INFLUENCE OF VAM INOCULATION ON NUTRIENT UPTAKE, GROWTH, YIELD AND BACTERIAL WILT INCIDENCE IN TOMATO
(*Lycopersicon esculentum* Mill.)

By

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THESIS

Submitted in partial fulfilment of the requirement for the degree of

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DEPARTMENT OF PLANT PATHOLOGY
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DECLARATION

I here by declare that this thesis entitled "Influence of VAM inoculation on nutrient uptake, growth, yield and bacterial wilt incidence in tomato (*Lycopersicon esculentum* Mill.) is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **"Influence of VAM inoculation on nutrient uptake, growth, yield and bacterial wilt incidence in tomato (*Lycopersicon esculentum* Mill.)"** is a record of research work done independently by **Smt. P. Raji**, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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CERTIFICATE

We, the undersigned members of the Advisory Committee of **Smt. P.Raji**, a candidate for the degree of Doctor of Philosophy in Agriculture, agree that the thesis entitled **"Influence of VAM inoculation on nutrient uptake, growth, yield and bacterial wilt incidence in tomato (*Lycopersicon esculentum* Mill.)"** may be submitted by Smt. P. Raji in partial fulfilment of the requirement for the degree.

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Introduction

INTRODUCTION

The beneficial effects of Arbuscular Mycorrhizal Fungi (AMF) which are popularly known as Vesicular Arbuscular Mycorrhizal fungi (VAM) in the nutrition and development of host plants are well known. VAM fungi occupy a unique ecological position among the rhizosphere colonizing micro flora as they are partly inside and partly outside the root. During the past two decades, there has been growing appreciation of importance of VAM in improving plant growth through increased uptake of water and nutrients, particularly phosphorus. The nutritionally significant function of VA mycorrhiza depends on soil exploration by hyphae that grows from the root. These hyphae act as extension of absorbing surface of root beyond the zone explored by the root hairs. Hyphae have very large surface volume ratio and therefore provide an extra well distributed absorbing surface to the plant. They are also known to induce biological suppression of soil borne pathogens and help in biological nitrogen fixation, hormone production, and drought resistance.

Integrated Nutrient Management (INM) and Integrated Pest Management (IPM) are the two recent strategies in any crop production system where biofertilizers and biological control agents form an integral part. Here comes the importance of VAM fungi, which can play both the roles of biofertilizer and biocontrol agent. In vegetable production, the use of bio fertilizers and biocontrol agents is gaining importance due to the increasing awareness of deleterious effects of chemical pesticides and fertilizers. The main handicap in exploitation of VAM in crop production is the difficulty in large scale multiplication of the inoculum for field application because of the obligate nature of the fungi. But the potential of using VAM is high in nursery raised crops and in poly bag seedlings where colonization can be brought in the nursery with a limited quantity of inoculum.

Tomato is one of the popular vegetables grown in many parts of Kerala and is a good source of vitamin A and C. Being a transplanted crop, it appears practicable to raise mycorrhizal seedlings before transplanting to the field. Even though some pot culture trials revealed the positive response of tomato to VAM inoculation, no field studies have been conducted to select an efficient VAM for tomato.

Researchers have observed a wide variation among and within different species of VAM fungi, in their ability to promote plant growth (Rao, *et al.*, 1983). Recently scientists noticed host preference for VAM endophytes (Hetrick, 1984; Sreenivasa and Rajashekhara, 1989). These findings suggest that selection of VAM fungus suitable for a particular host-soil-climate combination is advantageous (Powell, 1982). In this background the present investigation of "Influence of VAM inoculation on nutrient uptake, growth, yield and bacterial wilt incidence in tomato" was undertaken with the following objectives.

- Isolation of VAM fungi associated with tomato from different locations of Kerala.
- Screening these isolates for their efficiency in improving nutrient uptake, growth and yield of tomato.
- Evaluation of the selected isolates for their efficiency in economising the added phosphorus fertilizer.
- To study the effect of VAM fungi on the incidence of bacterial wilt of tomato.

Review of literature

2. REVIEW OF LITERATURE

Vesicular arbuscular mycorrhizal associations are ubiquitous and occur through out the plant kingdom (Gerdemann, 1968). The importance of VAM fungi as a tool for improving the growth and productivity in diverse groups of plants was recognized only after the work of Gerdemann (1968), Baylis (1972) and Mosse (1972). However during the last three decades a lot of information on the taxonomy, ecology, physiology and anatomy has been gathered about VAM fungi and also their relationship with the host plants especially with reference to uptake of water, phosphorus and other nutrients, hormone production and root diseases. (Gianinazzi *et al.*,1982; Harley and Smith,1983; Gianinazzi-Pearson and Gianinazzi.,1983 and Graham,1988).

The typical mycorrhizal association was first reported by Treub (1885) in sugarcane. After that, several workers reported the presence of VAM in various crop plants. Gerdemann (1968) reported the presence of VAM association in tomato. The presence of VAM association has been reported in various crop plants in Kerala such as tuber crops (Potty, 1978), rubber (Sivaprasad *et al.*, 1982), cocoa (Sivaprasad, *et al.*, 1984), plantation crops, fodder grasses, vegetables like chilli, brinjal and tomato (Girija and Nair, 1985) and fruit crops (Nair and Girija, 1986). VA mycorrhizae have been observed in 1000 genera of plants representing some 200 families (Bagyaraj, 1991).

2.1 Beneficial effects of VAM

Several field and laboratory experiments have demonstrated that vesicular arbuscular mycorrhizal fungi can greatly improve growth and nutrition of host plants (Mosse, 1973). It is well established that VAM can improve P nutrition of the host particularly in low fertility soils. VAM fungi have been shown to double the efficiency of P fertilizers and help the utilization of traditional sources of P fertilizer like bone meal and rock phosphate more efficiently (Powell and Daniel, 1978).

Increased uptake of phosphorus is not the only effect of VAM fungi on plant growth but they also stimulate plant uptake of zinc, copper, sulphur, potassium and calcium although not as markedly as phosphorus (Cooper and Tinker,1978).

VAM fungi play an important role in the water economy of plants. It help the roots in better absorption of water by exploring water in wider zones of soil and there by imparting drought tolerance (Saffir *et al.*, 1971, Saffir *et al.*, 1972). VAM fungi develop an extensive network of external hyphae which increase the absorbing capacity of the plant roots by exploring a greater volume of soil normally inaccessible to the plants (Hayman, 1982, Gianinazzi-Pearson and Gianinazzi, 1983). Kehri and Chandra (1989 and 1990) suggested that VAM fungi help the plants in better absorption of water by the roots resulting in a better performance.

VAM fungi can induce biological suppression of soil borne pathogens. The role of VAM fungi in the management of soil borne diseases is well established (Schenck and Kellam, 1978; Schenck, 1981; Dehne, 1982; Bagyaraj, 1984 and Smith, 1988).

2.2 Effect of VAM on nutrient uptake, growth and yield of tomato

Increased dry matter production and rhizosphere bacterial population in mycorrhizal tomato plants were reported by Bagyaraj and Menge (1978). The response of tomato to inoculation with VAM fungus, *Glomus fasciculatum* and *Azotoabacter vinelandii* was tested in the field by Mohandas, 1987. VAM inoculation alone could bring about substantial increase in growth, nitrogen content, phosphorus content and yield. Its combination with *A. vinelandii* produced additional effects on leaf area, shoot dry weight, phosphorus content and yield.

Khaliel (1993) inoculated tomato seedlings with three different VAM fungi and evaluated the variations in growth, development and ion uptake. Ion uptake was increased most efficiently in tomato inoculated with *Glomus fasciculatum* and *Glomus deserticola* and these seedlings also gave the best growth response.

2.3 Effect of VAM on nutrient uptake, growth and yield of other crops

The first study on the uptake of phosphorus and other nutrient elements by VAM infected plants was carried out by Mosse in 1957. She reported that mycorrhizal apple absorbed more phosphorus, potassium, iron and calcium than nonmycorrhizal plants. Increased uptake of zinc and iron was reported by La Rue *et al.* (1975) in mycorrhizal peach. Bagyaraj and Manjunath (1980) reported an increased concentration of phosphorus and zinc in VAM inoculated cowpea, cotton and finger millet. Powell (1981) inoculated barley with a mixture of *Glomus mosseae, G. fasciculatum* and *Gigaspora margarita* or with indigenous mycorrhizal fungi. He found out that the introduced fungi stimulated seed yield by 27 per cent.

Inoculation of VAM fungi in seedling tray containing unsterilized potting mixtue was found to give vigorous seedlings of asparagus which performed well when planted out in the field (Powel *et al.*, 1985). Inoculation of nursery with efficient VAM fungi has been successful in the large scale production of white ash seedlings for reforestation in Canada (Furlan *et al.* 1985).

Rajapakse (1987) reported higher shoot dry weight in cowpea inoculated with *Glomus fasciculatum*. Rajapakse and Miller (1987) reported an increase in phosphorus and nitrogen content of the shoot of cowpea due to inoculation with *Glomus mosseae* or *Glomus fasciculatum*. Singh and Tilak (1989) studied the response of *Cicer arietinum* to inoculation with *Glomus versiforme* under field conditions. Inoculation with the mycorrhizal fungus resulted in increased growth, number of nodules per plant and P content of shoot. Role of VAM in growth and mineral nutrition of apple root stock cuttings was studied by Gnekow and Marschner (1989). Uptake of P was significantly enhanced by VAM inoculation.

In a study conducted by Paula *et al.* (1990) to evaluate the efficiency of eight VA mycorrhizal fungi in soybean, *Glomus fasciculatum* inoculation resulted in significantly high phosphorus concentration and dry weight of plants. Grain yield was also significantly higher. Indi *et al.* (1990) tested 11 genotypes of brinjal for their response to VAM inoculation. Inoculation was done in the nursery. Mycorrhizal seedlings were transplanted to main field. Different genotypes varied in their response to VAM inoculation.

Devi and Sitaramaiah (1991) reported the response of black gram to VAM inoculation. Plants grown in the field inoculated with any one of the four species of endomycorrhizal fungi *Glomus- constrictum*, *G. epigaeum* and *Acaulospora morroweae* gave increased mycorrhizal root colonization and had more root volume, fresh and dry shoot and root weights. Among the four mycorrhizal fungi tested, the maximum mycorrhizal root colonization of 84.1 per cent and root volume of 251 per cent were recorded in *Glomus- constrictum* inoculated plants. However, the rhizosphere microbial population was reduced in inoculated plants. A field study was conducted to determine the effect of vesicular arbuscular mycorrhizal fungi on growth and nutrient uptake of the drought hardy legumes, cluster bean (*Cyamopsis tetragonoloba*), mung bean (*Vigna radiata*) and moth bean (*Vigna aconitifolia*). Inoculation with VAM fungi increased significantly the nodulation, nitrogenase activity, percent root infection by VAM fungi and the number of VAM spores in the soil. Phosphatase activity was enhanced significantly due to VAM inoculation. Significant increase in concentrations of N, P, Cu, and Zn in mycorrhizal plants was also obtained. Singh *et al.* (1992) reported that the mycorrhizal inoculation of kinnow rough lemon seedlings significantly increased the root and shoot length and number of leaves per plant.

An *et al.* (1993) reported enhanced growth of apple seedlings accompanied by improved uptake of P, Cu, and Zn due to inoculation of VAM fungi *Glomus epigaeum* and *Glomus macrocarpum.* Elwan (1993) reported an increase in uptake of P, K, Ca, Mn, Fe, Mg, Cu and Zn in maize plants inoculated with VAM along with phosphorus fertilizer. Cheng *et al.*(1993) inoculated muskmelon with VA mycorrhizal fungus, *Glomus clarum.* Mycorrhizal plants grew faster and flowered seven days earlier than non mycorrhizal plants and both quality and quantity of fruits were enhanced.

Incorporation of VAM propagules in the nursery mixture enhanced the rooting and growth of pepper cuttings and biomass production (Anandaraj and Sharma, 1994). Pai *et al.* (1994) investigated the role of VAM in the uptake of calcium by cowpea. They found high ^{45}Ca levels in all parts of cowpea plants inoculated with *Glomus fasciculatum* compared with mycorrhizal plants. Zhao and Li (1994) studied the effect of VAM inoculation on *Capsicum annuum.* Seeds were sown in sterilized soil inoculated with *Glomus epigaeum* and *G. mosseae.* Mycorrhizal seedlings were transplanted. Plant height, number of leaves per plant, stem diameter and plant dry weight increased due to VAM inoculation and flowering occurred earlier. VAM inoculated plants recorded higher P and N content.

Dual inoculation of VAM (*Glomus fasciculatum*) and *Azospirillum* significantly augmented the root biomass, plant growth and increased the germination percentage and early vigour of cashew seedlings as compared to individual inoculation and untreated controls (Prabhakaran and Selvaraj, 1996). Singh and Kapoor (1996) studied the effect of phosphate solubilising microorganisms and VAM in wheat. The phosphate solubilizers, *Cladosporium* sp. and *Bacillus* sp. and VAM fungi *Glomus* sp. were used for inoculation. Root colonization was more when phosphate solubilising microorganisms, *Glomus* sp. and mussorie rock phosphate were used together as compared to the treatment which received only *Glomus sp*. The same treatment recorded more grain and straw yield compared to the treatments which received *Glomus sp* or phosphate solubilizers alone.

A field study was conducted by Tarafdar and Rao (1997) to determine the effect of *Glomus mosseae* and *Glomus fasciculatum* on cluster bean, mung bean and moth bean. They reported that all the legumes showed similar effects upon inoculation with VAM fungi and inoculation resulted in increased dry matter production and grain yield. Also the inoculated plants recorded significantly higher concentration of nitrogen, phosphorus, copper and zinc. Sitaramaiah *et al.* (1998) investigated the effect of *Glomus fasciculatum* on growth and chemical composition of maize. VAM fungal inoculation resulted in an increased vegetative growth, total chlorophyll content and uptake of nutrients *viz.*, nitrogen, potassium, calcium and magnesium compared to nonmycorrhizal plants. Mycorrhizal plants recorded increased fresh weights of root and shoot and dry weight of shoot over nonmycorrhizal plants. Beena (1999) studied the interaction between VAM and *Bradyrhizobium* in cowpea and reported that inoculation of VAM along with *Bradyrhizobium* could substitute the N and P fertilizers to the extent of half the recommendation

Nirmala *et al.* (1999) studied the effect of organic manures (FYM, neem cake and groundnut oil meal) and bioagents (*Azospirillum*, phosphobacteria and vesicular arbuscular mycorrhiza) on fruit characters and yield of cucumber. The first female flower in earlier node, closest sex ratio, largest fruit size and highest number of tender fruits were recorded from FYM + *Azospirillum* + phosphobacteria + VAM. This treatment resulted in a fruit yield of 2053 g vine $^{-1}$, while the controls had the lowest fruit yield, 810 g vine $^{-1}$.

Improved growth and productivity of *Sesbania grandiflora* under salinity stress through mycorrhizal inoculation was reported by Giri and Mukerji (1999). Inoculation of *Sesbania* with *Glomus macrocarpum* in saline soils resulted in increased growth and biomass of the plants. The percentage VAM colonization of roots, production of VAM fungal spores in the rhizosphere soil and number of root nodules were significantly higher. *Sesbania grandiflora* was highly dependent on vesicular arbuscular mycorrhiza, with maximum dependency at early stages of plant growth. *Glomus macrocarpum* protected *Sesbania grandiflora* against salinity stress by increasing its establishment and survival.

The effect of VAM fungi and *Rhizobium* on growth and yield of green gram was studied by Hazarika *et al.* (2000) in a field experiment. VAM fungus, *Glomus fasciculatum* and *Glomus mosseae* were inoculated individually and also in combination with *Rhizobium*. The inoculation of individual VAM fungi with *Rhizobium* significantly increased growth, dry matter and nodulation compared to uninoculated control or plants inoculated only with VAM fungi or *Rhizobium*. Results also revealed that the content of N, P, K and their uptake in plants inoculated with VAM fungi + *Rhizobium* were significantly greater compared to uninoculated control or plants that received only mycorrhiza or *Rhizobium.*

Khaliq and Sanders (2000) conducted an experiment to study the effect of inoculation of *Glomus mosseae* and application of P fertilizer in field grown barely. The mycorrhizal root colonization, crop yield and P uptake were calculated in natural or methyl bromide fumigated soil. Only a small increase of three per cent in total P uptake was recorded due to inoculation.

In a green house pot experiment, Ozcan and Taban (2000) studied the effect of VAM on growth and nutrient content of maize in acid and alkaline soils. Maize plants were grown in sterilized acid or alkaline soils inoculated with a mixture of *Glomus etunicatum* and *Glomus intraradices* and given 100 ug N g^{-1} as urea and 40 mg kg^{-1} as K_2SO_4 and 40 mg Pg^{-1} (as triple super phosphate). Inoculation and P application increased the dry weight of maize in both soils compared to the untreated control. The mycorrhizal infection of root was 48.3 per cent and 68.3 per cent in alkaline and acid soils respectively. Inoculation did not affect the P concentration of maize in alkaline soil. It increased the P content of the plant in acid soil. The inoculation increased Cu and Mn concentration of maize plants in both the soils.

Potato plants were inoculated with three commercial arbuscular mycorrhizal inoculants *viz.*, Vamico, Endorize IV and *Glomus intraradices*. Vamico and Endorize IV promoted growth and promoted flowering relative to the control whereas *Glomus intraradices* reduced growth and delayed and reduced flowering (Duffy and Cassells, 2000). Grotkass *et al.*(2000) reported that inoculation of *Baptisia tinctoria* micro propagated plantlets with *Glomus etunicatum* increased the survival rate. The growth of micro propagated garlic mother plants was enhanced due to inoculation with *Glomus mosseae* (Lubraco *et al.* 2000).

The occurrence and performance of VAM fungi on the growth of rice plant under rainfed lowland condition of Asssam was reported by Singha *et al.* (2000). Out of the 15 tested transplanted rice cultivars, only seven were found to be colonized by VAM fungi. Studies with inoculation of rice cv. Ranjit with 20 – 200g pot^{-1} of *Acaulospora sp.* showed that a level of 100g pot^{-1} was best for plant growth and root colonization. Dry weight of plants and root colonization were significantly higher in mycorrhizal plants than nonmycorrhizal plants, but root proliferation was lower. Uptake of P was significantly higher in mycorrhizal plants than nonmycorrhizal plants. Rupnawar and Navale (2000 a) conducted a pot culture experiment in a deficient soil to study the effect of VAM inoculation to pomegranate layers with respect to N and P uptake. The layers inoculated with VAM fungi were superior to non mycorrhizal layers for root colonization and N and P uptake.

A pot culture experiment conducted by Rupnawar and Navale (2000 b) to study the symbiotic relationship of pomegranate layers with VAM fungi, *Glomus mosseae* and *Gigaspora calospora*. The results revealed that mycorrhizal treatments were superior to non mycorrhizal treatments in improving the growth. *G. mosseae* alone or the mixture of the VAM fungi recorded the maximum height, root length, number of leaves, dry weight of shoot and root and mycorrhizal dependency percentage. Matsubara *et al.* (2000) reported the better survival rate and growth of VAM inoculated tissue culture plantlets of asparagus. Tissue culture plantlets of asparagus were inoculated with VAM fungi *Glomus etunicatum,* @ 1000 spore g^{-1}. The survival rates of plantlets and the growth increments in both shoots and storage roots during the acclimatization period were higher in a VAM inoculated plants than in uninoculated ones.

Schubert and Lubraco (2000) reported the enhanced nutrient uptake and growth of micro propagated apple rootstock due to the inoculation with VAM fungi, *Glomus mosseae.* A similar positive response of micropropagated potatoes to inoculation with VAM fungi and soil bacteria was reported by Vosatka and Gryndler (2000).

Cigsar *et al.* (2000) reported the positive response of cucumber to VAM inoculation. The seeds were grown in sterile and nonsterile growing medium (1:1:1 mixture of organic manure : soil : sand). The mixed inoculum containing *G. mosseae* and *G. fasciculatum* spores @ 10 g $plant^{-1}$ was placed 5cm below the cucumber seed before sowing. The results revealed that the VAM inoculation had positive effect on plant growth. Mycorrhizal plants recorded higher uptake of P, Zn and Mn. Five levels of organic manures with or without inoculation of VAM fungus, *Glomus etunicatum* were tested for the growth and establishment of papaya seedlings. Inoculation of *G. etunicatum* was efficient for development of plants in soil with upto 10 per cent of manure (Trindade *et al.*, 2000).

Kumar *et al.*(2001) studied the impact of VAM, *Azotobacter* and *Rhizobium* on growth and nutrition of cowpea in a pot culture using sterilized soil. Plants inoculated with mycorrhiza in combination with *Rhizobium* and *Azotobacter* had highest germination, number of nodules, nodule dry weight, plant height, mycorrhizal colonization and nutrient content as compared to inoculation with either one organism or two organisms. Mycorrhiza alone increased the seed germination, plant height and dry weight, N P K content of roots and shoots of cowpea plants compared to control.

The improvement in nodulation and nitrogen fixation was also resulted due to the combined inoculation or individual inoculation of VAM or, *Azotobacter* or *Rhizobium.*

2.4 Screening the efficiency of VAM in tomato

Fairweather and Parbery (1982) conducted an experiment to select an efficient VAM fungus for tomato. Seedlings were inoculated with four different VAM fungi in sterile sand in pots. All tomato seedlings grew very slowly for the first four weeks, after which the leaves of some plants showed symptoms of phosphorus deficiency and some toxicosis. The plants inoculated with *Gigaspora margarita* grew well and developed no symptoms of toxicosis or phosphorus deficiency. Each of the fungi stimulated root growth, but only *Gigaspora margarita* induced a significant increase in shoot growth. The root dry weight of tomato plants infected with *Gigaspora margarita* was 13 times more than that of control plants. A twelve fold increase in total plant dry weight and a ten fold increase in the dry weight of shoots were gained in plants infected with *G. margarita*. The percentage root length infected with mycorrhiza was also much greater for plants infected with *Gigaspora margarita* than for others. From the study, it was evident that different mycorrhizal fungi differ in their capacity to overcome the constraint imposed on growth of the control plants in sterile soil.

An investigation was carried out by Mallesha *et al.* (1994) to screen and select efficient vesicular arbuscular mycorrhizal fungi for tomato. The seedlings were inoculated with nine different VAM fungi *viz., Acaulospora laevis, Gigaspora margarita, Glomus caledonicum, Glomus fasciculatum, Glomus intraradices, Glomus leptoticum, Glomus monosporum, Glomus mosseae and Scutellispora calospora.* Inoculated plants had higher plant biomass, plant P content, root volume and number of fruits. Inoculated plants had more per cent mycorrhizal colonization of the root system. Tomato seedlings responded best to inoculation with *Glomus leptoticum* followed by *Glomus intraradices*.

Edathil *et al.*(1996) inoculated tomato seedlings with four species of VAM fungi, *Glomus aggregatum, G. fasciculatum, G. geosporium and G. sinuosum* in 15 possible combinations . Mycorrhizal plants exhibited a significantly higher shoot length and biomass than non mycorrhizal plants. VAM also increased host tissue Zn and P content. In the case of mixed inocula containing four endophytes, spore yields were lower. But the shoot length and biomass were higher for plants inoculated with this mixed inocula. Shrestha *et al.* (1996) studied the effect of vesicular arbuscular mycorrhizal fungi on Satsuma mandarin rootstock at low P application rates. The VAM fungi used were *Glomus ambisporum, G.fasciculatum, G.mosseae* and *Gigaspora margarita*. The trees that were inoculated with VAM fungi grew larger and had better fruit quality than uninoculated control trees.

Iqbal and Mahmood (1998) studied the effect of single and multiple VAM inoculants on the growth parameters of tomato. Three species of VAM fungi (*Glomus constrictum, Glomus mosseae,* and *Glomus fasciculatum*) were tested singly and in various combinations. Maximum growth in plants and spore count were observed by the inoculation of *Glomus mosseae* followed by *G. constrictum* and *G.fasciculatum* respectively. All the treatments showed improvement in mycorrhizal colonization, number of spores, plant biomass and P content of the shoot and root. In combination the maximum increase was observed in plants which received *Glomus mosseae* and *Glomus constrictum.*

2.5 Screening the efficiency of VAM in other crops

In a pot culture experiment using sterilized soil, inoculation of soybean plants with *Glomus fasciculatum, G. mosseae, G. etunicatum or Acaulospora scrobiculatus* increased plant dry weight and seed yield . Inoculation with a mixture of *G. fasciculatum* , *G. mosseae* and *G. etunicatum* or *G. fasciculatum* alone increased seed yields and other agronomic traits of soybean plants grown in a no tillage rice stubbled field (Kuo and Huang, 1982). In a study conducted by Krishna and Dart (1984), VAM fungi showed variation in their ability to stimulate the growth and phosphorus uptake of pearl millet. Six mycorrhizal fungi, *viz*., *Gigaspora calospora* , *Glomus fasciculatum*, *Gigaspora margarita*, *Glomus mosseae and Acaulospora laevis* were tested as inoculants for pearl millet grown in pots in a green house. Inoculation with *Gigaspora margarita* , *Gigaspora calospora* and *Glomus fasciculatum* increased shoot dry matter 1.3 fold over uninoculated control. In another pot trial *Gigaspora calospora* and *Glomus fasciculatum* resulted in dry matter and phosphorus uptake equivalent to that produced by adding phosphorus at 8 kg ha^{-1}.

Sreeramalu and Bagyaraj (1986) inoculated chilli nursery beds with four different VAM fungi, *Glomus fasciculatum Glomus albidum*, *Glomus macrocarpum* and isolate I_4 . Mycorrhizal seedlings were transplanted to the field. Of the VAM fungi studied, inocution of *Glomus fasciculatum* resulted in maximum increase in plant height, number of flowers, shoot dry weight and yield.

Costa and Paulino (1990) studied the effect of four VAM fungi in leucaena. They recorded increased dry matter, yield and also phosphorus and nitrogen content and their uptake. The response of chilli (*Capsicum annuum* L.) to inoculation with selected vesicular arbuscular mycorrhizal fungi was studied by Sreenivasa (1992) in a pot culture experiment. The local isolate *Glomus macrocarpum* was compared with the standard genera of VAM fungi *viz*., *Glomus fasciculatum*, *Gigaspora margarita* , *Acaulospora laevis* and *Sclerocystis dussii*. The local isolate *Glomus macrocarpum* was found to be the best for improving growth and P, Zn, Cu, Mn and Fe nutrition among all VAM fungi inoculated in non sterilized soil. Sivaprasad *et al.* (1992) studied the growth and P uptake of cashew as influenced by VAM. Cashew seed nuts were sown in pots filled with unstertilized soil : sand : FYM mixture (1:1:2). On germination, seedlings were transplanted to pots containing P fixing oxisol soil.

Glomus fasciculatum, G. constrictum G. mosseae, G. etunicatum and *Acaulospora morroweae* were used for inoculation. After eight months plants uprooted and mycorrhizal infection was assessed. Among the five fungi tested, *G. fasciculatum* was more effective in stimulating growth and P uptake.

Ho (1993) tested six different VAM fungi viz., *Glomus fasciculatum, Scutellispora gilmorei, Glomus mosseae, Glomus monosporum, Acaulospora laevis* and *Scutellispora calospora* in *Zea mays*. The inoculated plants were compared with uninoculated control plants for the content of nitrogen, phosphorus, potassium , and micronutrients *viz*, zinc, copper, iron, magnesium and manganese. Maize plants inoculated with VAM fungi generally contained significantly greater concentrations of all nutrients except potassium in both roots and leaves, phosphorus in leaves, and zinc in roots. There were apparently significant differences among the six mycorrhizal fungi. *Scutellispora calospora* seemed consistently more efficient in nutrient uptake with the *Zea mays.*

Pattanaik *et al.* (1995) studied the effect of two VAM fungi *G. fasciculatum* and *Glomus mosseae* along with uninoculated control. They found that *Glomus fasciculatum* was more effective than *G. mosseae* in increasing the plant growth and nodulation. The effect of vesicular arbuscular mycorrhizal fungi *Glomus fasciculatum* and *Glomus mosseae* with or without rock phosphate on initial establishment and mineral nutrition of teak stumps in polybags was studied by Durga and Gupta (1995). The plants inoculated with *G. mosseae* + *G. fasciculatum* treated plants registered greater growth and also showed an increase in concentration of phosphate, K and Mn. The plants treated with *G. fasciculatum* + rock phosphate gave the next best growth, followed by those treated with *Glomus fasciculatum* alone.

Ortas (1996) inoculated sorghum and leak plants with four mycorrhizal fungi and recorded maximum spore population with *Glomus mosseae* in sorghum and with *Glomus etunicatum* in leak plants. A survey was carried out by Indian Institute of Spices Research in Kerala and Karnataka to isolate and identify VAM fungi associated with Black pepper. The different VAM fungi obtained were *Glomus fasciculatum, G. monocarpum and Gigaspora gigantia* . Based on their ability to enhance rooting and colonization on black pepper roots, seven isolates were identified as efficient strains for black pepper. The establishment of VAM treated rooted cuttings of black pepper in the field was as high as 98 per cent. Besides, tolerance to moisture stress was also noticed as there was stability of enzymes namely acid phosphatase, peroxidase and nitrate reductase in VAM treated cuttings (Sharma *et al.* , 1996).

Reddy *et al.* (1996) screened thirteen mycorrhizal fungi for their symbiotic response with acid lime. *G. macrocarpum, G. mosseae, Acaulospora leavis, G. caledonicum and Gigapora margarita* were found to improve growth and nutrition resulting in greater plant biomass, plant height, plant girth, leaf number, P and Zn content of acid lime.

In a pot culture experiment Gnanadevi and Haripriya (1999) studied the response of three chrysanthemum cultivars to three VAM fungi (*Glomus mosseae, G. fasciculatum* and *Acaulospora laevis*). All VAM fungi increased growth and yield of chrysanthemum cultivars compared to control. *Glomus fasciculatum* inoculated plants had the greatest average plant height, flower yield and early flowering. Nagaraju *et al.* (1999) screened VAM fungi for selecting an efficient one for aggregatum onion (*Allium cepa* var. *aggregatum*). They inoculated onion with *Glomus mosseae, G. fasciculatum and Acaulospora laevis. Glomus mosseae* was found to be the best root colonizer with a percentage increase of 13.86 and 22.14 over *G. fasciculatum* and *A. leaves*, respectively. *G. mosseae* treated plants had the highest number of bulbs, bulb weight and plant height. Similarly percentage increase for leaf number in *G. mosseae* was 59.42 followed by *G. fasciculatum* (34.04) and *A. laevis* (21.8). The percentage increase for the number of tillers was also highest in *G. mosseae*, followed by *G. fasciculatum* and *A. laevis.*

Paroha *et al.* (1999) studied the growth performance of *Bambusa arundinacea* in relation to VA mycorrhizal inoculation. One month old seedlings were transplanted to poly bags filled with mixture of soil : sand (1:1) inoculated with mixed VAM fungi (*Acaulospora, Glomus mosseae* and *Glomus intraradices*). All the inoculated seedlings grew better than uninoculated controls. After nine months, the growth was increased by 59.4 per cent in the spore treatment and 71.6 per cent in the spore + infected roots treatment compared to control.

The influence of different VAM fungi on growth of onion was studied by Ramananda and Sreenivasa (2000). In a pot culture experiment. *Glomus macrocarpum, Glomus fasciculatum, Gigaspora margarita, Acaulospora laevis* and *Sclerocystis dussii* were used for inoculation. Onion cultivar Bellari red inoculated with *A. laevis* and cultivar N 53 inoculated with *Gigaspora margarita* gave the highest values for root colonization and spore count, shoot P content, dehydrogenase and alkaline phosphatases activities and bulb yield.

2.6 Economising phosphorus fertilizer using VAM fungi

Ross (1971) studied the effect of phosphate fertilization on yield of mycorrhizal and nonmycorrhizal soybeans. Inoculation of soybean plants with endogone mycorrhizal fungi resulted in increase in yield by 122, 67 and 12 per cent respectively at low, medium and high phosphate levels. Mycorrhizal plants contained greater concentrations of N, P, Ca, and Cu in foliage than non mycorrhizal plants at the various phosphate levels. The concentration of phosphorus in foliage of mycorrhizal plants at the lowest phosphate level was greater than that in non mycorrhizal plants at the highest phosphate level. Clarke and Mosse (1980) conducted a field experiment in which barley was inoculated with three VAM fungi. Half the plots were given phosphate before sowing . Growth and infection were recorded twice during the experiment and at harvest. In the plots without added phosphate, the fresh weight of ear heads was doubled by inoculation irrespective of the endophytes. Added phosphate increased this more than the inoculation and weight of ears increased further.

The improvement of growth and yield of chilli by pre inoculation with VA mycorrhiza was reported by Bagyaraj and Sreeramulu (1982). Nursery beds were inoculated with four different mycorrhizal fungi, *Glomus fasciculatum* and three local isolates I_4, I_6 and I_{14}. Seedlings were transplanted to field plots with two levels of phosphatic fertilizers (0 P and half P). The isolate I_4 significantly increased the growth, P and Zn nutrition, flowering, yield of chilli plants and ascorbic acid content of green chillies. Yield of plants inoculated with I_4 isolate given half the recommended level of P fertilizer was slightly more than the uninoculated plants given the full level of phosphartic fertilizer. Effect of mycorrhiza and soluble phosphorus on *Abelmoschus esculentus* was studied by Krishna and Bagyaraj (1982). The mycorrhizal infection and spore production were reduced by an increase of added soluble phosphorus. Root, shoot and total plant dry weight were significantly greater in mycorrhizal plants than in non mycorrhizal controls, at all levels of added soluble P. With increase in added soluble P, mycorrhizal dependency was found to decrease. Depression of growth was noticed when 200 per cent of recommended P was added when compared to 100 per cent recommended P.

Krishna and Dart (1984) studied the influence of inoculating *Gigaspora calospora* on pearl millet at different levels of phosphorus fertilizer (0-60 kg P ha^{-1}) as triple super phosphate in sterile and unsterile alfisol soil. Mycorrhizal inoculation increased dry matter and phosphorus uptake at levels less than 20 kg ha^{-1}. The mycorrhizal effect was decreased at higher P levels. The results of this study performed in sterile soil suggest that inoculation of pearl millet with efficient VAM fungi could be extremely useful in P deficient soils.

Sreeramulu and Bagyaraj (1986) studied the field response of chilli to VAM inoculation at two levels of phosphorus fertilizer. Four different VAM isolates were tried, of which *Glomus fasciculatum* resulted in maximum increase in growth parameters like plant height, number of flowers per plant, shoot dry weight and the P and Zn content of the shoot. Fruit yield of the plants inoculated with *Glomus fasciculatum* at half the dose of P was more than that of plants which received full dose of P. Babu *et al.* (1988) inoculated Chilli cultivar Pusa Jwala, with *Gigaspora calospora, G. margarita* and *Glomus fasciculatum* in the nursery and transplanted to plots supplied with 0, 25 and 50 per cent of recommended P. It was found that, VAM inoculation with 25 and 50 percent of P were better than control and equal to uninoculated plants at 100 per cent of P.

Champawat (1990) tested different mycorrhizal fungi *Glomus fasciculatum, G. constrictum* and *Gigaspora calospora* at four levels of P (0,25,50 and 75 kg ha^{-1}) on growth of pigeon pea. They found that, the crop responded to all VAM fungi and the response was prominent at low levels of P. Among the three VAM fungi, *G. constrictum* was found best in enhancing plant dry weight at all P levels. Significant increase in shoot and root P and N uptake was observed by inoculation with all VAM fungi. Maximum growth improvement was observed at 50 kg P ha^{-1} .

A pot culture experiment was conducted by Sreenivasa *et al* (1993) to study the response of chilli (*Capsicum annuum* L.) to VAM inoculation in unsterile soil. Two vesicular arbuscular mycorrhizal fungi, *Glomus macrocarpum* and *Glomus fasciculatum* were tried to find out their efficiency in improving the growth of chilli, at different levels of phosphorus fertilization (0, 25, 50 and 100 per cent of the recommended dose). Of the two VAM fungi, *Glomus macrocarpum* caused increase in growth, yield and nutrient status of chilli, especially phosphorus, zinc, copper, manganese and iron at 50 per cent of the recommended dose added as super phosphate.

The influence of VA mycorrhizal inoculation and phosphorus amendments on growth and nutrient uptake by rough lemon seedlings was studied by Singh *et al.* (1993). The inoculation of *Glomus fasciculatum* was done at three levels of P (0, 40 and 80 mg kg^{-1} soil) and compared with uninoculated control. Inoculation of *Glomus fasciculatum* significantly increased mycorrhizal colonization, spore population in soil, dry weight of seedlings as well as N, P and K content in rough lemon seedlings.

Wang *et al.* (1993) studied the effect of VAM inoculation on micro propagated plantlets of gerbera, nephrolepis and syngonium. Mortality of gerbera plants was reduced and flowering was earlier. Inoculation of *G. fasciculatum* and *G. etunicatum* in the planting medium resulted in 80-100 per cent survival of tissue cultured jack plantlets (Ramesh *et al.*, 1993). Increased survival of tissue cultured plant lets of anthurium and rose was reported (KAU, 1994).

Araujo *et al.* (1994) studied the effect of VAM fungi in tomato at different phosphorus levels. *Glomus clarum, Glomus etunicatum* and *Gigaspora margarita* were tested for their capacity to improve shoot P content . They studied the effect of VAM inoculation at four levels of added P (30, 60, 120 and 240 mg P kg^{-1} soil). Shoot and root dry matter increased with added soil P upto 120 mg kg^{-1} soil. Photosynthetic efficiency was highest at 60 mg kg^{-1} soil. At this P level, mycorrhizal plants had higher shoot dry matter and a higher P utilisation index than non mycorrhizal plants. Sreenivasa (1994) studied the response of chilli to inoculation of VAM fungi at different phosphorus levels in the field. Root colonization and sporulation by both VAM fungi tested viz., *Glomus macrocarpum* and *Glomus fasciculatum* increased with the addition of P upto 56.2 kg ha^{-1}, but decreased with further increase in P. At 56.2 kg ha^{-1} phosphorus dose, *G. macrocarpum* recorded higher root colonization and sporulation. They suggested that the application of phosphorus fertilizer could be reduced through efficient use of suitable mycorrhizal fungi.

De Prager (1995) studied the effect of VAM fungi in tomato. Tomato plants were inoculated with one of the VAM from CIAT germplasm collection or with a native VAM at different levels of P. Mycorrhizal inoculation increased plant height and dry matter content with increase in P application rate.

The influence of VAM fungi on growth, P nutrition and yield of wheat at different P levels, 0, 50, 75 and 100 per cent of recommended dose (75 kg ha^{-1}) was studied by Majjigudda and Sreenivasa (1996). The highest root colonization, rhizosphere spore count and population of free living nitrogen fixers and P solubilizers were recorded in the rhizosphere soil of plants inoculated with *G. fasciculatum*. In general per cent root colonization and spore count were increased with increase in P level upto 75 per cent of the recommended dose, while the population of free living nitrogen fixers and P solubilizers increased with increase in P level. Plant dry weight, shoot P content, seed protein content and seed yield which increased with increase in P level were maximum at 100 per cent of the recommended P dose. However, they did not differ significantly from 75 per cent of the recommended P with inoculation of efficient VA mycorrhizal fungus, *G. fasciculatum*.

A pot culture experiment was conducted by Kashappanavar and Sreenivasa (2000) to study the effect of VAM inoculation at different P levels in onion cv N-53. Plants were inoculated with *Gigaspora margarita* or *Acaulospora laevis* along with 0, 50, 75 and 100 per cent of the recommended dose of P. The per cent root colonization and spore count were highest in *Gigaspora margarita* inoculated plants at 75 per cent P level. The shoot P concentration, alkaline phosphatase activity, plant dry biomass and fresh bulb weight were also highest in *Gigaspora margarita* inoculated plants. However the difference between 75 and 100 per cent P level was non significant.

Eucalyptus tererticorins was grown in green house in a low phosphorus soil inoculated with mixed indigenous arbuscular mycorrhizal fungi. Soil was amended to achieve P levels of 10, 20, 25, 30 and 40 ppm to evaluate the growth response and dependence of *E. tereticornis* to inoculation with AM fungi (Sharma and Adholeya, 2000). A positive response to mycorrhizal inoculation was evident at lower levels of P only. Dry matter yield of inoculated plants beyond 20 ppm soil was similar or even less compared to their uninoculated counterparts. Inoculated plants produced maximum dry matter at 10 ppm soil P, whereas uninoculated plants did not produce until the level reached 20 ppm. The percentage of root length colonized by AM fungi decreased from 31 percent to three per cent as the concentration of P increased beyond 10 ppm soil P. However at the first two lower levels of soil P, inoculated plants showed significantly higher shoot P and N contents over their respective uninoculated counterparts. The increasing shoot P accumulation beyond 10 ppm did not enhance dry matter yield.

The interactions between phosphorus supply and total nutrient availability on mycorrhizal colonization, growth and photosynthesis of cucumber was studied by Valentine *et al.* (2001) in sand culture using nutrient solutions. VAM infection was found to depend on both P supply and the availability of other nutrients. Plants grown at low P with high concentrations of other nutrients had the highest VAM infection and a higher biomass due to an enhanced maximum net photosynthetic rate. Roy and Kumari (2001) studied the phosphate mobilization in relation to the growth performance of ragi. Two levels of phosphorus P_0 (no phosphorus) and P_{20} (20 kg ha^{-1}) was applied along with VAM inoculation. VAM inoculation resulted in 40 and 50 per cent increase in P content over control at P_0 and P_{20} levels respectively. Plant growth performance in terms of shoot and root length, root volume, fresh weight and dry weights of plants was also found to increase significantly at both the levels of phosphate treatments.

2.7 Crop response to different sources of P along with VAM inoculation

Mycorrhizal fungi have been shown to tap organic and inorganic phosphorus sources in soils which are normally unavailable to nonmycorrhizal plants (Powell,1979). Jalali and Thareja (1985) studied the utilisation of rock phosphate by chickpea plants grown in soils of contrasting fertility status in response to inoculation with vesicular arbuscular mycorrhizal fungus (*Glomus* sp.). In nutrient deficient , especially phosphate deficient soils, plants responded significantly to rock phosphate + VA mycorrhizal treatments in terms of total dry matter production and phosphate uptake. The root and shoot dry weights remained unaffected with rock phosphate treatment alone in nutrient rich soils, but when such plants were inoculated with mycorrhizal fungus, significant increase in these growth parameters was recorded. In phosphate rich soils , mycorrhizal density was poor, while root samples from soils of low phosphate status had extensive mycorrhizal colonization.

Manjunath and Bagyaraj (1986) studied the response of black gram, chickpea and mung bean to inoculation with the mycorrhizal fungus, *Glomus fasciculatum* with and with out added phosphorus in a P deficient unsterile soil. VA mycorrhizal fungi increased the dry weight and P content of the shoot and root significantly when compared to control. Application of phosphorus as super phosphate did not reduce the percentage root colonization by VAM fungi but increased the extramatrical chlamydospores in the soil. Phosphorus application also increased the dry weight and P content of the inoculated plants.

Meenakumari and Nair (1992) studied the effect of application of phosphatic fertilizer on vesicular arbuscular mycorrhizal infection in cowpea. The extent of mycorrhizal infection was significantly increased in different treatments involving mycorrhizal inoculation and phosphate application , either in the form of rock phosphate or super phosphate. Sreenivasa *et al.* (1993) studied the response of chilli to VAM inoculationat different levels of P. Two sources of phosphorus, soluble super phosphate and insoluble rock phosphate were used.The response of chilli to inoculation of either VAM fungi in the presence of rock phosphate was not encouraging when compared with the super phosphate. It was concluded that phosphorus fertilizers in their soluble form could be used more efficiently in the presence of an efficient VAM fungus and there by the application of phosphate fertilizers could be reduced.

A pot culture trial was conducted by Geethakumari *et al.* (1994) to study the effect of mycorrhizal inoculation on growth and yield of grain type of cowpea and also to compare the efficiency of mussorie rock phosphate and single super phosphate when applied along with mycorrhiza. The results of this trial revealed the beneficial effect of mycorrhiza on growth and yield of cowpea. Mycorrhizal inoculation increased the number of leaves plant^{-1}, pods plant^{-1}, pod yield and seed yield when compared to control. The results showed that mussorie rock phosphate in combination with mycorrhiza could be very well used as a source of phosphorus for cowpea grown in pots and also revealed the possibility of saving phosphorus at 7.5 kg P_2O_5 ha^{-1} by inoculating mycorrhiza with mussorie rock phosphate.

The response of black gram to inoculation with the endomycorrhizal fungi, *Glomus fasciculatum* and *Glomus constrictum* with and without added phosphorus (super phosphate and rock phosphate) was studied in field soil at two levels (full and half dose). Vegetative growth was more in plants supplied with super phosphate compared to rock phosphate treatments in the presence of the two species of *Glomus*. This increase was attributed to the increased root colonization by endomycorrhizal fungi in super phosphate treatment. However phosphorus content of black gram plants was more in rock phosphate treatment in the presence of both the fungi. There were significant differences among the vegetative growth parameters at different levels of both sources of phosphorus (Devi and Sitaramaiah, 1998).

A field experiment was conducted by Salas and Blanco (1999) to study the effect of inoculation of *Glomus manihotis* along with two phosphorus fertilizers, rock phosphate and super phosphate on yield and nodulation of common bean (*Phaseolus vulgaris*). Fertilizer was applied at 45 kg P_2O_5 ha^{-1} as rock phosphate or triple super phosphate with or without mycorrhizal inoculation in seed hole. Mycorrhizal colonization and yield were not affected by inoculation. It was proposed that the lack of response to inoculation with *Glomus manihotis* was due to the high effectiveness of the native VAM fungi population.

Fathima *et al.* (2000) studied the effect of different levels and sources of phosphorus on VAM mycorrhizal root colonization and spore load in mulberry CV. Kanva –2 saplings. Saplings inoculated with or *G.fasciculatum* were treated with P (30 or 60 kg ha^{-1} year^{-1}) in the form of single super phosphate (SSP), diammonium phosphate (DAP) or mussorie rock phosphate (MRP) in a two year field trial. Controls were either inoculated with VAM fungi without P application, given P at 120 kg ha^{-1} $year^{-1}$ as SSP without VAM inoculation, or given neither. In saplings inoculated with *G. fasciculatum* root colonization was highest with P at 30 kg ha^{-1} $year^{-1}$ in the form of DAP. In the case of *G. mosseae* inoculated saplings, root colonization was highest with a application of 30 kg ha^{-1} $year^{-1}$ in the form of MRP. Spore load in the mulberry rhizosphere was significantly higher with P applied at 30 kg ha^{-1} $year^{-1}$ as MRP than with at the recommended rate of 120 kg ha^{-1} $year^{-1}$ as SSP.

A glasshouse experiment was conducted by Alloush *et al.*(2000) to study the effect of phosphorus source, organic matter and arbuscular mycorrhiza effect on growth and mineral acquisition of chickpea grown in acidic soil. Soil treatments of P (0 P, 50 mg soluble P kg^{-1} as KH_2PO_4 and 200 mg P kg^{-1} as rock phosphate), organic matter at 12.5 g kg^{-1}, VAM (*Glomus clarum*) and various combinations of these were added to steam treated acidic soil of pH 5.8. The various treatment applications increased shoot dry matter compared to control. The percentage of root colonization increased two fold or more when mycorrhizal plants were grown with organic matter + soluble phosphorus and organic matter + rock phosphate. Regardless of P source, plant acquisition of P, S, Mg, Ca and K was enhanced compared to control and mineral enhancement was greater in rock phosphate applied plants compared to soluble phosphate applied plants. They suggested the application of rock phosphate and organic matter to VAM plants as low cost, attractive and ecologically sound alternative to intensive use of P fertilizers for crops grown in acidic soils.

2.8 VAM as a biocontrol agent

The use of VAM as biocontrol agent is gaining considerable attention in the present day agriculture. There are several reports of effectiveness of VAM for the management of soil borne diseases and nematodes.

2.8.1 VAM fungi for the management of fungal diseases

The first report describing the interaction between VAM fungus and plant pathogenic fungi was documented by Saffir (1968). A significant reduction in wilt caused by *Fusarium oxysporum* f.sp *lycopersici* was observed in tomato inoculated with *G. mosseae* (Dehne and Schonbeck, 1975). VAM inoculation resulted in increased tolerance of poinsettia plants to infection by *Pythium ultimum* (Stewart and Pfleyer,1977). Schonbeck and Dehne (1977) reported that mycorrhizal cotton seedlings were able to tolerate damage caused to roots by *Thielaviopsis basicola* better than nonmycorrhizal seedlings of cotton.

A study conducted by Zambolin and Schenck (1983) showed that soybean plants colonized by *Glomus mosseae* appeared to tolerate infection by *Macrophomina phaseolina*, *Rhizoctonia solani* and *Fusarium solani* better than nonmycorrhizal plants. The poinsettia plants recorded reduced inoculum density of *Pythium ultimum* in the rhizosphere of VAM inoculated plants (Kaye *et al.* 1984). The influence of *Glomus fasciculatum* on damping off of tomato caused by *Pythium aphanidermatum* was studied by Hegde and Rai (1984) . The inoculation of mycorrhizal fungus reduced the damping off and increased plant height and shoot and root weights. Caron *et al.* (1985, 1986 a, 1986 b) studied the effect of *G. intraradices* on crown and root rot of tomato caused by *Fusarium oxysporum* f.sp *radicis lycopersici.* The results revealed that the propagules of the pathogen were reduced when plants were inoculated with *G. intraradices*.

Chakravarty and Mishra (1986) reported that there was a reduction in fusarial wilt of *Cassia tora* by VAM inoculation. The seedlings inoculate with *G. fasciculatum* or *G. tenue* showed enhanced growth and there was a reduction in rhizosphere population of *Fusarium oxysporum.* A significant reduction in infection by *Rhizoctonia solani* in chick pea by VAM inoculation was reported by Jalali and Chand (1987).

In an experiment conducted by Al - Momany and Al -Radad (1988) seven species of *Glomus* including *G. mosseae* and *G. fasciculatum* were used to control wilt of tomatoes caused by *Fusarium oxysporum* f.sp. *lycopersici* and wilt of *Capsicum frutescens* caused by *Fusarium oxysporum* f.sp. *vasinfectum*. Mycorrhizal plants inoculated with *Fusarium oxysporum* had significantly higher shoot and root weights and plants were higher than the plants only inoculated with *Fusarium oxysporum*. *C. fruitscens* plants inoculated with *G. mosseae* had higher fresh weight than mycorrhizal plants inoculated with *Fusarium oxysporum* and plants inoculated with *Fusarium oxysporum* alone. Hwang (1988) reported a reduction in severity of alfalfa sickness caused by *Pythium parocandrum* due to inoculation of VAM fungi. The results showed that the introduction of VAM fungi in the soil caused stimulation of alfalfa growth even in the presence of the pathogen. The infection of green gram and black gram by dry root rot pathogen *Macrophomina phaseolina* was reduced significantly by VAM inoculation. (Jalali *et al.*, 1990; Kehri and Chandra, 1990).

Kobayashi (1991) reported a reduction in the incidence of damping off caused by *Pythium splendens* and *Rhizoctonia solani* in cucumber seedlings by VAM inoculation. Cassiolata and Melo (1991) tested the effect of VAM inoculation on damping off of tomato caused by *Rhizoctonia*. *G.leptoticum* and *Acaulospora morrowae* were tested for the control of damping off. Plants colonized by VAM fungi showed greater disease resistance than nonmycorrhizal ones.The influence of different VAM fungi, viz.,*Glomus fasciculatum*,*G.macrocarpum*, *Gigaspora margarita*, *Acaulospora laevis* and *Sclerocystis dusii* and their combinations on *Sclerotium rolfsi* in chilli was studied under glass house conditions (Sreenivasa *et al.*, 1992).

Thomas *et al.* (1994) conducted a field experiment to study the possibility of using *Glomus fasciculatum* in biological control of damping off of cardamom caused by *Fusarium moniliformae*, *Fusarium vexans* and *Rhizoctonia solani*. Only *Fusarium moniliformae* produced symptoms in mycorrhizal plants. A significant inhibition of sclerotial bodies was observed in plants inoculated with *Glomus fasciculatum* and *Glomus macrocarpum*. Dual inoculation of VAM fungi suppressed the pathogen more effectively than single inoculation. The interaction between *Glomus mosseae* and *Pythium ultimum* in marigold (*Tagetes erecta*) was studied by Calvet *et al.* (1995). Mycorrhizal fungus protected the plant against *P. ultimum* since both phytomass production and foliar development were higher in mycorrhizal plants. Reduction in the incidence of foliar disease of mulberry by VAM inoculation was reported by Sharma *et al.* (1995). The mulberry variety Kanva-2 was inoculated with *G. fasciculatum* and *G. mosseae* at different P levels recorded the minimum incidence of foliar diseases, leaf spot (*Cercospora moricola*), rust (*Cerotelium fici*) blight (*Fusarium pallidoroseum*) and powdery mildew (*Phyllactinia corylea*). Sivaprasad *et al.* (1995) reported that the association of VAM fungi *Glomus fasciculatum* and *G. macrocarpum* reduced the foot rot incidence in black pepper.

An experiment was conducted by Mohan (2000) to study the interaction of VAM fungi with rhizosphere and rhizoplane mycoflora of four important arid zone tree species, viz. *Acacia nilotica, A. senegal, A. tortilis* and *Prosopis cineraria.* Seedlings were raised under sterile conditions and then transplanted either to rhizosphere soil enriched with mixed VAM inocula containing *Glomus fasciculatum* and *G. aggregatum* or raised under ordinary nursery conditions without inoculation. After 60 days, the mycoflora of rhizosphere and rhizoplane was very much less in VAM inoculated seedling than in the uninoculated control plants. In all the tree species, *Cylindrocladium, Fusarium sp, Fusarium oxysporum, Rhizoctonia bataticola and Rhizoctonia solani* were suppressed or completely eliminated from VAM inoculated plant root and the rhizosphere soil samples.

The impact of colonization by arbuscular mycorrhizal fungus, *Glomus mosseae* on tomato root necrosis caused by soil borne pathogen *Phytophthora parasitica* was investigated (Vigo and Hooker 2000). Seven and sixteen days after inoculation with zoospores of the pathogen, roots of plants colonized by the VAM had 39 per cent and 30 per cent fewer infection loci respectively than those that were not inoculated. Concurrent studies of the rate of spread of necrosis within roots showed no changes caused by the VAM. At harvest, 26 days following inoculation with the pathogen, 61 per cent of roots of non colonized plants were necrotic compared with only 31 per cent in VAM colonized plants.

2.8.2 VAM fungi for the management of nematodes

Rao *et al.* (1995) studied the integration of endomycorrhiza *Glomus mosseae* and neem cake on the control of root rot nematode in tomato. Mycorrhizal seedlings when transplanted in neem cake amended soil were least infected by *Meloidogyne incognita*. An increase in plant growth parameters and a decrease in root knot index and final population of *M. incognita* were observed where mycorrhizal seedlings were transplanted in neem cake amended soil. Sunderababu and Sankaranarayanan (1995) reported that inoculation of *Glomus fasciculatum* in nursery beds helped in root colonization of tomato before transplanting to the mainfield. Mycorrhizal inoculation resulted in reduction in nematode infection and increased the yield by 91.3 per cent compared to untreated control.

In a study conducted by Mishra and Shukla (1996) it was revealed that inoculation with *Glomus fasciculatum* improved the growth and nutrient uptake of tomato and decreased the size and number of galls. Rao *et al.* (1997) reported the possibility of integration of *Glomus fasciculatum* with castor cake in tomato nursery for the management of root knot nematode, *Meloidogyne incognita*. Integration of *G. fasciculatum* with castor cake resulted in significant reduction in root galling and increased root colonization.

Sivaprasad and Sheela (1998) conducted an extensive survey in three major pepper growing districts of Kerala, *viz.*, Kannur, Wynad and Idukki. The survey revealed high VAM colonization and spore count, coupled with low population levels of *Meloidogyne incognita* and *Radopholus similis* in different pepper cultivars. Plant height and dry weight of shoot and root of pepper plants were increased due to *Glomus etunicatum* inoculation. *Glomus mosseae* was more effective in surppressing the nematode population in root and soil.

A pot culture experiment conducted by Sosamma *et al.* (1998) revealed that *Glomus mosseae* was effective in reducing the nematode populations, especially *Meloidogyne incognita* and *Radopholus similis* infecting banana, as well as enhancing banana growth and bunch weight. The VAM inoculation resulted in increase in plant height (18%), number of leaves (2.5%), leaf area (30%), bunch weight (35.7%), number of hands (30%), number of fingers (39.6%), and shoot weight (30.1%) compared to control.

The effect of three endomycorrhizal fungi, viz., *Glomus occultum, Entrophospora colombiana and Gigaspora margarita,* an organic compost and their interactions were compared with terbufos for the control of *Radopholus similis* in banana. The mycorrhizal fungi were more effective than terbufos in reducing the damage caused by *R.. similis* in the primary roots. The addition of compost along with VAM inoculation gave best results. Increased concentration of nutrients, particularly calcium and magnesium were recorded in mycorrhizal plants (Urribarri *et al.* 2000).

Bhagawati *et al.* (2000) reported the effectiveness of mustard cake and *Glomus etunicatum* for the management of disease complex of tomato caused by *Meloidogyne incognita* and *Fusarium oxysporum* f.sp. *lycopersici*. Tomato cv Pusa Ruby plants were grown in pots containing mustard cake (0.5% g w/w) and or the VAM *Glomus etunicatum* (50 chlamydospores 500 g^{-1} soil) and soil was inoculated with the nematode and pathogens. Growth parameters viz., height, fresh and dry weight of shoot and fresh weight of root were improved by mustard cake and / or VAM application. Mustard cake and VAM were equally effective in reducing the damage caused by *Meloidogyne incognita* and /or *F. oxysporum*. The combined application resulted in better efficacy than single treatment. The green house experiment conducted by Bhat and Mahmood (2000) showed that tomato root knot nematode *Meloidogyne incognita* was controlled by the combined use of *Paecelomyces lilacinus* and *Glomus mosseae*. The highest root development was achieved when mycorrhizal plants were inoculated with *P. lilacinus* to combat root knot nematode.

2.8.3 VAM fungi for the management of bacterial diseases

There are only few reports of biological suppression of bacterial diseases by VAM fungi. Reduction in severity of bacterial wilt of tomato caused by *Pseudomonas solanacearum* was reported by Halos and Zorilla (1979). Garcia-Garrido and Ocampo (1989) studied the effect of inoculation of *Glomus mosseae* on *Pscudomonas syringae* in tomato. They reported the protection of tomato by *Glomus mosseae* against the pathogen and reduction in colony forming units of *P. syringae* in rhizosphere. Interactions between vesicular arbuscular mycorrhizas or charcol compost and several soil borne diseases were described by Kobayashi (1991). Inoculation of VAM fungi along with application of charcol compost was effective in reducing the level of bacterial wilt of tomato caused by *Pseudomonas solanacearum* under green house conditions.

A reduction in bacterial blight of mulberry (*Pseudomonas syringae* pv.*mori*) due to inoculation of *Glomus mosseae and G. fasciculatum* was reported by Sharma *et al.* (1995). Sood *et al.* (1997) reported that VAM isolate Gm1 of *Glomus mosseae* provided complete control of bacterial wilt of tomato caused *Ralstonia solanacearum* and disease development was considerably delayed by another isolate G1 of *Glomus fasciculatum*. Five isolates of VAM fungi were evaluated for the control of bacterial wilt of tomato c.v. Roma. *Glomus mosseae* was found to be highly effective in promoting germination, seedling vigour and completely controlling the disease till the termination of potted experiment 48 days after challenge inoculation with *Ralstonia solanacearum* (race1 biovar III), followed by *G. fasciculatum* in which disease appeared after 35 days of challenge inoculation.

Materials and methods

3. MATERIALS AND METHODS

The study on 'Influence of VAM inoculation on nutrient uptake, growth, yield and bacterial wilt incidence in tomato (*Lycopersicon esculentum* Mill.)' was conducted at the College of Horticulture, Vellanikkara, Thrissur, during the period 1996-2000. A survey for the collection of VAM associated with tomato from different locations of Kerala, two pot culture experiments and two field experiments were conducted for this purpose. The details of materials used and methods followed are presented below.

3.1 Survey and collection of VAM associated with tomato from different locations of Kerala

A survey was conducted to collect VAM associated with tomato from different locations of Kerala (Table 1). The tomato plants were uprooted with least disturbance to the root system. Rhizosphere soil and root samples of five plants were collected from each location for the isolation of spores and for the estimation of VAM colonization. The roots were washed in tap water to remove the adhering soil particles and were then cut into bits of one cm length and fixed in formalin : acetic acid : alcohol mixture (FAA) (Appendix -1).

3.2 Estimation of VAM root colonization

The VAM root colonization was assessed following the method described by Phillips and Hayman (1970). The root bits fixed in FAA were washed thoroughly in water to remove the fixative. The washed root bits were softened by simmering in 10 per cent KOH at 90^0 C for one hour. After cooling the excess KOH was washed off in tap water and then neutralized with two per cent HCl. The root bits were then stained with 0.05 per cent trypan blue in lacto phenol (Appendix-II) for three minutes. The excess stain from the root tissue was removed by clearing in lacto phenol. The root

Table 1. Locations surveyed for the collection of VAM fungi associated with tomato

Sl. No	Locations	District
1	Farmer's field, Muvattupuzha	Eranakulam
2	College of Agriculture, Vellayani	Thiruvananthapuram
3	Farmer's field, Karimbam	Kannur
4	RARS, Neeleswaram	Kasaragod
5	College of Agriculture, Padanakkad	Kasaragod
6	Integrated seed development farm Eruthempathi	Palakkad
7	Farmer's field, Chittur	Palakkad
8	Farmer's field, Vadakarappathi	Palakkad
9	Farmer's field, Ottapalam	Palakkad
10	Farmer's field, Kenichira	Wyanad
11	Farmer's field, Sultanbattery	Wyanad
12	ARS, Mannuthy	Thrissur
13	College of Horticulture, Vellanikkara	Thrissur
14	Farmer's field, Pandikkad	Malappuram
15	Farmer's field, Anakkayam	Malappuram

bits were examined under microscope for VAM colonization. The per cent VAM colonization was worked out for each location using the following formula.

$$\text{Per cent VAM root colonization} = \frac{\text{No. of positive root segments}}{\text{Number of root segments observed}} \times 100$$

3.3 Isolation of VAM spores

VAM spores were extracted from the rhizosphere soil by wet sieving and decanting method (Gerdemann and Nicolson, 1963). Fifty grams of rhizosphere soil was suspended in 500 ml water and stirred well. After settling the heavier particles, the supernatant was filtered through a set of sieves 1mm, 450, 250, 100 and 45 microns. Finally, the materials present in 45, 100 and 250 micron sieves were transferred to 100 ml beakers separately by gentle washing and allowed for settling. This was filtered through nylon mesh of 45 micron size. The nylon mesh containing spores were placed in a petridish with grids marked on it and observed under stereomicroscope. The number of spores obtained in the three sieves was counted and total number of spores present in 50 grams of the soil was determined. The spores were separated based on the size, shape, and colour and were transferred to moistened filter paper.

3.4 Single spore isolation and pure culturing

For identification, single spore isolation and pure culturing was done. For this, a funnel was filled with sterilized soil : sand mixture (1:1). The tail end was plugged with cotton. The upper portion was covered with a paper and tied. The assembly was autoclaved. After cooling, a hole of two cm depth was made at the centre of the paper through the soil : sand mixture with a sterile glass rod. The spore for multiplication was surface sterilized in streptomycin sulphate solution (0.02%) and washed in sterile water. Using a sterile brush, the spore was placed at the centre of the hole and the surface sterilized maize seed was placed on it and covered with soil. Watering was done daily with sterile water. One month after germination of the seed, the maize plant along with soil was transferred to pots containing sterilized soil:

sand mixture (1:1). Ruakura nutrient solution (Smith *et al.*; 1983) was applied at 15 days interval. The inoculam multiplied like this served as starter inoculum.

3.5 Measurement of VAM spores

The spores from the pure cultures were measured using ocular micrometer precalibrated with stage micrometer.

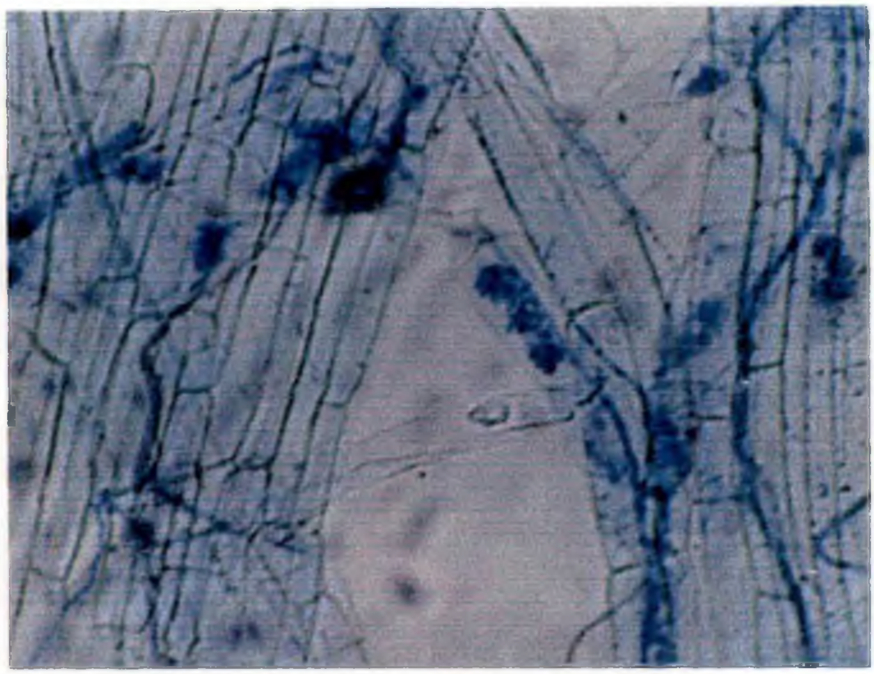
3.6 Spore characters

The spore colour, shape, nature of attachment of the hyphae and surface texture were observed and compared with the keys described by Trappe (1982) and Morten and Benny (1990).

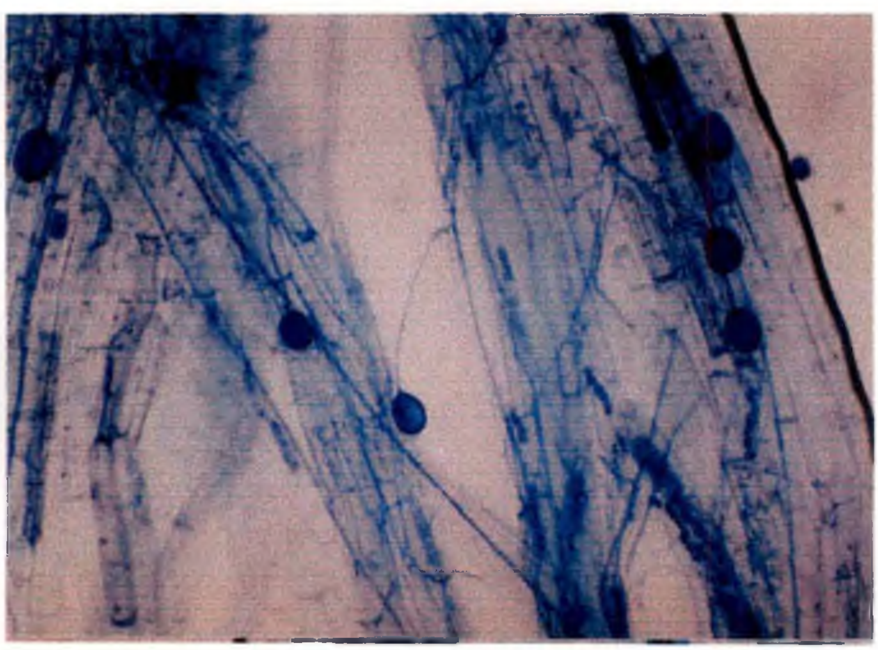
3.7 Mass multiplication of VAM inoculum

The pots of five kg capacity were filled with sterilized soil : sand mixture (1:1). Fifty grams of the mixed inocula containing rhizosphere soil and root bits from the starter culture was placed in a hole made of two cm depth at the center. A surface sterilized maize seed was placed on the inoculum and covered with soil. The Ruakura nutrient solution was applied at fifteen days interval. The maize plants were grown for three months. The standard cultures of *Glomus fasciculatum* and *Glomus mosseae* procured from UAS, Bangalore and *Glomus intraradices* and *Gigaspora margarita* procured from IARI, New Delhi were also multiplied in a similar manner. The root colonization (Plate. 1) was confirmed by the procedure described in section 3.2. The infected roots and rhizosphere soil from these pots were used as inoculum for further studies.

PLATE-1
VAM COLONIZATION IN MAIZE ROOTS



1a. Arbuscules in maize root (200X)



1b. Vesicles in maize root (100X)

3.8 Screening the efficiency of VAM in tomato

A pot culture experiment was conducted for screening the efficiency of VAM in improving the nutrient uptake, growth and yield of tomato during September to December 1998. Fifteen native isolates of VAM were screened along with four standard cultures (Table 2).

Table 2. VAM fungi used in the screening trial

Standard cultures	
T_1	*Glomus fasciculatum*
T_2	*Glomus mosseae*
T_3	*Glomus intraradices*
T_4	*Gigaspora margarita*
Local isolates	
T_5	Muvattupuzha (Eranakulam)
T_6	Vellayani (Thiruvananthapuram)
T_7	Karimbam (Kannur)
T_8	Neeleswaram (Kasaragod)
T_9	Padanakkad (Kasaragod)
T_{10}	Eruthempathi (Palakkad)
T_{11}	Chittur (Palakkad)
T_{12}	Vadakarappathi (Palakkad)
T_{13}	Ottapalam (Palakkad)
T_{14}	Kenichira (Wyanad)
T_{15}	Sultansbattery, (Wyanad)
T_{16}	Mannuthy (Thrissur)
T_{17}	Vellanikkara (Thrissur)
T_{18}	Pandikkad (Malappuram)
T_{19}	Anakkayam (Malappuram)
T_{20}	Uninoculated control

The experiment was conducted in earthen pots of five kg capacity. The pots were filled with sterililized soil: sand mixture (2:1). The experiment was laid out in Completely Randomized Design with four replications.

3.8.1 Tomato variety

Tomato variety 'Sakthi' was used for this experiment. Seeds were obtained from Department of Olericulture, College of Horticulture.

3.8.2 VAM inoculation

The nursery was raised in pots of capacity five kg filled with sterililized soil : sand mixture in the ratio 1:1. Fifty grams of mixed inocula containing root pieces of maize and rhizosphere soil containing spores of VAM were placed two cm below the surface of the soil as a thin uniform layer and the seeds of tomato variety Sakthi were sown.

3.8.3 Transplanting

The seedlings were transplanted 25 days after sowing to the pots filled with sterile soil: sand mixture. The VAM colonization of the roots of seedlings was assessed before transplanting as per the root clearing and staining method described in section 3.2

3.8.4 Application of nutrient solution

Plants were given Ruakura nutrient solution (Smith *et al.*, 1983) with out P at the rate of 50 ml per pot at 30 days interval.

3.8.5 Observations

Biometric observations of the plant, *viz.*, height, number of leaves, root length, root volume, fresh and dry weights of shoot and root were recorded at 90 days after transplanting. Fruit yield was recorded at each harvest and total yield per plant was determined. VAM colonization and rhizosphere spore count were also recorded at 90 days after transplanting.

3.8.5.1 Height of the plant

Height of the plant was measured from the soil level to the top most part of the plant.

3.8.5.2 Number of leaves

Total number of leaves was taken by counting from oldest to youngest leaves of the plant.

3.8.5.3 Fresh weight of shoot

Immediately after uprooting, the shoot portion was separated and weight was recorded.

3.8.5.4 Fresh weight of root

Root system of the plants were separated, washed, allowed to drain and weight was recorded.

3.8.5.5 Root length

Root length was taken from the collar region to the tip of the longest root.

3.8.5.6 Root volume

A known volume of water was taken in a measuring cylinder. Root system of the plant was immersed in it. The quantity of water displaced by the root system was found out to get the root volume.

3.8.5.7 Dry weights of shoot and root

Dry weights of shoot and root were determined after drying the plant samples to a constant weight at 60 ^{0}C.

3.8.5.8 Days to flowering

Number of days to flowering from the date of transplanting was recorded.

3.8.5.9 Fruit Yield

Number of fruits and fruit weight were recorded at each harvest to get the total per plant yield.

3.8.5.10 VAM spore count

The rhizosphere spore count was determined as per the procedures described in section 3.3

3.8.5.11 VAM root colonization

The VAM root colonization was determined as per the procedures described in section 3.2

3.8.6 Analysis of fruit quality

3.8.6.1 Ascorbic acid content

Ascorbic acid content of the ripe fruit was determined by the procedure described by Sadasivam and Manickam (1996).

3.8.6.2 Total soluble sugar content

Total soluble sugar content of the fruit was determined by phenol sulphuric acid method (Sadasivam and Manickam, 1996).

3.8.7 Nutrient analysis of the plant

The plant top was oven dried at 60^0c to get a constant weight. They were then powdered in a laboratory mill and this powder was used for the analysis of the nutrients. The N, P, K Ca and Mg content of the shoot were determined as per the procedures given in Table 3.

Table 3. Methods of nutrient analysis of plant

Nutrient	Method of estimation	Reference
Nitrogen	Microkjeldahl method	Jackson, 1958
Phosphorus	Vandomolybdophosphoric yellow colour method	Jackson, 1958
Pottassium	Flame photometry	Jackson, 1958
Calcium	Titration	Jackson, 1958
Magnesium	Titration	Jackson, 1958

3.9 Study on colonization pattern of VAM

In order to study the colonization pattern , plants were raised in pots filled with sterilized potting mixture consisted of soil : sand : FYM in the ratio (2:1:1). Tomato variety Sakthi was used for the study. Ten plants per pot were maintained to accommodate for destructive sampling.

VAM isolate found best in the screening trial was used for the study. VAM inoculation was done at the rate of 50 g pot^{-1}. of mixed inoculum.

3.9.1 Observations

The VAM root colonization was recorded at 10 days interval by the procedure described in section 3.2.

3.10 Examination of VA mycorrhizal roots under light microscope

Root samples were stained by the method described earlier (Philips and Hayman, 1970) and examined under light microscope for the presence of mycorrhizal structures inside the root.

3.11 Evaluation of selected isolates of VAM for their efficiency in economising phosphorus fertilizer

This study was conducted as a pot culture experiment during December to March 1998. It was laid out in Completely Randomised Design with four replications Tomato variety Sakthi was used for this study. The treatments were as follows.

Factor 1 : VAM

M_0 - No inoculation

M_I - *Glomus* sp from Eruthempathi (Palakkad)

M_2 - *Glomus* sp. from Padanakkad (Kasaragod)

M_3 - *Glomus* sp from Sultansbattery (Wyanad)

Factor 2 : Sources of phosphorus

SP - Super phosphate

MP - Mussorie rock phosphate

Factor 3 : Different levels of phosphorus

P_0 - No phosphorus

P_1 - 25 per cent of recommended dose of P (10 kg ha^{-1})

P_2 - 50 per cent of recommended dose of P (20 kg ha^{-1})

P_3 - 75 per cent of recommended dose of P (30kg ha^{-1})

P_4 - Full dose of recommended dose of P (40 kg ha^{-1})

Nursery was raised in pots filled with unsterile soil : sand : FYM mixture (2:2:1). The VAM multiplied in sterile soil : sand mixture using maize as host plant was used for inoculation. The mixed inoculum containing root pieces of maize and rhizosphere soil with spores at the rate of 50 g was placed as a thin layer just below the soil surface and seeds were sown. Twenty five days old seedlings were transplanted to the pots filled with unsterile field soil. Two sources of phosphorus, viz. super phosphate (SP) and mussorie rock phosphate (MP) were applied at 0, 25, 50,75 and 100 per cent of the recommended dose. The N and K fertilizers were applied at the rate of 75:25 kg ha^{-1} as per the Package of Practices Recommendations-Crops (KAU, 1996).

3.11.1 Observations

Biometric observations, shoot P content and VAM root colonization were recorded as described in section 3.8.5.

3.12 Influence of VAM on nutrient uptake, growth and yield of tomato

A field experiment was conducted to study the influence of VAM on nutrient uptake, growth and yield of tomato at the vegetable research farm of College of Horticulture, Vellanikkara during September to December 2000 using the variety Sakthi. The experiment was laid out in Randomised Block Design with four replications. The plot size was 3m x 2.5m.

Ttreatments

T_1 - FYM + N + MP + K
T_2 - VAM + N + SP + K
T_3 - VAM alone
T_4 - VAM + FYM
T_5 - VAM + FYM + N + K
T_6 - VAM + FYM + N + 25 %MP+ K
T_7 - VAM + FYM + N + 25 %SP+ K
T_8 - VAM + FYM + N + 50% MP + K
T_9 - VAM + FYM + N + 50% SP + K
T_{10}- VAM + FYM + N + 75%M P + K
T_{11} - VAM + FYM + N +75%S P+ K
T_{12} - VAM + FYM + N + M P+ K
T_{13} - VAM + FYM + N + S P+ K
T_{14} - VAM + N + M P+ K
T_{15} - VAM + N + S P + K

FYM at the rate of 20 t ha $^{-1}$ and NPK at the rate of 75: 40: 25 kg ha $^{-1}$ was applied as per the Package of Practices Recommendations - Crops (KAU, 1996). Different doses of phosphorus (0, 10, 20, 30 and 40 kg ha^{-1}) were applied as mussorie rock phosphate (MP) and single super phosphate (SP). Nursery was inoculated with VAM isolate collected from Eruthempathi at the rate of 500g m^{-2}. Twenty five days old seedlings were transplanted to the field at a spacing of 60 x 60 cm. The uninoculated seedlings served as control. FYM and half the recommended dose of N, full dose of P and half dose of K were applied as basal. Remaining N and K were applied as top dressing.

3.12.1 Observations

Biometric observations, viz. plant height, number of leaves, length of root, fresh and dry weights of shoot and root were recorded as described earlier at 90 days after transplanting. Yield was recorded at each harvest and total yield was determined. VAM root colonization and rhizosphere spore count were also determined as described in sections 3.2 and 3.3

3.12.2 Nutrient analysis of the plant

The N, P and K content of the plants were analysed as per the methods described in section 3.8.7

3.12.3 Nutrient analysis of the soil

The N, P, K content of the soil was determined by the following methods.

Table 4. Methods of chemical analysis of soil

Nutrient	Method of estimation	Reference
Available N	Alkaline permanganate method	Subbiah and Asija, 1956
Available P	Ascorbic acid blue blue colour method (Bray-1 extraction)	Watanabe and Olsen, 1965
Available K	Flame photometry	Jackson, 1958

3.13 Influence of VAM inoculation on bacterial wilt incidence of tomato

A field experiment was conducted to study the influence of VAM inoculation on bacterial wilt incidence of tomato at the vegetable research farm of College of Horticulture during September-December 2000. This was laid out as Factorial experiment in Randomised Block Design with four replications. The plot size was 3m x 2.5m.

Treatments

Factors

1.Varieties (V)

Three varieties coming under resistant (Sakthi), moderately resistant (BWR-1) and susceptible (Pusa Ruby) groups were used.

V1- Sakthi

V2 - BWR-1

V3 - Pusa Ruby

2. VAM inoculation (M)

M_0 - No inoculation

M_1 - VAM inoculation

The local isolate of VAM collected from Eruthempathi was used for the inoculation in the nursery at the rate of 500g m^{-2}. Twenty five days old seedlings were transplanted to the wilt sick field.

3.13.1 Observations

3.13.1.1 VAM root colonization

The per cent root colonization of the VAM fungi was determined as per the procedure described in section 3.2

3.13.1.2 Population of *Ralstonia solanacearum* (Smith) Yabuchi *et al.*

Rhizosphere population of *Ralstonia solanacearum* was estimated by serial dilution method using Triphenyl Tetrazolium Chloride medium at weekly interval.

3.13.1.3 Wilt incidence

Wilt incidence per cent was recorded at weekly interval.

3.13.1.4 Biometric observations

Biometric observations were recorded at 90 days after transplanting as described in section 3.8.5. Yield was recorded at each harvest and total yield was determined.

3.13.2 Total phenol content of the plant

Total phenol content of the stem and leaf was estimated at the flowering stage as described by Sadasivam and Manickam (1996)

3.13.3 Nutrient content of the plant

N, P and K content of the plant were determined as per the procedures described in section 3.12. 3.

3.14 Statistical analysis

The data pertaining to each experiment were subjected to appropriate statistical analysis using MSTAT package.

4. RESULTS

4.1 Survey and collection of native isolates of VAM associated with tomato from different locations of Kerala

A survey was conducted to collect the VAM fungi associated with tomato from fifteen locations of Kerala. The pH of these locations were acidic to alkaline ranging from 5.2 to 7.5 (Table 5).

4.1.1 VAM colonization

The results showed that, natural root colonization of VAM ranged from 19 .6 to 35.4 per cent (Table 5). The highest colonization was recorded at Ottapalam, (35.4%) followed by Kenichira (31.2%). At Vellanikkara, the VAM colonization recorded was 23.2 per cent.

4.1.2 VAM spore count in the rhizosphere soil

VAM spore count in the rhizosphere soil of different locations is presented in Table 5. The spore count ranged from 18.4 to 49 per 50 g of soil. The maximum spore count was recorded at Eruthempathi (49.0) followed by Chittur (47.6). At Vellanikkara, the spore count recorded was 27.2.

4.2 Spore characters

The characters *viz.*, size, shape, colour, texture and hyphal attachment of the VAM spores from the pure cultures were studied (Table 6 and Plate 2) The predominant VAM spores from all the locations were identical to that of *Glomus* sp having yellow to brown colour, globose shape, single hyphal attachment with an average size ranging from 106.2 to 272.2 m.

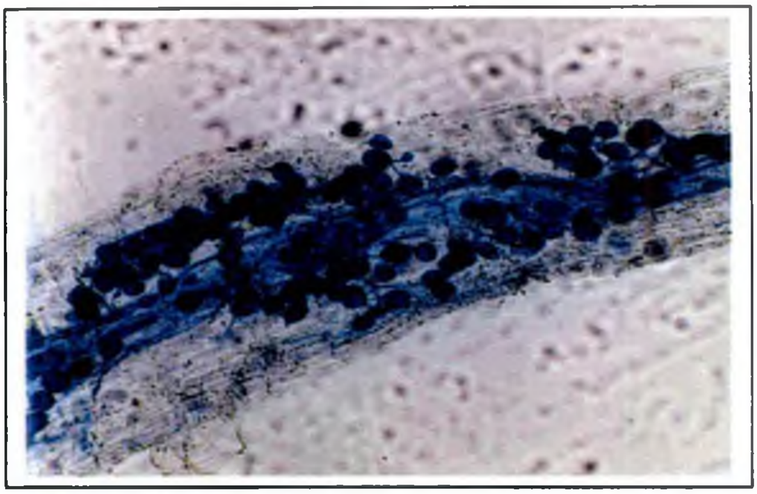
Table 5. VAM root colonization and rhizosphere spore count and soil pH recorded at different survey locations.

Survey locations	VAM colonization (%)	VAM spore count (50 g of soil $^{-1}$)	Soil pH of the locations
1.Muvattupuzha	23.6	34.4	5.7
2.Vellayani	19.4	18.4	5.6
3.Karimbam	28.2	36.4	5.6
4.Neeleswaram	22.2	25.2	5.5
5.Padanakkad	29.0	32.0	5.6
6. Eruthempathi	27.0	49.0	7.5
7. Chittur	24.4	47.6	7.1
8. Vadakarappathi	20.0	18.8	7.0
9. Ottapalam	35.4	21.0	5.7
10. Kenichira	31.2	18.6	5.9
11. Sultansbattery	29.0	22.6	5.8
12. Mannuthy	21.2	18.8	5.5
13.Vellanikkara	23.2	27.2	5.4
14.Pandikkad	19.6	40.0	5.2
15.Anakkayam	25.0	38.4	5.4

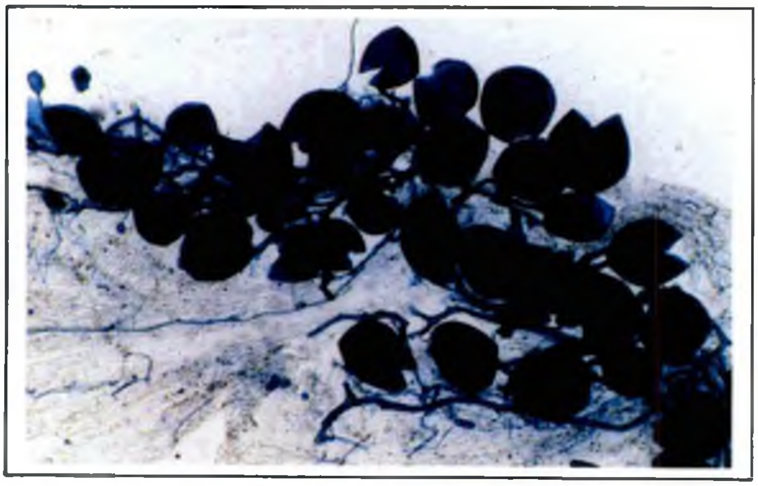
Table 6. Characters of VAM spores collected from different locations.

VAM isolate	Average size (μm)	Shape	Color	Surface texture	Hyphal attachment
1.Muvattupuzha	106.2	Globose	Brown	Smooth	Single
2.Vellayani	139.0	Globose	Brown	Smooth	Single
3.Karimbam	141.7	Globose	Brown	Smooth	Single
4.Neeleswaram	161.0	Globose	Brown	Smooth	Single
5.Padanakkad	141.4	Globose	Brown	Smooth	Single
6. Eruthempathi	150.0	Globose	Yellow-Brown	Smooth	Single
7. Chittur	174.0	Globose	Brown	Smooth	Single
8. Vadakarappathi	139.0	Globose	Brown	Smooth	Single
9. Ottapalam	165.0	Globose	Yellow	Smooth	Single
10. Kenichira	272.2	Globose	Brown	Smooth	Single
11. Sultanbattery	156.5	Globose	Brown	Smooth	Single
12. Mannuthy	164.2	Globose	Brown	Smooth	Single
13.Vellanikkara	172.8	Globose	Yellowish brown	Smooth	Single
14.Pandikkad	186.5	Globose	Brown	Smooth	Single
15.Anakkayam	130.4	Globose	Brown	Smooth	Single

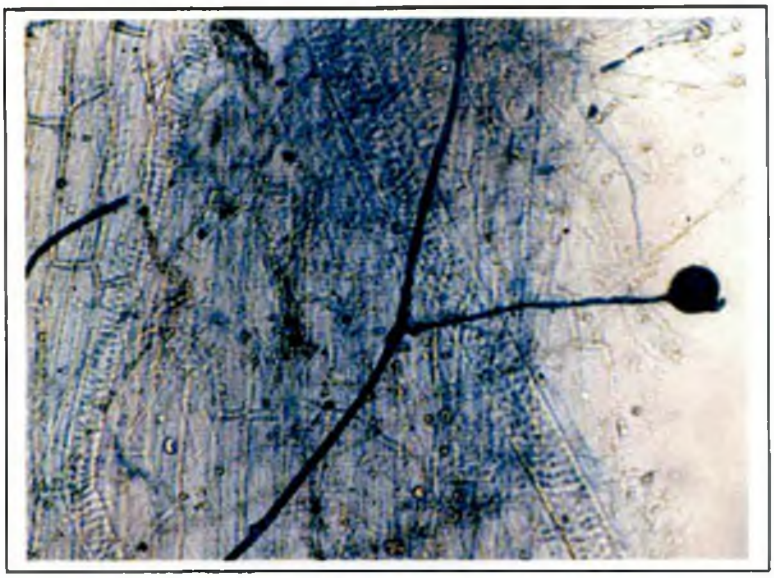
PLATE II VAM SPORES



2a.VAM spores inside the tomato roots (100 X)



2b. VAM spores inside the tomato roots (200 X)



2 C. Single spore with direct hyphal attachment (100x)

2d. Spore of *Glomus* sp. with hyphal attachment (400 X)

4.3 Screening of VAM for their efficiency in tomato

Fifteen native isolates and four commercial cultures were screened for their efficiency in improving nutrient uptake, growth and yield of tomato in a pot culture experiment (Plate 3). The results of the experiment are presented below.

4.3.1 Growth parameters of tomato as influenced by VAM

4.3.1.1 Plant height

The influence of VAM on plant height is presented in Table 7. The heights of plants inoculated with VAM fungi, except T_{19} and T_{13} were significantly superior to control. The plants inoculated with VAM isolates T_{15} and T_7 recorded the maximum plant height (36.25 cm). It was followed by T_{17}, T_1, T_{18}, T_{16}, T_{14} and T_{10} which were on par. Control plants recorded the lowest height of 22 cm.

4.3.1.2 Number of leaves

There were significant differences among treatments in their effect on the number of leaves (Table 7). The highest number of leaves was recorded by T_7 (30.38) and T_{15} (29.38) followed by T_{16}, T_{17} and T_{10}, which were significantly superior to control (13.75). The number of leaves in plants inoculated with T_{13} was on par with control.

4.3.1.3 Root length

The plants inoculated with the isolate T_{10} recorded the maximum root length of 61.50 cm where as the root length recorded by control was 27cm. The root length recorded by the plants inoculated with T_9, T_3 and T_1 were also on par with T_{10} (Table 7 and Plate 4a and 4b).

PLATE 3.
SCREENING VAM FOR TOMATO

3a VAM inoculated **Control**

3b. Pot culture experiment for screening

Table 7. Effect of VAM inoculation on plant height, number of leaves, root length and root volume

Treatments	Plant height (cm)	No. of leaves	Root length (cm)	Root volume (cm^3)
T_1	33.13 ^{ab}	17.50 ^{bcd}	52.75 ^{ab}	21.17 ^{abcd}
T_2	29.25 ^{b}	16.13 ^{bcd}	30.75 ^{ef}	21.06 ^{abcd}
T_3	29.38 ^{b}	15.88 ^{bcd}	55.25 ^{ab}	20.63 ^{cd}
T_4	29.25 ^{b}	16.38 ^{bcd}	34.50 ^{def}	20.58 ^{cd}
T_5	29.38 ^{b}	20.38 ^{bcd}	37.00 ^{def}	20.08 ^{d}
T_6	29.63 ^{b}	16.38 ^{bcd}	49.50 ^{bc}	20.50 ^{cd}
T_7	36.25 ^{a}	30.38 ^{a}	44.25 ^{bcd}	21.08 ^{abcd}
T_8	29.38 ^{b}	18.50 ^{bcd}	41.00 ^{cde}	20.55 ^{cd}
T_9	28.13 ^{b}	18.50 ^{bcd}	55.00 ^{ab}	21.50 ^{abc}
T_{10}	30.00 ^{ab}	22.38 ^{abcd}	61.50 ^{a}	22.13 ^{a}
T_{11}	28.75 ^{b}	14.13 ^{cd}	40.50 ^{cde}	21.25 ^{abc}
T_{12}	28.50 ^{b}	17.75 ^{bcd}	32.00 ^{def}	20.58 ^{cd}
T_{13}	27.00 ^{bc}	13.50 d	34.00 ^{def}	20.49 ^{cd}
T_{14}	30.63 ^{ab}	19.00 ^{bcd}	44.25 ^{bcd}	20.75 ^{bcd}
T_{15}	36.25 ^{a}	29.38 ^{a}	40.50 ^{cde}	21.88 ^{ab}
T_{16}	31.30 ^{ab}	25.38 ^{ab}	49.25 ^{bc}	21.05 ^{abcd}
T_{17}	33.55 ^{ab}	23.38 ^{abc}	34.00 ^{def}	21.00 ^{abcd}
T_{18}	33.13 ^{ab}	20.50 ^{bcd}	35.50 ^{def}	21.65 ^{abc}
T_{19}	26.88 ^{bc}	19.13 ^{bcd}	27.25 ^{f}	20.80 ^{bcd}
T_{20}	22.00 ^{c}	13.75 ^{d}	27.00 ^{f}	20.50 ^{cd}

Values with different superscripts differ significantly at 5 % level.

PLATE 4.
EFFECT OF VAM INOCULATION ON TOMATO

4a.
Control Inoculated (T_{10})

4b.
Control Inoculated (T_9)

4c.
Control Inoculated (T_{10})

4d.
Control Inoculated (T_9)

4.3.1.4 Root volume

Inoculation of VAM fungi increased the root volume (Table 7). The highest root volume was recorded by the plants inoculated with T_{10} (22.13 cm^3). It was followed by T_{15} and T_9. The control plants recorded a root volume of 20.50 cm^3

4.3.1.5 Shoot fresh weight

The highest shoot fresh weight was recorded by the plants inoculated with T_{10} (60.10g) followed by T_1, T_{16} and T_9 (Table 8). The control plants recorded a shoot fresh weight of 21.40g.

4.3.1.6 Root fresh weight

The plants inoculated with T_{10} recorded the highest root fresh weight of 17.27g (Table 8) followed by T_9 (15.50 g) and T_{15} (13.31 g), which were significantly superior to control (5.71g).

4.3.1.7 Shoot dry weight

The shoot dry weight of plants inoculated with T_{10} (21.89g) was the highest and significantly superior to control. It was followed by T_9 (17.96 g) and T_{16} (16.72 g) which were on par with T_{10}. The control plants recorded a shoot dry weight of 10.09g. (Table 8)

4.3.1.8 Root dry weight

The highest root dry weight was recorded by T_{10} (2.57g) followed by T_9 (1.99g) and T_{15} (1.91g) which were significantly superior to control (1.29 g) (Table 8). The VAM fungi T_6, T_5 and T_{12} were significantly inferior to control in their effect on root dry weight.

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Table8. Effect of VAM inoculation on fresh and dry weights of shoot and root.

Treatments	Shoot fresh weight (g)	Root fresh weight (g)	Shoot dry weight (g)	Root dry weight (g)
T_1	48.33 ^{ab}	5.72 ^{cd}	15.25 ^{bcd}	1.38 ^{bc}
T_2	32.31 ^{bcde}	7.43 ^{bcd}	13.59 ^{bcd}	1.58 ^{bc}
T_3	32.77 ^{bcde}	7.43 ^{bcd}	13.34 ^{bcd}	1.39 ^{bc}
T_4	32.08 ^{bcde}	5.07 ^{cd}	11.96 ^{bcd}	1.23 ^{bc}
T_5	20.40 ^{e}	3.39 ^{d}	10.60 ^{d}	1.11 ^{c}
T_6	24.39 ^{de}	3.56 ^{d}	9.47 ^{d}	1.12 ^{c}
T_7	35.39 ^{bcde}	9.24 ^{bcd}	15.64 ^{bcd}	1.51 ^{bc}
T_8	27.94 ^{cde}	5.06 ^{cd}	12.81 ^{bcd}	1.28 ^{bc}
T_9	42.85 ^{bc}	15.50 ^{ab}	17.96 ^{ab}	1.99 ^{ab}
T_{10}	60.10 ^{a}	17.27 ^{a}	21.89 ^{a}	2.57 ^{a}
T_{11}	40.38 ^{bcd}	7.29 ^{bcd}	15.02 ^{bcd}	1.83 ^{bc}
T_{12}	26.40 ^{cde}	4.57 ^{d}	10.83 ^{cd}	1.08 ^{c}
T_{13}	23.35 ^{de}	3.25 ^{d}	10.69 ^{cd}	1.31 ^{bc}
T_{14}	30.40 ^{bcde}	7.55 ^{bcd}	15.35 ^{bcd}	1.36 ^{bc}
T_{15}	32.69 ^{bcde}	13.31 ^{abc}	14.81 ^{bcd}	1.91 ^{ab}
T_{16}	43.78 ^{bc}	9.19 ^{bcd}	16.72 ^{abc}	1.68 ^{bc}
T_{17}	29.16 ^{cde}	8.59 ^{bcd}	12.5 ^{bcde}	1.62 ^{bc}
T_{18}	23.04 ^{de}	7.55 ^{bcd}	12.28 ^{bcd}	1.57 ^{bc}
T_{19}	32.12 ^{bcde}	8.25 ^{bcd}	14.76 ^{bcd}	1.39 ^{bc}
T_{20}	21.40 ^{e}	5.71 ^{cd}	10.09 ^{d}	1.29 ^{bc}

Values with different superscripts differ significantly at 5 % level.

4.3.1.9 Days to flowering

The flowering in control plants occurred 26 days after transplanting. Early flowering was induced by VAM inoculation. Flowering was recorded in 17 days in T_{17}, 18 days in T_{10} and 21 days in T_5 and T_2 (Table 9).

4.3.1.10 Number of fruits

The maximum number of fruits was recorded by T_{10} (8.0) which was significantly superior to control and all other treatments except T_9 (6.75g) (Table 9).

4.3.1.11 Fruit Yield

There were significant differences among treatments in fruit yield (Table 9 and Plate 4c and 4d). The plants inoculated with T_{10} recorded the highest yield of 205.2 g and which was significantly superior to control and all other treatments, followed by T_9 (156g). The yield recorded by the control plant was 66.2g.

4.3.2 Fruit Quality

4.3.2.1 Ascorbic acid content

The treatment T_{10} recorded maximum ascorbic acid content (38.43 mg) followed by T_{14} (38.07 mg). The control plants recorded the ascorbic acid content of 27.07 mg (Table 9).

4.3.2.2 Total soluble sugar content

Total soluble sugar content of the fruits did not differ significantly from each other. However the highest fruit sugar content was recorded by T_{17} and T_6, followed by, T_{10} (Table 9).

Table 9. Effect of VAM inoculation on days to flowering, fruit yield and fruit quality

Treatments	Days to flowering	Number of fruits	Fruit yield (g)	Ascorbic acid mg g^{-1} of fruit	Soluble sugar (%)
T_1	23.00 ^{cd}	4.0 ^{de}	99.61 ^{cdef}	29.24 ^{c}	6.00 ^{a}
T_2	21.00 ^{bc}	5.25 ^{bcde}	114.4 ^{bcde}	29.44 ^{c}	5.88 ^{a}
T_3	21.75 ^{bcd}	4.50 ^{cde}	100.1 ^{cdef}	30.90 ^{abc}	6.97 ^{a}
T_4	27.50 ^{ef}	5.75 ^{bcd}	126.7 ^{bcde}	30.90 ^{abc}	6.54 ^{a}
T_5	20.75 ^{bc}	4.00 ^{de}	98.67 ^{cdef}	34.40 ^{abc}	6.06 ^{a}
T_6	22.00 ^{bcd}	4.00 ^{de}	101.50 ^{cdef}	28.74 ^{c}	8.19 ^{a}
T_7	23.25 ^{cd}	5.75 ^{bcd}	137.80 ^{bc}	32.51 ^{abc}	6.73 ^{a}
T_8	24.25 ^{abc}	4.75 ^{cde}	104.0 ^{cdef}	34.56 ^{abc}	7.01 ^{a}
T_9	22.25 ^{bcd}	6.75 ^{ab}	156.0 ^{b}	32.92 ^{abc}	6.76 ^{a}
T_{10}	18.50 ^{ab}	8.00 ^{a}	205.2 ^{a}	38.43 ^{a}	7.92 ^{a}
T_{11}	25.50 ^{def}	6.00 ^{bc}	125.5 ^{bcde}	26.67 ^{c}	6.87 ^{a}
T_{12}	23.00 ^{cd}	5.25 ^{bcde}	122.1 ^{bcde}	27.17 ^{c}	7.48 ^{a}
T_{13}	24.00 ^{cde}	4.00 ^{de}	85.63 ^{ef}	29.67 ^{bc}	5.98 ^{a}
T_{14}	23.25 ^{cd}	5.00 ^{bcde}	113.3 ^{cde}	38.07 ^{bc}	7.42 ^{a}
T_{15}	23.75 ^{cde}	6.00 ^{bc}	131.3 ^{bcd}	29.78 ^{bc}	6.98 ^{a}
T_{16}	23.00 ^{cd}	6.25 ^{bc}	128.5 ^{bcde}	28.56 ^{c}	7.41 ^{a}
T_{17}	17.00 ^{a}	6.00 ^{bc}	141.9 ^{bc}	34.42 ^{abc}	8.19 ^{a}
T_{18}	22.75 ^{cd}	5.50 ^{bcd}	92.30 ^{def}	31.70 ^{abc}	6.79 ^{a}
T_{19}	21.00 ^{bc}	4.75 ^{cde}	116.4 ^{bcde}	34.13 ^{abc}	6.95 ^{a}
T_{20}	26.25 ^{f}	3.50 ^{e}	66.22 ^{f}	27.07 ^{c}	6.20 ^{a}

Values with different superscripts differ significantly at 5 % level.

4.3.3 VAM spore count

The Number of VAM spores present in the rhizosphere soil differed significantly between treatments (Table 10). The spore count in the rhizosphere soil of plants inoculated with T_{10} was maximum (269.5 per 50g of soil). It was significantly superior to all other treatments and was followed by T_9 (188) and T_7 (180).

4.3.4 VAM root colonization

The highest VAM colonization (96.75%) was recorded by T_{10} (Table 10) It was significantly superior to all other VAM fungi and was followed by T_9 (88.50%) and T_{15} (88.25%)

4.3.5 Nutrient content of the plant

4.3.5.1 Nitrogen

There were no significant differences among treatments in their effect on nitrogen content of the shoot (Table 10). However the highest content of N was recorded by the plants inoculated with T_{10} (4.3%) as against the nitrogen content of 3.09 per cent in control plants.

4.3.5.2 Phosphorus

There were significant differences among treatments in their effect on P content (Table 10). The plants inoculated with T_{12} recorded the highest shoot P content (0.55 %). It was followed by T_{10} (0.52 %), T_{15} and T_9 which were on par and significantly superior to control. The P content recorded by the control was 0.29 per cent.

Table10. Effect of VAM inoculation on spore count, root colonization and nitrogen and phosphorus content of shoot.

Treatments	VAM spore count ($50g^{-1}$ soil)	VAM colonization (%)	Nitrogen content of the shoot (%)	Phosphorus content of the shoot (%)
T_1	170.5^{bcde}	84.25^{bc}	4.24^{a}	0.44^{abcd}
T_2	178.5^{bcd}	88.00^{b}	3.92^{a}	0.36^{bcd}
T_3	167.8^{bcde}	83.75^{bc}	3.51^{a}	0.44^{abcd}
T_4	173.8^{bcde}	83.50^{bc}	4.17^{a}	0.51^{abc}
T_5	161.5^{bcde}	73.25^{e}	3.68^{a}	0.39^{bcd}
T_6	176.0^{bcd}	75.50^{de}	3.61^{a}	0.37^{bcd}
T_7	186.5^{b}	87.85^{b}	3.72^{a}	0.49^{abc}
T_8	180.0^{bc}	85.25^{bc}	4.01^{a}	0.46^{abc}
T_9	188.0^{b}	88.50^{b}	4.00^{a}	0.50^{abc}
T_{10}	269.5^{a}	96.75^{a}	4.34^{a}	0.52^{ab}
T_{11}	163.0^{bcde}	84.75^{bc}	3.87^{a}	0.50^{abc}
T_{12}	158.5^{bcde}	88.00	3.51^{a}	0.55^{a}
T_{13}	163.3^{bcde}	83.50^{bc}	3.86^{a}	0.35^{cd}
T_{14}	143.3^{c}	79.00^{cde}	4.31^{a}	0.38^{bcd}
T_{15}	177.8^{bcd}	88.00^{b}	3.42^{a}	0.51^{abc}
T_{16}	170.8^{bcde}	84.00^{bc}	3.82^{a}	0.46^{abc}
T_{17}	147.3^{de}	86.75^{bc}	4.13^{a}	0.38^{bcd}
T_{18}	151.0^{cde}	80.75^{bcd}	3.96^{a}	0.37^{bcd}
T_{19}	158.5^{bcde}	82.00^{bcd}	3.50^{a}	0.47^{bcd}
T_{20}	8.25^{f}	7.50^{f}	3.09^{a}	0.29^{d}

Values with different superscripts differ significantly at 5 % level.

4.3.5.3 Potassium

There were significant differences among the treatments in their effect on K content of the shoot (Table 11). The plants inoculated with T_{10} recorded the highest K content (4.23 %). It was followed by T_{15} (3.9%).

4.3.5.4 Calcium

There were significant differences among the treatments in their effect on Ca content of the plant (Table 11). The maximum Ca content was recorded by T_1 (1.66%) and T_{16} (1.66%) which were significantly superior to control (0.96%) and all other treatments.

4.3.5.5 Magnesium

There were no significant differences among treatments in their effect on Mg content of the plant (Table 11). However the highest Mg content was recorded by T_9 (0.70%). The Mg content of the control plant was 0.04 per cent.

4.4 Colonization pattern of VAM

In VAM inoculated plants, root colonization was observed even at 10 days after sowing (39.60%) whereas in control no colonization was observed, (Table 12). The root colonization increased with increase in age of the plant in the initial stages and reached maximum at 50 days after sowing (89.20%). There was not much difference in root colonization between 50^{th} and 60^{th} days after sowing. Further there was a reduction in root colonization and reached 72.4 per cent at 70 days after sowing. There was not much reduction further in root colonization upto 90 days after sowing.

Table 11. Effect of VAM inoculation on potassium, calcium and magnesium content of the shoot

Treatments	Potassium content of the shoot (%)	Calcium content of the shoot (%)	Magnesium content of the shoot (%)
T_1	3.55 ^{abcd}	1.66 ^{a}	0.55 ^{a}
T_2	3.73 ^{abc}	1.38 ^{abc}	0.59 ^{a}
T_3	2.73 ^{d}	1.42 ^{abc}	0.58 ^{a}
T_4	3.55 ^{abcd}	1.42 ^{abc}	0.59 ^{a}
T_5	3.50 ^{abcd}	1.58 ^{ab}	0.39 ^{a}
T_6	3.45 ^{abcd}	1.44 ^{abc}	0.57 ^{a}
T_7	2.93 ^{cd}	1.46 ^{abc}	0.56 ^{a}
T_8	2.93 ^{cd}	1.44 ^{abc}	0.57 ^{a}
T_9	3.83 ^{ab}	1.08^{abc}	0.70 ^{a}
T_{10}	4.23 ^{a}	1.44 ^{abc}	0.58 ^{a}
T_{11}	3.85 ^{ab}	1.10 ^{bc}	0.61^{a}
T_{12}	3.88 ^{ab}	0.96^{c}	0.65 ^{a}
T_{13}	3.88 ^{ab}	1.12 ^{bc}	0.67 ^{a}
T_{14}	3.08 ^{bcd}	1.52 ^{ab}	0.59 ^{a}
T_{15}	3.90 ^{ab}	1.28 ^{abc}	0.55 ^{a}
T_{16}	2.95 ^{cd}	1.66 ^{a}	0.52 ^{a}
T_{17}	2.88 ^{cd}	1.36 ^{abc}	0.68 ^{a}
T_{18}	2.95 ^{cd}	1.28 ^{abc}	0.65 ^{a}
T_{19}	3.68 ^{abc}	1.64 ^{a}	0.54 ^{a}
T_{20}	2.70 ^{d}	0.96 ^{c}	0.54 ^{a}

Values with different superscripts differ significantly at 5 % level.

Table 12. VAM root colonization at different growth stages of tomato.

Age of the plant (Days)	VAM colonization (%)	
	Inoculated plants	Control
10	39.6	0.0
20	68.6	0.0
30	74.8	0.0
40	73.73	3.06
50	89.20	3.40
60	83.60	4.30
70	72.40	4.40
80	72.86	3.60
90	69.60	2.90

Means of 15 observations

4.5 Light microscopy of VA mycorrhizal roots.

Light microscopy showed the presence of mycorrhizal structures in the root cortex (Plate 5a –5e). The hyphal colonization was observed in roots of 10 days old seedlings. The hyphae were observed almost parallel to the root axis. At this initial stage of growth arbuscules were observed inside the cells. Vesicles were also observed along with arbuscules at 20 days after sowing. Further the arbuscules disintegrated. Maximum root colonization was observed at 50days after sowing. Only vesicles were found at this stage.

4.6 Evaluation of selected isolates of VAM fungi for their efficiency in economising phosphorus fertilizers

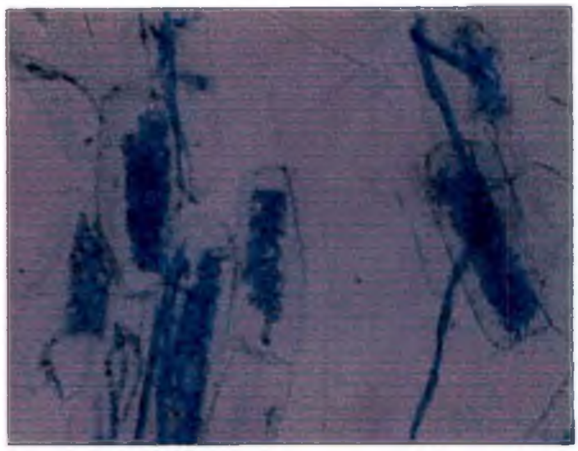
The results of the pot culture experiment conducted to study the efficiency of selected isolates of VAM fungi in economising the added phosphorus fertilizers are presented below.

4.6.1 Shoot fresh weight

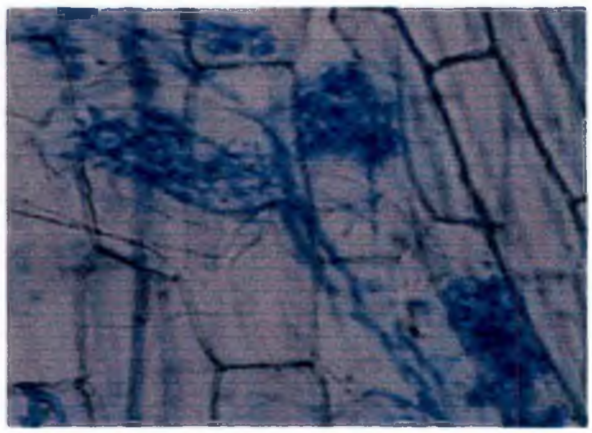
The effect of inoculation of VAM fungi and different sources and levels of phosphorus on shoot biomass are presented in Table 13. There were significant differences among the VAM fungi in their effect on shoot fresh weight. The highest shoot fresh weight was recorded by the plants inoculated with the isolate M_1 (132.65g). It was significantly superior to the control (104.70g). The shoot fresh weight recorded by the plants inoculated with M_2 and M_3 were also on par with that of M_1 and was significantly superior to control.

There was significant difference between the super phosphate (SP) and mussorie rock phosphate (MP) in their influence on shoot fresh weight. The shoot fresh weight recorded by the plants, which received SP was 127.24g which was

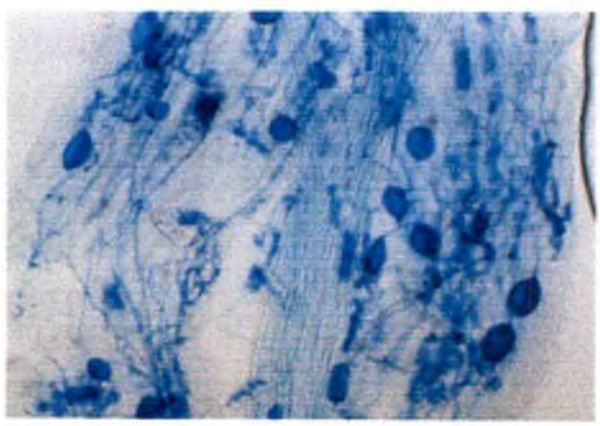
PLATE 5
VAM COLONIZATION PATTERN IN TOMATO



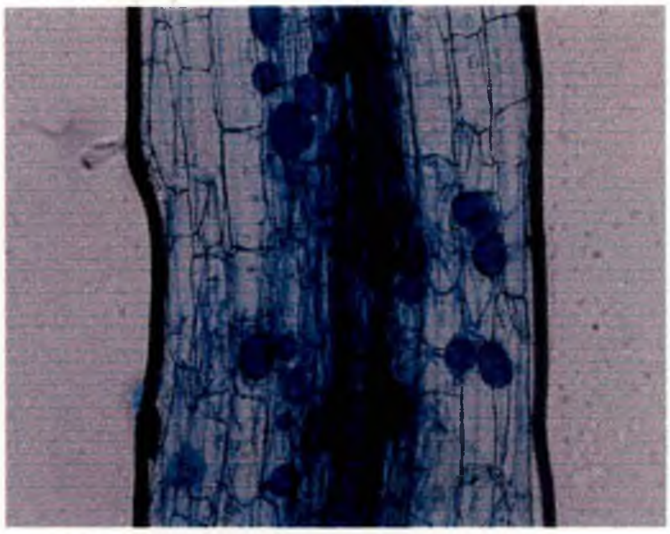
5a. Arbuscules inside the tomato root (200X)



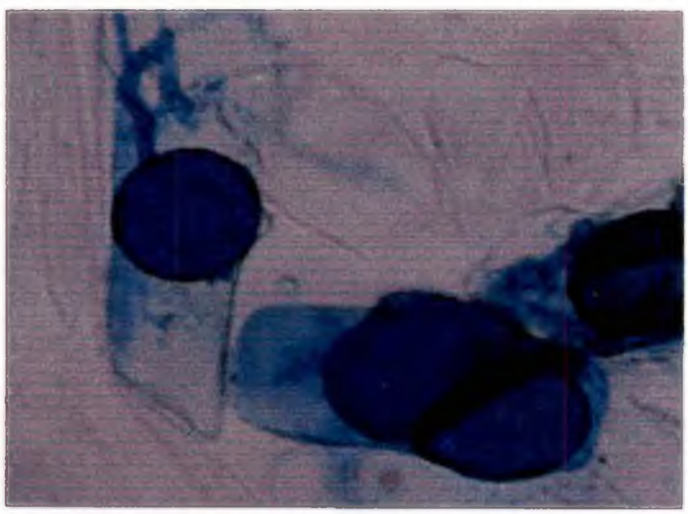
5b. Arbuscules inside the tomato root(400X)



5c. Vesicles and arbuscules inside the root (100X)



5d. Vesicles inside the root (100X)



5e. Vesicles inside the root (200X)

Table 13 . Effect of VAM inoculation and different sources and levels of P on fresh weight of shoot and root and shoot dry weight

Treatments		Shoot fresh weight (g)	Shoot dry weight (g)	Root fresh weight (g)
VAM inoculation	M_0	104.70 [b]	14.32 [b]	12.31 [c]
	M_1	132.65 [a]	17.96 [a]	19.55 [a]
	M_2	122.38 [a]	15.97 [ab]	18.23 [a]
	M_3	128.13 [a]	15.34 [a]	15.61 [b]
Sources of P	SP	127.24 [a]	15.94 [a]	16.57 [a]
	MP	116.67 [b]	15.92 [a]	12.28 [a]
Levels of P (% of recommended dose)	0	90.88 [b]	11.29 [b]	10.02 [c]
	25	95.25 [b]	17.93 [b]	12.34 [c]
	50	136.22 [a]	17.92 [a]	17.63 [b]
	75	146.25 [a]	19.46 [a]	21.29 [a]
	100	141.22 [a]	18.54 [a]	22.85 [a]

Values with different superscripts differ significantly at 5 per cent level.

significantly superior to the fresh weight recorded by the plants, which received MP (116.67g).

Among the different doses of phosphorus there were significant differences in shoot fresh weight . The shoot fresh weight recorded by the plants, which received higher doses of P, was significantly superior to that of lower doses. The shoot fresh weight recorded by the plants applied with full dose of P (141.2 g) was statistically on par with the shoot fresh weight recorded by the plants, which received 50 and 75 per cent of the recommended dose of P.

The interactions between different levels of phosphorus and VAM inoculation were statistically significant in influencing shoot fresh weight (Table14). The inoculation of VAM fungi along with 25 per cent level of the recommended dose of phosphorus did not result in significant increase in shoot fresh weight. There was significant increase in shoot fresh weight due to the inoculation of VAM fungi at 50 per cent level of P. Among the VAM isolate, M_1 recorded maximum shoot fresh weight (154.8 g) at this level of applied phosphorus. The shoot fresh weight recorded by the plants inoculated with M_2 and M_3 were also on par with M_1. At 75 per cent and full doses of applied phosphorus, the inoculation of VAM fungi did not result in any significant increase in shoot fresh weight over uninoculated control. Even though there were no significant differences among the treatments, the plants inoculated with the isolate M_1 recorded maximum shoot fresh weight of 156.1 g and 153.9 g respectively at 75 per cent and full dose of applied P respectively. The interactions among the different forms and levels of phosphorus and inoculation of VAM fungi were not statistically significant.

4.6.2 Shoot dry weight

The effect of VAM inoculation and different forms and different levels of phosphorus is given in the Table 13. There were significant differences among the VAM fungi in their effect on shoot dry weight. The inoculation of VAM isolate M_1

Table 14. Interaction between VAM fungi and different doses of P on fresh and dry weight of shoot and root fresh weight

Levels of P (% of recommended dose)	VAM fungi	Shoot fresh weight (g)	Shoot dry weight (g)	Root fresh weight (g)
0	M_0	71.25 ^{f}	10.59 ^{fgh}	7.53
	M_1	95.75 ^{ef}	13.15 ^{defg}	11.05
	M_2	94.25 ^{ef}	10.49 ^{h}	10.67
	M_3	102.30 ^{cde}	10.94 ^{fgh}	10.85
25	M_0	82.50 ^{ef}	12.13 ^{cdef}	8.90
	M_1	102.80 ^{cde}	14.24 ^{ab}	12.61
	M_2	95.63 ^{ef}	18.60 ^{a}	16.34
	M_3	100.10 ^{def}	18.70 ^{abcd}	11.51
50	M_0	110.40 ^{bcde}	14.74 ^{bcde}	11.34
	M_1	154.8 ^{a}	19.66 ^{a}	20.34
	M_2	130.9 ^{abc}	18.60 ^{a}	22.35
	M_3	148.9 ^{a}	18.70 ^{abcd}	16.48
75	M_0	127.4 ^{abcd}	16.80 ^{bcd}	17.38
	M_1	156.1 ^{a}	21.38 ^{ab}	26.25
	M_2	152.9 ^{a}	21.50 ^{ab}	21.93
	M_3	148.6 ^{a}	18.06 ^{abcd}	19.64
100	M_0	132.0 ^{ab}	17.26 ^{efg}	16.43
	M_1	153.9 ^{a}	19.98 ^{gh}	27.68
	M_2	138.3 ^{ab}	19.95 ^{fgh}	19.88
	M_3	140.8 ^{a}	16.98 ^{bcde}	19.59
				NS

Values with different superscripts differ significantly at 5 per cent level.

resulted in a maximum shoot dry weight of 17.96 g as against 14.32 g by the control plants. The shoot dry weight recorded by the plants inoculated with M_2 and M_3 were also on par with that of M_1. There was no significant difference between SP and MP in their effect on shoot dry weight.

Among the different doses of P, the highest shoot dry weight was recorded by the plants, which received 75 per cent of the recommended dose (19.46g). It was significantly superior to the shoot dry weight recorded by the plants which did not receive any P and 25 per cent of the recommended dose of P, but was on par with 50 per cent and full dose of P.

The interactions between different levels of P and VAM inoculation recorded significant differences in shoot dry weight (Table 14). At 25 per cent of the recommended dose of P, there was significant increase in shoot dry weight due to inoculation of the isolates of M_1 and M_2. At 50 per cent dose of applied P, maximum shoot dry weight of 19.66 g was recorded by the plants inoculated with the VAM isolate, M_1. The inoculation of VAM isolate M_2 also resulted in significant increase in shoot dry weight over the uninoculated control. At 75 and full dose of applied P there was no significant increase in shoot dry weight, due to VAM inoculation. The interactions between different doses and forms of P and VAM inoculation were not statistically significant in influencing shoot dry weight.

4.6.3 Root fresh weight

The effect of VAM inoculation and different sources and levels of P on root fresh weight are given in Table 13. The VAM isolates differed significantly in their effect on root fresh weight. The isolate M_1 performed best in improving the root fresh weight recording a root fresh weight of 19.55 g as against 12.31 g in the control plants. It was significantly superior to the root fresh weight recorded by the plants inoculated with M_3. The root fresh weight recorded by the plants inoculated with M_2 (18.23g) was on par with M_1. There was no significant difference between SP and MP in their effect on root fresh weight.

Among the five levels of P, the plants which received full dose of P recorded the maximum root fresh weight (22.85 g). It was statistically on par with the root fresh weight recorded by the plants which received 75 per cent dose of P and significantly superior to the root fresh weight recorded by the plants that received the lower three doses of P. The interactions between the different doses of P and VAM inoculation as well as the interaction effect of different levels and forms of P and VAM inoculation were not statistically significant.

4.6.4 Root dry weight

The effect of VAM inoculation, different sources and levels of P on the root dry weight are presented in the Table 15. VAM inoculation had significant effect on root dry weight. The maximum root dry weight of 5.11g was recorded by the plants inoculated with the isolate M_1. The root dry weight recorded by the plants inoculated with M_2 and M_3 were also on par with M_1 and were significantly superior to uninoculated plants (3.33g).

The two sources of P differed significantly in their effect on root dry weight. The plants that received SP recorded higher root fresh weight (4.58 g) than the plants applied with MP (3.81 g). Among the different doses of P, the highest root dry weight of 5.09g was recorded by the plants, which received 75 per cent of the recommended dose of P. It was statistically on par with the root dry weight recorded by the plants, which received 50 per cent (4.82 g) and full dose of P (4.59 g).

The interactions between VAM inoculation and different levels of P were statistically significant in their effect on root dry weight (Table 16). No significant increase in root dry weight due to the inoculation of VAM was recorded at zero and 25 per cent level of P. At 50 per cent level of applied P, only the inoculation of VAM

Table 15. Effect of VAM inoculation and different sources and levels of P on root dry weight, shoot phosphorus content, VAM root colonization and yield

Treatments		Root dry weight (g)	Shoot P content (%)	VAM colonization (%)	Yield (g $plant^{-1}$)
VAM inoculation	M_0	3.33 ^{b}	0.17 ^{d}	27.27 ^{c}	225.87 ^{b}
	M_1	5.11 ^{a}	0.28 ^{a}	74.95 ^{a}	280.80 ^{a}
	M_2	4.55 ^{a}	0.24 ^{b}	73.02 ^{ab}	261.50 ^{a}
	M_3	3.80 ^{a}	0.22 ^{c}	71.38 ^{b}	250.93 ^{ab}
Sources of P	SP	4.58 ^{a}	0.23 ^{a}	61.70 ^{a}	258.60 ^{b}
	MP	3.81 ^{b}	0.22 ^{a}	61.69 ^{a}	250.00 ^{b}
Levels of P (% of recommended dose)	0	2.88 ^{b}	0.16 ^{b}	53.25 ^{d}	178.88 ^{b}
	25	3.59 ^{b}	0.19 ^{b}	57.63 ^{d}	199.18 ^{b}
	50	4.82 ^{a}	0.25 ^{a}	66.81 ^{b}	286.47 ^{a}
	75	5.09 ^{a}	0.27 ^{a}	69.13 ^{b}	311.75 ^{a}
	100	4.59 ^{a}	0.27 ^{a}	61.76 ^{c}	297.59 ^{a}

Values with different superscripts differ significantly at 5 per cent level.

Table 16. Interaction between VAM fungi and different doses of P on root dry weight, shoot phosphorus content, VAM colonization and yield

Levels of P (% of recommended dose)	VAM fungi	Root dry weight (g)	Shoot phosphorus content (%)	VAM colonization (%)	Yield (g plant^{-1})
0	M_0	2.38 ^{g}	0.10^{h}	22.00^{f}	136.3 ^{h}
	M_1	3.65 ^{defg}	0.20 ^{ef}	61.00^{e}	183.8 ^{fgh}
	M_2	3.00 ^{fg}	0.19 ^{ef}	65.25^{de}	222.0 ^{cdefg}
	M_3	2.50 ^{g}	0.15 ^{fg}	63.50^{e}	291.1 ^{abc}
25	M_0	3.09 ^{efg}	0.13 ^{gh}	27.00^{f}	174.0 ^{gh}
	M_1	3.46 ^{defg}	0.24 ^{cde}	74.75^{bc}	227.5 ^{cdefg}
	M_2	3.69 ^{defg}	0.19 ^{ef}	63.38^{de}	194.6 ^{efgh}
	M_3	4.15 ^{cdefg}	0.19 ^{ef}	65.38^{de}	200.6 ^{defgh}
50	M_0	3.19 ^{efg}	0.21^{e}	32.00^{f}	258.1 ^{cdef}
	M_1	6.34 ^{a}	0.28 ^{bc}	79.63^{abc}	317.3 ^{ab}
	M_2	4.80 ^{abcdef}	0.27 ^{bcd}	78.75^{abc}	278.1^{bcd}
	M_3	4.96 ^{abcde}	0.22 ^{de}	76.87^{abc}	292.4 ^{abc}
75	M_0	4.24 ^{bcdefg}	0.20 ^{ef}	30.13^{f}	263.9 ^{abcde}
	M_1	5.93 ^{abc}	0.34 ^{ab}	85.13^{a}	363.1^{a}
	M_2	6.05 ^{ab}	0.28 ^{bc}	82.88^{ab}	321.6 ^{ab}
	M_3	4.16 ^{cdefg}	0.27 ^{bcd}	78.38^{abc}	298.4 ^{abc}
100	M_0	3.75 ^{defg}	0.23 ^{cde}	24.60^{f}	297.1^{abc}
	M_1	6.15 ^{a}	0.31 ^{ab}	73.75^{c}	312.4 ^{ab}
	M_2	5.23 ^{abcd}	0.28 ^{bc}	74.88 ^{c}	291.1 ^{abc}
	M_3	8.22 ^{efg}	0.27 ^{bcd}	72.75 ^{abc}	289.8 ^{abc}

Values with different superscripts differ significantly at 5 per cent level.

fungi M_1 resulted in significant increase in root dry weight. Even though there was no statistical significance, the inoculation of M_1 and M_2 resulted in an increase in root dry weight at 75 per cent level of applied P. At full dose of applied P, the root dry weight recorded by the plants inoculated with M_1 was significantly superior to uninoculated control.

4.6.5 Shoot phosphorus content

The effect of VAM inoculation and different sources and levels of phosphorus are presented in the Table15. There was significant increase in shoot phosphorus content due to VAM inoculation. The maximum phosphorus content of 0.28 per cent was recorded by the plants inoculated with the isolate M_1. It was significantly superior to control (0.17 %). The isolates M_2 and M_3 were also significantly superior to control in improving the shoot P content.

There was no significant difference between SP and MP in their effect on shoot P content. Among the five levels of P, the highest shoot P content was recorded by the plants which received 75 per cent and 100 per cent of the recommended dose of P (0.27 %). It was on par with the P content of the plants, which received 50 per cent of the recommended dose of P. The phosphorus content of the plants , which received higher doses of P (50,75 and 100) were on par and were significantly superior to the plants received 25 per cent of the P.

The interaction effects of VAM inoculation and different levels of P are presented in Table 16. The inoculation of VAM fungi along with 25 per cent of the recommended dose of P resulted in significant increase in shoot P content. The maximum shoot P content was recorded by the plants inoculated with VAM isolate M_1. The isolate M_2 was also on par with M_1 in its effect on shoot P content at 25 per cent level of the P. The inoculation of all the fungal isolates resulted in significant increase in shoot P content at 50 per cent level of applied P. The inoculation of VAM fungi M_1 along with 50 per cent of the recommended dose of P resulted in maximum shoot P content of 0.28 per cent. This was followed by M_2 and M_3. At 75 per cent level of P, the maximum shoot P content was recorded by the plants inoculated with the VAM isolate M_1 (0.34 %). It was significantly superior to the shoot P content of the plants, which received 75 per cent of the recommended dose of the P alone. The other two isolates M_2 and M_3 were also significantly superior to control. The plants, which received full recommended dose of P along with VAM inoculation resulted in significant increase in shoot P content. The shoot P content recorded by the plants inoculated with VAM isolate M_1 along with full dose of P was 0.31 per cent. The shoot P content recorded by M_2 (0.28 %) and M_3 (0.27 %) were statistically on par.

4.6.6 VAM root colonization

The effect of VAM inoculation, different forms and levels of P on root colonization are presented in the Table 15. The inoculation of VAM fungi resulted in significant increase in root colonization compared to control. The highest root colonization was recorded by the isolate M_1 (74.95%) followed by M_2 and M_3. There was no significant difference between SP and MP in VAM root colonization.

Different levels of P differed significantly in their effect on VAM root colonization. The highest root colonization was recorded by the plants, which received 75 per cent of the recommended dose of P. It was on par with the VAM root colonization recorded by 50 per cent and full dose of P and significantly superior to the VAM colonization recorded by the plants which received 25 per cent dose of P and full dose of P.

The interaction effects of VAM fungi and different doses of on root colonization is presented in Table 16. With the increase in dose of P upto 75 per cent, there was increase in root colonization due to VAM inoculation. Further it decreased. The highest root colonization of 85.13 per cent was recorded by the plants inoculated with the VAM isolate M_1 along with 75 per cent of the recommended dose of P. But it was statistically on par with the root colonization recorded by the plants inoculated with the VAM isolate M_1 along with 50 per cent dose of P. The isolates M_2 and M_3 were also on par with M_1 at 50 and 75 per cent level of P in their effect on VAM root colonization. At the full dose of P, the inoculation of VAM resulted an increase in VAM colonization. The root colonization recorded by the isolate M_1 was the highest (0.31 %) which was on par with VAM colonization recorded at 75 per cent level of P.

4.6.7 Fruit yield

The effect of VAM inoculation and different forms and sources of P on yield are presented in Table 15. There was significant difference in the yield recorded by the VAM inoculated plants over uninoculated plants. The highest yield was recorded by the plants inoculated with the isolate M_1. No significant difference between SP and MP was recorded in their effect on yield.

The interaction effect of inoculation of VAM and different levels of P is presented in the Table 16. There was no significant increase in yield due to inoculation of VAM fungi at lower doses of P (0 and 25 %). At 50 per cent level of P, The plants inoculated with the VAM isolate M_1 recorded the highest yield of 317g. The yield recorded by the plants inoculated with VAM isolate M_2 and M_3 were also on par with M_1. At 75 per cent level of the recommended dose of P, the yield recorded by the plants inoculated with VAM isolate M_1 was the highest (363g). It was significantly superior to the yield recorded by the uninoculated plants, which received only 75 per cent of the P. The inoculation of VAM isolates, M_2 and M_3 also resulted in increase in yield, which was on par with the yield recorded by M_1.

4.7 Influence of VAM inoculation on nutrient uptake, growth and yield of tomato

A field experiment was conducted to study the effect of VAM fungi on growth, nutrient uptake and yield of tomato (Plate 6). The results are described below.

4.7.1 Biometric characters

The effect of different treatments on growth characters are presented in Tables 17-19.

4.7.1.1 Plant height

There were no significant differences among treatments in their effect on plant height (Table 17). However, the highest plant height (64.63 cm) was recorded by the treatment T_{10} (VAM + FYM + N +75% MP + K). T_1 (FYM + N + MP + K) and T_2 (FYM + N + SP + K) recorded a plant height of 62.9cm and 60.4 cm respectively.

4.7.1.2 Number of leaves

The effect of different treatments consisting of inoculation of VAM fungi along with different levels and forms of P are presented in the Table 17. The application of full dose of P as MP along with N,K and FYM as per the package of practices recommendations (T_1) recorded 64.8 leaves plant^{-1}. The number of leaves recorded by the plants which received full dose of P as SP along with NK and FYM (T_2) was 117.5. At this level of P either as MP (T_{12}) or as SP (T_{13}) inoculation of VAM fungi did not result in increase in number of leaves. There were no significant differences among the treatments consisting lower doses of MP along with VAM inoculation in their effect on number of leaves. The maximum number of leaves of 85.82 was recorded by the plants inoculated with VAM fungi along with 30 kg P ha^{-1}

PLATE 6. Field view

Table 17 Effect of VAM and different sources and doses of P on plant height, number of leaves and root length

Treatment	Plant height (cm)	Number of leaves	Root length (cm)
T_1 - FYM + N + MP + K	62.90 [a]	64.80 [b]	24.52 [b]
T_2 - FYM + N + SP + K	60.40 [a]	117.50 [a]	27.70 [b]
T_3 - VAM alone	54.22 [a]	77.80 [b]	29.63 [b]
T_4 - VAM + FYM	61.10 [a]	67.32 [b]	25.46 [b]
T_5 - VAM + FYM + N + K	63.03 [a]	76.67 [b]	29.27 [b]
T_6 - VAM + FYM + N + 25 %MP+ K	56.84 [a]	83.67 [ab]	32.70 [ab]
T_7- VAM + FYM + N + 25 %SP+ K	57.72 [a]	82.45 [ab]	29.29 [b]
T_8 - VAM + FYM + N + 50% MP + K	54.67 [a]	49.83 [b]	31.67 [ab]
T_9- VAM + FYM + N + 50% SP + K	59.72 [a]	89.39 [ab]	31.24 [ab]
T_{10} - VAM + FYM + N + 75%M P + K	64.63 [a]	85.82 [ab]	38.01 [a]
T_{11}- VAM + FYM + N +75%S P+ K	61.06 [a]	61.80 [b]	30.66 [ab]
T_{12}- VAM + FYM + N + M P+ K	58.52 [a]	71.38 [b]	27.73 [b]
T_{13}- VAM + FYM + N + S P+ K	54.69 [a]	56.97 [b]	29.25 [b]
T_{14}- VAM + N + M P+ K	54.35 [a]	4.70 [b]	25.79 [b]
T_{15}- VAM + N + S P+ K	58.65 [a]	7.70 [b]	29.52 [b]

The values with different superscripts differ significantly at 5 % level

(T_{10} - VAM+ FYM+ N + 75%MP + K). It was on par with the application of full dose of nutrients and FYM as per the package of practices recommendations (T_1 and T_2).

Among the plants inoculated with VAM fungi which received SP, maximum number of leaves was recorded by T_7 (VAM+FYM + N + 25% SP + K). It was on par with all other levels of SP along with inoculation of VAM fungi and T_2 (FYM + N + SP + K).

4.7.1.3 Root Length

There were significant differences among the treatments in their effect on root length (Table 17). The application of full dose of P as MP along with N, K and FYM (T_1) recorded a root length of 24.52 cm and SP along with N,K and FYM (T_2) recorded a root length of 27.7 cm. Inoculation of VAM fungi along with full dose of P (T_{12} and T_{13}) did not influence root length significantly. The different levels of MP along with VAM fungi differed significantly in their effect on root length. The maximum root length (38 cm) was recorded by the plants which received 30 kg P as MP along with VAM inoculation (T_{10}). It was on par with lower doses of MP (T_6 and T_8) and significantly superior to full dose of MP (T_{12} - VAM + FYM+ N+ MP + K).

The plants applied with SP, differed significantly in their effect on root length. The maximum root length of 31.24 cm was recorded by the plants which received 50 per cent of SP along with N, K and FYM (T_9). It was on par with all the other treatments consisting of different doses of SP along with inoculation of VAM fungi.

4.7.1.4 Shoot fresh weight

The effect of different treatments on the shoot fresh weight is presented in the Table 18. The application of full recommended dose of P as MP along with N, K and FYM (T_1) resulted in a shoot fresh weight of 228.5 g. When full dose of P was applied as SP (T_2 - FYM + N +SP + K), the shoot fresh weight recorded was 266.3 g. The inoculation of VAM fungi at this level of P did not result in a significant increase in shoot fresh weight, irrespective of the forms of P applied (T_{12} and T_{13}). Highest shoot fresh weight (340.5 g) was recorded by VAM inoculation along with 30 kg P ha^{-1} as MP (T_{10}). It was significantly superior to the treatments consisting lower doses of 25 per cent (T_6), 50 per cent (T_8) and the full dose as MP (T_{11}).

In the presence of VAM, different doses of SP differed significantly in their effect on shoot fresh weight. Inoculation of VAM at 25 per cent level of SP resulted in a shoot fresh weight of 286.1 g which was on par with T_9 (50%), T_{11} (75%) and of T_{13} (full dose of P). Inoculation of VAM fungi along with application of FYM alone recorded a shoot fresh weight of 181.5 g, which was on par with T_1 (FYM + N + MP + K) and T_2 (FYM + N + SP + K). The inoculation of VAM fungi along with different doses of P, N, K and FYM resulted in shoot fresh weight on par with or superior to that of T_1 and T_2.

4.7.1.5 Shoot dry weight

The effect of different treatments on shoot dry weight is presented in Table 18. The application of full dose of P as MP along with N, K and FYM (T_1) resulted in a shoot dry weight of 29.54 g. When P was given as SP (T_2) the shoot dry weight recorded was 32.65g. The inoculation of VAM fungi at this level of P (T_{12} and T_{13}) did not result in significant increase in shoot dry weight irrespective of the form of P applied. There were significant differences among the treatments consisting of different doses of P in their effect on shoot dry weight. Maximum shoot dry weight (37.54 g) was recorded when 75 per cent MP was applied along with N, K, FYM and VAM (T_{10}). It was significantly superior to all other treatments consisting of different doses of MP along with VAM and also T_1 (FYM + N + MP + K). There were significant differences among treatments consisting of different doses of SP in shoot dry weight. The highest shoot dry weight (31.36g) was recorded by T_7. It was on par with T_9 (50 %SP) and T_2 (75%SP) and T_{13} (SP). The inoculation of VAM fungi along

Table 18 Effect of VAM and different sources and doses of P on fresh weight of shoot and root and shoot dry weight

Treatment	Shoot fresh weight (g)	Shoot dry weight (g)	Root fresh weight (g)
T_1 - FYM + N + MP + K	228.5 ^{bcd}	29.54 ^{abc}	30.25 ^{bcd}
T_2 - FYM + N + SP + K	266.3 ^{abc}	32.65 ^{ab}	30.42 ^{bcd}
T_3 - VAM alone	134.8 ^{e}	17.29 ^{d}	13.88 ^{f}
T_4 - VAM + FYM	181.5 ^{cde}	24.40 ^{bcd}	27.45 ^{bcde}
T_5 - VAM + FYM + N + K	222.3 ^{bcd}	25.01 ^{bcd}	24.20 ^{de}
T_6 - VAM + FYM + N + 25 %MP+ K	230.3 ^{bcd}	26.87 ^{abcd}	25.77 ^{cde}
T_7- VAM + FYM + N + 25 %SP+ K	286.1 ^{ab}	31.36 ^{ab}	32.52 ^{abc}
T_8 - VAM + FYM + N + 50% MP + K	210.0 ^{bcd}	25.34 ^{bcd}	29.42 ^{bcd}
T_9- VAM + FYM + N + 50% SP + K	247.5 ^{bc}	27.22 ^{abcd}	34.47 ^{ab}
T_{10} - VAM + FYM + N + 75%M P + K	340.5 ^{a}	37.54 ^{a}	38.13 ^{a}
T_{11}- VAM + FYM + N +75%S P+ K	249.8 ^{bc}	31.02 ^{ab}	31.56 ^{abcd}
T_{12}- VAM + FYM + N + M P+ K	220.4 ^{bcd}	24.15 ^{bcd}	29.42 ^{bcd}
T_{13}- VAM + FYM + N + S P+ K	186.3 ^{cde}	21.99 ^{bcd}	24.77 ^{de}
T_{14}- VAM + N + M P+ K	146.8 ^{de}	16.24 ^{d}	20.42 ^{e}
T_{15}- VAM + N + S P+ K	179.6 ^{cde}	18.77 ^{bcd}	21.92 ^{e}

The values with different superscripts differ significantly at 5 % level

with FYM alone resulted in a shoot dry weight of 24.4 g, which was on par with T_1 and T_2.

4.7.1.6 Root fresh weight

Significant differences among the treatments were recorded in their effect on root fresh weight (Table 18). Maximum root fresh weight of 38.13 g was obtained when 75 per cent MP was applied with N,K and FYM along with VAM (T_{10}). It was significantly superior to all the other treatments consisting different doses of MP along with VAM inoculation (T_6, T_8 and T_{12}) and also to T_1 (FYM + N + MP+K). There were significant differences among the treatments consisting of different doses of SP along with VAM inoculation in their effect on root fresh weight. Maximum root fresh weight of 34.47 g was recorded by T_9 (VAM + FYM +50% SP +K). It was on par with T_7 (VAM + FYM +25% SP +K) and T_{11} (VAM + FYM +75% SP +K) and significantly superior to full dose of SP (T_{13}- VAM + FYM + SP +K). Inoculation of VAM fungi at full dose of P irrespective of the form used (T_{12} and T_{13}) did not result in significant increase in root fresh weight. VAM inoculation along with FYM alone (T_4) recorded root fresh weight of 27.45 g, which was on par with T_1 and T_2. It was also on par with T_6 (25% MP) and T_8 (50% MP). The shoot fresh weight recorded by different levels of SP and MP tried were on par with T_1 and T_2.

4.7.1.7 Root Dry weight

There were significant differences among treatments in their effect on root dry weight (Table 19). The treatments consisting inoculation of VAM fungi along with full recommended dose of P (T_{12} and T_{13}) did not reveal any significant influence on root dry weight. There were significant differences among the treatments consisting of different doses of MP along with VAM in their effect on root dry weight. The maximum root dry weight of 6.89 g was recorded by T_{10}. It was significantly superior to all the other treatments consisting lower doses of MP and was on par with full dose of MP along with VAM inoculation (T_{12}).

There were significant differences among different doses of SP along with VAM inoculation in their effect on root dry weight. Highest root dry weight of 6.38 g was recorded by the application of 50 per cent of SP (T_9). It was on par with the treatments consisting of 25 per cent of SP (T_7) and 75 per cent of SP (T_{11}) and significantly superior to the treatments consisting of full dose of SP (T_{13}). The root dry weight recorded by T_9 was also on par with T_{10} (75% MP). Inoculation of VAM fungi along with the application of FYM alone resulted in a root dry weight of 3.43 g, which was on par with that of T_1 (FYM+N+MP+K) and T_2 (FYM+N+SP+K).

4.7.1.8 Fruit yield

Significant differences among treatments were recorded in their effect on fruit yield (Table 19). The yields recorded by T_1 and T_2 were 4.53 and 5.53 kg plot^{-1} respectively. When VAM fungi was inoculated at this level of P, no significant increase in yield was recorded. The yield recorded by T_{12} and T_{13} were 6.23 and 5.54 kg plot^{-1} respectively. But there were significant differences in yield among the treatments consisting of the lower doses of P. The yield recorded by the application of 25 and 50 per cent of MP along with VAM were (6.0 and 6.59 kg plot^{-1}) statistically on par with the yield recorded by T_1 and T_2. The highest fruit yield of 8.90 kg plot^{-1} was recorded by T_{10} (FYM +VAM + N + 75% MP + K) and it was significantly superior to the yield recorded by the lower doses of P (T_6 - FYM+N+25%MP+K and T_8 - FYM+N+50% MP+K) and full dose of P (T_{12} - FYM+N+MP+K).

There were significant differences among the different treatments consisting of different doses of SP in yield. The maximum yield of 7.38 kg plot^{-1} was recorded by plants treated with T_{11} (VAM + FYM + N + 75%SP + K). But it was statistically on par with T_9 (VAM+FYM+50% SP+K), which recorded an yield of 7.38 kg plot^{-1} and was significantly superior to T_2 (FYM + MP + SP + K), which recorded a yield of 5.53 kg plot^{-1}.

Table 19 Effect of VAM and different sources and doses of P on root dry weight and fruit yield

Treatment	Root dry weight (g)	Fruit yield (kg plot^{-1})
T_1 - FYM + N + MP + K	4.47 ^{bcd}	4.53 ^{defg}
T_2 - FYM + N + SP + K	4.83 ^{abcd}	5.53 ^{cdef}
T_3 - VAM alone	2.14 ^{e}	2.58 ^{gh}
T_4 - VAM + FYM	3.43 ^{cde}	3.31 ^{fgh}
T_5 - VAM + FYM + N + K	4.23 ^{bcde}	5.33 ^{cdef}
T_6 - VAM + FYM + N + 25 %MP+ K	4.06 ^{cde}	6.00 ^{bcde}
T_7- VAM + FYM + N + 25 %SP+ K	4.79 ^{abcd}	5.93 ^{cdef}
T_8 - VAM + FYM + N + 50% MP + K	4.11 ^{cde}	6.59 ^{bcd}
T_9- VAM + FYM + N + 50% SP + K	6.38 ^{ab}	7.38 ^{ab}
T_{10} - VAM + FYM + N + 75%M P + K	6.89 ^{a}	8.90 ^{a}
T_{11}- VAM + FYM + N +75%S P+ K	5.45 ^{abc}	7.95 ^{ab}
T_{12}- VAM + FYM + N + M P+ K	4.86 ^{abcd}	6.23 ^{bcd}
T_{13}- VAM + FYM + N + S P+ K	3.78 ^{cde}	5.54 ^{cde}
T_{14}- VAM + N + M P+ K	2.99 ^{de}	2.14 ^{h}
T_{15}- VAM + N + S P+ K	3.91 ^{cde}	3.88 ^{cfgh}

The values with different superscripts differ significantly at 5 % level

4.7.2 VAM root colonization

There were significant differences among the treatments in their effect on root colonization. (Table 20). The per cent VAM colonization recorded by T_1 and T_2 were 24.5 and 21 respectively. When VAM fungi was inoculated along with MP, the colonization increased with increase in the level of P from 25 to 75 per cent and then decreased. The treatment T_{10} (VAM + FYM + N + 75% MP + K) recorded a maximum colonization of 87.75 per cent. When NPK alone was applied without FYM, there was still decrease in VAM colonization. The treatment T_{14} (VAM + N + MP + K) and T_{15} (VAM + N + SP + K) recorded the VAM colonization of 50 and 51 per cent respectively. When SP was applied, there was an increase in VAM colonization with increase in the level of P from 25 to 50 per cent. The colonization percentage recorded by the treatment T_9 (VAM + FYM +N + 50%SP + K) was the maximum (83 %) which was on par with the VAM colonization recorded by the treatment consisting of 75 per cent of SP (T_{11}).

4.7.3 VAM spore count

There were significant differences among the treatments in their effect on VAM spore count (Table 20). When MP was applied a gradual increase in spore count was recorded with increase in the level of P from 25 to 100 per cent. Maximum spore count of 417.5 was recorded by T_{10} (VAM+FYM+N+75% MP+K). It was on par with T_{12} (VAM + FYM + N + MP + K) When SP was applied, maximum spore count of 358.8 was recorded by T_9 (VAM+FYM+N+50%MP+K). It was statistically on par with T_6 (VAM+FYM+N+25%SP+K) and T_{11} (VAM+FYM+N+75% SP+K).

Table 20 Effect of VAM and different sources and doses of P on root colonization and rhizosphere spore count

Treatment	VAM colonization (%)	VAM spore count (50 g^{-1} soil)
T_1 - FYM + N + MP + K	24.50 [e]	55.0 [g]
T_2 - FYM + N + SP + K	21.00 [e]	83.0 [g]
T_3 - VAM alone	50.00 [d]	119.0 [fg]
T_4 - VAM + FYM	64.00 [cd]	221.5 [de]
T_5 - VAM + FYM + N + K	68.75 [bc]	257.8 [cde]
T_6 - VAM + FYM + N + 25 %MP+ K	66.50 [bcd]	246.5 [cde]
T_7- VAM + FYM + N + 25 %SP+ K	58.25 [cd]	272.5 [cde]
T_8 - VAM + FYM + N + 50% MP + K	69.50 [bc]	329.0 [bcd]
T_9- VAM + FYM + N + 50% SP + K	83.00 [a]	358.8 [abc]
T_{10} - VAM + FYM + N + 75%M P + K	87.75 [ab]	417.5 [ab]
T_{11}- VAM + FYM + N +75%S P+ K	78.75 [ab]	323.0 [bcd]
T_{12}- VAM + FYM + N + M P+ K	68.00 [bc]	411.3 [ab]
T_{13}- VAM + FYM + N + S P+ K	55.25 [cd]	274.5 [cde]
T_{14}- VAM + N + M P+ K	50.00 [d]	182.5 [ef]
T_{15}- VAM + N + S P+ K	51.00 [d]	265.0 [cde]

The values with different superscripts differ significantly at 5 % level

4.7.4 Nutrient content of the shoot.

4.7.4.1 Nitrogen content

There were no significant differences among the treatments in their effect on nitrogen content of the shoot (Table 21). However the highest nitrogen content of 5.74 per cent was recorded by the treatment T_{10} (FYM +VAM + N + 75% MP + K) followed by T_{12} (FYM + N+ MP+ K) and T_{13} (FYM + N+ SP+ K)

4.7.4.2 Phosphorus content

There were significant differences among the treatments in their influence on P content of the shoot (Table 21). The application of full dose of P as MP along with N, K and FYM (T_1) resulted in the shoot P content of 0.20 per cent. The shoot P concentration of plants which received full dose of P as SP along with N, K and FYM (T_2) was 0.23 per cent. The inoculation of VAM fungi at this level of P (T_{12} and T_{13}) did not influence the shoot P content significantly.

There were no significant differences among the treatments consisting of different doses of MP in their effect on P content of shoot. The highest shoot P content of 0.37 per cent was recorded by T_{10} (VAM + FYM + N + 75% MP + K). It was on par with the treatments consisting the lower doses of MP. But it was significantly superior to the treatments consisting full dose of MP along with VAM and other nutrients (T_{12}) and also to T_1 (FYM + N +MP + K).

There were no significant differences among the treatments consisting of different doses of SP. However the highest P content was recorded by T_9. It was on par with T_{10} (VAM + FYM + N + 75% MP + K) and was significantly superior to the present package of practices recommendations (T_2). Plants inoculated with VAM fungi along with FYM alone recorded a P content of 0.25 per cent. It was on par with T_1 and T_2

Table 21 Effect of VAM and different sources and doses of P on NPK content of the shoot

Treatment	Shoot N content (%)	Shoot P content (%)	Shoot K content (%)
T_1 - FYM + N + MP + K	4.48[a]	0.20[cd]	3.45[a]
T_2 - FYM + N + SP + K	4.97[a]	0.23[cd]	3.90[a]
T_3 - VAM alone	4.34[a]	0.17[d]	3.82[a]
T_4 - VAM + FYM	4.06[a]	0.25[bcd]	3.60[a]
T_5 - VAM + FYM + N + K	4.97[a]	0.25[bcd]	3.65[a]
T_6 - VAM + FYM + N + 25 %MP+ K	4.55[a]	0.29[abc]	3.70[a]
T_7- VAM + FYM + N + 25 %SP+ K	4.48[a]	0.29[abc]	3.47[a]
T_8 - VAM + FYM + N + 50% MP + K	4.83[a]	0.29[abc]	3.05[a]
T_9- VAM + FYM + N + 50% SP + K	4.41[a]	0.34[ab]	3.45[a]
T_{10} - VAM + FYM + N + 75%M P + K	5.74[a]	0.37[a]	4.66[a]
T_{11}- VAM + FYM + N +75%S P+ K	4.76[a]	0.27[bc]	4.10[a]
T_{12}- VAM + FYM + N + M P+ K	5.59[a]	0.28[bc]	3.37[a]
T_{13}- VAM + FYM + N + S P+ K	5.32[a]	0.26[bcd]	3.32[a]
T_{14}- VAM + N + M P+ K	4.69[a]	0.22[cd]	3.25[a]
T_{15}- VAM + N + S P+ K	4.97[a]	0.23[cd]	3.47[a]

The values with different superscripts differ significantly at 5 % level

4.7.4.3 Potassium content

There were no significant differences among treatments in their effect on plant K content. (Table 21). However the maximum K content was recorded by the plants treated with T_{10} (VAM + FYM + N + 75% MP + K) followed by T_{11} - (VAM + FYM + N + 75% MP + K).

4.7.5 · Nutrient content of the soil

4.7.5.1 Nitrogen content of the soil

There were no significant differences among the treatments in their effect on soil nitrogen content (Table 22).

4.7.5.2 Phosphorus content

The data revealed that VAM inoculation along with different doses of P fertilizers differed significantly in their influence on soil phosphorus content (Table 22). The highest soil phosphorus content (148.1kg ha^{-1}) was recorded by the treatment T_9 (VAM + FYM + N + 50%SP + K). The soil phosphorus content recorded by T_{11} (VAM + FYM + N + 75%SP + K) and T_{13} (VAM + FYM + N + SP + K) were on par with T_9.The soil P content recorded by T_9 was on par with T_1 (FYM + N + M P+ K) and T_2 (FYM + N + SP + K). Among the treatments consisting of different doses of MP, there were no significant differences in soil P. The maximum soil P content of 131.1kg ha^{-1} was recorded by the treatment T_8 (VAM + FYM + 50% MP + K). The soil P content recorded by T_{10} was on par with that of T_8

4.7.5.3 Potassium content of the soil

There were significant differences among the different treatments in their effect on soil K content. The treatment T_9 (VAM + FYM + N + 50%SP +K) resulted in highest K content in soil (71.68 kg ha^{-1}). It was statistically on par withf T_{11} (VAM + FYM + N + 75%SP +K). Among the different treatments consisting of MP, the

Table 22 Effect of VAM and different sources and doses of P on NPK status of the soil

Treatment	N content of the soil (kg ha^{-1})	P content of the soil (kg ha^{-1})	K content of the soil (kg ha^{-1})
T_1 - FYM + N + MP + K	309.7	131.1 ^{abc}	61.2 ^{bcd}
T_2 - FYM + N + SP + K	327.6	129.7 ^{abcd}	57.12 ^{cd}
T_3 - VAM alone	299.0	115.6 ^{de}	52.08 ^{de}
T_4 - VAM + FYM	337.9	143.3 ^{ab}	63.28 ^{bcd}
T_5 - VAM + FYM + N + K	291.7	133.8 ^{abcd}	60.48 ^{bcd}
T_6 - VAM + FYM + N + 25 %MP+ K	316.7	116.6 ^{abcd}	56.62 ^{cde}
T_7- VAM + FYM + N + 25 %SP+ K	321.4	104.6 ^{a}	57.10 ^{cd}
T_8 - VAM + FYM + N + 50% MP + K	283.8	131.1 ^{abcd}	53.20 ^{de}
T_9- VAM + FYM + N + 50% SP + K	295.5	148.1 ^{a}	71.68 ^{abc}
T_{10} - VAM + FYM + N + 75%M P + K	316.0	122.52 ^{bcde}	58.80 ^{cd}
T_{11}- VAM + FYM + N +75%S P+ K	341.0	143.9 ^{ab}	68.32 ^{bcd}
T_{12}- VAM + FYM + N + M P+ K	285.4	125.2 ^{bcde}	39.20 ^{e}
T_{13}- VAM + FYM + N + S P+ K	319.1	133.0 ^{abcd}	52.08 ^{de}
T_{14}- VAM + N + M P+ K	313.5	130.6 ^{abcd}	57.12 ^{cd}
T_{15}- VAM + N + S P+ K	349.4	142.9 ^{ab}	54.32 ^{cd}
	NS		

The values with different superscripts differ significantly at 5 % level

highest soil P content (58.8%) was recorded by the treatment T_{10} and it was on par with T_1 (FYM + N + MP + K).

4.8 Influence of VAM on bacterial wilt incidence of tomato

The results of the field experiment conducted to study the influence of VAM inoculation on bacterial wilt incidence of tomato are presented below.

4.8.1 Wilt incidence

The influence of varieties, VAM inoculation and their interactions on wilt incidence is presented in Tables 23 and 24. There were significant differences among varieties in bacterial wilt incidence at one week after transplanting. Wilt incidence was found the highest in variety Pusa Ruby (11.20%) followed by Sakthi (3.59%). Wilt was not observed in variety BWR-1. The main effect of VAM inoculation showed significant difference between VAM inoculated and uninoculated plants in wilt incidence. The VAM inoculated plants recorded wilt incidence of (3.61%) as against (6.24%) in control.

The interaction effect showed statistical significance. There was significant difference in bacterial wilt incidence between inoculated and uninoculated plants of variety Sakthi at seven days after transplanting. There was no wilt incidence in VAM inoculated plants. But 7.18 per cent wilt was recorded in uninoculated plants of variety Sakthi. Bacterial wilt was not observed in variety BWR-1 at seven days after transplanting. Highest wilt incidence of 11.55 per cent was recorded in uninoculated plants of variety Pusa Ruby and there was no significant difference in wilt incidence between VAM inoculated and uninoculated plants.

There were significant differences among the varieties in wilt incidence at two weeks after transplanting (Table 23). The highest wilt incidence was recorded by the variety Pusa Ruby (45.49%) followed by BWR –1 (10.11%) and Sakthi (3.59%).

Table 23. Influence of VAM inoculation on bacterial wilt incidence

Treatments		Wilt incidence (%)		
		One week after transplanting	Two weeks after transplanting	Three weeks after transplanting
Variety (V)	Sakthi (V_1)	3.59 [b]	3.59 [b]	11.05 [b]
	BWR-1 (V_2)	0.00 [b]	10.11 [b]	14.81 [b]
	Pusa Ruby (V_3)	11.20 [a]	45.49 [a]	72.48 [a]
VAM inoculation (M)	M_0	6.24 [a]	21.15 [a]	34.55 [a]
	M_1	3.61 [b]	17.54 [b]	30.60 [b]
V x M	$V_1 M_0$	7.18 [b]	7.18 [a]	12.07 [a]
	$V_1 M_1$	0.0 [c]	0.0 [a]	10.02 [a]
	$V_2 M_0$	0.0 [c]	13.03 [a]	20.60 [a]
	$V_2 M_1$	0.0 [c]	7.18 [a]	9.03 [a]
	$V_3 M_0$	11.55 [ab]	45.52 [a]	72.20 [a]
	$V_3 M_1$	10.85 [a]	45.46 [a]	72.75 [a]

Values with different superscripts differ significantly at 5% level

The effect of VAM inoculation on wilt incidence showed statistical significance. In VAM inoculated plants wilt incidence was (17.54) as against 21.15% per cent in uninoculated plants. The interaction effect of varieties and VAM inoculation was not significant. At two weeks after transplanting wilt incidence was noticed in variety BWR-1 also. Incidence of bacterial wilt was recorded in both VAM inoculated and uninoculated plants of varieties BWR-1 and Pusa Ruby. Bacterial wilt recorded in uninoculated plants of variety Sakthi was 7.18 per cent. Bacterial wilt was not observed in VAM inoculated plants of variety Sakthi .

There were significant differences among varieties in wilt incidence at three weeks after transplanting (Table 23). The highest wilt incidence was recorded by Pusa Ruby (72.48%). No significant difference in wilt incidence was recorded between Sakthi (11.05%) and BWR-1 (14.81%). There was significant difference in wilt incidence recorded between VAM inoculated (30.60%) and uninoculated plants (36.59%). The interaction between varieties and VAM inoculation had no statistical significance. Even though there was no significant difference in wilt incidence recorded between VAM inoculated and uninoculated plants, the wilt incidence recorded was less in VAM inoculated plants of variety Sakthi (10.02 %) compared to uninoculated controls (12.07%). The wilt incidence recorded in VAM inoculated plants of variety BWR-1 was 9.03 per cent as against 20.60 per cent in uninoculated plants. There was no significant difference in wilt incidence recorded by the VAM inoculated and uninoculated plants of variety Pusa Ruby.

At four weeks after transplanting there was significant difference in wilt incidence recorded by different varieties (Table 24). The highest wilt incidence was recorded by Pusa Ruby (74.76%), followed by BWR –1 (32.49%) and Sakthi (13.45%). The main effect of VAM inoculation showed that there was significant difference in wilt incidence between VAM inoculated (38.76%) and uninoculated plants (41.71%). The interaction effects of varieties and VAM inoculation were not statistically significant. However, the wilt incidence in VAM inoculated plants of variety Sakthi (10.12%) was less compared to uninoculated plants (16.79%).

At five weeks after transplanting , there were significant differences among the varieties in wilt incidence (Table 24). The wilt incidence was maximum in Pusa Ruby (88.43%). BWR –1 recorded a wilt incidence of 39.85 per cent, which was on par with Sakthi (29.29%). Main effect of VAM inoculation showed statistical significance. Wilt incidence recorded by the uninoculated plants was 57.64 per cent as against 46.76 per cent in inoculated plants. The interaction effect between varieties and VAM inoculation showed statistical significance. There was significant difference in bacterial wilt incidence recorded by VAM inoculated and uninoculated plants of variety Sakthi. The per cent wilt incidence recorded by VAM inoculated plants of variety Sakthi (15.83%) was significantly less than the wilt incidence recorded by uninoculated plants (40.75%). There was no significant difference in bacterial wilt incidence observed in VAM inoculated and uninoculated plants of tomato variety BWR-1 and Pusa Ruby. However the wilt incidence recorded in mycorrhizal plants of variety BWR-1was less compared to uninoculated plants.

At six weeks after transplanting, there was significant differences among the varieties in their effect on wilt incidence (Table 24). The variety Sakthi recorded the lowest wilt incidence (32.94 %).The varieties BWR-1 and Pusa Ruby recorded 41.01 per cent and 99.38 per cent wilt respectively. The main effect of VAM inoculation showed that the inoculated plants recorded significantly less wilt incidence (51.54%) than uninoculated plants (63.98%). The interaction effects of varieties and VAM inoculation also showed statistical significance . There was significant difference in bacterial wilt incidence recorded between VAM inoculated and uninoculated plants of variety Sakthi. The wilt incidence observed in uninoculated plants of variety Sakthi was 48.25 per cent as against 17.62 per cent in VAM inoculated plants. Even though there was no significant difference, the wilt incidence recorded by the VAM inoculated plants of variety BWR-1 (38.33%) was less compared to uninoculated plants (43.70%). There was no significant difference between VAM inoculated and uninoculated plants of variety Pusa Ruby in wilt incidence.

Table 24. Influence of VAM inoculation on bacterial wilt incidence

Treatments		Wilt incidence (%)		
		Four weeks after transplanting	Five weeks after transplanting	Six weeks after transplanting
Variety (V)	Sakthi (V_1)	13.45 [c]	29.29 [b]	32.94 [b]
	BWR-1 (V_2)	32.49 [b]	39.85 [b]	41.01 [b]
	Pusa Ruby (V_3)	74.76 [a]	88.43 [a]	99.38 [a]
VAM inoculation (M)	M_0	41.71 [a]	57.64 [a]	63.98 [a]
	M_1	38.76 [b]	46.76 [b]	51.54 [b]
V x M	$V_1 M_0$	16.79 [bc]	40.75 [b]	48.25 [b]
	$V_1 M_1$	10.12 [c]	15.83 [d]	17.62 [c]
	$V_2 M_0$	32.48 [b]	43.06 [bc]	43.70 [bc]
	$V_2 M_1$	31.65 [b]	36.65 [c]	38.33 [c]
	$V_3 M_0$	75.52 [a]	89.13 [a]	100.00 [a]
	$V_3 M_1$	74.51 [a]	87.80 [a]	98.75 [a]

Values with different superscripts differ significantly at 5% level

4.8.2 Rhizosphere population of *Ralstonia solanacearum*(Smith)Yabuchi *et al.*

The effect of varieties, VAM inoculation and their interactions on rhizosphere population of *Ralstonia solanacearum* are presented in Tables 25 and 26. There were significant differences among varieties in their influence on *Ralstonia solanacearum* population at one week after transplanting (Table 25). The population of *Ralstonia solanacearum* was highest in variety Pusa Ruby (3.83 x 10^5 c.f.u g^{-1} soil) followed by BWR –1 (2.73 x 10^5 c.f.u g^{-1} soil) and Sakthi (2.4 x 10^5 c.f.u g^{-1}soil). VAM inoculation influenced the *Ralstonia solanacearum* population significantly. The rhizosphere population of *Ralstonia solanacearum* of VAM inoculated plants was 2.70 x 10^5 c.f.u g^{-1} soil as against 3.25 x 10^5 c.f.u g^{-1} soil in uninoculated plants. The interactions showed no statistical significance.

The main effect of varieties showed statistical significance on rhizosphere population of *Ralstonia solanacearum* at two weeks after transplanting (Table 25). The rhizosphere population of *Ralstonia solanacearum* was maximum in Pusa Ruby (6.56 x 10^5 c.f.u g^{-1} soil). VAM inoculation had no significant effect on bacterial population. The interactions were also not statistically significant.

The effect of varieties and VAM inoculation on rhizosphere population of *Ralstonia solanacearum* at three weeks after transplanting is presented in Table 25. There were significant differences among the varieties in rhizosphere population of *Ralstonia solanacearum.* The highest population of *Ralstonia solanacearum* was recorded by the variety Pusa Ruby (8.56 x 10^5 c.f.u g^{-1} soil). No significant difference in rhizosphere population of *Ralstonia solanacearum* was noticed between the varieties Sakthi and BWR–1. VAM inoculation had no significant effect on pathogen population. The interaction effects of varieties and VAM inoculation showed no statistical significance

The effect of varieties and VAM inoculation on population of *Ralstonia solanacearum* was statistically significant at four weeks after transplanting (Table

Table 25. Rhizosphere population of *Ralstonia solanacearum* as influenced by VAM inoculation

Treatments		Rhizosphere population of *Ralstonia solanacearum* (c.f.u x 10^5 g^{-1} soil)		
		One week after transplanting	Two weeks after transplanting	Three weeks after transplanting
Variety (V)	Sakthi (V_1)	2.40 [a]	2.45 [b]	3.16 [b]
	BWR-1 (V_2)	2.73 [b]	3.13 [b]	3.32 [b]
	Pusa Ruby (V_3)	3.83 [b]	6.56 [a]	8.56 [a]
VAM inoculation (M)	M_0	3.25 [a]	4.32 [a]	5.49 [a]
	M_1	2.70 [b]	3.78 [a]	4.54 [b]
V x M	$V_1 M_0$	2.65 [a]	3.03 [a]	3.97 [a]
	$V_1 M_1$	2.15 [a]	1.88 [a]	2.35 [a]
	$V_2 M_0$	3.15 [a]	3.55 [a]	3.73 [a]
	$V_2 M_1$	2.30 [a]	2.70 [a]	2.92 [a]
	$V_3 M_0$	3.97 [a]	4.38 [a]	6.8 [a]
	$V_3 M_1$	3.68 [a]	4.75 [a]	6.4 [a]

Values with different superscripts differ significantly at 5% level

26). The highest population of *Ralstonia solanacearum* was recorded by the variety Pusa Ruby (9.73 x 10^5 c.f.u g^{-1}soil). There was no significant difference in *Ralstonia solanacearum* population between the varieties Sakthi (3.73 x 10^5 c.f.u g^{-1} soil) and BWR-1 (4.15x 10^5 c.f.u g^{-1}soil). The main effect of VAM inoculation showed statistical significance. The inoculation of VAM resulted in reduction in *Ralstonia solanacearum* population (5.18 x 10^5 c.f.u g^{-1} soil) compared to uninoculated plants (6.28 x 10^5 c.f.u g^{-1} soil). Even though the interaction effects were not significant (Table 26), the VAM inoculated plants of varieties Sakthi and BWR-1 recorded low population of *Ralstonia solanacearum* compared to uninoculated control plants. The *Ralstonia solanacearum* population of VAM inoculated plants of Sakthi and BWR–1 were 3.15x10^5 c.f.u g^{-1} soil and 3.30x10^5 c.f.u g^{-1} soil respectively. Whereas, the *Ralstonia solanacearum* population of uninoculated plants of varieties Sakthi and BWR–1 were 4.30x10^5 c.f.u g^{-1} soil and 5x10^5 c.f.u g^{-1} soil respectively..

The varieties, VAM inoculation and their interaction were statistically significant in influencing rhizosphere population of *Ralstonia solanacearum* at five weeks after transplanting (Table 26). Among the varieties Pusa Ruby recorded maximum rhizosphere population of *Ralstonia solanacearum* (9.73 x 10^5 c.f.u g^{-1} soil). No significant difference between BWR –1 and Sakthi was noticed in rhizosphere population of *Ralstonia solanacearum*. The main effect of VAM inoculation showed statistical significance. The VAM inoculated plants recorded a rhizosphere population of 5.71 x 10^5 c.f.u g^{-1}soil as against 6.61 x 10^5 c.f.u g^{-1}soil in uninoculated plants. The interactions of varieties and VAM inoculation had significant influence on rhizosphere population of *Ralstonia solanacearum*. There was significant reduction in *Ralstonia solanacearum* population in VAM inoculated plants of variety Sakthi and BWR-1 compared to uninoculated plants. The VAM inoculated plants of variety Sakthi recorded a population of 3.47 x 10^5 c.f.u g^{-1} soil which was significantly less than that of uninoculated plants (5.37 x 10^5 c.f.u g^{-1} soil). The *Ralstonia solanacearum* population recorded by the VAM inoculated plants of variety BWR-1 was 3.77 x 10^5 c.f.u g^{-1} soil as against uninoculated plants 4.92 x 10^5 c.f.u g^{-1} soil.

Table 26. Rhizosphere population of *Ralstonia solanacearum* as influenced by VAM inoculation

Treatments		Rhizosphere population of *Ralstonia solanacearum* (c.f.u x 10^5 g^{-1} soil)	
		Four weeks after transplanting	Five weeks after transplanting
Variety (V)	Sakthi (V_1)	3.73 [b]	4.43 [b]
	BWR-1 (V_2)	4.15 [b]	4.35 [b]
	Pusa Ruby (V_3)	9.13 [a]	9.73 [a]
VAM inoculation (M)	M_0	6.28 [a]	6.61 [a]
	M_1	5.18 [b]	5.71 [b]
V x M	$V_1 M_0$	4.30 [a]	5.37 [b]
	$V_1 M_1$	3.15 [a]	3.47 [c]
	$V_2 M_0$	5.00 [a]	4.92 [b]
	$V_2 M_1$	3.30 [a]	3.77 [c]
	$V_3 M_0$	6.53 [a]	7.55 [a]
	$V_3 M_1$	6.10 [a]	6.90 [a]

Values with different superscripts differ significantly at 5% level

4.8.3 VAM root colonization

The effect of varieties, VAM inoculation and their interaction on root colonization is presented in Table 27. The main effects of verieties and VAM inoculation on root colonization showed statistical significance. The highest root colonization was recorded by the variety Sakthi (45.5%) followed by BWR –1 (34.13%). Pusa Ruby recorded the lowest root colonization (28.38%). The main effect of VAM inoculation showed statistical significance. The VAM root colonization recorded by inoculated plants was 66 per cent where as uninoculated plants recorded a root colonization of six per cent. The interaction effects of varieties and VAM inoculation also showed statistical significance. At the time of transplanting the per cent VAM colonization of uninoculated plants of variety Sakthi was 7.25. Where as the plants inoculated with VAM recorded a root colonization per cent of 83.25. The per cent root colonization in uninoculated plants of varieties BWR-1 and Pusa Ruby were 4.5 and 6.25 per cent respectively. The VAM inoculated plants of variety BWR-1 and Pusa Ruby recorded a colonization per cent of 63.75 and 50.25 respectively.

The effect of varieties, VAM inoculation and their interactions on VAM root colonization at five weeks after transplanting is presented in Table 27. The main effects of varieties and VAM inoculation showed statistical significance. The highest colonization was recorded by the variety Sakthi (57%). The varieties BWR – 1 and Pusa Ruby recorded VAM colonization percentage of 49.75 and 41.25 respectively. The interaction of varieties and VAM inoculation was also statistically significant. The uninoculated plants of variety Sakthi recorded a colonization per cent of 28 as against 86.5 per cent in inoculated plants. The per cent VAM colonization recorded by VAM inoculated plants of variety BWR-1 was 70 and that of Pusa Ruby was 60.5. But the uninoculated plants of varieties BWR – 1 and Pusa Ruby recorded a colonization per cent of 29.5 and 22 .0 respectively.

Table 27. Effect of VAM inoculation on root colonization

Treatments		VAM root colonization (%)	
		At the time of transplanting	Five weeks after transplanting
Variety (V)	Sakthi (V_1)	45.5 [a]	57.0 [a]
	BWR-1 (V_2)	34.13 [b]	49.75 [ab]
	Pusa Ruby (V_3)	28.38 [b]	41.25 [b]
VAM inoculation (M)	M_0	6.00 [b]	26.50 [a]
	M_1	66.00 [a]	72.17 [b]
V x M	$V_1 M_0$	7.25 [d]	28.0 [d]
	$V_1 M_1$	83.25 [a]	86.5 [a]
	$V_2 M_0$	4.50 [d]	29.5 [d]
	$V_2 M_1$	63.75 [b]	70.0 [b]
	$V_3 M_0$	6.25 [d]	22.0 [d]
	$V_3 M_1$	50.25 [c]	60.5 [c]

Values with different superscripts differ significantly at 5% level

4.8.4 Total phenol content

The effect of varieties, VAM inoculation and their interactions on the total phenol content of leaf and root are presented in Table 28.

4.8.4.1 Total phenol content of leaf

There were no significant differences among the treatments in their effect on total phenol content of the leaf. However the highest phenol content was recorded by the variety Pusa Ruby (3.70 mg g^{-1}). The variety Sakthi recorded the lowest phenol content of the leaf (2.95 mg g^{-1}). Even though there was no statistical significance the mycorrhizal plants recorded a higher leaf phenol content (3.50 mg g^{-1}) than the uninoculated plants (3.31 mg g^{-1}). The interaction effects showed no statistical significance in leaf phenol content.

4.8.4.2 Total phenol content of the root

There were significant differences among the varieties in root phenol content. The variety BWR-1 recorded the maximum root phenol content (1.75 mg g^{-1}). The root phenol content was lowest in the variety Sakthi (0.37 mg g^{-1}). The effect of VAM on root phenol content showed no statistical significance. But the total phenol content of mycorrhizal plant (0.93 mg g^{-1}) was slightly higher than uninoculated control (0.89 mg g^{-1}). The interaction effect showed no statistical significance.

4.8.5 Biometric characters

The biometric observations, VAM colonization and rhizosphere spore count were recorded at 90 days after transplanting. By this time the variety Pusa Ruby was completely wilted . So the observations were recorded only for the varieties

Table 28. Effect of VAM inoculation on total phenol content

Treatments		Total phenol content (mg g^{-1} of tissue)	
		Leaf	Root
Variety (V)	Sakthi (V_1)	2.95 [a]	0.37 [b]
	BWR-1 (V_2)	3.56 [a]	1.75 [a]
	Pusa Ruby (V_3)	3.70 [a]	0.59 [a]
VAM inoculation (M)	M_0	3.31 [a]	0.89 [a]
	M_1	3.50 [a]	0.93 [a]
V x M	$V_1 M_0$	2.80 [a]	0.40 [a]
	$V_1 M_1$	3.09 [a]	0.35 [a]
	$V_2 M_0$	3.44 [a]	1.66 [a]
	$V_2 M_1$	3.69 [a]	1.89 [a]
	$V_3 M_0$	3.68 [a]	0.63 [a]
	$V_3 M_1$	3.72 [a]	0.57 [a]

Values with different superscripts differ significantly at 5% level

Sakthi and BWR-1. The data on biometric characters are presented in Tables 29, 30 and 31.

4.8.5.1 Shoot fresh weight

The influence of varieties, VAM inoculation and their interactions on shoot fresh weight is presented in Tables 29. The main effect of varieties showed statistical significance. VAM inoculation had significant influence on shoot fresh weight. The inoculated plants recorded a shoot fresh weight of 149.28 g as against 124.90 g in uninoculated plants. Even though there were no significant differences among the treatments, the mycorrhizal plants of both the varieties recorded more fresh weight compared to uninoculated plants. The shoot fresh weight recorded by the uninoculated plants of varieties Sakthi and Pusa Ruby were 100 g and 157g respectively. Whereas the mycorrhizal plants of these varieties recorded shoot fresh weight of 127.5 g and 187.0 g respectively.

4.8.5.2 Shoot dry weight

The influence of varieties, VAM inoculations and their interactions on shoot dry weight are presented in Table 29. The main effects were not statistically significant. However the shoot dry weight recorded by the VAM inoculated plants was 20.06g as against 15.15g in uninoculated control. The interaction effects also showed no statistical significance. However the inoculated plants of variety Sakthi recorded the highest shoot dry weight (20.76 g). The shoot dry weight recorded by the VAM inoculated plants of BWR –1 was 19.36 g. The uninoculated plants of the varieties Sakthi and BWR –1 recorded a shoot dry weight of 17.11 g and 13.19 g respectively.

Table 29. Effect of VAM inoculation on fresh and dry weight of shoot

Treatments		Shoot fresh weight (g)	Shoot dry weight (g)
Variety (V)	Sakthi (V_1)	112.72 [a]	18.94 [a]
	BWR-1 (V_2)	163.28 [a]	16.28 [a]
VAM inoculation (M)	M_0	124.90 [b]	15.15 [a]
	M_1	149.28 [a]	20.06 [a]
V x M	$V_1 M_0$	100.0 [a]	17.11 [a]
	$V_1 M_1$	127.5 [a]	20.76 [a]
	$V_2 M_0$	157.0 [a]	13.19 [a]
	$V_2 M_1$	187.0 [a]	19.36 [a]

Values with different superscripts differ significantly at 5% level

4.8.5.3 Root fresh weight

There were no significant effect of varieties, VAM inoculation and their interactions on root fresh weight (Table 30). The VAM inoculated plants recorded slightly higher root fresh weight (17.25 g) than uninoculated control (14.73 g). The interaction effect showed that, the mycorrhizal plants of variety Sakthi recorded a root fresh weight of 21.0 g as against 16.9 g in uninoculated control.

4.8.5.4 Root dry weight

The main effect of varieties showed statistical significance. The root dry weight of variety Sakthi (3.5 g) was significantly superior to BWR-1 (1.79 g). There was no significant difference between VAM inoculated and uninoculated plants in root dry weight (Table 30). Even though the main effect was not statistically significant the VAM inoculated plants had higher root dry weight (3.10 g) compared to uninoculated plants. The interaction effect showed that the mycorrhizal plants of the variety Sakthi recorded higher value for root dry weight (4.43 g) compared to in uninoculated control (2.58g).

4.8.5.5 Fruit yield

The influence of varieties, VAM inoculation and their interactions showed statistical significance (Table 31). The main effect of varieties showed that there was significant difference between varieties in yield. The variety Sakthi recorded an yield of 5.64 kg plot $^{-1}$ as against 3.59 kg plot $^{-1}$ in BWR-1. The main effect of VAM inoculation revealed a significant positive influence on yield. The mycorrhizal plants recorded a yield of 5.13 kg plot $^{-1}$ as against 4.09 kg plot $^{-1}$ in uninoculated plants. The interactions between varieties and VAM inoculation were statistically significant. The yield recorded in uninoculated plants of Sakthi was 4.7 kg per plot $^{-1}$, whereas the yield obtained in VAM inoculated plants was 6.75 kg plot^{-1}. There was no

Table 30. Effect of VAM inoculation on fresh and dry weight of root

Treatments		Root fresh weight (g)	Root dry weight (g)
Variety (V)	Sakthi (V_1)	18.45 [a]	3.50 [a]
	BWR-1 (V_2)	13.51 [a]	1.79 [b]
VAM inoculation (M)	M_0	14.73 [a]	2.18 [a]
	M_1	17.25 [a]	3.10 [a]
V x M	$V_1 M_0$	16.90 [a]	2.58 [a]
	$V_1 M_1$	21.00 [a]	4.43 [a]
	$V_2 M_0$	13.52 [a]	1.78 [a]
	$V_2 M_1$	13.50 [a]	1.80 [a]

Values with different superscripts differ significantly at 5% level

significant difference between VAM inoculated uninoculated plants of variety BWR-1 in yield.

4.8.6 Nutrient content of the shoot

The N P K content of the shoot was analysied at 90 days after transplanting and data are presented in Table 31.

4.8.6.1 Phosphorus content of the shoot

The main effects and interactions effects of varieties and VAM inoculation on phosphorus content showed statistical significance. The shoot P content of variety Sakthi was 3.5 per cent, which was significantly higher than that of BWR–1 (1.78 %). The VAM inoculation had resulted in significantly higher shoot P content (3.11 %) than that of uninoculated plants (2.18 %). The interaction effect of varieties and VAM inoculation also showed statistical significance.The inoculated plants of variety Sakthi recorded a P content of 4.43 per cent. It was significantly higher than that of uninoculated control (2.58%). The shoot P content of VAM inoculated and uninoculated plants of variety BWR –1 showed no significant difference.

4.8.6.2 Nitrogen content of the shoot

The effect of varieties, VAM inoculation and their interactions on N content of shoot are presented in Table 31. There were no significant differences among treatments in their effect on plant nitrogen content.

4.8.6.3 Potassium content of the shoot

The effect of varieties, VAM inoculation and their interactions had no statistical significance on shoot K content Table 31. Even though there was no significant differences, the interaction effects showed that, the K content recorded by

Table 31. Effect of VAM inoculation on fruit yield and NPK content of the shoot

Treatment		Fruit yield (kg plot $^{-1}$)	P content of the shoot (%)	N content of the shoot (%)	K content of the shoot %)
Variety (V)	Sakthi (V_1)	5.64 [a]	3.50 [a]	4.29 [a]	2.34 [a]
	BWR-1 (V_2)	3.59 [b]	1.78 [b]	4.88 [a]	3.11 [a]
VAM inoculation (M)	M_0	4.09 [b]	2.18 [b]	4.40 [a]	2.49 [a]
	M_1	5.13 [a]	3.11 [a]	4.77 [a]	2.96 [a]
V x M	$V_1 M_0$	4.70 [b]	2.58 [b]	4.25 [a]	2.18 [a]
	$V_1 M_1$	6.75 [a]	4.43 [a]	4.34 [a]	2.50 [a]
	$V_2 M_0$	3.47 [c]	1.78 [b]	4.55 [a]	2.80 [a]
	$V_2 M_1$	3.70 [bc]	1.80 [b]	5.21 [a]	3.43 [a]

Values with different superscripts differ significantly at 5% level

the varieties Sakthi (2.5 %) and BWR – 1 (3.43 %) were higher than the uninoculated plants.

4.8.7 VAM root colonization

The main effect of varieties, VAM inoculation and their interaction effects on VAM root colonization were statistically significant (Table 32). The VAM colonization recorded by the variety Sakthi was 49.63 per cent as against 42.25 per cent in BWR –1. The VAM inoculation had positive influence on root colonization. Inoculated plants recorded a colonization per cent of 69.25 where as the uninoculated plants recorded 22.5 per cent colonization. The root colonization of VAM in the inoculated plants of variety Sakthi was 76.25 where as uninoculated plants recorded a root colonization per cent of 23. The root colonization per cent of uninoculated plants of variety BWR-1 was 22.0 as against 62.5 in VAM inoculated plants.

4.8.8 VAM spore count in the rhizosphere soil

The VAM spore count in the rhizosphere soil is presented in Table 32. The main effect of varieties showed no statistical significance. But the spore count recorded by the variety Sakthi was higher (193.25) than that of BWR-1 (159.63). The main effect of VAM inoculation showed that inoculation resulted in significantly higher spore count (289.13) than that of uninoculated plants (64.00). The interaction effects were also significant. The spore count in the rhizosphere soil of VAM inoculated plants of variety Sakthi was 322.5, whereas the spore count in the rhizosphere soil of uninoculated plant was 63.75. The rhizosphere spore count in the uninoculated plants of variety BWR-1 was 63 as against 235 in inoculated plants. The spore count recorded by the inoculated plants of variety Sakthi (322.50) was significantly higher than that recorded by the variety BWR-1 (235).

Table 32 Effect of VAM inoculation on spore count and root colonization

Treatments		VAM root colonization (%)	Spore count 50 g^{-1} soil
Variety (V)	Sakthi (V_1)	49.63 [a]	193.25 [a]
	BWR-1 (V_2)	42.25 [b]	159.63 [a]
VAM inoculation (M)	M_0	22.50 [b]	63.75 [b]
	M_1	69.25 [a]	289.13 [a]
V x M	$V_1 M_0$	23.00 [c]	64.00 [c]
	$V_1 M_1$	76.25 [a]	322.50 [a]
	$V_2 M_0$	22.00 [c]	63.00 [a]
	$V_2 M_1$	62.50 [b]	235.00 [b]

Values with different superscripts differ significantly at 5% level

5. DISCUSSION

The possibility of using VAM fungi for increasing crop production has been receiving considerable attention. But the obligate nature of VAM fungi hinders its large scale utilisation. Hence at present and till suitable methods are developed for mass multiplication, the best way to utilise VAM could be to concentrate on nursery raised crops where colonization can be brought in the nursery. This method has been successfully demonstrated in woody plant species like apple (Plenchette *et al.*, 1981) and vegetables like chilli (Bagyaraj and Sreeramulu, 1982, Sreeramulu and Bagyaraj, 1986 and Sreenivasa, 1992). Since tomato being a transplanted crop, it is practicable to raise mycorrhizal seedlings in the nursery.

5.1 Survey and collection of VAM associated with tomato

A survey was carried out and VAM fungi associated with tomato were collected from 15 locations of Kerala. The root colonization of VAM fungi and rhizosphere spore count in these locations were recorded. There was variation in VAM root colonization and rhizosphere spore count among the survey locations. The VAM root colonization ranged from 19.4 to 35.4 per cent. (Fig. 1). Such variations in VAM root colonization and spore count in cowpea among different locations of Thrissur District of Kerala was reported by Beena (1999). Vijayakumar *et al.* (2000) also reported the association of VAM fungi belonging to the genera *Acaulospora* and *Glomus* in tomato in Andrapradesh. They observed that VAM root colonization varied from 75 to 90 per cent. The rhizosphere spore count in these locations ranged from 18.4 to 49 per 50 g of soil. The maximum spore count was recorded at Eruthempathi, Palakkad. (Fig.2).

5.2. Spore characters

The spore characters studied, *viz.* size, shape, colour, surface texture and hyphal attachment. Predominant spores found in the survey locations showed the

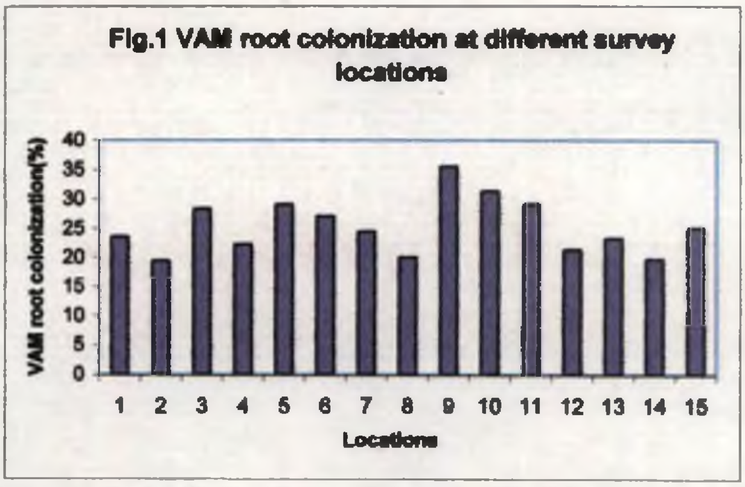


Fig.1 VAM root colonization at different survey locations
VAM root colonization(%)
0
5
10
15
20
25
30
35
40
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Locations

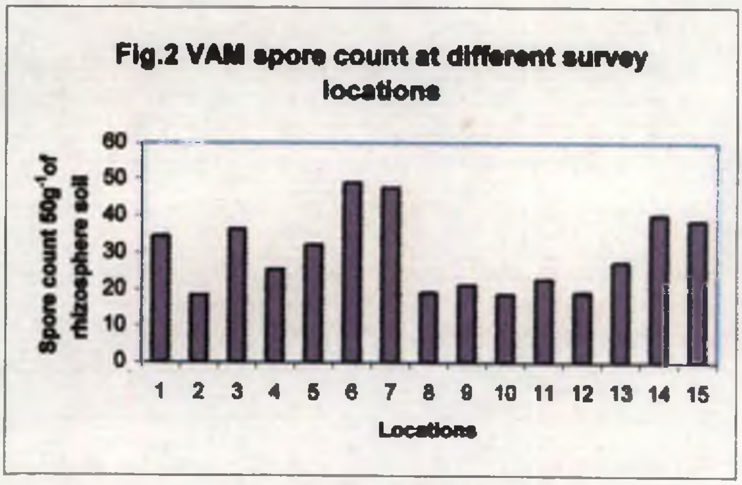


Fig.2 VAM spore count at different survey locations
Spore count 50g-1 of rhizosphere soil
0
10
20
30
40
50
60
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Locations

Fig. 3 Effect of VAM on shoot dry weight

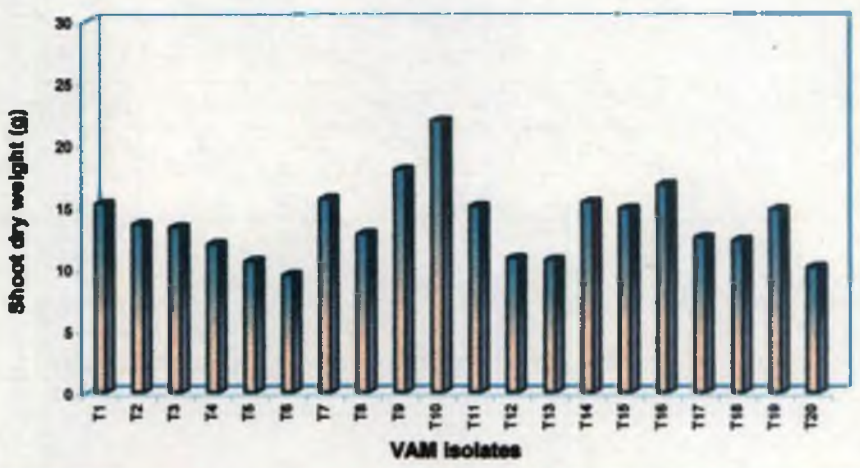
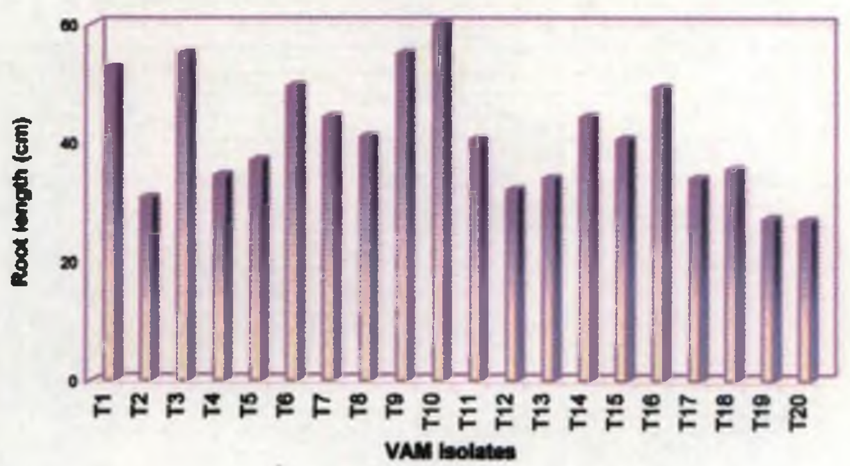


Fig.4 Effect of VAM on root length



characters in conformity with those described for *Glomus* sp. (Trappe, 1982 and Morten and Benny, 1990)

5.3. Screening the efficiency of VAM fungi in tomato

Fifteen native isolates and four standard cultures of VAM fungi, viz. *Glomus fasciculatum, Glomus mosseae, Glomus intraradices and Gigaspora margarita* were screened along with an uninoculated control for their efficiency in improving nutrient uptake, growth and yield of tomato in a pot culture experiment. The results of the study bring out clearly that tomato plants respond well to mycorrhizal inoculation. Inoculated plants had significantly higher amounts of nutrient content especially P in shoot and had better growth and yield compared to uninoculated control. The extent of response to inoculation varied with different VAM fungi. Few other studies also indicated the variation among VAM fungi in their ability to enhance nutrient uptake and plant growth (Vinayak and Bagyaraj, 1990 and Reena and Bagyaraj, 1990). The variation in response of tomato to different VAM fungi was reported earlier by Fairweather and Parbery (1982), Mallesha *et al.* (1994), Edathil *et al.* (1996) and Iqbal and Mahmood (1998).

The isolate of *Glomus* sp. collected from Eruthempathy, Palakkad district (T_{10}) ranked first in improving the nutrient uptake, growth and yield of tomato compared to control, followed by T_9 and T_{15}. The inoculation of this isolate resulted in significant increase in growth parameters viz. plant height (36.36 %) root length (127.7%), root volume (7.95%), shoot fresh weight (180.4%), shoot dry weight (116.94%), root fresh weight (202.5%), root dry weight (99.22%) and yield (209.87%) compared to uninoculated control (Table 7-9). Earlier the superiority of *Glomus leptoticum* in enhancing growth and yield of tomato was reported by Mallesha *et al.* (1994). In another screening trial conducted by Iqbal and Mahmood (1998), *Glomus mosseae* was found to be the best in enhancing the growth and yield of tomato. The isolate T_{10} was significantly superior to all other isolates in improving the shoot biomass (Fig.3) and root biomass, root length (Fig.4) and root volume and yield (Fig.5). The improvement of nutrient uptake and yield of tomato by inoculation with mycorrhizal fungi was reported by many other workers (Fairweather and Parbery, 1982, Mohandas, 1987, Khaliel, 1993, Mallesha *et al.*, 1994 and Iqbal and Mahmood, 1998).

VAM fungi are known to improve plant growth mainly through increased uptake of P and other nutrients (Plenchette *et al.*, 1981; Abbott and Robson, 1982; Jeffries, 1987 and Sreenivasa, 1992). In the present study, the inoculation of VAM increased the nutrient uptake of tomato. Inoculation of the isolate T_{10} resulted in increased content of P (0.52%), K (4.23 %) and Ca (1.66%) which were significantly superior to control (Fig. 6). Even though, there was no significant increase, nitrogen content of the plants inoculated with T_{10} (4.34 %) was more than that of control plants. Mohandas (1987) reported an increase in N and K content in tomato shoot due to VAM inoculation. Increased P content in shoot of tomato due to VAM inoculation was reported by Mallesha *et al.* (1994), Edathil *et al.* (1996) and also Iqbal and Mahmood (1998). Increased calcium content of mycorrhizal plants of apple was reported by Mosse (1957). Pai *et al.* (1994) recorded increased Ca content of cowpea plants inoculated with *G.fasciculatum.* Sitaramaiah *et al.* (1998) obtained increased uptake of Ca due to VAM inoculation in maize.

The extent of VAM colonization varied with different VAM fungi (Fig.7). The highest root colonization was recorded by plants inoculated withT_{10} (96.75%), followed by T_9 and T_{15}. Higher root colonization allows more contact between VAM fungi and host plant and exchange of nutrients, which ultimately helps in better plant growth (Abbott and Robson, 1982). The present study also shows the host preference by VAM fungi confirming the view of Bagyaraj *et al.*, (1989) Mallesha *et al.* (1994) and Reddy *et al.* (1996). The spore count in the rhizosphere soil was the highest in plants inoculated with T_{10} (270 per 50 gram of soil). followed by T_9 and T_7 (Fig.7). The per cent mycorrhizal colonization and VAM spore count in the rhizosphere soil were highest in plants inoculated with the isolate T_{10} bringing out a correlation

Fig. 5 Effect of VAM on fruit yield

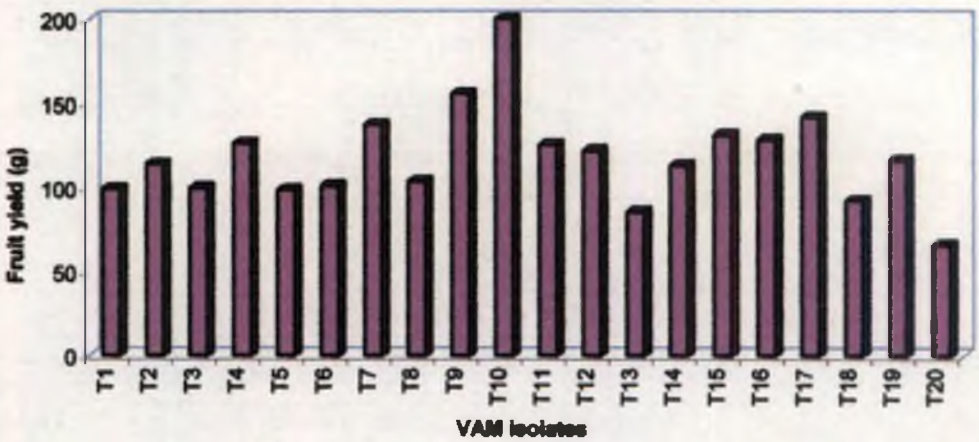


Fig.6 Effect of VAM on phosphorus, potassium and calcium content of shoot

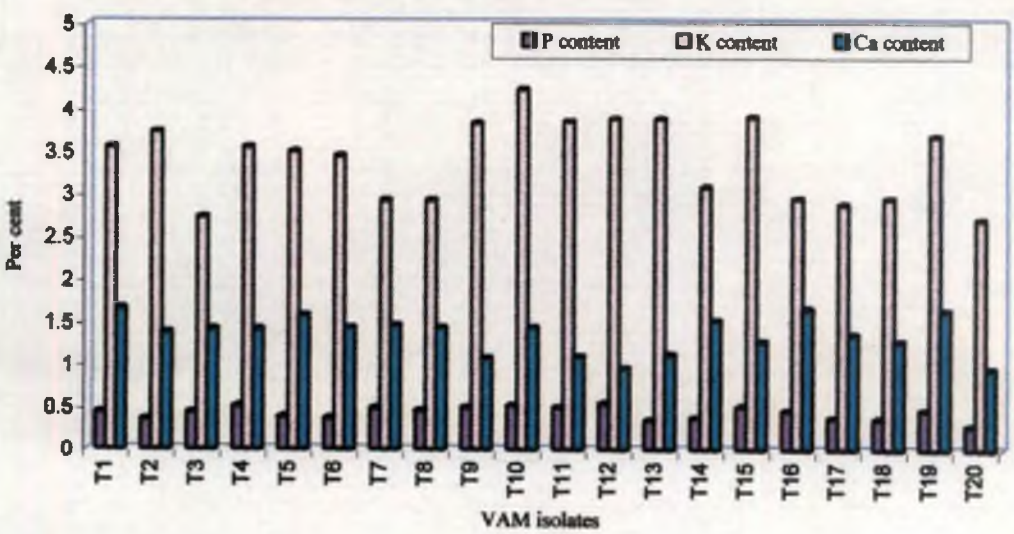


Fig.7 Effect of VAM on spore count and root colonization

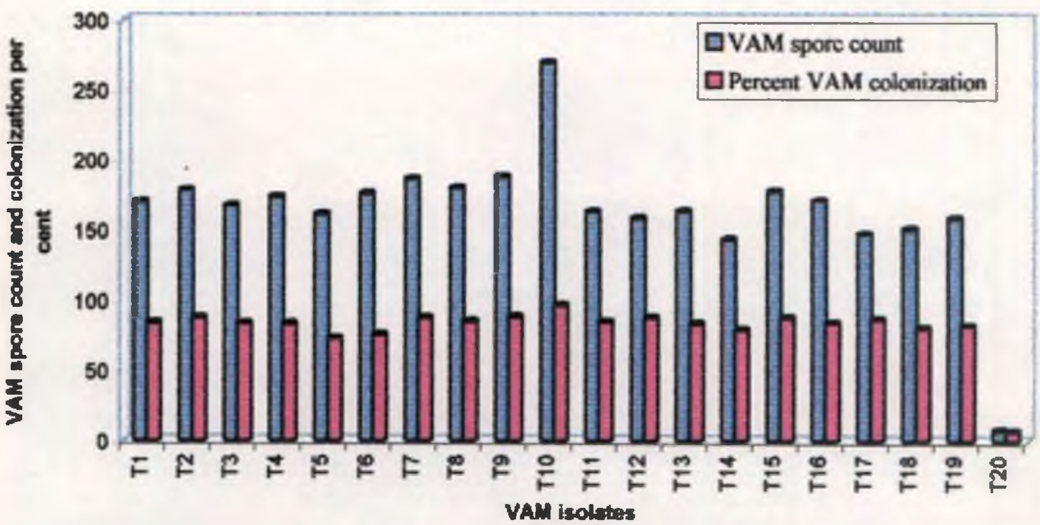
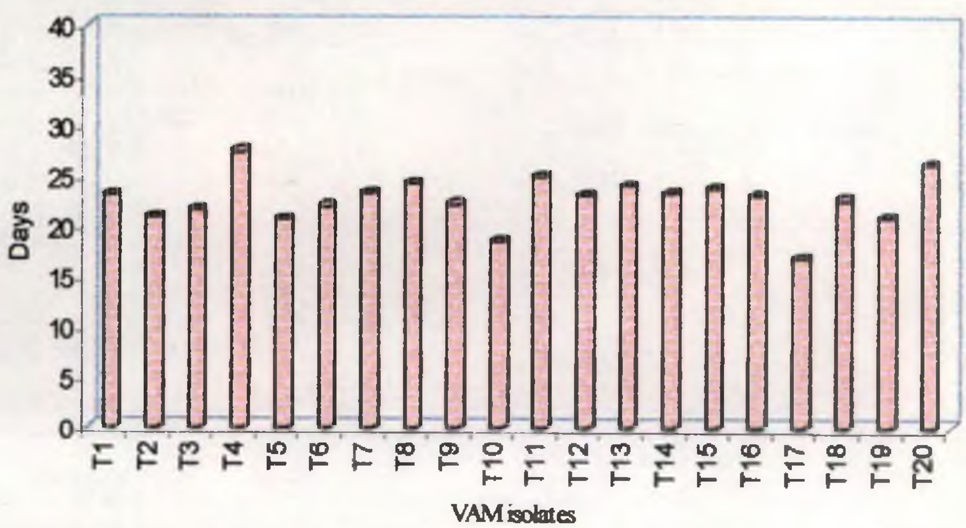


Fig.8 Effect of VAM on days to flowering



between intensity of mycorrhization and plant response as reported by earlier workers. (Mallesha *et al.*, 1994 and Reddy *et al.* 1996).

It was observed that, plants inoculated with VAM isolates T_{17} and T_{10} flowered early. The flowering was induced nine days and seven days earlier in plants inoculated with the isolates T_{17} and T_{10} respectively (Fig.8). Early flowering in Petunia (Daft and Okusanya, 1973), chilli (Bagyaraj and Sreeramulu, 1982), and musk melon (Cheng *et al.*, 1993) due to mycorrhizal inoculation has been observed earlier. The ascorbic acid content of the fruits was also showed an increase in mycorrhizal plants (Fig 9). The isolate T_{10} showed significant increase in the ascorbic acid content of the fruit compared to control. Increased ascorbic acid content of the chilli fruits in mycorrhizal plants was earlier reported by Bagyaraj and Sreeramulu (1982).

Bagyaraj *et al.* (1989) reported that species and strains of VAM fungi have differed to the extent by which they increase nutrient uptake and plant growth. Hence, some researchers suggested the need for selecting efficient VAM fungi that can be used for inoculating different plants. (Abbott and Robson, 1982, Bagyaraj *et al.*, 1989). In the present study also the response of tomato variety Sakthi varied with VAM fungi. Giving more weightage to per cent colonization, plant biomass, P nutrition and yield the most efficient VAM fungi for inoculating tomato found in the screening trial was the local isolate of *Glomus* sp collected from Eruthaempathi of Palakkad District. It was followed by the local isolates T_9 and T_{15} (isolates from Padanakkad, Kasaragod District and from Sultansbattery, Wyanad District).

5.4 Colonization pattern of VAM

Root colonization was observed at 10^{th} day after sowing and increased with age of the plant. Root colonization reached a peak at 50 days after sowing (Fig.10). Upto 60 days the root colonization remained almost same without much reduction. Further it declined and reached minimum at 90 days after sowing. Edathil *et al.*

Fig.9 Effect of VAM on ascorbic acid content of the fruit

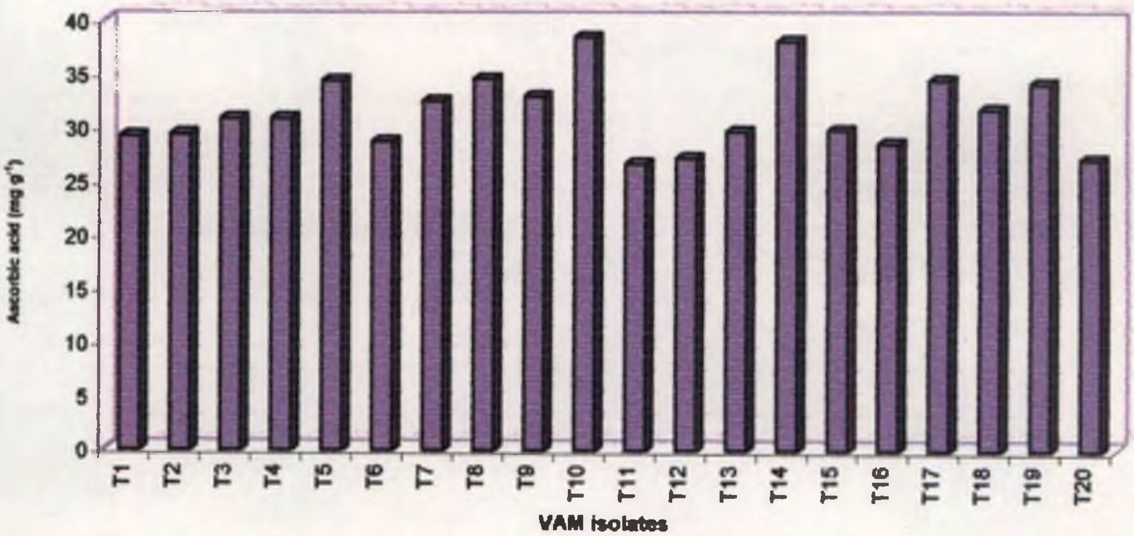
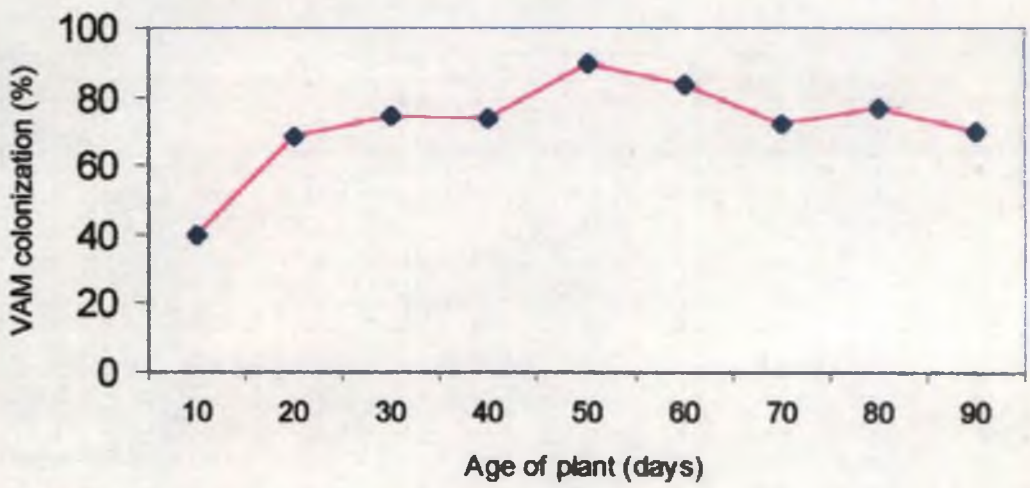


Fig.10 VAM colonization pattern



(1994) reported an increase in VAM colonization with increase in exposure period to VAM prior to transplanting upto 30 days. Beena (1999) also observed an increase in VAM colonization in cowpea with increase in age of the plant. Colonization reached the maximum at 40 days after sowing and remained without much reduction upto 50 days after sowing. Further root colonization decreased to minimum at 60 days after sowing.

5.5 Light microscopy of VAM colonization

Light microscopic studies revealed the presence of VAM hyphal colonization in the root cortex at 10 days old seedlings. Arbuscules were found only in the early stages. Further they started disintegration and vesicles were formed. Arbuscules were observed in root of 10 days old seedlings itself. At this stage no vesicles were found. At 20 days, both these structures were observed. But only vesicles were observed in late stage. The similar observations were made by Schmid and Oberwinkler (1995) and Beena (1999) in cowpea.

5.6 Evaluation of selected VAM fungi for their efficiency in economising the phosphorus fertilizer

The inoculation of different crop plants with VAM fungi is being investigated because of the possibility of saving phosphorus fertilizer and improving plant growth. Three isolates of VAM selected from the screening trial (T_{10}, T_9 and T_{15}) were used in this pot culture experiment. The study revealed that the tomato plants responded well to VAM inoculation and the extent of response varied with isolate and with the level of P fertilizer.

The isolate collected from Eruthempathi (M_1), was found best in improving root colonization, growth, uptake of P and yield confirming the results of screening trial. Inoculation of this isolate resulted in the highest root colonization (Fig. 11). which was 174.84 per cent more than that of control.

Fig.11 Influence of VAM isolates on root colonization

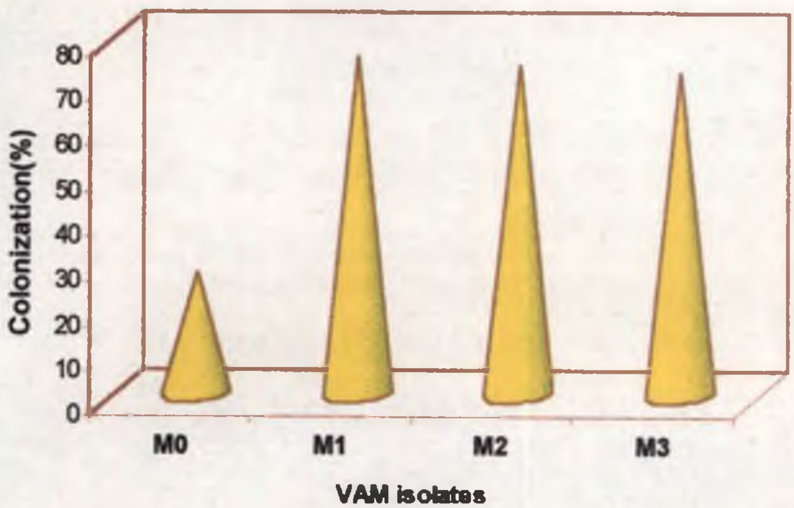
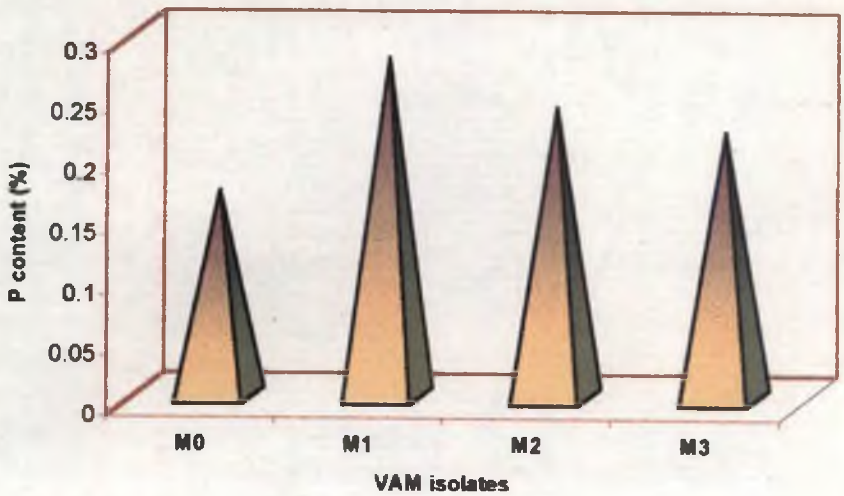


Fig. 12 Influence of VAM Isolates on shoot P content



Inoculation of the isolate (M_I) resulted in 25 per cent increase in shoot dry weight, 53.45 per cent increase in root dry weight, 64 per cent increase in shoot P content and 23 per cent increase in yield (Table 13 and 15). The shoot P content was increased by 64 per cent due to the inoculation of this isolates (Fig. 12).

The interaction effects revealed that, with the increase in dose of phosphorus upto 50 per cent of the recommended dose, the VAM inoculation resulted in significant increase in root colonization, growth characters, phosphorus content and yield. No further significant increase in these parameters were recorded with increase in dose of P upto 100 per cent.

With the increase in dose of P, there was increase in root colonization upto 75 per cent of the recommended dose (Table 16). But the root colonization recorded at 75 per cent of the dose of P was statistically on par with that recorded at 50 per cent level. There was significant reduction in root colonization compared to the lower dose when full dose of P was applied.

There are several reports showing that increasing rates above moderate levels of soluble phosphate fertilizer usually decreases the mycorrhizal colonization. (Krishna and Bagyaraj, 1982; Hirata *et al*, 1988). Majjigudda and Sreenivasa (1996) reported that VAM colonization in wheat was increased with increase in P levels upto 75 per cent of the recommended dose. Kashappanavar and Sreenivasa (2000) reported a decrease in VAM root colonization in onion with the increase in P fertilizer. The highest root colonization was recorded at 75 per cent P level. Valentine *et al.* (2001) reported a similar trend of reduction in VAM root colonization in cucumber with increase in P concentrations. According to Barea (1991) the amount of external mycelium, the density of arbuscular development and the number of entry points may be reduced by high levels of added P. Amijee *et al.* (1989) suggested that the major rate limiting step for colonization due to P additions is probably the formation of entry points.

The overall growth of mycorrhizal plants were superior to that of uninoculated plants. It is evident that maximum beneficial effect of mycorrhizal symbiosis is achieved at lower levels of applied P. With the increasing levels of P, increase in shoot fresh weight, shoot dry weight, root dry weight and yield were achieved due to VAM inoculation. But there were no significant differences in these parameters among 50, 75 and 100 per cent of the recommended dose of P. The inoculation of VAM isolate M_1 resulted in a shoot fresh weight of 154.8g shoot dry weight of 19.66 g, root dry weight of 6.34 g and yield of 367.3 g at 50 per cent of the recommended dose of P which were on par with shoot fresh weight of 153.9 g, shoot dry weight of 19.98 g, root dry weight of 6.15 g and yield of 312.4 g recorded at 100 per cent of the recommended dose of P (Table 14 and 16).

Significant increase in shoot P content was resulted due to VAM inoculation. The plants inoculated with the isolate M_1 resulted in the highest P content (0.28%) which was significantly superior to all other isolates (Table 16). The shoot P content of the plants inoculated with the isolate M_1 increased with increase in P level upto 75 per cent. But the P content recorded by the plants at this level of P was statistically on par with that of plants, which received 50 per cent dose of P. The difference in P content was more prominent at low levels of added P. This can be attributed to high affinity of mycorrhizal roots to P compared to nonmycorrhizal roots. While at high levels of added P affinity for P is similar in mycorrhizal and nonmycorrhizal plants.

Sreenivasa *et al.* (1993) reported a similar trend of increase in shoot dry weight and fruit yield of chilli due to VAM inoculation with the increase in the dose of phosphorus fertilizer upto 50 per cent of the recommended dose. Bagyaraj and Sreeramulu (1982) and Sreeramulu and Bagyaraj (1986) also obtained a higher yield of chilli due to inoculation of VAM along with half the recommended dose of P than that of plants given full dose of P.

The overall results of the present study revealed that the inoculation of local isolate of VAM (M_1) was found promising in improving growth, P content and yield of tomato. Further, the results suggests the possibility of reducing the application of phosphorus fertilizer through the inoculation of efficient strains of VAM fungi to the tune of half.

5.7 Influence of VAM fungi on nutrient uptake, growth and yield of tomato

Pot culture trials have proved beyond doubt that plants do respond to inoculation with efficient strains of VAM. Field results showing a clear yield response to inoculation with VAM are scanty (Tinker, 1980). The results of the field experiment to study the effect of VAM inoculation on growth, nutrient uptake and yield of tomato showed that tomato plants responded well to inoculation with the local isolate of *Glomus* sp collected from Eruthempathi, Palakkad District. The plants inoculated with mycorrhizal fungi had higher root colonization and spore production in the rhizosphere soil compared with these characters produced by native endophytes in the uninoculated plants (Table 20).

VAM colonization increased with increase in dose of P upto 50 per cent when SP was used and decreased there after (Fig.13). The rhizosphere spore count also showed a similar trend. The spore count increased with increase in P levels upto 50 per cent (T_9). Further there was a reduction. When MP was used there was gradual increase in VAM colonization upto 75 per cent of the P (T_{10}). The VAM spore count in the rhizosphere soil was more in plants which received 75 per cent of MP. But it was statistically on par with that recorded by the plants, which received full dose of MP.

The results indicated that irrespective of the form of P used, the VAM colonization and spore count were less at higher levels compared to the lower doses of phosphorus. The high availability of P might have depressed VAM development at the higher doses of P fertilizers. Bagyaraj and Powell (1985) also support this view.

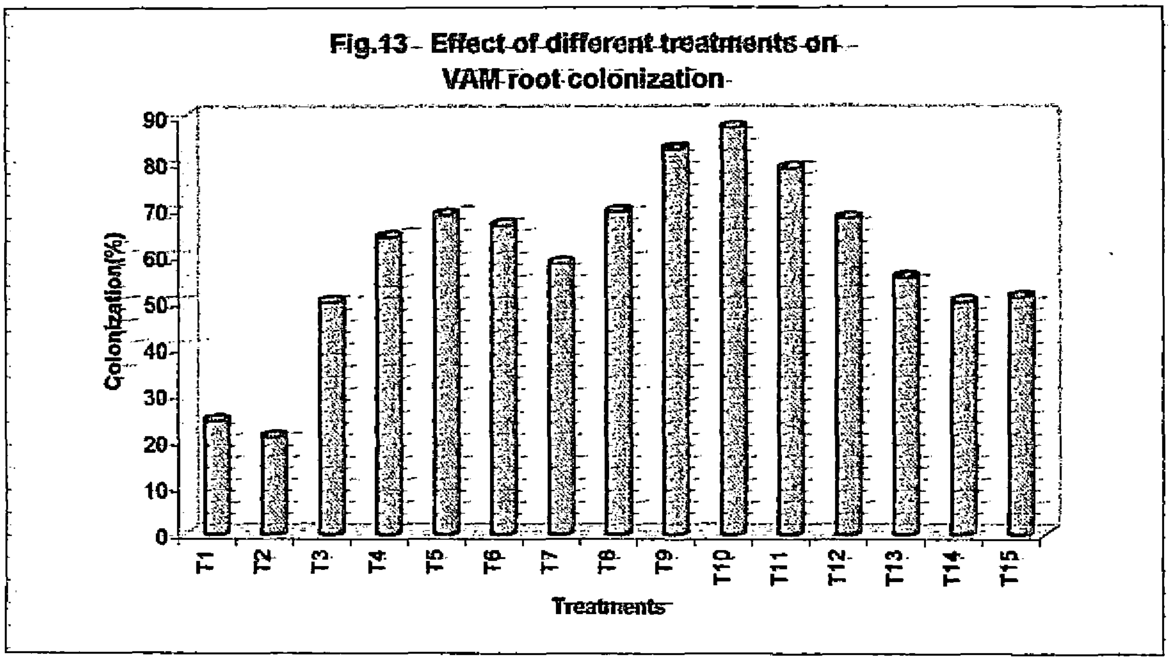


Fig.13 - Effect of different treatments on VAM root colonization
Colonization(%)
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
T12
T13
T14
T15
Treatments

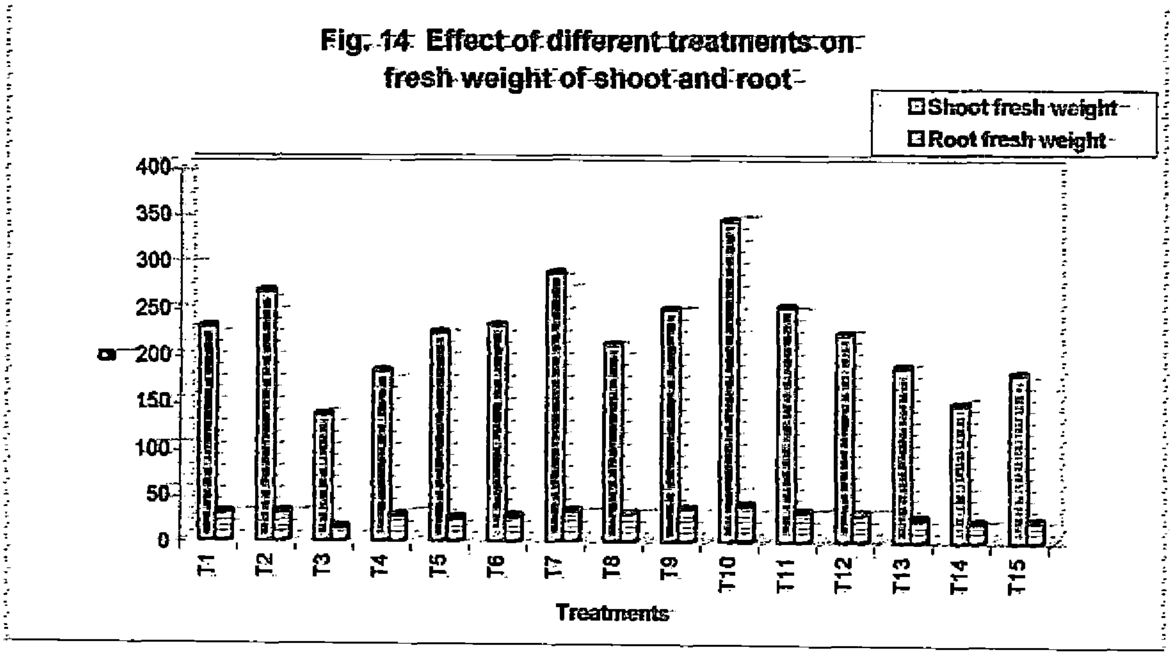


Fig. 14 Effect of different treatments on fresh weight of shoot and root
Shoot fresh weight
Root fresh weight
g
400
350
300
250
200
150
100
50
0
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
T12
T13
T14
T15
Treatments

The mechanism for P inhibition of mycorrhizal formation may be associated with membrane mediated root exudation (Ratnayake *et al.*, 1978 and Graham *et al*, 1981). Krishna and Bagyaraj (1982) reported that the mycorrhizal infection and spore production decreased with increase in level of added soluble P fertilizer in *Abelmoschus esculentus.* Majjigudda and Sreenivasa (1996) reported that per cent root colonization and spore count increased with increase in P fertilizer upto 75 per cent of the recommended dose in maize. Similar results of maximum spore count and VAM colonization by *Glomus fasciculatum* at 50 per cent level of SP compared to full dose of P in chilli was reported by Sreenivasa *et al.* (1993). The reduction in root colonization and spore count with increase in dose of P was more prominent when super phosphate was used than rock phosphate. The increased availability of the former might have suppressed the VAM colonization and spore production.

VAM colonization and spore count still decreased when only chemical fertilizers alone were applied along with VAM. VAM + FYM recorded more colonization than VAM along with fertilizers. The addition of organic manures was reported to be benefited to mycorrhizal development (Mosse, 1986).

Both fresh and dry weights of shoot and root of inoculated plants increased with increase in dose of MP from 25 to 75 per cent (Fig.14 and 15). These parameters recorded at 75 per cent dose of MP (T_{10}) were superior to that of plants which received full dose of MP (T_{12}-VAM+FYM+N+MP+K). When SP was used as a source of P no significant differences among the lower doses of P, in their effect on these characters was noticed. However the shoot biomass recorded by the plants applied with 50 per cent SP (T_9) was superior to all other treatments. Root biomass of the plants applied with 50 per cent SP was on par with that of plants received full dose of SP. Similar results were reported in chilli by Sreeramulu and Bagyaraj (1986). They studied the effect of four VAM fungi at two different doses of P. Inoculation of *G.fasciculatum* along with 50 per cent of P fertilizer resulted in higher shoot dry weight compared to the plants, which received full dose of P without VAM inoculation. Sreenivasa *et al.* (1993) also obtained such increased shoot biomass due

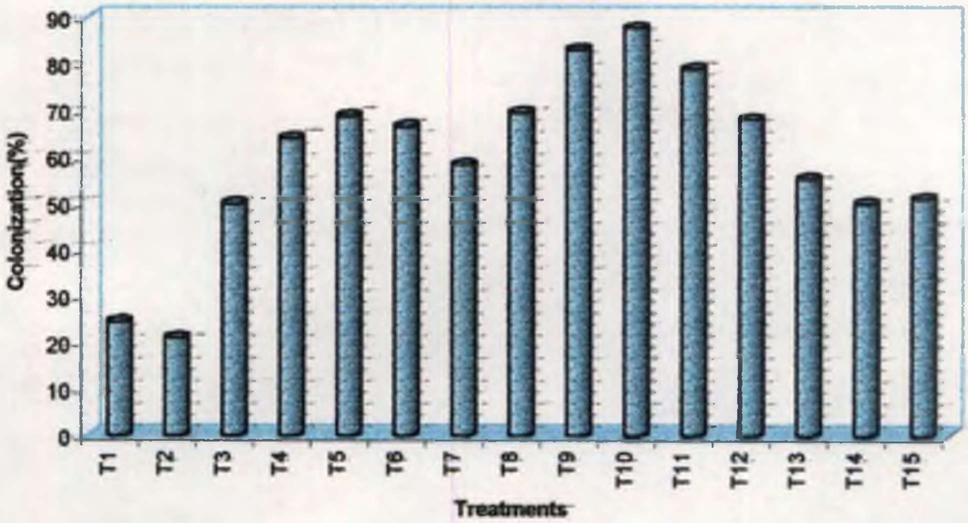


Fig.13 Effect of different treatments on VAM root colonization

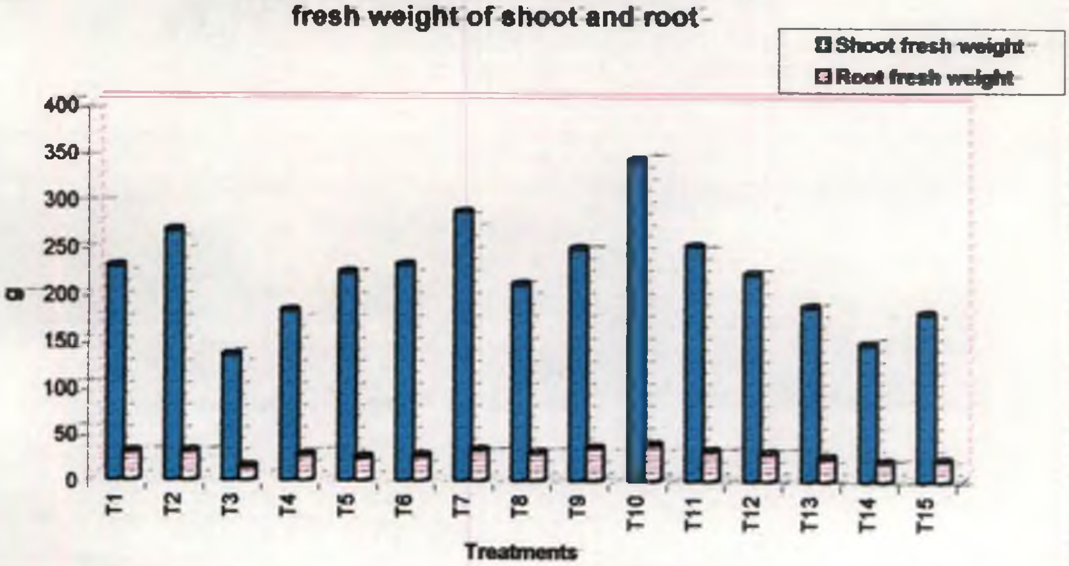


Fig. 14 Effect of different treatments on fresh weight of shoot and root

Fig.15 Effect of different treatments on dry weight of shoot and root

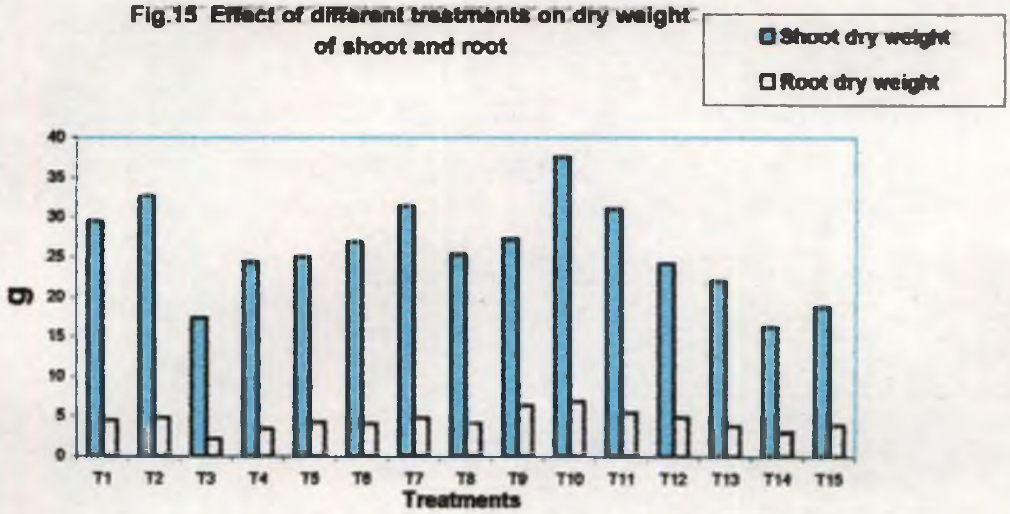
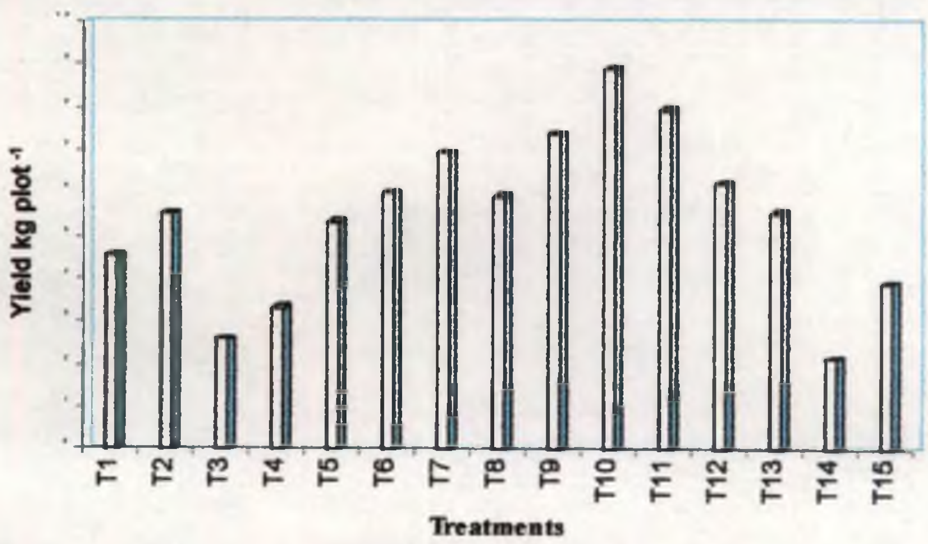


Fig.16 Fruit yield as influenced by different treatments



to VAM inoculation along with 50 per cent of the recommended dose of P than the application of full dose of P alone in chilli.

The highest fruit yield of 8.9 kg $plot^{-1}$ was recorded by T_{10} (VAM + FYM + N + 75%MP + K). It was significantly superior to all other treatments consisting of lower doses of MP, full dose of MP (T_{12} –VAM+FYM+N+MP+K) and the present package of practices recommendations (Fig.16). When SP was applied, highest fruit yield was recorded by the plants treated with T_{11} (VAM+FYM+N+75%SP+K). It was statistically on par with the yield recorded by the plants which received half dose of P (T_9) and full dose of SP along with VAM (T_{13}) and significantly superior to T_1 (FYM+N+MP+K) and T_2 (FYM+N+SP+K). Similar results of increased yield of chilli plants inoculated with *Glomus fasciculatum* at half the recommended dose of P than that of full dose of P was reported in chilli by Sreeramulu and Bagyaraj (1986) and Sreenivasa *et al.* (1993).

The shoot P content of plants applied with MP was increased with increase in dose upto 75 per cent. The treatment T_{10} recorded the highest shoot P content (Fig.17). Among the plants which received SP, the highest shoot P content was recorded by T_9 (VAM+FYM+N+50%SP+K). It was statistically on par with plants applied with 75 per cent and 100 per cent SP (T_{11} and T_{13}). Similar results were reported by Krishna and Bagyaraj (1982) in *Abelmoschus esculentus*. Bagyaraj and Sreeramulu (1982) obtained a higher shoot P content of chilli inoculated with VAM along with 50 per cent of P fertilizer than the plants applied with full dose of P alone.

It is known that mycorrhizal plants can respond greatly to the addition of sparingly soluble P sources like rock phosphate (Barea,, 1991). Some studies supported the presence of mycorrhiza specific phosphatases related to P uptake.(Fabig *et al.* 1989). Siderophore production by VAM appears as a feasible mechanism to account for the accessibility of mycorrhizal plants to P sources unavailable to non mycorrhizal controls (Jayachandran *et al.* 1989). VAM hyphae can make closer contact than roots with P containing particles to take advantage of the phosphate ions

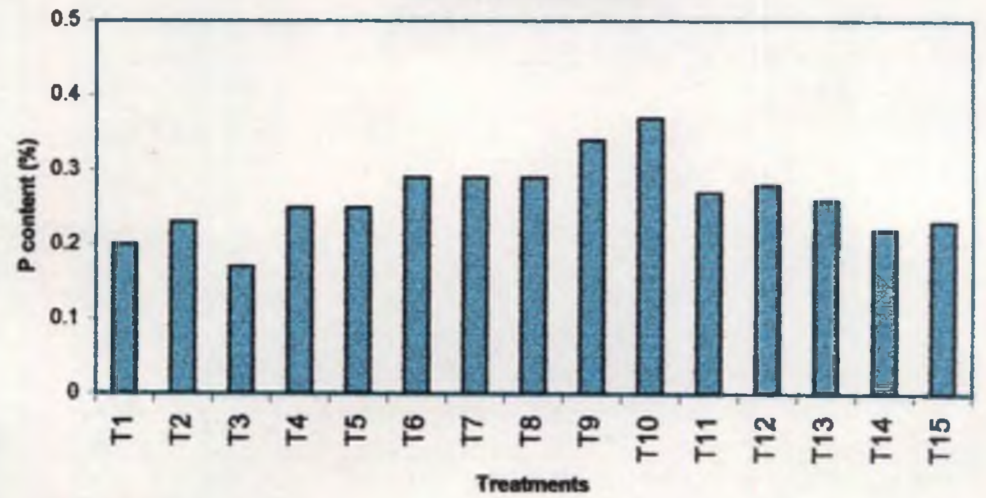


Fig.17 Effect of different treatments on P content of the shoot

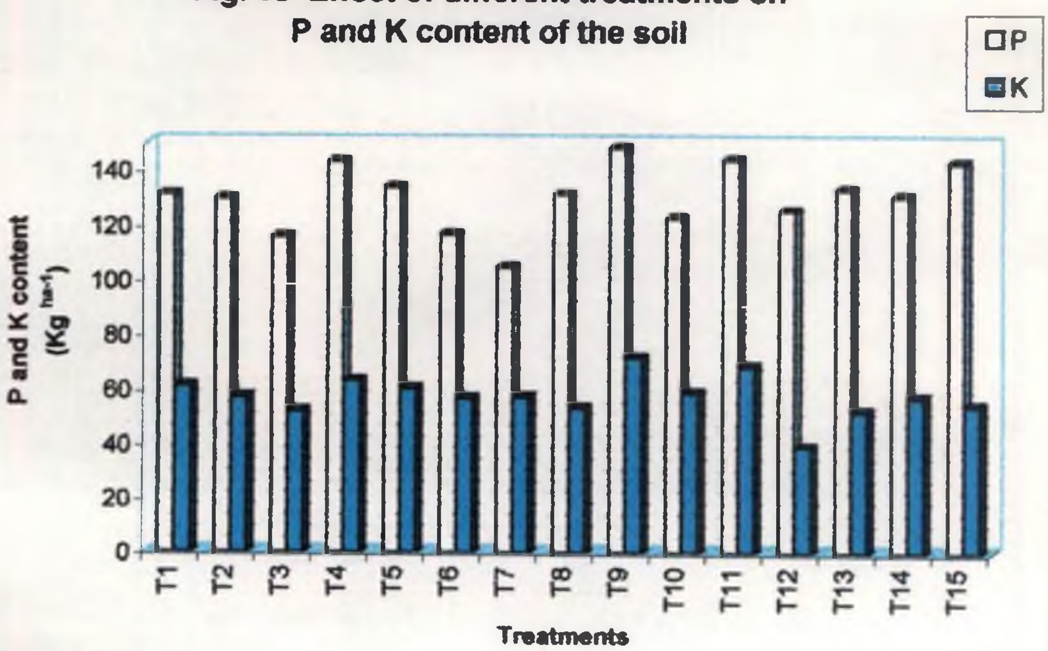


Fig. 18 Effect of different treatments on P and K content of the soil

that are being even slowly, naturally dissociated by physico chemical or biochemical mechanisms (Barea 1991). The improvement in plant use of rock phosphate at low pH levels by VAM was reported earlier (Barea and Azcon Aguilar, 1983 and Fabig *et al.* 1989).

The results of the field experiment revealed that P and K status of the soil was improved due to the VAM inoculation (Fig. 18). No change in nitrogen content of the soil was resulted due to the VAM inoculation. Among the treatments involving SP, T_9 (FYM VAM+N+50%SP+K) resulted in maximum soil phosphorus content (148kg ha^{-1}). There were no significant differences among different doses of MP along with VAM inoculation in their effect on soil phosphorus content. As far as potassium is concerned T_9 (FYM +VAM+N+50% SP+K) recorded maximum soil K status (71.68 kg ha^{-1}).

The overall results of the field experiment indicate that the inoculation of VAM fungi in tomato is effective in improving the phosphorus uptake, growth and yield. The inoculation of VAM fungi is benefited more at the lower doses of phosphorus fertilizer. The inoculation of VAM fungi along with the application of full dose of FYM, N, K and lower doses of P was equally effective as application of full dose of FYM and NPK as per the Package of Practices Recommendations. The maximum benefit of VAM fungi was obtained at the 75 per cent dose of MP with respect to VAM colonization, growth and yield followed by the application of 50 per cent of the recommended dose of SP along with VAM (T_9). Similarly, Bagyaraj and Sreeramulu (1982) reported that it was possible to reduce the application of phosphatic fertilizer by 50 per cent through inoculation with an efficient strain of mycorrhizal fungi in chilli. The better performance of cowpea along with 75 percent of the recommended dose of rock phosphate was reported by Geethakumari *et al* (1994). The increased growth and yield of cowpea in the presence of rock phosphate was reported by Islam *et al.* (1980) and Meenakumari and Nair (1992). The comparison between RP and SP is complicated due to the lower availability of the former. However, considering the improvement in growth and yield of tomato, the

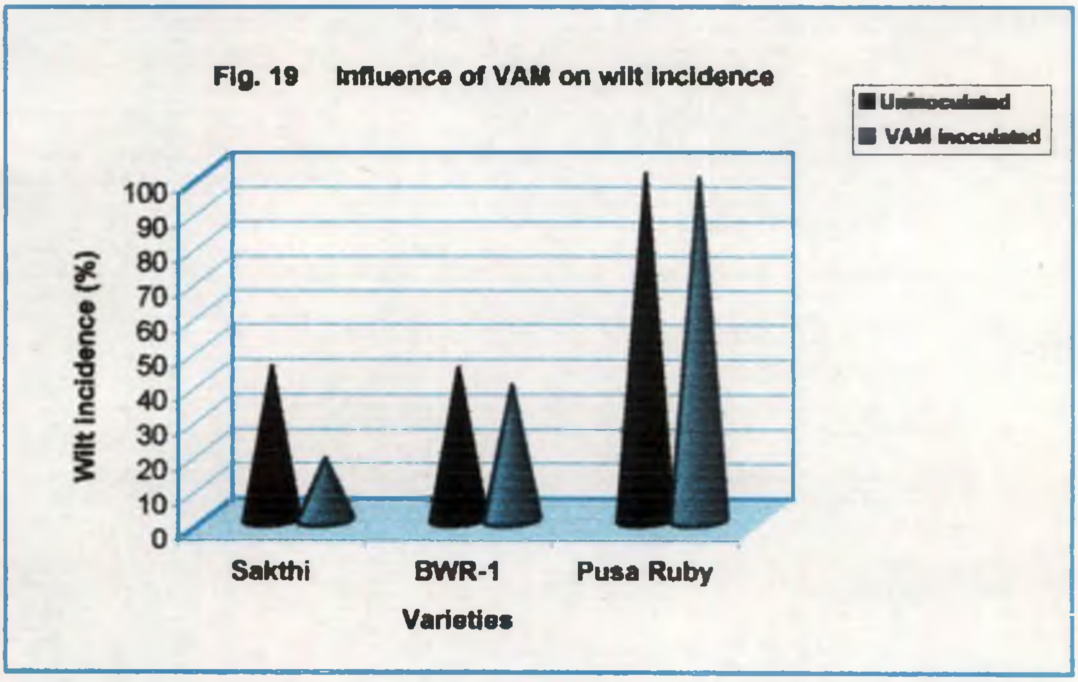


Fig. 19 Influence of VAM on wilt incidence

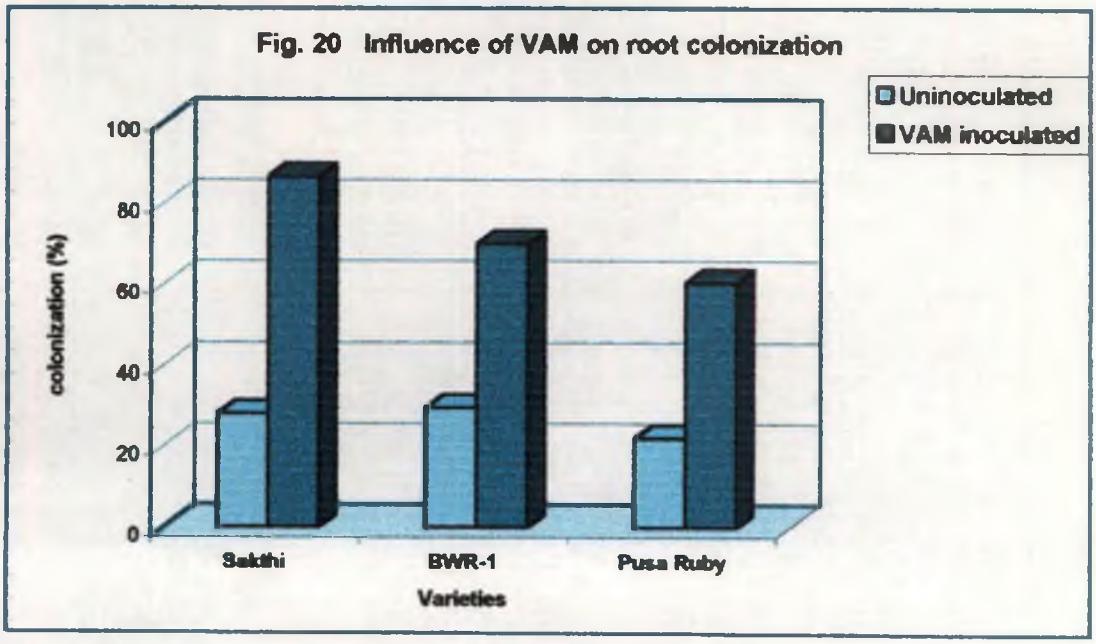


Fig. 20 Influence of VAM on root colonization

application of the 50 per cent of the recommended dose of P can be saved by the inoculation of VAM fungi if super phosphate is used. If rock phosphate is used, 25 per cent could be reduced in tomato variety Sakthi. So the best treatment combination would be VAM + FYM + N + 50% SP + K or VAM + FYM + N + 75% MP + K for better performance of tomato.

5.8 Influence of VAM inoculation on bacterial wilt of tomato

The field experiment carried out to study the effect of VAM inoculation on the incidence of bacterial wilt of tomato revealed that the inoculation of selected VAM fungi could reduce the bacterial wilt incidence. The role of VAM fungi in the management of soil borne diseases is well established. (Hussey and Roncadori 1977; Schenck and Kellam, 1978; Schenck, 1981; Dehne, 1982; Bagyaraj, 1984; Smith 1988; Chakravarthy and Mishra, 1986). Since VAM fungi are ubiquitous, it is common to observe these fungi and soil borne plant pathogens in the same root (Smith, 1988). There are only few reports of biological control of bacterial diseases using VAM fungi.

The main effect of VAM inoculation on wilt incidence showed that there was 21.79 per cent reduction in bacterial wilt due to VAM inoculation (Table 24). Among the three varieties tested, Pusa Ruby was highly susceptible to bacterial wilt. Even though there was no significant difference between BWR-1 and Sakthi in wilt incidence, Sakthi recorded less wilt incidence (35.93 %) compared to BWR-1 (41.23%). Wilt incidence was observed in the first week after transplanting in the uninoculated plants of variety Sakthi. In VAM inoculated plants bacterial wilt was observed only three weeks after transplanting. A significant difference in total wilt incidence between VAM inoculated and uninoculated plants was noticed in variety Sakthi (Fig.19). There was a reduction of 59 per cent in wilt incidence due to the inoculation of VAM in the field in variety Sakthi. In variety BWR-1 wilt incidence was noticed during the second week of transplanting. Even though there was no significant difference in wilt incidence between VAM inoculated and uninoculated plants, there was five per cent reduction in wilt incidence in mycorrhizal plants. But no reduction in bacterial wilt incidence was noticed in variety Pusa Ruby due to VAM inoculation. Earlier Halos and Zorilla (1979) reported a reduction in bacterial wilt of tomato by inoculation of mycorrhizal fungi. The reduction in bacterial wilt incidence of tomato caused by *Ralstonia solanacearum* by the combined use of arbuscular mycorrhizae and charcol compost was reported by Kobayashi (1991). Sood *et al.* (1997) also reported that the inoculation of *Glomus mosseae* was found effective in controlling the bacterial wilt of tomato cv. Roma in a pot culture study. They evaluated five isolates of VAM fungi for the control of bacterial wilt of tomato. *Glomus mosseae* was found to be highly effective in promoting germination, seedling vigour and completely controlling the disease. Sood (1998) obtained complete control of tomato wilt using VAM fungal isolate Gm-1 of *Glomus mosseae*.

There were significant differences in VAM colonization among the varieties (Table 27). The lowest colonization was in variety Pusa Ruby (41.25%). Sakthi recorded the highest colonization (57 %) followed byBWR-1 (49.75%). VAM inoculation resulted in significant increase in root colonization. The interaction effect showed that there was significant difference in VAM root colonization between the inoculated and uninoculated plants of all the three varieties (Fig. 20). Highest colonization was recorded by the inoculated plants of variety Sakthi (86.5%) followed by BWR-1 (70%) and Pusa Ruby (60.5%).

Among the three varieties, rhizosphere population of *Ralstonia solanacearum* was highest in Pusa Ruby. No significant difference between BWR-1 and Sakthi was noticed in the population of *Ralstonia solanacearum*. VAM inoculation resulted in significant reduction in *Ralstonia solanacearum* population (Table 25 and 26). The interaction effects showed that VAM inoculation resulted in reduction in the rhizosphere population of *Ralstonia solanacearum* in variety Sakthi and BWR-1 (Fig. 21and 22). But no reduction in *Ralstonia solanacearum* population was resulted due to VAM inoculation (Fig.23). While studying the interaction between *Glomus mosseae* and *Pseudomonas syringae* in tomato, Garcia

Fig.21 *Ralstonia solanacearum* poulation as influenced by VAM in variety Sakthi

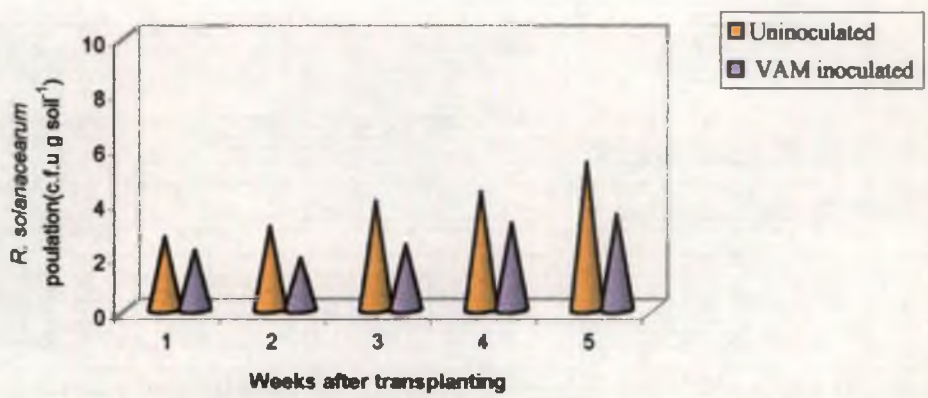


Fig.22 *Ralstonia solanacearum* population as influenced by VAM in variety BWR-1

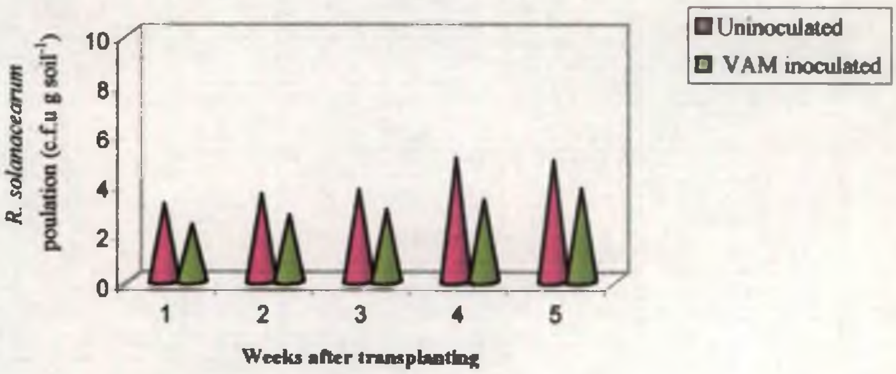
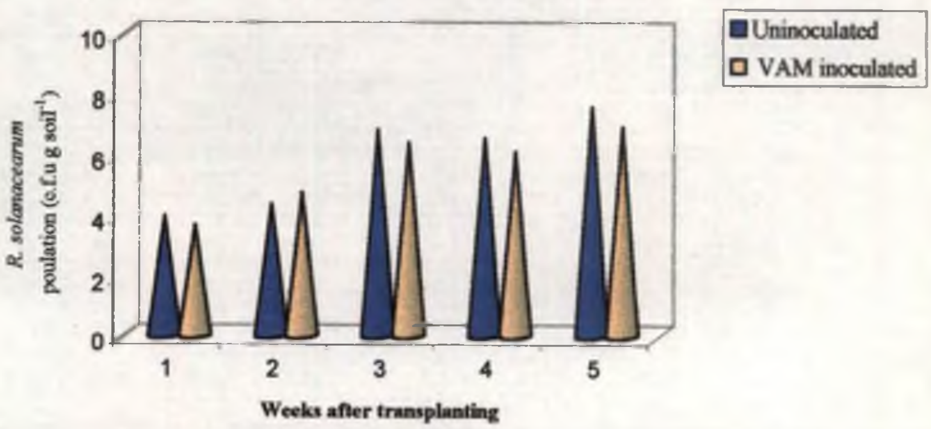


Fig.23 *Ralstonia solanacearum* population as influenced by VAM in variety Pusa Ruby



Garrido and Ocampo (1989) observed a reduction in colony forming units of *Pseudomonas syringae* in the rhizosphere of VAM inoculated plants

No significant changes in total phenol content of the plant was observed due to VAM inoculation in all the three varieties (Table 28). The VAM inoculation resulted in higher P content in the shoot and better yield than uninoculated plants of variety Sakthi.

The overall result of the study shows that the inoculation of VAM resulted in significant increase in root colonization of all the three varieties. However the root colonization was the highest in variety Sakthi, which was significantly superior to BWR-1 and Pusa Ruby. There was a significant reduction (59%) in wilt incidence due to VAM inoculation variety Sakthi. Only a slight reduction in wilt incidence (5%) was observed in variety BWR-1 and no reduction in wilt was achieved in Pusa Ruby due to VAM inoculation. The improvement in growth, yield and shoot P content was also observed only in variety Sakthi. This emphasis the need for proper selection of VAM fungi suitable for not only a particular crop but also for the varieties of the crop. This preference of crop varieties was reported earlier by Bagyaraj and Sreeramulu (1982) Sreeramulu and Bagyaraj (1986) in chilli and Sreenivasa and Rajasekhara (1989) in wheat. Variability in genotypes of field bean (Manjunath and Bagyaraj, 1982) and cowpea (Mercy *et al.*, 1990 and Mercy *et al.*, 1991) to VAM colonization was also reported earlier.

The reduction in rhizosphere population of *Ralstonia solanacearum* was observed in varieties Sakthi and BWR-1 but a corresponding reduction in wilt incidence was not noticed in BWR-1. This indicates that the reduction in pathogen population is not the only mechanism of disease suppression involved. Improved phosphorus nutrition of plants is one of the most popular theories used to explain the suppression of diseases mediated by VAM fungi. The increase in phosphorus uptake by plants due to mycorrhizal fungi is thought to lead to reduce the severity of diseases caused by soil borne fungi and nematodes (Davies and Menge, 1980; Graham and

Menge, 1982; Smith *et al.*, 1986 and Carling *et al.*, 1989). Here also the P content of the variety Sakthi inoculated with VAM is significantly higher compared to control. This might have also lead to the diseases suppression. Along with the improved P nutrition, a corresponding phosphorus induced decrease in root exudation resulting in lower activities of soil born pathogens and there by a reduction in disease severity was reported by Ratnayake *et al.*, 1978 and Graham *et al.*, 1981. Apart from these, physiological and biochemical changes might also have involved in increasing the resistance of variety Sakthi to bacterial wilt. Such mechanisum responsible for biocontrol of soil borne fungi was reported by Dehne *et al.* (1978) and Duchesne *et al.* (1987). The results of this study open up the feasibility of integrating VAM with host resistance for the management of bacterial wilt of tomato.

Perspectives for future research include identification of more efficient strains of VAM fungi for the management of bacterial wilt of tomato by variety specific screening. The study point towards scope for development of multiple inoculum of VAM fungi as well as the combination of VAM fungi along with other biological control agents for better management of bacterial wilt of tomato. The biochemical and physiological bases of disease resistance could also be worked out for unraveling the VAM induced disease resistance. There is excellent possibility that tomato cultivars with high response to VAM inoculation could also be developed.

Summary

6. SUMMARY

An investigation was carried out to find out the influence of VAM inoculation on nutrient uptake, growth, yield and bacterial wilt incidence in tomato at the college of Horticulture, Vellanikkara, during the period 1996-2000. The Results of the experiment are summarised below.

The survey conducted to collect VAM fungi from different locations of Kerala revealed the natural occurrence of VAM fungi in tomato in all the 15 locations. Among the locations surveyed, there was variation in VAM root colonization and rhizosphere spore count. Predominant VAM spores found in the survey locations were that of *Glomus* sp.

Fifteen native isolates were screened along with four standard cultures, *Glomus fasciculatum*, *Glomus mosseae*, *Glomus intraradices* and *Gigaspora margarita* in a pot culture experiment for their efficiency in improving nutrient uptake, growth and yield of tomato. This screening trial showed that tomato plants responded well to VAM inoculation. The extent of response varied with different VAM isolates. The inoculated plants had higher nutrient content particularly phosphorus, better growth and yield compared to uninoculated control. Among the VAM isolates tested, T_{10} (the isolate collected from Eruthempathi, Palakkad District) was significantly superior in improving nutrient uptake growth and yield. The plants inoculated with this isolate resulted in highest root colonization (96.75%), spore count (269.5 g per 50 g of soil) fresh weight of shoot (60.1 g) and root (17.27 g), dry weights of shoot (17.96 g) and root (1.99 g), root length (40.5 cm), root volume (21.25 cm^3) and yield (205.2 g). It was followed by T_9 (isolate from Padanakkad, Kasaragod District) and T_{15} (isolate from Sulthansbattery, Wyanad District). VAM inoculation induced early flowering. The isolate T_{17} and T_{10} resulted in nine and seven days early flowering respectively. The ascorbic acid content of the fruit also increased due to inoculation. The ascorbic acid content of the fruit recorded by the plants inoculated with the isolate T_{10} was the highest (38.43 mg g^{-1}) which was significantly superior to control (27.07 mg g^{-1}).

VAM inoculation increased nutrient uptake of the tomato plants. The inoculation of T_{10} resulted in a shoot P content (6.52 %) significantly superior to that of control (0.29 %). The K content of the plants inoculated with T_{10} (4.23 %) was also significantly superior to control (3.9 %). Even though there was no significant difference, the nitrogen content of plants inoculated with T_{10} was higher than that of uninoculated plants (8.25 %). The plants inoculated with T_{10} recorded a calcium content of 1.44 per cent as against 0.96 per cent in control

The pot culture experiment conducted to study the possibility of saving phosphorus fertilizer by VAM inoculation, showed that among the three VAM isolates tested, the isolate M_1 (isolate from Eruthempathi) performed best in improving growth, phosphorus uptake and yield. Inoculation of this isolate resulted in highest shoot fresh weight (132.65 g), shoot dry weight (17.96 g), root fresh weight (19.55 g), root dry weight (5.11 g), shoot phosphorus content (0.28%) and yield (280.8 g).

The interaction effects of VAM inoculation and levels of P showed that with the increase in dose of P up to 50 per cent there was significant increase in root colonization, fresh weights and dry weights of shoot and root and yield. No further significant increase in these parameters were recorded with the increase in dose of P upto 100 per cent. The inoculation of VAM isolate M_1 resulted in a shoot fresh weight of 154.8 g, shoot dry weight of 19.66 g, root dry weight of 6.34 g and yield of 367. 3 g at 50 per cent level of P. These were on par with the shoot fresh weight, shoot dry weight, root dry weight and yield recorded by the plants which received full dose of P along with VAM inoculation and superior to these parameters recorded by the plants received full dose of P without VAM inoculation. This suggests the possibility of reducing the phosphorus fertilizer to half the recommended dose by the use of efficient strain of VAM fungi.

The field experiment conducted to study the effect of VAM inoculation on nutrient uptake, growth and yield of tomato confirmed the results obtained in the pot culture experiment. The plants inoculated with VAM (*Glomus* sp. collected from Eruthempathi) had higher percentage of root colonization and spore count in the rhizosphere soil compared to uninoculated plants. The results indicated that irrespective of the form of P used, the VAM colonization and spore count were less at higher doses of P compared to lower doses.

The VAM colonization recorded by the treatment T_9 (VAM+ FYM+N+50%SP+K) was 83 per cent which was significantly superior to T_{13} (VAM+FYM+N+SP+K) which recorded only 55.25 per cent colonization. When MP was used, there was increase in root colonization with the increase in dose of P, upto 75per cent of the recommended dose. The treatment T_{10} (VAM+FYM+N+75%MP+K) recorded a VAM colonization of 85.75 per cent which was significantly superior to that of T_{12} (VAM+FYM+N+MP+K), which recorded a colonization of 68 per cent. The spore count recorded by the treatment T_9 (358.8) was significantly superior to that of T_{13} (274.5). The spore count recorded by T_{10} (417.5) was statistically on par with the spore count recorded by T_{12} (411.3).

VAM colonization and spore count still decreased when chemical fertilizers alone was applied. The treatment T_{14} (VAM+N+MP+K) recorded a VAM colonization of 50 per cent and spore count of 182.5 per 50 grams of soil and T_{15} (VAM+N+SP+K) recorded a VAM colonization of 51 per cent and spore count of 265.

Among the different treatments involving SP, T_9 revealed its superiority in improving fresh weight and dry weight of root and yield. The root fresh weight (34.47 g) and root dry weight (6.38 g) recorded by T_9 were significantly superior to these parameters recorded by T_{13} (VAM+FYM+N+SP+K) and T_2 (FYM+N+SP+K). Among the different treatments consisting of SP, the treatment T_9 recorded maximum root length (31.24 cm), which was on par with T_{13} and T_2.

The treatment T_9 (VAM+ FYM+N+50%SP+K) recorded a shoot phosphorus content of 0.34 per cent which was significantly superior to the shoot phosphorus content (0.23 %) recorded by T_2 (FYM+N+SP+K) and it was on par with that of T_{13} (VAM+FYM+N+SP+K). Among the different treatments involving SP, maximum fruit yield (7.95 kg $plot^{-1}$) was recorded by the plants inoculated with VAM along with 75 per cent of P and other nutrients (T_{11}) which was statistically on par with T_9 (7.38 kg $plot^{-1}$) and significantly superior to T_{13} (5.54 kg $plot^{-1}$) and T_2 (5.53 kg $plot^{-1}$).

Among the treatments involving MP, T_{10} (VAM+FYM+N+75% MP+K) recorded the highest shoot fresh weight (340.5 g), shoot dry weight (37.54 g), root fresh weight (38.13 g), shoot dry weight (6.89 g) and root length (38.01 cm). The shoot phosphorus content recorded by T_{10} (0.37%) was the highest among the treatments. It was significantly superior to T_{12} (VAM+FYM+N+MP+K) and T_1 (FYM+N+MP+K). The yield recorded by T_{10} was the highest (8.9 kg $plot^{-1}$) which was significantly superior to that of T_{12} (6.23 kg plot $^{-1}$), T_1 (4.53 kg $plot^{-1}$) and T_2 (5.53 kg $plot^{-1}$).

The nutrient status of the soil revealed that the inoculation of VAM along with the application of FYM+N+50%SP+K ranked top in increasing the soil phosphorus content (148 kg ha^{-1}). There was no significant difference in soil phosphorus content due to VAM inoculation along with the application of different doses of MP. Among the different treatments involving SP, T_9 (VAM+ FYM+N+50%SP+K) resulted in highest soil K content (71.68 kg $ha^{-1)}$ and among the different treatments involving MP, T_{10} recorded the highest soil K content (58.8 kg ha^{-1}).

The field experiment conducted in wilt sick field to study the effect of VAM inoculation on bacterial wilt incidence of tomato revealed that the inoculation of selected VAM fungi could reduce bacterial wilt of tomato. Among the three varieties, Sakthi, BWR-1 and Pusa Ruby, significant reduction in bacterial wilt incidence due to inoculation of VAM fungi collected from Eruthempathi was recorded by the variety Sakthi only. The bacterial wilt incidence recorded by the mycorrhizal plants of variety Sakthi was 17.72 per cent as against 44.25 per cent in uninoculated control. Even though there was no significant difference in wilt incidence, the VAM inoculated plants of variety BWR-1 recorded a five per cent reduction in wilt incidence compared to control. There was no significant difference in wilt incidence recorded between inoculated and uninoculated plants of variety Pusa Ruby. The wilt incidence recorded by control plants was 100 per cent as against 98.75 per cent in inoculated plants.

The rhizosphere population of *Ralstonia solancearum* was significantly less in VAM inoculated plants of variety Sakthi (3.47 c.f.u g^{-1} of soil) compared to uninoculated control (5.37 c.f.u g^{-1} of soil). There was also significant reduction in *R. solancearum* population in VAM inoculated plants of BWR-1 (3.77 c.f.u g^{-1} of soil) compared to control (4.92 c.f.u g^{-1} of soil). No significant difference in the pathogen population was noticed between VAM inoculated and uninoculated plants of variety Pusa Ruby.

There were significant differences in VAM root colonization among the varieties. The highest root colonization was recorded in variety Sakthi (59.0 %) followed by BWR-1 (49.75 %) and Pusa Ruby (41.25 %). VAM inoculation resulted in significant increase in root colonization of all the three varieties compared to control. However the variety Sakthi showed highest colonization due to inoculation (86.5%) followed by BWR-1 (70.0%) and Pusa Ruby (60.5%).

The biometric characters were recorded at 90 days after transplanting. Even though there was no significant difference between VAM inoculated and uninoculated plants in shoot and root biomass, the shoot fresh weight (127.5 g) shoot dry weight (20.76 g) root fresh weight (21.0 g) and root dry weight (4.43 g) recorded by VAM inoculated plants of variety Sakthi were more than that of uninoculated plants. The inoculated plants recorded significantly higher yield (6.75 kg plot $^{-1}$). No significant increase in yield was recorded in variety BWR - 1 by VAM inoculation. The shoot phosphorus content recorded by VAM inoculated plants of variety Sakthi (0.23 %) was significantly superior to that of uninoculated plants (0.16 %)

The results of entire study revealed that, the tomato variety Sakthi responded well to VAM inoculation. The VAM isolate, *Glomus* sp collected from Eruthempathi, Palakkad District performed best in improving nutrient uptake particularly P, growth and yield of tomato variety Sakthi. Apart from increasing growth and yield it could reduce the bacterial wilt incidence also. VAM inoculation could substitute the phosphorus fertilizer, to the extent of 50 per cent of the recommended dose, if super phosphate is used and to 25 per cent of the recommended dose, if rock phosphate is used. Thus a judicious treatment combination would be VAM+FYM+N+50%SP+K or VAM+FYM+N+75%MP+K instead of the present package of practices recommendations of FYM and NPK to get the best performance of tomato variety Sakthi. Thus the results revealed the potential of VAM as a biofertilizer and as a biocontrol agent for tomato.

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* Originals not seen

Appendices

APPENDIX-I

Composition of F. A. A.

Formalin (40 %)	- 5 ml
Glacial acetic acid	- 5 ml
Ethanol (95%)	- 90 ml

APPENDIX-II

Composition of Trypanblue

Trypanblue	- 50 mg
Lactophenol	- 100 ml

Lactophenol

Lactic acid	- 10 ml
Phenol	- 10 ml
Glycerol	- 20 ml
Water	- 20 ml

INFLUENCE OF VAM INOCULATION ON NUTRIENT UPTAKE, GROWTH, YIELD AND BACTERIAL WILT INCIDENCE IN TOMATO
(*Lycopersicon esculentum* Mill.)

By

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ABSTRACT OF THE THESIS

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ABSTRACT

An investigation on the influence of VAM inoculation on nutrient uptake, growth, yield and bacterial wilt incidence of tomato (*Lycopersicon esculentum* Mill.) was carried out at the College of Horticulture, Vellanikkara during the period 1996 - 2000. The objectives of the study were to select an efficient VAM fungus for improving nutrient uptake, growth and yield of tomato, to explore the possibility of reducing the use of phosphorus fertilizer by VAM inoculation and also to study its influence on bacterial wilt incidence.

The survey conducted revealed the natural occurrence of VAM association in tomato at different locations of Kerala. There was variation in VAM colonization and rihzosphere spore count among the locations. Predominant VAM fungi associated with tomato at the survey locations belonged to the genus *Glomus*.

Out of the fifteen native isolates and four standard cultures, *Glomus mosseae, Glomus fasciculatum, Glomus intraradices* and *Gigaspora margarita,* the native isolate collected from Eruthempathi (Palakkad District) was found to be the best in improving nutrient uptake, growth and yield of tomato variety, Sakthi. Inoculation of this isolate resulted in increased root colonization, spore count, shoot and root biomass, root volume and yield. It induced seven days early flowering and increased the ascorbic acid content of the fruit. The uptake of nutrients particularly P, K and Ca was improved by the inoculation of this isolate.

The pot culture experiment conducted to study the possibility of reducing phosphorus fertilizer due to VAM inoculation showed the superiority of VAM isolate collected from Eruthempathi in improving growth, P uptake and yield. With the increase in dose of P upto 50 per cent, there was a significant increase in root colonization, fresh weights and dry weights of shoot and root and also the yield. No further increase in these parameters was recorded with the increase in dose of P upto 100 per cent. The plants inoculated with the VAM isolates along with 50 per cent P

recorded shoot and root biomass and yield significantly superior to that of these parameters recorded by the plants which received full dose of P alone.

The results of the field experiment showed that the plants inoculated with VAM had higher root colonization and rihzosphere spore count compared to uninoculated plants. Irrespective of the form of P used the rihzosphere spore count and VAM colonization were less at higher doses of P compared to lower doses. Among the treatments involving super phosphate, the treatment T_9 (VAM + FYM + N + 50% SP + K) was significantly superior in improving root colonization, spore count, fresh weight and dry weight of root, root length, shoot P content and yield compared to the package of practices recommendations (T_2 – FYM + N + SP + K). Among the treatments involving mussorie rock phosphate, the treatment T_{10} (VAM + FYM + N + 75% MP + K) was significantly superior to the present package of practices recommendations in its effects on fresh weight and dry weight of shoot and root, root length, shoot P content and yield.

The nutrient status of the soil with respect to P and K content was improved by the treatment T_9 (VAM + FYM + N + 50% SP + K). No significant change in soil P content was observed by the VAM inoculation along with MP. The treatment T_{10} (VAM+FYM+75%MP+K) recorded the highest soil K content.

The field experiment conducted in the wilt sick field revealed that inoculation of selected VAM fungi could reduce the bacterial wilt incidence. Among the three varieties tested *viz.*, Sakthi, BWR-1 and Pusa Ruby, a significant reduction in bacterial wilt incidence due to inoculation of VAM fungi collected from Eruthempathi was recorded by the variety, Sakthi. The inoculated plants of BWR-1 showed only five per cent reduction in wilt incidence. No reduction in wilt incidence was observed in variety, Pusa Ruby.

The rhizosphere population of *Ralstonia solanacearum* was significantly less in VAM inoculated plants of varieties Sakthi and BWR-1. No reduction in

Ralstonia solanacearum population was noticed in variety Pusa Ruby due to VAM inoculation.

There was significant difference in VAM colonization among the three varieties. The variety Sakthi recorded the highest colonization due to VAM inoculation, followed by BWR-1 and Pusa Ruby. There was no significant difference in total phenol content of VAM inoculated and uninoculated plants in all the three varieties. The growth characters, shoot P content and yield of the VAM inoculated plants of variety Sakthi were superior to that of uninoculated plants.

The results of the entire study revealed that the tomato variety Sakthi responded well to VAM inoculation. The response varied with the VAM isolates. The isolate (*Glomus* sp.) collected from Eruthempathi, performed best in improving the nutrient uptake, growth and yield of tomato variety Sakthi. Inoculation of this isolate could substitute the phosphorous fertilizer, to the extent of 50 per cent and 25 per cent of the recommended dose as super phosphate and mussorie rock phosphate respectively. There was appreciable reduction in bacterial wilt due to the inoculation of this isolate.