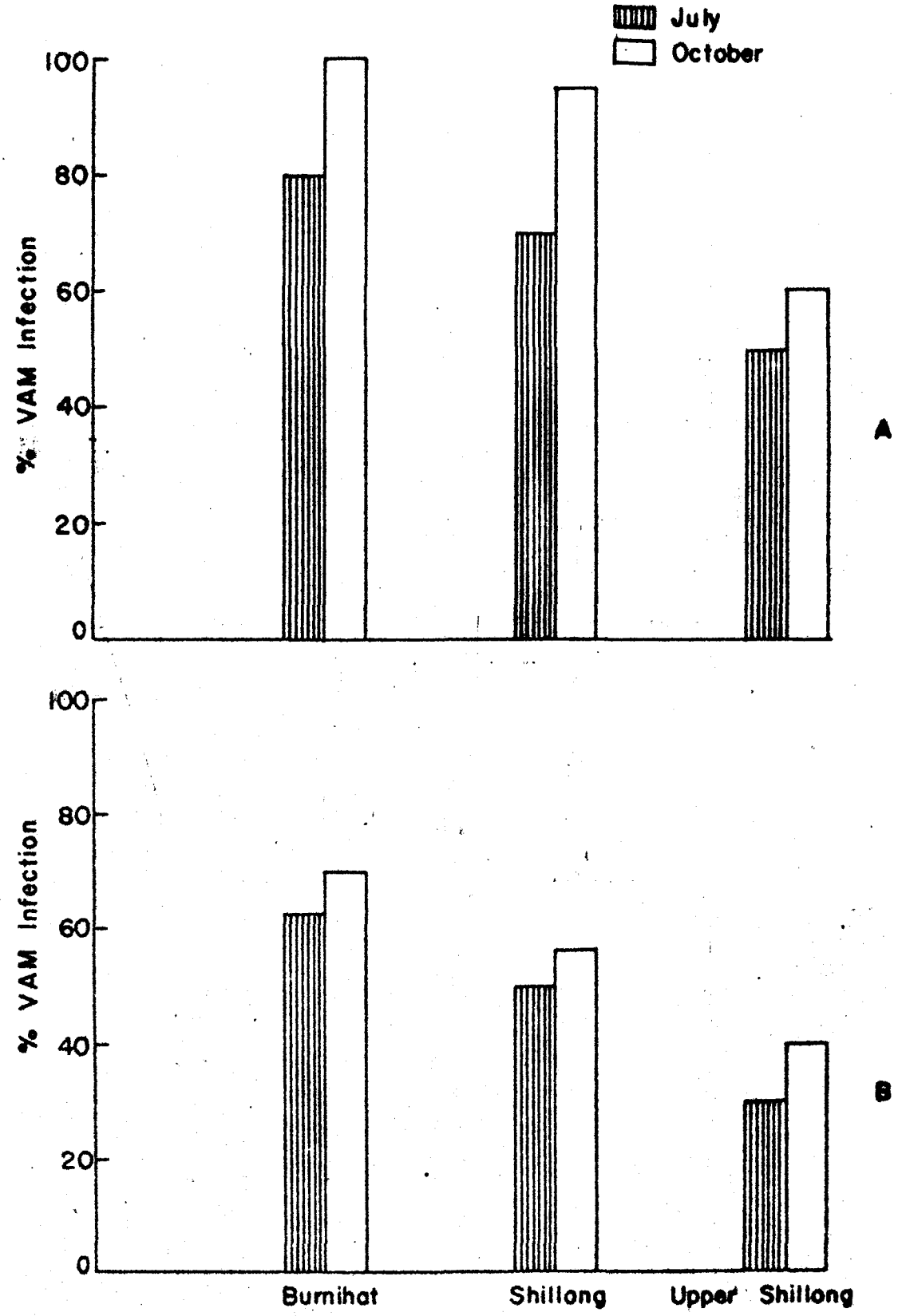

July
October
100
80
60
40
20
0
% VAM Infection
A
100
80
60
40
20
0
% VAM Infection
B
Burnihat
Shillong
Upper Shillong
Sampling places

Fig. 29

Fig. 30: Endogone spore population at three different maize fields (each located at Burnihat, Shillong and Upper Shillong) in July and October.

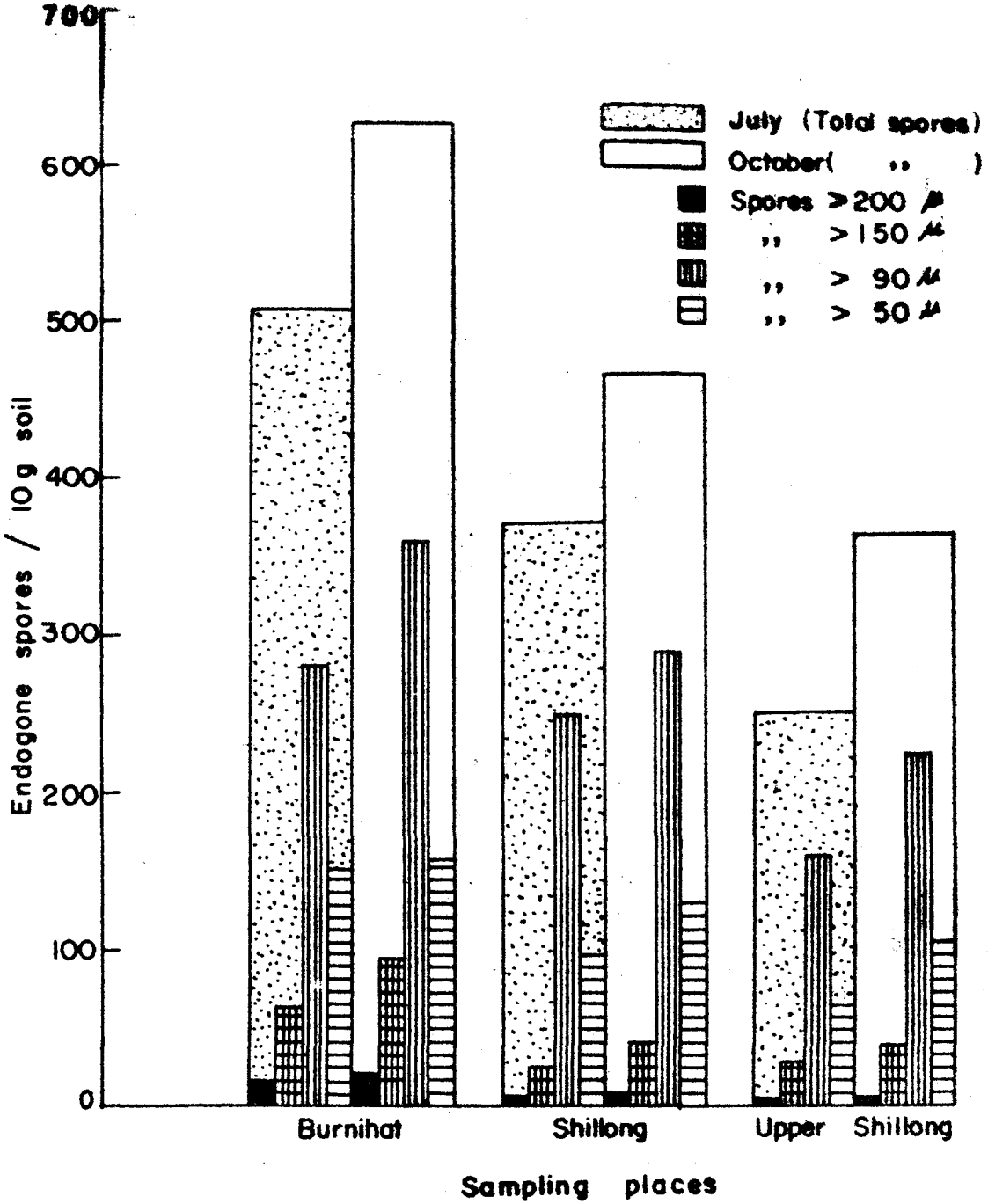

700
600
500
400
300
200
100
0
Endogone spores / 10 g soil
July (Total spores)
October(,,)
Spores >200 μ
,, >150 μ
,, > 90 μ
,, > 50 μ
Burnihat
Shillong
Upper Shillong
Sampling places

Fig. 30

Fig. 31: Endogone spore population at three different paddy fields (each located at Burnihat, Shillong and Upper Shillong) in July and October.

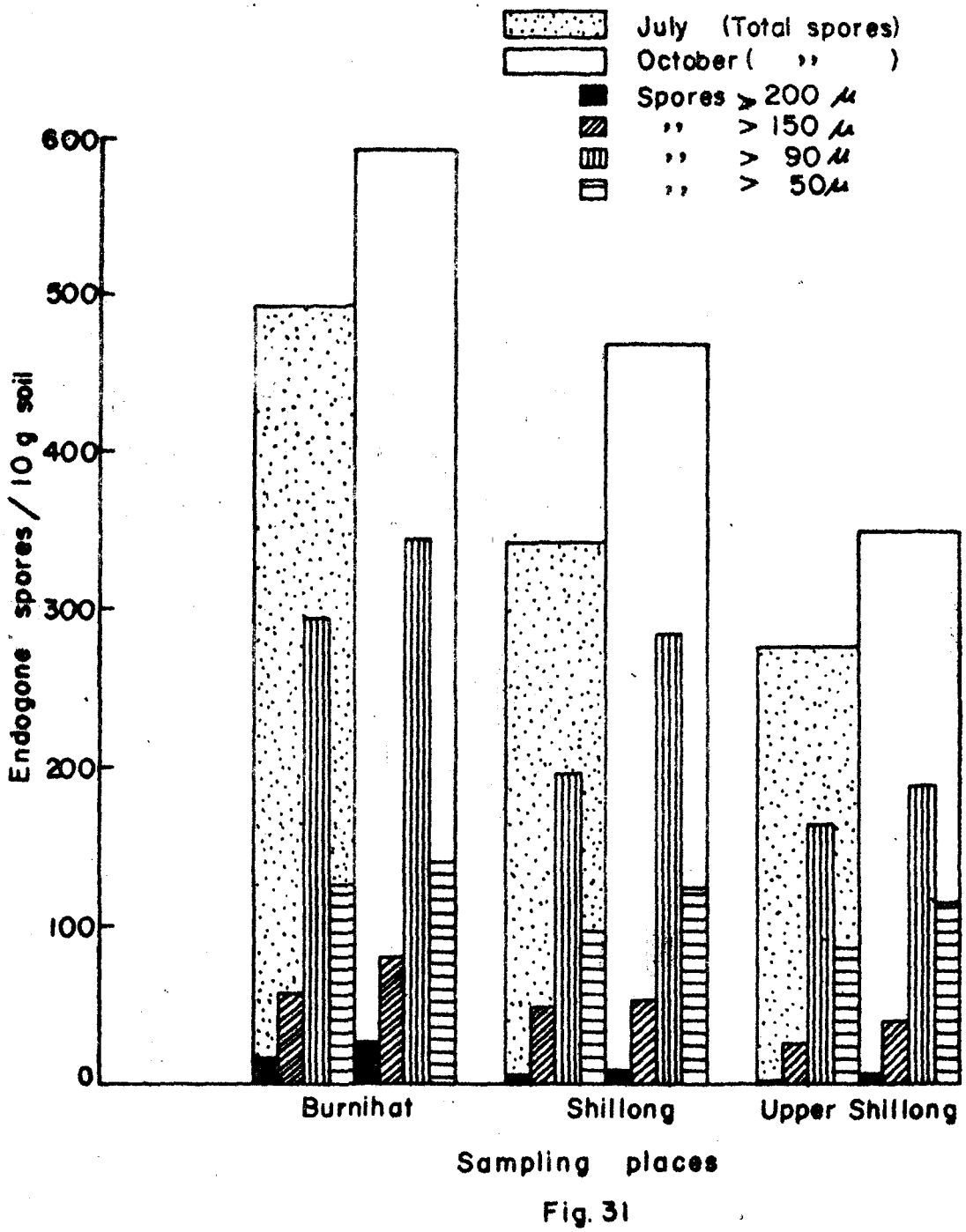

July (Total spores)
October (,,)
Spores ≥ 200 μ
,, > 150 μ
,, > 90 μ
,, > 50 μ
Endogone spores / 10 g soil
600
500
400
300
200
100
0
Burnihat
Shillong
Upper Shillong
Sampling places

Fig. 31

Table 34: Rhizosphere soil properties of potato, from different fields.

	April 1981		May 1981		June 1981	
	I	II	I	II	I	II
pH	5.05	6.00	5.45	6.20	5.60	5.85
Moisture content (%)	22.0	20.00	24.00	22.00	26.50	25.50
Organic matter (%)	2.59	2.25	2.59	2.55	2.84	2.70
Total nitrogen (%)	0.20	0.30	0.30	0.33	0.35	0.33
Available phosphorus (ppm)	4.81	3.94	5.69	3.06	7.00	3.06
Exchangeable potassium (mg/g)	0.40	0.28	0.58	0.25	0.45	0.25

I = Upper Shillong; II = Shillong.

Table 35: Rhizosphere soil properties of maize and paddy from different fields

Crop plant	Sampling month		pH	Moisture content (%)	Organic matter (%)	Total nitrogen (%)	Available phosphorus (ppm)	Exchangeable potassium (mg/g)
Maize	July 1981	I	5.05	26.00	2.59	0.20	3.25	0.25
		II	6.20	25.00	3.36	0.30	3.50	0.38
		III	5.45	18.00	2.84	0.25	3.31	0.25
	October 1981	I	5.30	23.00	1.82	0.20	2.50	0.25
		II	6.50	22.00	3.62	0.30	2.63	0.28
		III	5.65	18.50	3.88	0.40	1.75	0.25
Paddy	July 1981	I	5.49	30.00	4.77	0.39	5.69	0.58
		II	5.85	29.50	4.14	0.25	2.63	0.28
		III	5.40	18.00	2.59	0.20	2.50	0.63
	October 1981	I	5.45	34.00	4.40	0.25	3.31	0.15
		II	5.55	33.50	4.55	0.30	3.06	0.15
		III	5.78	18.50	2.59	0.20	2.19	0.18

I = Upper Shillong; II = Shillong; III = Burnihat.

It was observed that in the potato and paddy fields moisture content and phosphorus increased with the increase of altitude (Tables 34, 35). However, in maize field, though the moisture content increased with the increase of altitude but no definite trend was observed in case of phosphorus (Table 35).

DISCUSSION

The establishment and development of VAM fungi were early and rapid in the disease resistant cultivars of both potato and paddy compared to the disease-susceptible ones (Fig. 3, 8). The delay in the initiation of infection in the susceptible cultivars might be due to some antagonistic effect of the pathogen on the endophyte, but it needs further investigation before any conclusion could be drawn. Not much difference was observed between the mycorrhizal status of local and composite varieties of maize (Fig. 6). Among the two local cultivars, 'Local Yellow' showed some superiority in mycorrhizal behaviour over 'Local White'. The local cultivar of paddy, 'village paddy' and the slightly improved local cultivar, 'Khonorullu' did not show much difference in mycorrhizal behaviour. In general, the mycorrhizal infection showed an increasing trend with increase in the age of plants in all the three crop types, as has also been reported by Hayman (1970).

No colonization by the fungus was observed until some days after the emergence of the seedlings when hyphae were frequently observed in the root cortex. The first infection was observed in 12 days and 8 days old seedlings in Kufri Jyoti and SSC 1174 in the year 1980 and 1981 respectively. In the different cultivars of maize, it was observed in 12 days old seedlings in 1980, and in 9 days old seedlings in Local Yellow in 1981. In 'Khonorullu' the first infection was observed in 12 days old seedlings in both the years. After the initiation the infection increased rapidly. Lag periods

at the beginning of the infection process have also been reported by Sutton (1973), Saif (1977) and Carling et al. (1979). As suggested by Sutton (1973), the time required for spore germination, germ tube elongation and root penetration obviously contribute to the delay.

The arbuscules increased in number rapidly at the beginning of the growing season, but later on decreased with the increase of age of the plants in all the cultivars of the three crop plants (Fig. 5A, B and 9A). The decrease was mainly due to the degeneration of arbuscules which was frequent and vigorous at the later phase of the growing period. The number of vesicles increased very slowly at the beginning, which was followed by a rapid increase at the later phase of the life cycle of plants (Fig. 4, 7 and 9B). In 1981, however, some vesicular degeneration was observed in the cultivars of potato and maize in the last phase of the life cycle of plants which resulted in the decrease in vesicle number. The intensity of mycorrhizal infection increased with increase in age of plants at the beginning, but later on decreased, in the disease resistant cultivars of potato and paddy and in all the cultivars of maize (Table 1, 2 and 3). The decrease was caused mainly by the arbuscular degeneration which was more frequent at the later phase of the life cycle of plants. In the disease-susceptible cultivars of potato and paddy, the mycorrhizal intensity was very low from the very beginning and it maintained a constancy throughout the growing period

(Table 1, 3). The probable explanation for this is that the pathogen might produce some inhibitory substances which probably retarded the development of the endophyte within the root.

The fine endophyte, Glomus tenuis was observed in the comparatively cooler months of the year (March in potato, September-October in maize, and October-November in paddy), whereas, the external vesicles of Gigaspora sp. were observed in the month of July in maize. The occurrence of fine endophytic infection (Rhizophagus tenuis) in tussock grasses in New Zealand at higher altitude (Crush, 1973), the presence of G. tenuis as the dominant endophyte in most of the plant species of higher alpine vegetation (Haselwandter and Read, 1980), and the occurrence of G. tenuis in the comparatively cooler months of the year in potato, maize and paddy in the present study suggests that the activity of G. tenuis might be favoured by the lower temperature. On the other hand, the occurrence of Gigaspora sp. in the comparatively warmer month (July) suggests that the higher temperature of the environment might favour its activity. Schenck and Hinson (1971) also observed frequent occurrence of Gigaspora species from the warm regions of Florida. The co-existence of the fine and the coarse endophytes, which has been observed in the present study, was also reported by Ali (1969) and Crush (1973).

In all the cultivars of the three crop plants, the Endogone spore population at first decreased and then increased

with increase in the age of plants (Fig. 10, 11 and 12). The decrease at the beginning was probably due to the germination of spores for the initiation of infection. Except the initial decrease, the spore population showed an increasing trend with increase of the age of plants, as has also been reported by Hayman (1978). The decline in the spore population at the start of the growing season, was also reported by Saif (1977) and Smith (1980). Not much difference was observed in the spore population between the different cultivars of each crop plant. This result confirms the finding of Kruckelmann(1975) who reported that the spore population is not related to the host species.

The correlation of the spore population as well as the percentage mycorrhizal infection with respect to the rhizosphere soil properties did not show any clear trend in all the crop types (taking both the years into consideration). This might be due to the topography of the region, which results in the large amount of surface run-off carrying the soil particles, the organic matter and the nutrients along with the Endogone spores, because most of the spores are present in the upper 15 cm depth of the soil (Mosse, 1973).

The mycorrhizal infection showed an increasing trend with the increase in the soil fertility level upto the recommended dose of NPK ferilizer. However, above the recommended dose of the fertilizer the mycorrhizal infection

decreased and it was least in the soil amended with four times the normal dose of NPK fertilizer (Fig, 13, 14). Hayman (1970, 1975), Porte and Bente (1972), Mosse (1973), and Kruckelmann (1975) suggested that excessive high or extremely poor nutrient status of the soils are inhibitory to mycorrhizal formation. Ames and Linderman (1978) also reported more mycorrhizal infections in low fertilizer treatments than in the high- or no- fertilizer treatments.

Both the arbuscules and the vesicles were first observed quite early in all the fertility levels, except the highest one (4 NPK level) where they were observed quite late. Their number increased with increase of the fertility level upto the recommended dose and then decreased in the subsequent higher fertility levels (Fig. 16, 17). In the highest fertility level the number of vesicles was very less. The intensity of the infection was the highest in the soil amended with recommended dose of NPK fertilizer, and then decreased with further increase in the fertility level (Table 24). It may be concluded that the recommended dose of NPK fertilizer enhanced the development of mycorrhizal fungi within the root. Abbott and Robson (1979) also reported that the normal doses of phosphorus had no effect on the formation of arbuscules and the density of hyphae within the infected root, but the addition of P above that required for maximum plant yield eliminated the vesicle formation. The Endogone spore population also increased with the increase in the fertility level

upto one normal dose of NPK and then decreased with further increase in the fertility level (Fig. 17B). Csinos (1981) also reported greater number of spores in soils with lowest fertilization.

With the increase of the age of plants the mycorrhizal infection showed an increasing trend in all the fertilizer treatments. Like the mycorrhizal infection the glucosamine (Chitin) content of the root also increased with increase in the fertility level upto the normal dose of NPK fertilizer and subsequently decreased with increase in the fertility level (Fig. 14). The percentage mycorrhizal infection showed a significant positive correlation ($r = 0.90$) with the glucosamine content. Becker and Gerdemann (1977) also found the similar relationship between percentage mycorrhizal infection and the glucosamine content of the mycorrhizal roots. In this experiment, the percentage mycorrhizal infection by root slide technique together with the chitin digestion method gave more clear clue about the mycorrhizal development within the root. This result is in agreement with Hepper (1977) who suggested to use the Chitin assay technique in combination with the stained root slide observation.

The nitrogen and phosphorus contents in the root showed a negative correlation ($r = -0.34$ and -0.29 respectively) with the percentage root infection. This observation is similar to the findings of Sanders (1975) and Menge et al. (1978a), who

found that the infection and colonization of mycorrhizal fungi was regulated by the high phosphate concentration within the root system and not by the phosphate concentration of the soil. Hall (1977a) and Jasper et al. (1979) also found that the phosphorus application to soil depressed the mycorrhizal infection by increasing plant P status. Similar view point may be extended to the nitrogen content in the root, as Johnson et al. (1980) have reported that nitrogen fertilization reduced the percentage mycorrhizal infection.

Further it was found that the mycorrhizal development was more in the soils amended with twice the normal doses of phosphorus and nitrogen to the normal NK $[(NK)_1P_2]$ and PK dose $[(PK)_1N_2]$ respectively compared to the ones fertilized with three times the normal doses of each P and N i.e. $(NK)_1P_3$ and $(PK)_1N_3$ (Table 25). This finding leads to the conclusion that with the increase of both phosphorus and nitrogen in the soil the mycorrhizal development decreased. Chambers et al. (1980) also reported reduction in VAM development in Trifolium subterraneum by the addition of combined nitrogen. The reduction in mycorrhizal infection with increase in nitrogen and phosphorus fertilizers, was also reported by Jensen and Jakobsen (1980).

It was observed that the mycorrhizal infection increased with the increase in the phosphate level upto 0.5 g/pot and then decreased abruptly in the higher levels (Table 27). This result is in agreement with Howeler et al. (1982)

who observed heavy mycorrhizal infection at lower phosphate levels which decreased at higher levels. Mosse and Phillips (1971) and Abbott and Robson (1977) also observed an increase in percentage infection with the addition of small amounts of phosphorus to phosphorus-deficient media.

The general growth superiority of the mycorrhizal maize plants over nonmycorrhizal ones at lower soil phosphate levels seemed to be the direct effect of the mycorrhizal induced increased growth of the former. Abbott and Robson (1977) also reported a marked increase in the growth and phosphorus content of mycorrhizal plants at intermediate levels of superphosphate. At the higher phosphate levels however the growth of the mycorrhizal as well as the nonmycorrhizal plants was almost similar. Daft and Nicolson (1966) and Pairman et al. (1980) also reported a reduction in the mycorrhizal induced growth when phosphorus in the soil was no longer a limiting factor. The shoot growth was significantly greater ($P < 0.01$) in the mycorrhizal plants compared to the non-mycorrhizal ones upto the intermediate level (0.5 g/pot) of phosphate, whereas, the root growth was significantly greater only upto 0.1 g/pot phosphate level (Fig. 18A, B). It may be concluded that the stimulatory growth influence of the mycorrhizal infection is less in the case of root than the shoot, since the roots in the non-mycorrhizal plants being in direct contact with the P-source would have responded earlier than the shoot. The lesser root/shoot ratio in mycorrhizal plants compared to the

non-mycorrhizal ones has been observed in the present study (Table 28). The similar results were reported by Hayman and Mosse (1971) and, Becker and Gerdemann (1977). Sanders (1975) suggested that the reduction in root/shoot ratio in mycorrhizal plants may be due to the improved nutrition.

The higher concentrations of nitrogen and phosphorus in the leaf than the stem and the root in both mycorrhizal and non-mycorrhizal plants may be attributed to the preferential demanding sites, explained as the point of greatest meristematic activity or 'Sink-Strength' by Chapin (1980). The higher amounts of phosphate in the leaf, stem and root of the mycorrhizal plants, compared to the non-mycorrhizal ones at lower levels of phosphate was due to the mycorrhizal infection, which declined at the higher phosphate levels probably due to the reduction in the mycorrhizal activity (Fig. 20). In case of the present study the same explanation may hold good in case of higher nitrogen content in the leaf, stem and root of mycorrhizal plants compared to the non-mycorrhizal ones at lower phosphate levels (Fig. 21). Gerdemann (1975) also reported mycorrhizal induced nitrogen uptake in leguminous plants. The exceptionally greater growth performance of the mycorrhizal maize plants compared to the non-mycorrhizal ones even without any addition of phosphate in the soil, confirms it to be a highly mycorrhizal plant.

Vesicular-arbuscular fungi, Glomus fasciculatus stimulated growth in both the crops viz. potato and maize, as evident

from the higher biomass, leaf number, leaf area, shoot and root lengths, in mycorrhizal plants compared to the non-mycorrhizal ones (Table 29, 30, 31, 32). Bagyaraj and Manjunath(1980) also reported increased shoot and root weights in cotton, cowpea and finger millet inoculated with G. fasciculatus in a unsterile field soil deficient in phosphorus. The mycorrhizal potato plants had higher tuber number and tuber weight when compared to the non-mycorrhizal ones (Table 30). Graham et al. (1976) also reported increased growth and tuberization in inoculated potato plants compared to the non-inoculated ones. Swaminathan and Verma (1979) are of the opinion that large amount of dry matter in mycorrhizal potato plants resulted from the improved P uptake. The mycorrhizal maize plants had greater number of grain per ear compared to the non-mycorrhizal ones, but the grain weight did not show any significant difference in both the sets (Table 33). The increased growth and yield in mycorrhizal maize and wheat plants has also been reported by Khan (1972, 1975), and increase in the growth and yield of the mycorrhizal soybean plants has been observed by Carling et al. (1980).

The mycorrhizal maize and potato plants had higher phosphorus content than the non-mycorrhizal plants (Fig. 22, 25), as has also been reported by Ross and Gilliam (1973), Hughes et al. (1979) and Bagyaraj and Manjunath (1980). The increased growth in the mycorrhizal plants might be due to the improved P uptake, as has been noticed by Menge et al. (1978). Besides P, mycorrhizal plants had higher nitrogen content compared to the nonmycorrhizal ones (Fig. 23, 26) as has been observed by

Gerdemann (1975) in leguminous plants. Increased plant P, growth, nodulation and nitrogen fixation resulting from mycorrhizal inoculation has also been reported by Smith and Daft (1978). The possibility of the uptake of other nutrients besides phosphorus by VAM fungi has been indicated by Janos (1975). Though the mycorrhizal potato and maize plants had more potassium content than the nonmycorrhizal plants (Fig. 24, 27), the difference, however, was not significant. This might be due to the increased growth in the mycorrhizal plants. The dilution of the nutrient in the large volume of plant tissue of the mycorrhizal plants has also been discussed by Menge et al. (1978b).

In the survey work, it was found that the mycorrhizal infection in case of all crops viz., potato, maize and paddy, decreased with the increase in the altitude (Fig. 28A and 29A, B). Similar trend was observed in case of Endogone spore population (Fig. 28B, 30 and 31). The temperature might play an important role in the mycorrhizal development. Furlan and Fortin (1973) suggested that with the increase of temperature the mycorrhizal infection and Endogone spore population might increase. This is just a survey work and needs further investigation before any conclusion is drawn.

SUMMARY

The establishment and development of vesicular-arbuscular mycorrhizal (VAM) fungi was studied in the three important crop plants of Meghalaya viz., potato (Solanum tuberosum L.), maize (Zea mays L.) and paddy (Oryza sativa L.). Different cultivars were selected in each crop type to observe the VAM development at varietal level. Among the three different cultivars of potato, the disease-resistant ('Late blight' of potato) cultivars 'SSC 1174' and 'Kufri Jyoti' were highly mycorrhizal, whereas, the development of VAM fungi was feeble in the disease-susceptible cultivar, 'up-to-date'. The first mycorrhizal infection in both SSC 1174 and Kufri Jyoti was observed in 12 days and 8 days old seedlings in the year 1980 and 1981 respectively, whereas, in up-to-date, it was observed in 19 days and 12 days old seedlings in 1980 and 1981 respectively. Similar result was observed in the different cultivars of paddy. The disease-resistant ('Leaf spot' disease of rice) cultivar, 'Khonorullu' showed superiority in mycorrhizal behaviour over the disease-susceptible cultivar, 'Mirikrak'. Not much difference was observed in mycorrhizal activity between local 'village paddy' and Khonorullu (which is slightly improved local paddy). In Khonorullu, the first mycorrhizal infection was observed in 12 days old seedlings in both the years (1980 and 1981), whereas, in Ngoba and village paddy it started in 15 days and 12 days old seedling in 1980 and 1981 respectively. In Mirikrak the first infection was noted in 15 days old seedlings. Though not much difference was observed in mycorrhizal behaviour between the different cultivars of maize (Local Yellow,

Local White and Vijaya), yet 'Local Yellow' showed some supremacy over 'Local White'. The first infection was noted in 12 days old seedlings in all the three cultivars of maize in the year 1980, and at the same time in 'Local White' in the following year. However, in 'Local Yellow' infection could establish in 9 days old seedlings in 1981. The mycorrhizal infection showed an increasing trend with increase in the age of plants. It was found that the establisment and development of VAM fungi was early and rapid in the disease-resistant cultivars of both potato and paddy compared to the disease-susceptible ones.

The spore population decreased at the start of the growing season, but afterwards increased with increase in the age of plants in all the cultivars of the three crop types (potato, maize and paddy). Mainly two spore types could be identified from the soil viz., Glomus spp. and the Gigaspora sp. The observation of the roots revealed that the fine endophytic infection (Glomus tenuis) occurred in the month of March in potato, September-October in maize and October-November in paddy. Whereas, the external vesicles, characteristic of Gigaspora sp. was observed in the month of July in maize. The coarse endophyte, characteristic of one or more strains of Glomus sp. was observed throughout the growing season in all the cultivars of the three crop types.

The effect of soil fertility level on the establishment and development of VAM fungi was studied in maize. The

original fertility of the soil was decreased by adding sand in different proportions and increased by adding different doses of NPK fertilizer. It was observed that the mycorrhizal infection increased with increase in the soil fertility level upto the reccmmended dose of NPK fertilizer and then decreased abruptly in the higher fertility levels. The Endogone spore population also showed the similar pattern. The glucosamine (chitin) content in the root also increased with the increase in the soil fertility upto the recommended dose of NPK level, followed by an abrupt decrease in the higher fertility levels. The glucosamine content of the root showed a positive significant relationship ($r = 0.90$) with the mycorrhizal infection. Whereas, the total nitrogen and phosphorus content of the root was negatively correlated ($r = -0.34$ and -0.29 respectively) with the mycorrhizal infection.

The effect of six different levels of superphosphate, i.e. 0, 0.1, 0.5, 2.0, 5.0 and 10.0 g/pot, on the efficiency of Glomus tenuis in nutrient uptake, was studied in maize. Better plant growth was observed in the mycorrhizal sets at lower to medium doses of phosphate. The shoot biomass and the total biomass produced by the mycorrhizal plants were significantly greater (P 0.01) upto 0.5 g/pot phosphate level. The root biomass of the mycorrhizal plants was, however, greater (significant at 1% level) in the two lower phosphate levels (0 and 0.1 g/pot) only. At the two higher phosphate levels (5.0 and 10.0 g/pot), the non-mycorrhizal plants produced more

root biomass. Increased phosphorus content in the leaves of mycorrhizal plants was observed upto 0.5 g/pot phosphate which declined at the higher phosphate levels. Whereas, in non-mycorrhizal plants the phosphorus content of the leaf increased upto 2.0 g/pot phosphate level and then showed a decreasing trend. The nitrogen content of the leaf, in mycorrhizal plants was found to be maximum at the lowest phosphate level and minimum at the highest phosphate level. Whereas, in non-mycorrhizal plants the nitrogen content of the leaf increased with increase in the phosphate level upto 0.5 g/pot and then decreased abruptly in the subsequent level (2.0 g/pot) followed by an increase in the higher levels. The mycorrhizal infection increased with the increase of phosphate level upto 0.5 g/pot and then decreased abruptly with further increase in the phosphate level.

The effect of VAM fungi Glomus fasciculatus on the growth and productivity of the plants was studied in potato and maize. Better plant growth was observed in the mycorrhizal potato and maize plants compared to the non-mycorrhizal ones. The mycorrhizal potato plants had higher shoot biomass, tuber number and tuber weight than the non-mycorrhizal ones. Similarly, the mycorrhizal maize plants had higher shoot biomass and number of grain per ear than the non-mycorrhizal plants. In both potato and maize, the mycorrhizal plants had higher phosphorus content than the non-mycorrhizal ones, being maximum in the leaf followed by stem and root. The nitrogen

content was also more in the treated plants compared to the untreated ones. Though the potassium content was more in the mycorrhizal plants than the non-mycorrhizal ones, the difference, however, was not significant.

A survey work was conducted to study the VAM fungi of maize, paddy and potato from different agricultural fields of Meghalaya. For this, the root system along with rhizospheric soil of the above mentioned crop plants were collected from various agricultural fields located at different altitudes, viz., Burnihat (100 m), Shillong (1496 m) and Upper Shillong (1890 m). It was observed that the mycorrhizal infection in all crop plants decreased with the increase of altitude. The Endogone spore population also followed the similar pattern. The spores more than 90 u in size constituted the major portion of the spore population in all the crops at each altitude. Besides this, the spores more than 200 /u and 150 /u in size were more abundant at the lower altitude.

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