# PHOSPHORUS USE EFFICIENCY AND PRODUCTIVITY AS INFLUENCED BY MICROBIAL INOCULANTS IN VEGETABLE COWPEA

(*Vigna unguiculata sub sp. sesquipedalis* (L.) Verdcourt) var.Sharika


BY

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THESIS

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# DECLARATION

I hereby declare that this thesis entitled "Phosphorus use efficiency and productivity as influenced by microbial inoculants in vegetable cowpea *(Vigna unguiculata* sub sp. *sesquipedalis* (L.) Verdcourt) var. Sharika" 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, associateship, fellowship or other similar title, of any other University or Society.

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# CERTIFICATE

Certified that this thesis entitled "Phosphorus use efficiency and productivity as influenced by microbial inoculants in vegetable cowpea *(Vigna unguiculata* sub sp. *sesquipedalis* (L.) Verdcourt) var. Sharika" is a record of research work done independently by MEENA MARY MATHEW under my guidance and supervision and that it has not formed the basis for the award of any degree, fellowship or associateship to her.

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# LIST OF ABBREVIATIONS USED IN THIS THESIS

| | | |
|---|---|---|
| @ | - | at the rate of |
| AMF | - | arbuscular mycorrhizal fungus |
| $^{0}C$ | - | degree celsius |
| cv. | - | cultivar |
| cm | - | centimeter |
| mm | - | millimeter |
| m | - | meter |
| $m^3$ | - | cubicmeter |
| g | - | gram |
| kg | - | kilogram |
| t | - | tonnes |
| LAI | - | leaf area index |
| DAS | - | days after sowing |
| ANOVA | - | Analysis of Variance |
| N | - | nitrogen |
| P | - | phosphorus |
| K | - | potassium |
| ha | - | hectare |
| PSM | - | phosphate solubilising microorganism |
| G | - | granular |

# INTRODUCTION

# INTRODUCTION

Meeting the domestic food requirements has been the foremost social priority before India, since independence. Vegetables play a vital role in the health and nutrition of people throughout the world. The food experts and nutritionists have realised and appreciated the food value of vegetables because of its low calorific value, high contents of protein, vitamins and minerals.

In the recent years, the importance of consuming vegetables for the maintenance of normal health is being realised in all parts of the world and a consciousness for quality has also been developed. India is the second largest producer of vegetables in the world next only to China with a production of 66.58 million tonnes from 4.80 million hectare land (Singh, 1997). This accounts for 12 percent of the world output of vegetables. The production however does not meet the requirement, the per capita availability of vegetables being only 135.82 g day $^{-1}$ as against the recommended daily intake of 280 g. By the turn of the century, our requirement of vegetable production will be 110 million tonnes to feed one billion population (Singh, 1997). Our country is striving hard to achieve nutritional security because of the scarce supply of vegetables.

Kerala, with its unique wet tropical climate is ideal for the cultivation of a wide variety of vegetables. The total area under vegetables in Kerala is 15,250 ha (Syriac, 1998). It is estimated that the vegetable production in Kerala is only 1/3 of the vegetable requirement of the state. Among the various vegetable crops grown in our state, vegetable cowpea also known as Yard long bean (*Vigna unguiculata* sub sp. *sesquipedalis*) occupies a prime position due to its export potential and nutritive value. The tender green pod used as a delicious vegetable is rich in proteins, minerals, vitamins and dietary fibre.

As far as Kerala is concerned, the extent of cultivated land is limited and as such we have to exploit the potential of vegetable production fully through intensification of agronomic practices. Proper soil management without hampering soil health is a pre-requisite for achieving high productivity from agricultural land.

Fertilizer is considered as the most effective and expensive input in agriculture. It is the primary concern of scientists to help the farmer to derive maximum benefit out of this costly input by increasing the fertilizer use efficiency. Owing to the energy and cost in intensive manufacture of chemical fertilizers, use of microbial inoculants has attained immense importance.

Phosphorus is a vital element in all biological systems and being a leguminous crop, the phosphorus requirement is high in cowpea. Further, it is well documented that phosphorus is a limiting nutrient in the productivity of legumes. Even though our tropical soils are rich in phosphorus, its availability to plants is less due to fixation by various factors. Laterite soils accounting for 58 percent of the total geographical area of the state are noted for high phosphorus fixing capacity and lack of response to added phosphatic fertilizers. But, farmers resort to overdose of fertilizer application which is uneconomical as well as hamper soil health. The commonly applied phosphatic fertilizer is mussorie rock phosphate (MRP) which is slowly available to the crop. One approach is to reduce the fertilizer requirement by improving the capacity of plants to more effectively utilise native and applied nutrients in the soil. It appears that the only solution to the above mentioned problems would be the proper exploitation and use of biofertilizers.

The term 'mycorrhiza' which literally means 'fungus root' is the symbiotic association between the roots of higher plants and fungi. Arbuscular mycorrhizal fungal (AMF) colonisation significantly increases nutrient uptake, particularly immobile or sparingly soluble forms of soil phosphorus by the host plant. Phosphate solubilising microorganisms (PSM) help in the solubilisation of fixed forms of phosphorous supplied through fertilizers thereby enhancing phosphorus availability.

Although studies have been conducted on the application of microbial inoculants on grain cowpea, data involving research on vegetable cowpea is very meagre. As such, a planned development in the field of vegetable production will not only improve the nutritional quality of food for masses but can also meet the challenges of adequate supply to the growing population in India.

With all these objectives, the present investigation entitled "Phosphorus use efficiency and productivity as influenced by microbial inoculants in vegetable cowpea (*Vigna unguiculata* sub sp. *sesquipedalis* (L.) Verdcourt) var.Sharika" was taken up to exploit the synergistic effect of AMF and PSM in improving the phosphorus nutrition and growth of vegetable cowpea. The experiment was designed to find out the efficiency of the above mentioned microbial inoculants individually as well as in combination with different levels of phosphorus.

# REVIEW OF LITERATURE

# REVIEW OF LITERATURE

Phosphorus is one of the 'Big Three' in crop nutrition, it is referred to as the 'Master Key' element in crop production and 'King Pin' in Indian agriculture. One of the major constraints in tropical soils is low crop recovery of added phosphatic fertilizers due to chemical fixation. The long term use of phosphatic fertilizers leads to build up of insoluble phosphates which can become useful to crops under proper management. A perusal of the literature pertaining to the investigation revealed a dearth of specific information on the influence of bioagents viz. AMF and PSM on vegetable cowpea. Hence relevant literature on the role of phosphorus as well as use of these microbial inoculants in improving phosphorus use efficiency in various crops in India and abroad are briefly reviewed in this chapter.

## 2.1 Role of phosphorus in leguminous crops

Phosphorus occupies a unique position both in conventional as well as in alternative agriculture. Phosphorus is a major constituent of nucleic acids, phytin and phospholipids; stimulates root growth and helps to absorb plant nutrients and water from deeper layers of soil and ultimately results in better growth of plants (Tisdale *et al.* 1995). Application of phosphorus to legumes has improved the growth, yield, quality and nitrogen fixation resulting in restoration of soil fertility. Differential response of phosphorus can be attributed to its uptake efficiency and its utilisation, which inturn is greatly influenced by environmental factors (Abbas *et al.* 1994).

### 2.1.1 Effect of phosphorus on growth parameters

Singh (1985) observed an increase in plant height in summer cowpea at a higher level of phosphorus (60 kg $P_2O_5$ $ha^{-1}$) compared to lower levels of phosphorus (20 and 40 kg $ha^{-1}$). Jain *et al.* (1986) noted a better value for the length of main shoot in cowpea at 40 kg $P_2O_5$ $ha^{-1}$ compared to 20, 60 kg $P_2O_5$ $ha^{-1}$ and control. But with respect to the number of branches, the highest was with 60 kg which was on par with 40 kg but both levels gave significantly higher values compared to lower levels. Similar trend was noticed with the number of leaves per plant also. Kher *et al.* (1994) reported that phosphorus at 40 and 80 kg $ha^{-1}$ did not differ practically with respect to growth parameters (plant height and plant spread ) in cowpea but was apparently higher over the control. In summer cowpea, fertilising with $P_2O_5$ @ 50 kg $ha^{-1}$ improved the growth attributes like plant height, leaves per plant, canopy area significantly compared to control and 25 kg and was on par with 75 kg $ha^{-1}$ (Rajput, 1994).

In green gram, plant height was found to be significantly increased with 50 kg $P_2O_5$ $ha^{-1}$ over other treatments (0,25 and 75 kg $ha^{-1}$) (Arya and Kalra, 1988). Similarly, Singh and Chowdhary (1992) reported that phosphorus level of 30 kg $ha^{-1}$ significantly increased the plant height and number of branches over the control in green gram . A significant increase in the plant height and number of branches per plant by the application of phosphorus up to 60 kg $ha^{-1}$ was reported by Singh and Tripathi (1992) in black gram. Plant height at 45 DAS and at harvest and primary branches per plant in black gram showed significant response to the application of 30 and 60 kg $P_2O_5$ $ha^{-1}$ compared with the control and two levels were found to be on par (Shah *et al.*, 1994). Mohankrishna and Rao (1997) reported that plant height, LAI, dry matter production and nitrogenase activity increased linearly with the application of phosphorus up to 60 kg $P_2O_5$ $ha^{-1}$. Among the phosphorus levels, 60 and 90 kg $ha^{-1}$ were on par but significantly superior over other levels in soybean.

**2.1.2 Effect of phosphorus on yield attributes**

According to Patel and Patel (1979), maximum number and weight of green pods/plant was noted by the application of 60 kg $P_2O_5$ $ha^{-1}$ in summer vegetable cowpea compared to lower levels of 0,20 and 40 kg $ha^{-1}$. Subramanian *et al.* (1993) reported that in vegetable cowpea the application of graded levels of phosphorus had no significant effect on the pod length and number of seeds/pod.

Kumar and Pillai (1979) reported that the application of phosphorus up to 40 kg $P_2O_5$ $ha^{-1}$ profoundly influenced the number of pods/plant, number of seeds/pod and the length of pods in cowpea. Jayaram and Ramiah (1980) reported that the application of phosphorus in cowpea increased the number of pods/plant and number of grains/pod in both summer and kharif season up to 37.5 kg and 25 kg $P_2O_5$ $ha^{-1}$ respectively. In cowpea, response to phosphorus application up to 50 kg $P_2O_5$ $ha^{-1}$ was significant and influenced all the yield attributing characters viz. the number of pods/plant, seeds/pod and 100 grain weight. A further increase in dose up to 62.5 kg $ha^{-1}$ caused a reduction in all these yield attributes (Geethakumari and Kunju, 1984). The maximum weight of pods and the total green pod weight/plant in cowpea was noted with the application of 60 kg $P_2O_5$ $ha^{-1}$, but the increase in the number of seeds/pod was significant only up to 40 kg $P_2O_5$ $ha^{-1}$ (Jain *et al.*,1986). Ramamurthy *et al.* (1990) reported that maximum number of pods, pod weight/plant and seed yield was recorded by the application of 50 kg $P_2O_5$ $ha^{-1}$ in cowpea. In another study on the response of summer cowpea to phosphorus, Kher *et al.* (1994) noted that the application of 40 and 80 kg $ha^{-1}$ phosphorus did not differ practically in respect of yield attributes like the number of grains/pod, length of the pod and test weight but was apparently higher over the control. Rajput (1994) also found significant effect of phosphorus on yield attributes like the number of pods/plant and seeds/pod up to 50 kg $ha^{-1}$ which was on par with a higher level of 75 kg $ha^{-1}$ in cowpea.

In another experiment with summer green gram, Sarkar (1992) found that pod number, pod length, grains/pod and 1000 grain weight were significantly influenced by phosphorus application up to 80 kg $ha^{-1}$. Mishra (1993) also reported a significant increase in yield attributes like the pods/plant, seeds/pod and 1000 grain weight up to 60 kg $ha^{-1}$ in black gram.

### 2.1.3 Effect of phosphorus on yield

In vegetable cowpea, maximum dry matter production and vegetable yield was obtained at an applied phosphorus level of 100 kg $ha^{-1}$ which was on par with 50 kg $ha^{-1}$ (Subramanian *et al.*, 1993).

Regarding grain yield, Geethakumari and Kunju (1984) observed linear increase in yield of grain cowpea following phosphorus application from 12.5 to 50 kg $P_2O_5$ $ha^{-1}$. Muthuswamy *et al.* (1986) from an experiment on rainfed cowpea pointed out that there is a significant positive response in the grain yield for phosphorus application compared to no phosphorus, but the difference between the effects of different levels were insignificant. In cowpea, Ramamurthy *et al.* (1990) observed highest yield at a phosphorus level of 50 kg $ha^{-1}$. Gandhi *et al.* (1991) also reported significantly higher yield when cowpea was fertilised with 50 kg $P_2O_5$ $ha^{-1}$. In summer cowpea, maximum grain and fodder yield was obtained by applying phosphorus @ 80 kg $ha^{-1}$ (Raj and Patel,1991). Kher *et al.* (1994) observed that in summer cowpea application of phosphorus at 40 and 80 kg $ha^{-1}$ did not differ practically with respect to yield but was significantly higher over the control. Nutrient uptake in fodder cowpea increased significantly higher up to 75 kg $P_2O_5$ $ha^{-1}$, and on mean basis, the economic optimum dose of phosphorus was 39.06 kg $ha^{-1}$ while maximum production was obtained at 88.94 kg $P_2O_5$ $ha^{-1}$ (Rajput and Singh , 1996).

Rao *et al.* (1990) also observed a positive relationship between yield and phosphorus application in black gram up to 60 kg $ha^{-1}$ beyond which it decreased. Mishra (1993) found that grain yield increased progressively with an increase in the level of phosphorus and maximum response was at 60 kg $ha^{-1}$ in black gram. phosphorus application was reported to increase the grain, haulm and biological yields as well as dry matter production at harvest in black gram up to 30 kg $ha^{-1}$ beyond which the increase was not significant (Shah *et al.,* 1994). According to Detroja *et al.* (1997), pooled results showed that the levels of phosphorus did not exert their significant effect on growth characters, yield attributes, pod and haulm yield of groundnut.

## 2.2 Arbuscular mycorrhizal fungi (AMF)

Mycorrhizae are symbiotic associations that form between the roots of most plant species and fungi. The most common mycorrhizal association is from the endomycorrhizae also referred to as arbuscular mycorrhizal fungi (AMF) which produces fungal structures (vesicles and arbuscles) in the cortex region of the root. AMF with their extramatrical hyphae increased the absorption of relatively immobile elements in soil such as phosphorus, copper and zinc. (Mosse 1957., Haymann and Mosse, 1971).

The arbuscular mycorrhizal fungal association is found in most crop families such as Cruciferae, Chenopodiaceae, Junaceae and Cyperaceae (Barea, 1991).The importance of AMF associations in agricultural crops is well documented. (Bagyaraj , 1990., Jeffries and Dodd , 1991). Barea (1991) observed that a key determinant of the ability of a root system to acquire nutrients from the soil was the extent to which it was symbiotically colonized by the appropriate mycorrhizal fungi.

### 2.2.1 Nutrient uptake

Barea (1991) observed that AMF enhances plant growth as a result of improved mineral nutrition of the host plant and this has been confirmed with the use of isotopic tracers. Arbuscular mycorrhizal fungi are of particular importance for plant acquisition of phosphorus and other nutrients which are immobile in soil (Johansen *et al.*, 1993).

Krishna *et al.* (1982) reported that growth and phosphorus nutrition in finger millet on phosphorus deficient soil was improved by inoculation with AMF *Glomus fasciculatum*. Jensen (1983) investigated the effect of AMF on nutrient uptake and growth of barley at zero phosphorus level and stated that soil with no phosphorus treated with AMF increased concentration of phosphorus and total uptake of phosphorus. However, Krishna and Dart (1984) reported that there was no effect for mycorrhizal inoculation on phosphorus fertilization in unsterile soil. Le Tacon (1985) generalised that AMF increased the translocation of least soluble elements like phosphorus, zinc and copper. Khaliel and Elkhider (1987) opined that irrespective of nutrient, the uptake per unit root length was higher in plants inoculated with mycorrhiza. In maize grown in calcareous soil, AMF contribution to total uptake ranged between 16 and 25 percent for zinc and 13 to 20 percent for phosphorus (Kothari *et al.*, 1991).

According to Chapman (1980) there was no conclusive support for role of AMF in potassium uptake. Sieverding and Toro (1988) also felt that results on the role of mycorrhizae in potassium uptake were inconsistent and difficult to interpret.

### 2.2.2 Mechanism of nutrient uptake

It is well documented that AMF can absorb several times more nutrients and have greater nutrient inflow rates than roots (Barea and Azcon-Aguillar, 1983., Harley and Smith, 1983., Smith and Gianinazzi – Pearson, 1988).

Sanders and Tinker (1971) observed that the increased surface area due to mycelial network was primarily responsible for the enhanced uptake of phosphorus. The fungal hyphae actually transports phosphate over distances (several cms), into the root cortical cells (Pearson and Tinker, 1975). AMF hyphae growing through soil pore spaces are able to affect phosphate absorption beyond the depletion zone that develops around the roots (Rhodes and Gerdemann, 1980). Allen (1993) has reported that in one cubic centimetre of soil, there may be 2-4 cm of root, 1-2 cm of root hairs and 50 metres of mycorrhizal fungal hyphae which result in substantial increase in surface area of root system improving nutrient uptake. Marschner and Dell (1994) observed that mycorrhizal infection enhances plant growth by increasing nutrient uptake via increase in the absorbing surface area, by mobilizing sparingly available nutrient sources or by excretion of chelating compounds or ectoenzymes.

Bolan *et al.* (1983) documented the existence of a threshold concentration for effective phosphate uptake by non mycorrhizal clover, but not for AMF clover. $^{32}$P studies by Bolan *et al.* (1984) revealed that there are forms of phosphorus in soil that are accessible to AMF but not to non-mycorrhizal roots. They also suggested that the phosphorus that was better used by AMF was the phosphate adsorbed to iron phosphate. There are also evidences to show that AMF plants can readily respond to additions of sparingly soluble phosphorus such as rock phosphate (Manjunath *et al.*, 1989).

The qualitative and quantitative changes in the root exudation patterns (Harley and Smith, 1983) and the difference between AMF and non-mycorrhizal plants in the absorption of anions and cations (Buwalda *et al.*, 1983) which can change the pH of the rhizosphere are indirect mechanisms that Bolan *et al.* (1984) argued would explain the effect of AMF to increase phosphate availability to the plants.

### 2.2.3 Crop response to AMF

#### 2.2.3.1 AMF on crop growth

VAM increases the rate of growth of plants and also influence the partitioning of phytomass between shoot and root (Smith, 1980). It is well established that mycorrhizal association improves growth in a wide range of plants (Hayman, 1983., Jeffries, 1987).

Khaliel and Elkhider (1987) reported that *Glomus mossae* inoculated tomato transplants had greater dry weight and higher percentage surrival, number of nodes, lateral branches and the number of leaves per plant were almost double in mycorrhizal transplants. Senapathi *et al.* (1987) noticed increase in plant height and number of seeds per pod in AMF inoculated bhindi plants. Plant height and fruit yield was more in bell pepper inoculated with AMF grown in low phosphorus soil under water stress. (Waterer and Coltmann, 1989). Geethakumari *et al.* (1990) reported that the number of leaves $hill^{-1}$ of ragi was positively influenced by mycorrhizal inoculation. The possibility of saving phosphorus fertlizers using VAM in grain cowpea was reported by Geethakumari *et al.* (1994). Lu and Koide (1994) observed that in general mycorrhizal plants had much greater leaf area, leaf weight and also more number of leaves.

#### 2.2.3.2 AMF on root nodulation and nutrient uptake

In AMF inoculated plants, relatively less of the photosynthates are allocated to the roots and hence the root/shoot ratio is usually lower than in their non-mycorrhizal counter parts . Lower root/shoot ratios with VAM colonisation have been reported by Piccini *et al.* (1988) and also Berta *et al.* (1990).

Bagyaraj and Manjunath (1980) reported that mycorrhizal occurrence in crop plants stimulated more of root proliferation. Singh and Singh (1986) reported that lentil responded well to *Glomus fasciculatum* in the phosphorus deficient as well as in the soil amended with 40 mg P $kg^{-1}$ soil. They also observed that mycorrhizae proved effective in enhancing the activity of *Rhizobium* and in improving growth, nodulation, N-fixation, phosphorus uptake and yield of lentil. Leela and Dwivedi (1987) in a pot trial with pea (*Pisum satium*) observed that AMF treatment gave best results in terms of healthier root and shoot system, more number of leaves, increased height, greater biomass and more phosphate content in the plant ash. Godse *et al.* (1988) found that AMF inoculation of cowpea with Endogone spores increased nodulation, root and shoot development. Chandra and Maheswari (1990) found that *Glomus aggregatum*, promoted nodulation, growth and yield of bean. Osonubi (1994) observed a significant increase in total root length and root dry weight of maize due to mycorrhizal inoculation.

Stribley *et al.*(1980) reported that shoots of plants infected with VAM contained higher internal concentration of phosphorus than those of uninfected plants of equal size, over wide ranges of external supply and of host plants. Typically in mycorrhizal plants, the phosphorus concentration per unit dry weight was higher and thus the phosphorus utilisation efficiency lower than in non-mycorrhizal plants.

Manjunath and Bagyaraj (1984) studied the response of pigeonpea and cowpea (*Vigna unguiculata* (L.) Walp.) to dual inoculation with AMF and *Rhizobium* and found that plants inoculated with both organisms and supplemented with phosphorus recorded the highest shoot dry weight and nitrogen and phosphorus content. Similar increase in phosphorus uptake, shoot and grain dry weight was reported by Singh and Tilak (1989) in chickpea inoculated with *Glomus versiformae*. Shanthi and Leela (1990) studied the efficiency of AMF with different forms of phosphorus on the availability and uptake of nutrients and the yield of mung bean. They found that irrespective of the source and level of phosphorus, AMF inoculation increased uptake of phosphorus and other nutrients. Rock phosphate was more efficiently used by AMF and increased grain yield by 54% over control.

**2.2.3.3 AMF on yield**

Islam *et al.* (1980) recorded greater dry matter production and early flowering in inoculated cowpea. Significant increase in root length, shoot height and dry weight, number of nodules, percentage of mycorrhizal infection and yield over control was recorded when chickpea was subjected to AMF or *Rhizobium* inoculum alone or in combination (Chaturvedi *et al.*, 1987). In sweet potato, yield increase of 20-26 percent was noticed due to AMF inoculation (KAU, 1991). Sundaram and Arangarasan (1995) found 35 percent yield increase in Co-3 variety of tomato when inoculated with *Glomus fasciculatum*.

## 2.3 Phosphate solubilising microorganisms (PSM)

Utilisation of soil microorganisms as agents for mediating solubilisation of phosphorus from insoluble phosphate sources is a technique promulgated by microbiologists. In gerneral, PSM include different groups of microorganisms such as bacteria and fungi which convert insoluble organic and inorganic phosphatic compounds into soluble form. In India, a huge volume of research has been carried out on the usefulness of PSM in boosting phosphorus use efficiency in various crops. Cultures of different types of PSM are recommended for use along with rock phosphate in most of the Indian states.

### 2.3.1 Mechanism of solubilisation of rock phosphate

Sperber (1958) and Katznelson and Bose (1959) have reported that the P solubilising ability of PS organisms is due to the excretion of organic acids which directly dissolved inorganic phosphatic compounds or by chelation of the cationic partners of the P ion. Bromfield (1959) reported that rock phosphate solubility was closely related to the magnitude of acidity produced in the medium. Meyer and Konig (1960) observed that solubilisation of rock phosphate proceeds through the utilisation of small amounts of initial phosphorus available in the medium followed by the use of soluble P dissolved by organic acids secreted by the growing mycelia. Duff *et al.* (1963) observed that 2 – keto gluconic acid produced by several PS bacteria and fungi released several phosphates and silcates in solution.

Ahmad and Jha (1968) published positive results regarding the solubilisation of hydroxy apatite and rock phosphate by gram positive and gram negative, rods, cocci shaped bacteria, fungi (*Aspergillus*, *Penicillium* and *Rhizopus*) and species of *Nocardia* and *Micromonospora*. Gaur *et al.* (1973) and Khan and Bhatnagar (1977) have reported that the organic acids produced by *Aspergillus carbonum* and *Aspergillus awamori* can lower the pH of the medium to 2.7 and 3.8 respectively. *Invitro* evaluation of the cultures of *Bacillus*, *Pseudomonas*, *Penicillium* and *Aspergillus* sp. by Venkateswarlu *et al.* (1984) has shown that P released by these organisms was associated with the production of organic acids like lactic, glycolic and succinic acid in the media.

Bardiya and Gaur (1974) isolated yeasts, fungi and bacteria from the rhizosphere of leguminous crops and soils of rock phosphate deposit area which were capable of solubilising mussorie rock phosphate (MRP) and reported that *Schwanniomyces occidentalis*, *Aspergillus awamori* and *Penicillium digitatum* were better than others in rock phosphate solubilisation. The most efficient bacteria were identified as strains of *Pseudomonas striata*. Khan and Bhatnagar (1977) identified *Aspergillus niger* and *Penicillium* sp. as better solubilisers of rock phosphate. Singh *et al.* (1984) investigated microbial solubilisation of rock phosphate of varying origin in liquid medium and reported that *Pseudomonas striata* solubilised Jordan rock phosphate to the maximum extent followed by Jhabua, Mussorie and Udaipur. Gupta *et al.*(1993) assessed the ability of

*Bacillus licheniformis* to solubilise inorganic phosphates and low grade Indian rock phosphate in broth culture in a sandy loam soil. The results indicated that *Bacillus licheniformis* was able to solubilise rock phosphate in soil and thus had potential for improving soil phosphorus levels.

Moghimi *et al.* (1978) and Tinker (1980) have reported that PS organisms are capable of producing effective chelating materials in a micro environment such as in the immediate vicinity of rock phosphate or phosphatic materials or in the rhizosphere . Kumar and Dube (1993) observed the production of siderophores by phosphate solubilising bacteria which helped in P solubilistion.

Illmer and Schinner (1992) concluded that proton excretion accompanying $NH_4^+$ assimilation is the most probable explanation of microbial solubilisation of rock phosphate. Illmer *et al.* (1995) have also stated that while *Aspergillus niger* produced citrate, oxalate and gluconate, the other species of phosphate solubilising micro organisms did not produce any organic acid in detectable amounts.

### 2.3.2 PSM in enhancing P availability in soils

Bajpai and Sundara Rao (1971) conducted soil inoculation studies in the laboratory with super phosphate and apatite with and without FYM using *Bacillus megatherium* var *phosphaticum* and *Bacillus circulans*. They found that in sterilised soils, introduction of these organisms increased the available $P_2O_5$. Rangasamy and Morachan (1974) reported that application of phosphobacterin increased the available P content in soil. Banik and Dey (1981) obtained higher levels of available P in soils to which FYM, rock phosphate and PS isolates like *Bacillus*, *Streptomyces,Penicillium* and *Aspergillus* sps. were added.

In a pot culture experiment with jute, Banik *et al.* (1989), tested the effect of inoculation of two strains of PS bacteria, and observed that available phosphorus from rock phosphate increased to a maximum after 30 days of crop growth and declined after 120 days. Mohod *et al.* (1989) reported that the use of P solubilising culture alone or in combination with phosphatic fertilizers in rice increased the root CEC, and available P in soils and P uptake in rice. From the results of a laboratory experiment conducted to test whether phosphorus dissolving fungi are capable of increasing the amount of available P in calcareous soil treated with rock phosphate or triple super phosphate (TSP) and its subsequent uptake by sorghum, Salih *et al.* (1989) reported that *Penicillium* sp. and two *Aspergillus* sp. significantly increased the availability of P in soil during the growing season. The dry matter content and P uptake were better in soil treated with rock phosphate and inoculated with these fungi. Heggo and Barakah (1993) observed that the available P status in a calcareous soil increased significantly through the application of MRP and super phosphate in combination with P dissolving bacteria or VAM inoculants.

### 2.3.3 Crop response to PSM inoculation

#### 2.3.3.1 PSM inoculation on crop growth

A number of reports are available to affirm that inoculation of PS microorganisms promoted P uptake and growth of crops.

Rangasamy (1972) reported that phosphobacterin increased plant height, girth, root weight and uptake of phosphorus and potassium at all stages of growth of sorghum. Podile (1995) reported the effect of seed bacterisation of pigeon pea with *Bacillus subtilis* in enhancing the percentage emergence of seedlings.

#### 2.3.3.2 PSM inoculation on root nodulation

Vinayak and Patil (1978) observed better root development in corn, cabbage, millet and oats and reported 33 percent increase in yield of tomato due to combined inoculation of phosphobacterin_ and *Azotobacter sp.* In a pot experiment to study the effect of phosphate solubulising fungi on the availability of phosphorus from rock phosphate on the growth of chick pea, Rasal *et al.* (1988) observed that inoculation with *Aspergillus awamori* increased the availability of phosphorus in the soil leading to a significant improvement in nodulation. Srivastava and Ahlawat (1995) confirmed that seed inoculation with *Rhizobium* or phosphate solubilising bacteria alone or in combination resulted in considerable increase in nodulation, nitrogenase activity, growth, yield and nutrient uptake by cowpea over uninoculated control.

### 2.3.3.3 PSM inoculation on P uptake and yield

Bajpai and Sundara Rao (1971) conducted pot culture experiments in cowpea using SSP and apatite with and without farmyard manure using *Bacillus* species and reported an increased crop yield, as well as nitrogen uptake. Kavimundan and Gaur (1971) reported that inoculation of PDB increased P uptake and yield of maize. According to Sharma and Singh (1971) combined use of phosphobacterin along with bonemeal in a sandy loam soil improved the grain yield of rice as well as N and P content when compared to the application of N in combination with bonemeal. Subramanian and Purushothaman (1974) observed that bengal gram seeds treated with *Bacillus circulans* absorbed more phosphorus. Yousry (1978) and Patil *et al.* (1979) have obtained significantly higher dry matter and yield of cowpea when inoculated with phosphobacterin compared to an uninoculated control. A significant increase in grain yield of wheat was obtained in field conditions at Pura farm in Kanpur, when rock phosphate was applied to soil and seeds were inoculated with *Pseudomonas striata* (Gaur *et al.*, 1980). They have reported the response of the crop to bacterial inoculation as equivalent to 50 kg $P_2O_5$ ha $^{-1}$.

Khalafallah *et al.* (1982) reported that inoculation of fava bean with *Bacillus megatherium* var. *phosphaticum* resulted in increased plant height, phosphorus uptake and phosphorus concentration. Asea *et al.* (1988) using $^{32}P$ isotope dilution method found that wheat when inoculated with *Penicillium bilaji* was able to obtain 18 percent of its phosphorus from sources unavailable to the uninoculated plants and was also able to solubilise added rock phosphate. Dry matter production and phosphorus uptake in wheat has been reported to increase under field and green house conditions in response to *Penicillium bilaji* inoculation in the absence of added rock phosphate and addition of rock phosphate resulted in a further increase in the dry matter production (Kucey, 1988). In a field experiment with rice conducted in laterite soil of Maharashtra, Mohod *et al.* (1989) revealed that the use of phosphorus solubilising culture significantly increased the number of grains per panicle, weight of 1000 grains, grain weight per panicle, grain yield, straw yield, nitrogen uptake and the beneficial effect were greater with rock phosphate than single super phosphate. Gaur (1990) has reported that the grain yield of wheat was significantly increased ( 3070 kg $ha^{-1}$) due to inoculation of seed with *Pseudomonas striata, Bacillus polymyxa* and *Aspergillus awamori* as compared to uninoculated control (2650 kg $ha^{-1}$). The phosphorus uptake was also augmented due to the use of inoculants. Hnatowich *et al.* (1990) evaluated the effect of *Penicillium bilaji* at 38 locations across three Canadian Prairie provinces in 1988 and 1989 and reported that seed inoculation with *Penicillium bilaji* in the absence of phosphorus fertilizers gave an average increase in yield of 76 kg wheat per hectare. Prabhakar and Saraf (1990) and Kumar and Agarwal (1993) reported favourable effect of *Penicillium striata* on chickpea.

Rachewad *et al.* (1991) has reported that seed inoculation with *Bacillus polymyxa* and/or 75 kg phosphorus per ha increased the biomass production and phosphorus content in maize grown in a phosphorus deficient soil compared to the untreated control. Dubey and Billore (1992) reported that microbial inoculation and fertilization of phosphorus and their interaction significantly influenced grain and straw yield of chickpea. Rathore *et al.* (1992) conducted field trials using lentils inoculated with *Bacillus megatherium* and reported that seed inoculation significantly increased yield over the uninoculated control. Sushama *et al.* (1993) used different sources of phosphorus such as single super phosphate, mussorie rock phosphate (MRP), partially acidulated rock phosphate and MRP along with phosphorus solubilising fungi in rice and reported that the grain yield was highest with MRP and fungi when applied in conjunction with green manure or farm yard manure. The fertilizer use efficiency was highest for the combination of the MRP and fungi with green manure indicating that MRP is a better alternative to other expensive water soluble phosphate source for use in coastal laterites. Goos *et al.* (1994) has reported that in the absence of phosphorus fertilization, *Penicillium bilaji* inoculation increased the grain yield in spring wheat by an average of 66 kg $ha^{-1}$. Hegde and Dwivedi (1994) reported significant effect of inoculation with *Bacillus megatherium* and *Bacillus circulans* in rice and wheat which was equivalent to yield increase obtained with the use of 50 kg $P_2O_5$ $ha^{-1}$.

Hazra (1994) reported that phosphobacterin treated seeds produced 31 percent yield increase in oats. He also noted that seeds coated with *Bacillus polymyxa* gave higher forage yield than non bacterised seeds. Kathiresan *et al.*, (1995) have reported that soil inoculation with phosphobacterin (10 kg $ha^{-1}$) increased cane yield and its quality and application of 31.5 kg $P_2O_5$ + soil inoculation with PB gave similar cane yield as the application of 63 kg $P_2O_5$. Dubey (1996) reported that total dry matter and phosphorus content in different plant parts of soybean at various stages and yield increased with the use of *Pseudomonas striata* either alone or in conjunction with SSP and MRP. Vaishya *et al.* (1996) has observed that the use of phosphorus solubilising microorganisms (PSM) along with rock phosphate for bengal gram in a vertisol resulted in a significantly higher phosphorus uptake. Shehana (1997) reported that the available P content of soil, plant P content, P uptake, yield attributes and dry matter production in banana were favourably influenced by the use of PB along with a lesser amount of P than the present POP recommendation.

### 2.3.4 Effect of dual inoculation of AMF and PSM

Several authors have reported synergistic interaction between AMF and PSM.

The influence of inoculation of soil with AMF (*Glomus fasciculatum*) and phosphate dissolving microorganisms on phosphate solubilisation and phosphorus uptake from $^{32}P$-labelled tri calcium phosphate and super phosphate were studied in finger millet by

Raj *et al.* (1981). They observed that mycorrhizal plants produced more dry matter and removed more $^{32}P$ from the soil than non-mycorrhizal plants, but did not show increased $^{32}P$ activity per unit plant mass. However, $^{32}P$ activity and total phosphorus uptake were enhanced by soil inoculation with PSM and synergistic effect was recorded with phosphorus uptake and dry matter production. Azcon *et al.* (1986) studied the interactions between AMF and PSM on the utilization of the sparingly soluble $^{32}P$- Ca-tricalcium phosphate by *Glycine max* in a neutral calcareous soil and found that mycorrhizal inoculation improved plant utilization of sparingly soluble tricalcium phosphate. They observed an increased mycorrhizal infection by PSM at all levels of added phosphate. Dubey and Billore (1992) reported that combined inoculation with *Glomus fasciculatum* and PSM augmented haulm and grain yields in chickpea, but not significantly over their respective control. Synergistic effect of phosphate solubilising microorganisms and VAM on soybean had been reported by Tilak *et al.* (1995). Viswambaran (1995) has reported that the use of 100 percent phosphorus as rock phosphate along with AMF and PB resulted in the highest available phosphorus content in cowpea (var.C-152) in a red loam soil and the combined application of AMF and PB was found to be better than the individual applications.

# MATERIALS AND METHODS

# MATERIALS AND METHODS

The present investigation was carried out to evaluate the role of microbial inoculants viz. arbuscular mycorrhizal fungi (AMF) and phosphate solubilising microorganisms (PSM) in enhancing the phosphorus use efficiency and productivity of cowpea var. Sharika under different levels of phosphorus. Field experiment was conducted during December 1998 to April 1999 at the Instructional Farm, College of Agriculture, Vellayani. The details on materials used and methods followed are briefly described below.

## 3.1 Materials

### 3.1.1 Experimental site

The experiment was conducted at the Instructional Farm, attached to the College of Agriculture (COA), Vellayani located at 8°30' N latitude and 76°54'E longitude at an altitude of 29 m above MSL. The experimental area was under bitter gourd. [*Momordica charantia* L.] with recommended dose of fertilizers during the previous season.

### 3.1.2 Soil

The experimental soil was laterite which comes under the order oxisol. The soil belongs to the family of loamy skeletal kaolinitic iso hyperthermic Rhodic Haplustox. The soil was sandy loam in texture and acidic in reaction with a pH of 5.0. The initial data on the mechanical and chemical analysis of the soil are presented in Table 1.

**Table 1. Soil characteristics of experimental site**
**Mechanical composition**

| Sl.No. | Parameters | Content in soil (percent) | Method used |
|---|---|---|---|
| 1 | Coarse sand | 46.35 | Bouyoucos Hydrometer meter method. |
| 2. | Fine sand | 20.00 | Bouyoucos (1962) |
| 3. | Silt | 19.00 | |
| 4. | Clay | 5.00 | |

**Chemical properties**

| Parameters | Value | Rating | Method |
|---|---|---|---|
| Available nitrogen(kg $ha^{-1}$) | 78.40 | Low | Alkaline Potassium Permanganate method (Subbiah and Asija, 1956) |
| Available $P_2O_5$ (kg $ha^{-1}$) | 24.0 | Medium | Bray extraction and Klett Summerson Photoelectric Colorimetric method (Jackson, 1973) |
| Available $K_2O$ (kg $ha^{-1}$) | 29.12 | Low | Neutral Normal Ammonium Acetate method (Jackson, 1973) |
| pH | 5.00 | Acidic | 1:2.5 soil solution ratio using pH meter with glass electrode (Jackson, 1973) |

### 3.1.3 Season

Field experiment was conducted during summer season (period extending from the second fortnight of December to the first week of April of 1998-99).

### 3.1.4 Weather data

Vellayani experiences a wet humid tropical climate. The data on various weather parameters during the cropping period was collected from the Agrometeorological observatory attached to the Department of Agricultural Meteorology, College of Agriculture, Vellayani and presented in Appendix and Fig 1.

### 3.1.5 Crop and variety

Vegetable cowpea var. Sharika was selected for the study.

### 3.1.6 Source of seed material

The seeds for the experiment were obtained from the Instructional Farm, College of Agriculture, Vellayani.

### 3.1.7 Manures and Fertilizers

**Organic manure**

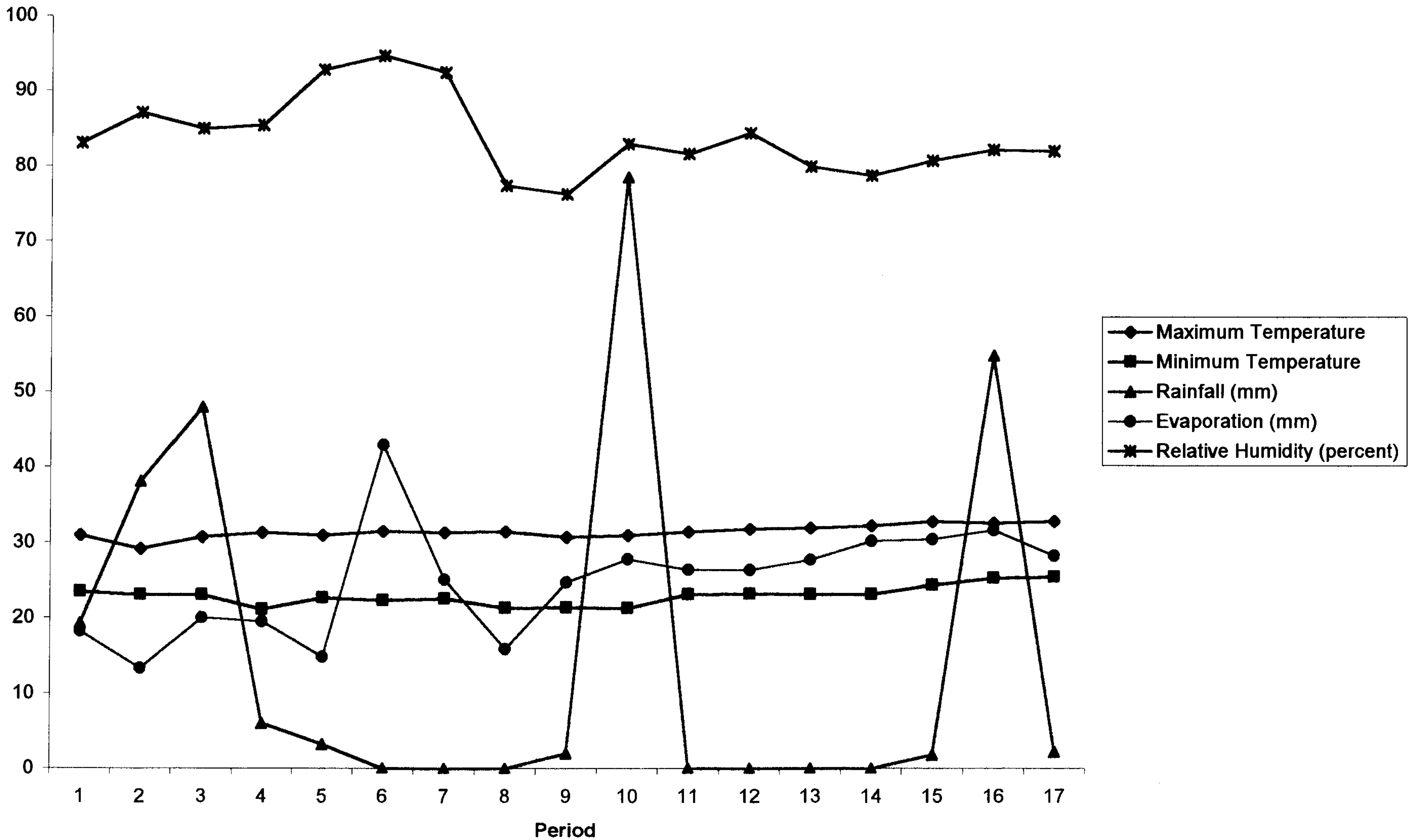
Well decomposed and dried farm yard manure (FYM) of the nutrient composition (N- 0.40 percent, $P_2O_5$- 0.30 percent, $K_2O$ – 0.20 percent ) was used for the study.

**Chemical fertilizers**

Fertilizers of the following analysis were used as sources of nitrogen, phosphorus and potassium respectively.

| | |
|---|---|
| Urea | -- 46.0 per cent nitrogen |
| Mussoriephos | -- 22.0 per cent $P_2O_5$ |
| Muriate of potash | -- 60.0 per cent $K_2O$ |

Fig.1 Weather data during the cropping period



**Biofertilizers**

**AMF**: Mixed cultures containing spores of *Glomus* sp. infected sorghum root pieces and infected medium (perlite vermiculite) were collected from pots maintained at the Department of Plant Pathology, College of Agriculture, Vellayani.

**Phosphate solubilising microbial culture**:

Phosphobacterin culture consisting of a mixture of bacteria (*Pseudomonas* and *Bacillus* sp. ) and fungi (*Aspergillus* sp.) obtained from University of Agricultural Sciences, Hebbal, Bangalore was used.

## 3.2 Methods

### 3.2.1 Experimental design and layout

The field experiment was laid out in factorial randomised block design (RBD) with three replications . The lay out plan of the experiment is depicted in Fig. 2

| | | |
|---|---|---|
| Design | : | Factorial RBD |
| Treatment combinations | : | 14 (3 x 4 + 2) |
| Number of treatments per block | : | 14 |
| Total number of plots | : | 42 |
| Plot size | : | 4 x 3.75m |
| Spacing | : | 1x 0.75m |

N

## Fig. 2 Lay out plan of the experimental field

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Replication III** | $T_8$ | $T_1$ | $T_4$ | $T_3$ | $T_5$ | $T_{10}$ | $T_{13}$ | $T_7$ | $T_9$ | $T_{11}$ | $T_{14}$ | $T_2$ | $T_6$ | $T_{12}$ |
| **Replication II** | $T_{13}$ | $T_{12}$ | $T_{14}$ | $T_9$ | $T_6$ | $T_2$ | $T_4$ | $T_{11}$ | $T_8$ | $T_3$ | $T_1$ | $T_7$ | $T_5$ | $T_{10}$ |
| **Replication I** | $T_9$ | $T_{11}$ | $T_8$ | $T_6$ | $T_7$ | $T_5$ | $T_{12}$ | $T_1$ | $T_4$ | $T_{13}$ | $T_{10}$ | $T_{14}$ | $T_2$ | $T_3$ |

**Plot size : 4 x 3.75 m**

**Design : Factorial Randomised Block Design**

| | | | |
|---|---|---|---|
| $T_1$ – $M_1P_1$ | $T_5$ – $M_2P_1$ | $T_9$ – $M_3P_1$ | $T_{13}$ – $C_1$ |
| $T_2$ – $M_1P_2$ | $T_6$ – $M_2P_2$ | $T_{10}$ – $M_3P_2$ | $T_{14}$ – $C_2$ |
| $T_3$ – $M_1P_3$ | $T_7$ – $M_2P_3$ | $T_{11}$ – $M_3P_3$ | |
| $T_4$ – $M_1P_4$ | $T_8$ -- $M_2P_4$ | $T_{12}$ – $M_3P_4$ | |

### 3.2.2 Treatment details

Treatment combinations : 14 (3 x 4 + 2)

**Factors**

Microbial inoculants

Levels : Three

$M_1$- Arbuscular mycorrhizal fungi (AMF)

$M_2$- Phosphate solubilising microorganisms (PSM)

$M_3$- AMF + PSM

Phosphorus

Levels : Four

$P_1$- 0 kg $P_2O_5$ ha $^{-1}$

$P_2$- 15 kg $P_2O_5$ ha $^{-1}$

$P_3$- 30 kg $P_2O_5$ ha $^{-1}$

$P_4$- 45 kg $P_2O_5$ ha $^{-1}$

Control treatments

$C_1$ - No bioinoculants + No NPK (Absolute control)

$C_2$ - No bioinoculants + N and K fertilizers + No $P_2O_5$

**Treatment combinations**

| | | | |
|---|---|---|---|
| $T_1$ - $M_1P_1$ | $T_5$ - $M_2P_1$ | $T_9$ - $M_3P_1$ | $T_{13}$ - $C_1$ |
| $T_2$ - $M_1P_2$ | $T_6$ - $M_2P_2$ | $T_{10}$ - $M_3P_2$ | $T_{14}$ - $C_2$ |
| $T_3$ - $M_1P_3$ | $T_7$ - $M_2P_3$ | $T_{11}$ - $M_3P_3$ | |
| $T_4$ - $M_1P_4$ | $T_8$ - $M_2P_4$ | $T_{12}$ - $M_3P_4$ | |

## 3.3 Field culture

### 3.3.1 Land preparation

The experimental field was dug twice, stubbles removed clods broken and laid out into blocks and plots.

### 3.3.2 Manure and fertilizer application

Farmyard manure was applied at the rate of 25 t $ha^{-1}$, uniformly to all the plots and mixed well with top soil. A common dose of 30 kg $ha^{-1}$ N and 10 kg $ha^{-1}$ $K_2O$ was given to all the plots except absolute control plot ($C_1$). Phosphorus was applied as per the treatments. Full dose of phosphorus and potassium along with half the dose of nitrogen was applied basally at the time of sowing and the remaining half dose of nitrogen in two equal split doses at 20 DAS and 40 DAS.

AMF was applied at the rate of 5g/plant. Along with this, PS culture was applied insitu @ 1 g/plant after thoroughly mixing with well rotten FYM.

### 3.3.3 Sowing

Plots were taken and seeds were dibbled at the rate of three per hole at a depth of 5 cm and at a spacing of 1.0 m between rows and 0.75 m between plants.

### 3.3.4 After cultivation

Uniform germination was observed in the field. Gap filling was done four days after sowing. The crop was thinned one week after emergence and the plants were trailed on standards. The crop was given regular weedings throughout the cropping period. Earthing up was also done along with topdressing of nitrogen. Five plants were selected randomly from the net plot area and tagged as observational plants.

### 3.3.5 Plant protection

Furadan 3G was applied against grass hopper attack. To prevent pod borer attack, which was found serious in the field, Ekalux 0.2 percent was sprayed. As a prophylactic measure against basal rot, Dithane M-45 0.2 percent was sprayed two weeks after sowing.

### 3.3.6 Harvesting

Pods were harvested for vegetable purpose from 50 DAS onwards. Subsequent harvests of green immature pods were done in alternate days from all the treatments up to 100 DAS and fresh weight recorded. After the crop period, when the vegetable yield had fallen well below the economic level, the plants were pulled out from the net area and bhusa yield recorded. After that the same was sun dried and oven dried and dry weight was recorded.

## 3.4 Biometric observations

### 3.4.1 Length of vine

The mean value of the length of five randomly selected observational plants from each net plot was computed at vegetative, flowering and harvest stages and recorded . Length was measured from the base of the plant to the terminal leaf bud and expressed in centimetres.

### 3.4.2 Number of primary branches

The mean value of number of primary branches per plant was computed from five observational plants at vegetative, flowering and harvest stages.

### 3.4.3 Number of leaves

The mean value of number of leaves per plant was computed from five observational plants at vegetative, flowering and harvest stages and recorded.

### 3.4.4 Leaf area index (LAI)

Leaf area index was measured using LI- 300 leaf area meter at three stages of growth viz. vegetative, flowering and harvest stages and expressed in square centimetre.

LAI was worked out using the following equation:

$$LAI = \frac{\text{Total leaf area}}{\text{Land area}}$$ (Watson, 1962)

### 3.4.5 Number of effective nodules

Three plant samples were collected from each plot at random without disturbing the root system and nodules were separated at flowering stage. The nodules with pink or reddish colour were counted to get the number of effective nodules. The average of these values was expressed to get the per plant value.

### 3.4.6 AMF colonisation percent

AMF colonisation percent at flowering and harvest stages was estimated by following the procedure of Phillips and Hayman (1970). Three plants were randomly selected and roots were washed and cut into 1 cm sized bits and fixed in FAA. [Formic Acetic acid- Alcohol (5:5:90)]. The roots were hydrolysed in 10 percent KOH at 100°C for 10-15 minutes. The alkalinity of root samples was neutralised with 1 percent HCl. Then the roots were stained with 0.05 percent Trypan blue in lactophenol . The stained roots were steamed for 15 minutes for proper stain absorption. A minimum of 24 root bits were arranged on a clean slide, covered with coverslip and observed under a compound microscope for the presence of mycelia, arbuscles and vesicles of AMF.

The AMF colonisation percent was calculated as follows.

$$\text{AMF colonisation percent} = \frac{\text{No. of root segments + ve for infection} \times 100}{\text{Total number of root segments observed}}$$

### 3.4.7 Root length

The mean value of the root length of three randomly selected plants at flowering stage was recorded. Each plant was uprooted, roots were thoroughly washed and length of largest main tap root was measured and expressed in centimeters.

### 3.4.8 Root mass

Root masses of three randomly selected plants were carefully separated at flowering stage. They were washed with clean water and dried to a constant weight at 65°C for ten hours in hot air oven. From the data obtained, mean value was worked out and expressed as g plant $^{-1}$.

### 3.4.9 Root volume

Root volume of three randomly selected plants was found out by water displacement technique. Plants were carefully uprooted at flowering stage and washed with clean water. The measurement was done in a container with an overflow spout. The container was filled with water until it overflowed from the spout. The freshly washed roots were inserted and the overflow water volume was measured in a graduated cylinder. From the data obtained, the mean value was computed and expressed in cubic centimetre.

## 3.5 Yield and yield attributes

### 3.5.1 Days to 50 percent flowering

The days for flowering of 50 percent of the net population was recorded for each treatment, and the period taken was calculated from the day of sowing.

### 3.5.2 Number of pods per plant

Pods collected from five observational plants were counted separately and averages were worked out.

### 3.5.3 Length of pods

Length of pods collected from five observational plants was measured separately and mean value was expressed in centimetres.

### 3.5.4 Number of beans per pod

Beans present in pods collected from five observational plants were separately counted and mean value was worked out.

### 3.5.5 Pod yield per plant

Pod yields of five observational plants were recorded separately. The mean value was computed and expressed in kg plant $^{-1}$.

### 3.5.6 Pod yield per hectare

Yield of vegetable obtained from each net plot was recorded separately and totalled up at the end of the cropping period and expressed in kg ha $^{-1}$.

### 3.5.7 Haulm yield per hectare

After the pods were picked from each net plot the plants were uprooted, sun dried uniformly and weighed. The weight was expressed in kg $ha^{-1}$.

### 3.5.8 Number of pickings

Number of vegetable pickings from each net plot during the total crop period was recorded treatment wise.

## 3.6 Analytical procedures

### 3.6.1 Soil analysis

Soil samples were taken from the experimental area before the start of the experiment, at vegetative stage, flowering stage and after the experiment. The air dried soil samples collected before and after the experiment were analysed for available nitrogen, $P_2O_5$ and $K_2O$ content. Apart from this, $P_2O_5$ content was analysed from soil samples collected at vegetative and flowering stages also. Available nitrogen (N) content was determined by Alkaline potassium permanganate method (Subbiah and Asija, 1956), available $P_2O_5$ content by Bray colorimetric method (Jackson, 1973) and available $K_2O$ by Ammonium acetate method (Jackson, 1973).

### 3.6.2 Plant analysis

Plant samples were analysed for phosphorus content at harvest stage. Samples were chopped and dried in an oven at 80°C $\pm$ 5°C till constant weights were obtained. Samples were ground and sieved through 60-mesh sieve. The required quantities of samples were then weighed out accurately in an electronic balance and used for chemical analysis. In addition to this, pods were collected at harvest stage, dried and ground separately and analysed for nitrogen and phosphorus content. The nitrogen content in pods was estimated by modified microkjeldahl method (Jackson,1973). The phosphorus content in plant and pods was estimated colorimetrically (Jackson,1973).

### 3.6.3 Protein content

The pod nitrogen values were multiplied by the factor 6.25 to obtain the protein content of pods and the values were expressed as percent. (Simpson *et al.*, 1965).

### 3.6.4 Fibre content

Five gram of the dried pods was boiled with 200 ml of 1.25 percent sulphuric acid for 30 minutes and filtered through muslin cloth and washed with boiling water. Then it was boiled with 200 ml of 1.5 percent sodium hydroxide solution for 30 minutes and filtered through muslin cloth again and washed with 25 ml of alcohol. The residue was removed and transferred to a silica dish. The residue was dried at 130°C for 2 hours, cooled and weighed . Then it was ignited for 30 minutes at 600°C, cooled and reweighed. The crude fibre content in the sample was expressed in percent (Kanwar and Chopra, 1976).

## 3.7 Economic analysis

The economics of cultivation of the crop was worked out and the net income and benefit-cost ratios (BCR) were calculated as follows.

$$\text{BCR} = \frac{\text{Gross income}}{\text{Total cost of cultivation}}$$

## 3.8 Statistical analysis

Data relating to each character was analysed by applying the Analysis of Variance Technique (ANOVA) (Gomez and Gomez,1984).

# RESULTS

# RESULTS

A field experiment on vegetable cowpea var. Sharika was conducted at the Instructional Farm attached to the College of Agriculture, Vellayani during December to April 1998 -99. The present investigation was done to evaluate the role of microbial inoculants viz. arbuscular mycorrhizal fungi (AMF) and phosphate solubilising microorganisms (PSM) in enhancing the phosphorus use efficiency and productivity under varying levels of phosphorus. The experimental data collected were statistically analysed and results obtained are presented below.

## 4.1 Growth characters

Plant growth was measured in terms of length of vine, number of primary branches, number of leaves per plant and leaf area index at three growth stages viz. vegetative, flowering and harvest.

### 4.1.1 Length of vine

The average length of vine at three stages of growth viz. vegetative, flowering and harvest are presented in Table 2. The results revealed that among the treatments bioinoculants had significant influence on length only at the vegetative stage. Application of different levels of phosphorus and their interaction effects had no statistical significance with respect to the length of vine in all stages of growth.

## Table 2

**Effect of microbial inoculants, phosphorus levels and interaction on length of vine.**

| Treatments | Lenght of vine | | |
|---|---|---|---|
| | at vegetative stage (cm) | at flowering stage (cm) | at harvest stage (cm) |
| $M_1$ | 147.38 | 259.42 | 342.58 |
| $M_2$ | 167.20 | 256.95 | 338.23 |
| $M_3$ | 174.50 | 269.03 | 350.45 |
| CD (0.01) | 13.70 | ns | ns |
| $P_1$ | 157.44 | 258.87 | 342.87 |
| $P_2$ | 165.00 | 268.09 | 348.33 |
| $P_3$ | 169.69 | 258.64 | 341.12 |
| $P_4$ | 159.98 | 261.60 | 342.69 |
| CD(0.05) | ns | ns | ns |
| $M_1P_1$ | 139.73 | 257.87 | 342.93 |
| $M_1P_2$ | 152.07 | 272.87 | 350.93 |
| $M_1P_3$ | 146.53 | 256.80 | 341.33 |
| $M_1P_4$ | 151.20 | 250.13. | 335.13 |
| $M_2P_1$ | 158.20 | 280.67 | 360.20 |
| $M_2P_2$ | 162.87 | 233.40 | 320.47 |
| $M_2P_3$ | 179.87 | 254.87 | 332.70 |
| $M_2P_4$ | 167.87 | 258.87 | 339.53 |
| $M_3P_1$ | 174.40 | 265.73 | 341.87 |
| $M_3P_2$ | 180.07 | 270.33 | 357.20 |
| $M_3P_3$ | 182.67 | 264.27 | 349.33 |
| $M_3P_4$ | 160.87 | 275.80 | 353.40 |
| CD (0.05) | ns | ns | ns |
| Treatment means | 163.03 | 261.80 | 343.75 |
| $C_1$ | 175.47 | 253.27 | 329.00 |
| $C_2$ | 152.80 | 261.93 | 342.53 |

Among the microbial inoculants at vegetative stage, treatments PSM alone ($M_2$) and dual inoculation of AMF and PSM ($M_3$) showed significant variation over the other treatment $M_1$ and were statistically on par.

The mean of these factorial treatment combinations did not show significant difference over the two control treatments ($C_1$ and $C_2$) at any stage. Similarly, treatments $C_1$ and $C_2$ could not produce significant variation between themselves also.

### 4.1.2 Number of leaves per plant

The mean number of leaves as influenced by the treatments are given in Table 3. Generally, the leaf number increased progressively from vegetative to harvest stage. Bioinoculants, different levels of phosphorus as well as their interaction effects revealed no significant influence on number of leaves.

Regarding phosphorus application, treatment $P_3$ gave the maximum number of leaves (17.20) at vegetative stage while treatment $P_2$ at flowering and harvest stages (31.24 and 61.84 respectively). Similarly, of the treatment combinations, $M_1P_2$, $M_3P_2$ and $M_3P_4$ recorded the highest number of leaves at vegetative, flowering and harvest stages.

In all the three stages of growth the mean of the two control treatments ($C_1$ and $C_2$) produced lower number of leaves compared to mean

**Table 3**

**Effect of microbial inoculants, phosphorus levels and interaction on number of leaves**

| **Treatments** | **Number of leaves** | | |
|---|---|---|---|
| | **At vegetative stage** | **At flowering stage** | **At harvest stage** |
| $M_1$ | 16.05 | 29.17 | 60.05 |
| $M_2$ | 15.60 | 29.68 | 60.67 |
| $M_3$ | 17.33 | 31.78 | 62.47 |
| CD (0.05) | ns | ns | ns |
| $P_1$ | 15.49 | 29.84 | 60.80 |
| $P_2$ | 17.07 | 31.24 | 61.84 |
| $P_3$ | 17.20 | 29.47 | 60.51 |
| $P_4$ | 15.56 | 30.29 | 61.09 |
| CD(0.05) | ns | ns | ns |
| $M_1P_1$ | 13.47 | 26.47 | 57.53 |
| $M_1P_2$ | 18.67 | 31.60 | 62.67 |
| $M_1P_3$ | 15.40 | 28.13 | 59.13 |
| $M_1P_4$ | 16.67 | 30.47 | 60.87 |
| $M_2P_1$ | 15.73 | 31.33 | 62.67 |
| $M_2P_2$ | 15.67 | 29.80 | 60.13 |
| $M_2P_3$ | 17.60 | 28.53 | 59.53 |
| $M_2P_4$ | 13.40 | 29.07 | 60.33 |
| $M_3P_1$ | 17.27 | 31.73 | 62.20 |
| $M_3P_2$ | 16.87 | 32.33 | 62.73 |
| $M_3P_3$ | 18.60 | 31.73 | 62.87 |
| $M_3P_4$ | 16.40 | 31.33 | 42.07 |
| CD (0.05) | ns | ns | ns |
| Treatment means | 16.33 | 30.21 | 61.06 |
| $C_1$ | 15.94 | 28.93 | 60.20 |
| $C_2$ | 17.14 | 29.27 | 60.27 |
| CD | ns | ns | ns |

of twelve treatments and there was no significant variation in number of leaves produced between the two control treatments.

### 4.1.3 Number of primary branches

The average number of primary branches as influenced by the treatments is presented in Table 4. Bioinoculants, phosphorus levels and interaction effects were found to be not significant at all the three stages of growth with regard to the number of primary branches produced.

At all the three stages of growth, no statistical significance was observed by the mean of twelve treatment combinations over the mean of control treatments ($C_1$ and $C_2$) as well as among themselves.

### 4.1.4 Leaf area index (LAI)

The mean value of LAI at vegetative, flowering and harvest stages is presented in Table 5. Bioinoculants, phosphorus levels and their interaction effects did not significantly influence LAI at vegetative, flowering and harvest stages. However, significant influence was exhibited by interaction effects on LAI at harvest stage.

The treatment combinations $M_1P_2$, $M_2P_2$, $M_2P_4$, $M_3P_1$ and $M_3P_4$ were statistically on par and significantly superior over the remaining treatment combinations.

## Table 4

**Effect of microbial inoculants, phosphorus levels and interaction on number of primary branches.**

| Treatments | Number of primary branches | | |
|---|---|---|---|
| | At vegetative stage | At flowering stage | At harvest stage |
| $M_1$ | 2.57 | 4.57 | 7.65 |
| $M_2$ | 2.62 | 4.98 | 7.90 |
| $M_3$ | 2.83 | 4.80 | 7.83 |
| CD (0.05) | ns | ns | ns |
| $P_1$ | 2.47 | 4.80 | 7.76 |
| $P_2$ | 2.87 | 4.82 | 7.78 |
| $P_3$ | 2.67 | 4.78 | 7.84 |
| $P_4$ | 2.69 | 4.73 | 7.80 |
| CD(0.05) | ns | ns | ns |
| $M_1P_1$ | 2.13 | 4.00 | 7.20 |
| $M_1P_2$ | 2.80 | 4.47 | 7.53 |
| $M_1P_3$ | 3.57 | 4.80 | 7.80 |
| $M_1P_4$ | 2.87 | 5.00 | 8.07 |
| $M_2P_1$ | 2.33 | 5.27 | 7.87 |
| $M_2P_2$ | 2.60 | 5.20 | 8.07 |
| $M_2P_3$ | 2.67 | 4.87 | 7.93 |
| $M_2P_4$ | 2.87 | 4.60 | 7.73 |
| $M_3P_1$ | 2.93 | 5.20 | 8.27 |
| $M_3P_2$ | 3.20 | 4.73 | 7.69 |
| $M_3P_3$ | 2.87 | 4.67 | 7.80 |
| $M_3P_4$ | 2.33 | 4.60 | 7.60 |
| CD (0.05) | ns | ns | ns |
| Treatment means | 2.67 | 4.78 | 7.79 |
| $C_1$ | 8.00 | 5.47 | 8.60 |
| $C_2$ | 2.07 | 4.40 | 7.67 |

**Table 5**

**Effect of microbial inoculants, phosphorus levels and interaction on leaf area index.**

| Treatments | Leaf area index At vegetative stage | At flowering stage | At harvest stage |
|---|---|---|---|
| $M_1$ | 2.47 | 2.41 | 2.32 |
| $M_2$ | 2.28 | 2.49 | 2.40 |
| $M_3$ | 2.37 | 2.50 | 2.39 |
| CD (0.05) | ns | ns | ns |
| $P_1$ | 2.37 | 2.36 | 2.43 |
| $P_2$ | 2.41 | 2.52 | 2.42 |
| $P_3$ | 2.37 | 2.56 | 2.25 |
| $P_4$ | 2.39 | 2.44 | 2.45 |
| CD(0.05) | ns | ns | ns |
| $M_1P_1$ | 2.23 | 2.16 | 2.36 |
| $M_1P_2$ | 2.55 | 2.52 | 2.30 |
| $M_1P_3$ | 2.56 | 2.80 | 2.47 |
| $M_1P_4$ | 2.53 | 2.43 | 3.21 |
| $M_2P_1$ | 2.24 | 2.69 | 2.01 |
| $M_2P_2$ | 2.36 | 2.51 | 3.77 |
| $M_2P_3$ | 2.21 | 2.27 | 2.84 |
| $M_2P_4$ | 2.42 | 2.56 | 2.07 |
| $M_3P_1$ | 2.67 | 2.25 | 3.30 |
| $M_3P_2$ | 2.31 | 2.63 | 2.36 |
| $M_3P_3$ | 2.35 | 2.74 | 2.29 |
| $M_3P_4$ | 2.23 | 2.35 | 3.13 |
| CD (0.05) | ns | ns | 0.56 |
| Treatment means | 2.39 | 2.50 | 2.68 |
| $C_1$ | 2.07 | 2.43 | 2.18 |
| $C_2$ | 2.42 | 2.35 | 2.57 |

The control treatments ($C_1$ and $C_2$) could not produce any significant variation in LAI between themselves as well as over the mean of other treatment combinations at all growth stages.

### 4.1.5 Days to 50 percent flowering

The average number of days taken for attaining 50 percent flowering is presented in Table 6. Results revealed that bioinoculants did not exert any significant influence in the days to 50 percent flowering.

Phosphorus application at all levels induced early flowering than no application of phosphorus. Phosphorus application significantly influenced early flowering. Treatment $P_4$ was found to be on par with $P_3$ and significantly superior over $P_2$ and $P_1$.

Interaction effects of the various treatment combinations were not significantly different with respect to this character.

The mean of the twelve treatment combinations showed significant influence compared to mean of two control treatments ($C_1$ and $C_2$) in earliness of flowering while there was no significant difference between $C_1$ and $C_2$. On comparison with $C_1$ and $C_2$ the treatment combination $M_3P_4$ was the earliest to flower.

## 4.2 Root characters

The average values of root length, root mass, and root volume as influenced by bioinoculants, levels of phosphorus and their interaction effects at flowering stage are presented in Table 7.

## Table 6

**Effect of microbial inoculants, phosphorus levels and interaction on days to 50 percent flowering**

| Treatments | Days to 50 percent flowering |
|---|---|
| $M_1$ | 51.25 |
| $M_2$ | 52.00 |
| $M_3$ | 51.25 |
| CD (0.05) | ns |
| $P_1$ | 54.33 |
| $P_2$ | 51.22 |
| $P_3$ | 50.67 |
| $P_4$ | 49.78 |
| CD(0.01) | 0.99 |
| $M_1P_1$ | 53.33 |
| $M_1P_2$ | 51.33 |
| $M_1P_3$ | 50.67 |
| $M_1P_4$ | 49.67 |
| $M_2P_1$ | 55.67 |
| $M_2P_2$ | 51.33 |
| $M_2P_3$ | 50.67 |
| $M_2P_4$ | 50.33 |
| $M_3P_1$ | 54.00 |
| $M_3P_2$ | 51.00 |
| $M_3P_3$ | 50.67 |
| $M_3P_4$ | 49.33 |
| CD (0.05) | ns |
| Treatment means | 51.50 |
| $C_1$ | 55.00 |
| $C_2$ | 54.33 |

### 4.2.1 Root length

Microbial inoculants and different levels of phosphorus favourably influenced root length. However, the interaction effects did not show any significant variation in root length.

Among the microbial inoculants, $M_1$ and $M_3$ were statistically on par and significantly superior over $M_2$.

Among the different levels of phosphorus, treatment $P_2$ recorded the maximum root length (31.30cm) and highly significant over the other P levels. Treatments $P_3$ and $P_4$ were found to be on par.

The root length recorded by the mean of the two control treatments ($C_1$ and $C_2$) was lower (27.11cm) compared to the mean of treatment combinations while $C_1$ and $C_2$ did not show any variation among themselves. The treatment combination $M_3P_2$ recorded the maximum root length (34.42 cm) over $C_1$ and $C_2$.

### 4.2.2 Root mass

The average values of root mass presented in Table 7 revealed that levels of phosphorus and interaction effects had strongly influenced the root mass. However, the microbial inoculants did not exhibit any significant variation in root mass.

## Table 7

**Effect of microbial inoculants, phosphorus levels and interaction on root length, root mass and root volume at flowering stage**

| Treatments | Root length (cm) | Root mass (g) | Root volume ( $cm^3$ ) |
|---|---|---|---|
| $M_1$ | 29.18 | 8.28 | 20.87 |
| $M_2$ | 27.36 | 7.77 | 24.12 |
| $M_3$ | 30.21 | 8.21 | 22.46 |
| CD (0.05) | 1.80 | ns | CD (0.01) 1.68 |
| $P_1$ | 27.31 | 7.59 | 17.64 |
| $P_2$ | 31.30 | 8.85 | 29.02 |
| $P_3$ | 28.86 | 7.95 | 20.21 |
| $P_4$ | 28.19 | 7.95 | 23.06 |
| CD(0.01) | 2.08 | CD (0.05) 0.90 | CD (0.01) 1.94 |
| $M_1P_1$ | 28.24 | 8.86 | 18.33 |
| $M_1P_2$ | 29.98 | 9.21 | 23.37 |
| $M_1P_3$ | 29.14 | 7.23 | 14.40 |
| $M_1P_4$ | 29.35 | 7.81 | 27.40 |
| $M_2P_1$ | 26.56 | 6.84 | 16.10 |
| $M_2P_2$ | 29.50 | 8.61 | 33.44 |
| $M_2P_3$ | 27.15 | 9.03 | 27.92 |
| $M_2P_4$ | 26.24 | 6.61 | 19.00 |
| $M_3P_1$ | 27.12 | 7.06 | 18.49 |
| $M_3P_2$ | 34.42 | 8.75 | 30.23 |
| $M_3P_3$ | 30.30 | 7.61 | 18.33 |
| $M_3P_4$ | 28.99 | 9.44 | 22.78 |
| CD (0.05) | ns | CD (0.01) 1.55 | CD (0.01) 3.36 |
| Treatment means | 28.92 | 8.09 | 22.48 |
| $C_1$ | 27.64 | 7.23 | 8.74 |
| $C_2$ | 26.57 | 8.37 | 9.58 |

Phosphorus application at all levels increased root mass than no application of phosphorus. Highest level of phosphorus application viz. $P_4$ was found to be statistically on par with $P_2$ and $P_3$.

Among the factorial treatment combinations, $M_1P_1$, $M_1P_2$, $M_2P_2$, $M_2P_3$, $M_3P_2$ and $M_3P_4$ were statistically on par and significantly superior over other treatment combinations.

However, the control treatments ($C_1$ and $C_2$) did not differ significantly over the twelve treatment combinations as well as among themselves.

### 4.2.3 Root volume

Root volume was observed to be strongly influenced by bioinoculants, different levels of phosphorus and their interaction effects.

Among the bioinoculants, $M_2$ and $M_3$ were significantly superior over $M_1$ and statistically on par.

Regarding phosphorus application, maximum root volume was recorded by treatment $P_2$ and significantly superior over $P_1$ and $P_4$. Factorial treatment combinations $M_2P_2$ and $M_3P_2$ were found to be statistically on par and significantly superior over other treatment combinations.

Significant differences in the root volume were observed between the mean of twelve treatment combinations and the two control treatments

($C_1$ and $C_2$), while the control treatments showed no significant difference between themselves. Comparatively, a higher mean value (33.44 $cm^3$) was recorded by the treatment combination $M_2P_2$.

### 4.2.4 Number of effective nodules

The mean number of effective nodules at flowering stage is presented in Table 8. Bioinoculants, levels of phosphorus and their interaction effects had exerted a strong positive influence on the number of effective nodules.

All the bioinoculants differed significantly from each other in producing the number of effective nodules. Among the bioinoculants, $M_1$ had produced the maximum number of effective nodules (26.88) over $M_2$ and $M_3$ .

Application of phosphorus significantly increased the number of effective nodules. $P_2$ was found to be superior over other phosphorus levels and recorded the maximum number (26.77).

Regarding the interaction effects, application of $M_1P_4$ produced highest number of effective nodules (39.66).

The twelve treatment combinations recorded significantly higher number of effective nodules (23.19) compared to the mean of two control treatments (8.09). However, no significant difference in the production of number of effective nodules was observed between $C_1$ and $C_2$ . The number of effective nodules recorded by $M_1P_4$, $M_3P_2$, $M_1P_1$ and $M_3P_1$

**Table 8**

**Effect of microbial inoculants, phosphorus levels and interaction on number of effective nodules at flowering stage**

| Treatments | Number of effective nodules |
|---|---|
| $M_1$ | 26.88 |
| $M_2$ | 17.89 |
| $M_3$ | 24.80 |
| CD (0.01) | 1.54 |
| $P_1$ | 22.39 |
| $P_2$ | 26.77 |
| $P_3$ | 19.66 |
| $P_4$ | 23.94 |
| CD(0.01) | 1.78 |
| $M_1P_1$ | 32.11 |
| $M_1P_2$ | 18.11 |
| $M_1P_3$ | 17.65 |
| $M_1P_4$ | 39.66 |
| $M_2P_1$ | 16.22 |
| $M_2P_2$ | 13.67 |
| $M_2P_3$ | 21.78 |
| $M_2P_4$ | 19.89 |
| $M_3P_1$ | 32.00 |
| $M_3P_2$ | 35.39 |
| $M_3P_3$ | 19.55 |
| $M_3P_4$ | 12.28 |
| CD (0.01) | 3.09 |
| Treatment means | 23.19 |
| $C_1$ | 6.99 |
| $C_2$ | 9.20 |

were 39.66, 35.39, 32.11 and 32 respectively whereas $C_1$ and $C_2$ recorded lower number of effective nodules of 6.99 and 9.2. Thus all the treatment combinations produced significantly higher number of effective nodules compared to $C_1$ and $C_2$ .

### 4.2.5 AMF colonisation percent

The data on AMF colonisation percent recorded by the factorial treatment combinations as well as control treatments at flowering and harvest stages of the crop are furnished in Table 9.

The data revealed that at flowering stage, maximum colonisation percent (95.83) was obtained with the treatment combination $M_3P_2$ followed by $M_3P_1$ (91.66). Among the treatment combinations, PSM with no phosphorus application gave the least count (37.50), but higher than $C_1$ (33.33). All the twelve treatment combinations recorded values higher than the absolute control ($C_1$).

At harvest stage, a reduction in colonistion was observed. The results followed the same trend as in flowering stage. AMF along with highest phosphorus level of 45 kg $P_2O_5$ $ha^{-1}$ recorded the lowest colonisation percent. Meanwhile all the twelve factorial treatment combinations recorded values higher than the two control treatments ($C_1$ and $C_2$).

# Table 9

## Effect of treatments on AMF colonisation percent*

| Treatments | AMF colonisation percent | |
|---|---|---|
| | Flowering stage | Harvest stage |
| $T_1$ | 83.33 | 66.66 |
| $T_2$ | 75.00 | 62.50 |
| $T_3$ | 66.66 | 50.00 |
| $T_4$ | 45.83 | 33.33 |
| $T_5$ | 37.50 | 41.66 |
| $T_6$ | 58.33 | 45.83 |
| $T_7$ | 58.33 | 37.50 |
| $T_8$ | 41.66 | 54.16 |
| $T_9$ | 91.66 | 66.66 |
| $T_{10}$ | 95.83 | 70.83 |
| $T_{11}$ | 79.16 | 54.16 |
| $T_{12}$ | 66.66 | 50.00 |
| $T_{13}$ ($C_1$) | 33.33 | 29.16 |
| $T_{14}$ ($C_2$) | 50.00 | 25.00 |

* Data statistically not analysed.

## 4.3 Yield and yield attributes

The average values of number of pods per plant, length of pod and number of beans per pod are presented in Table 10.

### 4.3.1 Number of pods per plant

The average number of pods per plant was favourably influenced by application of graded doses of phosphorus and interaction effects. Bioinoculants failed to show a significant variation with respect to this character.

Increasing the levels of phosphorus application upto $P_3$ (30 kg $ha^{-1}$) had significant influence on number of pods per plant. Maximum number of pods was produced at $P_3$ level which was significantly superior over other phosphorus levels.

Among the factorial treatment combinations, $M_3P_3$ produced the maximum number of pods per plant and statistically significant over other treatment combinations.

However, the twelve treatment combinations, recorded a mean higher number of pods per plant (4.92) compared to the mean of the two control treatments (4.85) but not statistically significant. No significant difference in number of pods was observed between the two control treatments.

## Table 10

**Effect of microbial inoculants, phosphorus levels and interaction on number of pods per plant, length and number of beans per pod**

| Treatments | Number of pods per plant | Length of pod (cm) | Number of beans per pod |
|---|---|---|---|
| $M_1$ | 4.85 | 33.49 | 16.49 |
| $M_2$ | 4.88 | 33.35 | 16.93 |
| $M_3$ | 5.05 | 33.63 | 16.94 |
| CD (0.05) | ns | ns | ns |
| $P_1$ | 4.56 | 32.74 | 16.52 |
| $P_2$ | 4.99 | 33.07 | 16.56 |
| $P_3$ | 5.18 | 33.57 | 16.88 |
| $P_4$ | 4.97 | 34.58 | 17.18 |
| CD(0.05) | 0.95 | ns | ns |
| $M_1P_1$ | 4.46 | 33.93 | 16.25 |
| $M_1P_2$ | 4.69 | 33.24 | 16.90 |
| $M_1P_3$ | 5.35 | 32.87 | 16.62 |
| $M_1P_4$ | 4.86 | 33.91 | 16.18 |
| $M_2P_1$ | 4.16 | 32.58 | 16.80 |
| $M_2P_2$ | 4.94 | 32.40 | 16.19 |
| $M_2P_3$ | 5.35 | 34.17 | 17.28 |
| $M_2P_4$ | 4.80 | 34.25 | 17.44 |
| $M_3P_1$ | 4.65 | 32.68 | 16.52 |
| $M_3P_2$ | 5.31 | 32.58 | 16.60 |
| $M_3P_3$ | 5.38 | 33.69 | 16.75 |
| $M_3P_4$ | 4.84 | 35.57 | 17.91 |
| CD (0.05) | 1.75 | ns | ns |
| Treatment means | 4.92 | 33.49 | 16.79 |
| $C_1$ | 4.78 | 33.61 | 16.95 |
| $C_2$ | 4.91 | 32.55 | 16.28 |

### 4.3.2 Length of pod

The average values of pod length presented in Table 10 revealed that bioinoculants, phosphorus levels and interaction effects had not exhibited any significant influence with respect to this character.

Even though no significant variation among the treatments was recorded, $M_3$ , $P_4$ and $M_3P_4$ gave the maximum pod length among the bioinoculants, phosphorus levels and treatment combinations respectively.

The twelve factorial treatment combinations did not differ significantly over the control treatments with respect to this character. Similarly, the two control treatments ($C_1$ and $C_2$) did not show any significant variation in pod length among themselves.

### 4.3.3 Number of beans per pod

Number of beans per pod had no significant variation due to bioinoculants or phosphorus levels.

The twelve factorial treatment combinations did not differ significantly over the control treatments ($C_1$ and $C_2$) with respect to this character. Meanwhile $C_1$ and $C_2$ themselves did not show any significant variation in number of beans per pod.

### 4.3.4 Yield

Data pertaining to the green pod yield per plant, pod yield $ha^{-1}$ and haulm yield $ha^{-1}$ are presented in Table 11.

Among the treatments, varying levels of phosphorus exerted a noticeable difference in pod as well as haulm yield. Bioinoculants failed to bring about a significant response on pod and haulm yield. However, interaction effects due to bioinoculants and phosphorus on pod and haulm yields were also significant.

Similar to the number of pods per plant, the green pod and haulm yields also increased significantly with graded doses of phosphorus upto $P_3$ level, but a higher dose did not exert a significant response. However, $P_2$ and $P_3$ were found to be on par.

Among the twelve factorial treatment combinations, $M_3P_3$ recorded the maximum pod as well as haulm yield and significantly superior over other treatment combinations.

The mean pod yield per plant and haulm yield recorded by all the twelve treatment combinations were higher than the two control treatments ($C_1$and $C_2$). But the control treatments ($C_1$ and $C_2$ ) gave a mean higher pod yield $ha^{-1}$ over the mean yield of the twelve factorial treatment combinations. No significant difference was observed in the pod as well as

## Table 11

**Effect of microbial inoculants, phosphorus levels and interaction on pod yield per plant (g), pod and haulm yield (kg ha$^{-1}$)**

| Treatments | Pod yield per plant (g) | Pod yield (kg ha$^{-1}$) | Haulm yield (kg ha$^{-1}$) |
|---|---|---|---|
| $M_1$ | 273.02 | 3827.94 | 7682.71 |
| $M_2$ | 310.73 | 4032.39 | 8066.09 |
| $M_3$ | 291.49 | 4087.28 | 8177.81 |
| CD (0.05) | ns | ns | ns |
| $P_1$ | 286.29 | 3645.02 | 7291.41 |
| $P_2$ | 293.63 | 3992.33 | 7985.69 |
| $P_3$ | 300.15 | 4339.78 | 8717.55 |
| $P_4$ | 286.92 | 3953.02 | 7907.49 |
| CD(0.05) | 6.70 | CD(0.01) 386.78 | CD(0.01) 811.06 |
| $M_1P_1$ | 281.78 | 3508.05 | 7018.20 |
| $M_1P_2$ | 277.70 | 3733.95 | 7469.10 |
| $M_1P_3$ | 270.28 | 4341.00 | 8783.00 |
| $M_1P_4$ | 262.33 | 3728.77 | 7460.54 |
| $M_2P_1$ | 299.83 | 3637.11 | 7276.25 |
| $M_2P_2$ | 304.58 | 4031.00 | 8065.15 |
| $M_2P_3$ | 315.41 | 4227.22 | 8454.44 |
| $M_2P_4$ | 298.60 | 4234.22 | 8468.52 |
| $M_3P_1$ | 277.25 | 3789.89 | 7579.78 |
| $M_3P_2$ | 275.07 | 4094.11 | 8188.22 |
| $M_3P_3$ | 323.08 | 4451.11 | 8915.22 |
| $M_3P_4$ | 315.05 | 4014.00 | 8028.00 |
| CD (0.05) | 3.95 | 3.70 | 7.70 |
| Treatment means | 291.75 | 3918.66 | 7804.36 |
| $C_1$ | 297.65 | 4002.89 | 7063.42 |
| $C_2$ | 329.22 | 4422.89 | 7968.14 |

haulm yield between $C_1$ and $C_2$, but comparatively higher values being recorded by $C_2$.

## 4.4 Phosphorus content of plant

The data presented in Table 12 revealed that the total phosphorus content of plant was positively and significantly influenced by application of bioinoculants, phosphorus and their interaction effects.

The three bioinoculant treatments $M_1$, $M_2$ and $M_3$ were found to be statistically on par.

Regarding phosphorus levels, the highest phosphorus content of plant (0.37 percent) was recorded by $P_3$ and was significantly superior over other levels of phosphorus. Treatments $P_2$ and $P_4$ were found to be on par.

Among the factorial treatment combinations, $M_1P_3$, $M_2P_3$, $M_3P_2$ and $M_3P_3$ were statistically on par and significantly superior over the remaining treatment combinations.

The mean of the two control treatments ($C_1$ and $C_2$) recorded lower total phosphorus content compared to the mean of the twelve treatment combinations. The treatment combination $M_3P_2$ recorded comparatively higher phosphorus content of 0.39 percent. All the treatment combinations gave significantly higher total phosphorus content compared to $C_1$ and $C_2$.

## Table 12

**Effect of microbial inoculants, phosphorus levels and interaction on total phosphorus content of plant.**

| Treatments | Total phosphorus content (percent) |
|---|---|
| $M_1$ | 0.32 |
| $M_2$ | 0.32 |
| $M_3$ | 0.34 |
| CD (0.05) | 0.02 |
| $P_1$ | 0.29 |
| $P_2$ | 0.33 |
| $P_3$ | 0.37 |
| $P_4$ | 0.33 |
| CD(0.01) | 0.02 |
| $M_1P_1$ | 0.28 |
| $M_1P_2$ | 0.29 |
| $M_1P_3$ | 0.37 |
| $M_1P_4$ | 0.35 |
| $M_2P_1$ | 0.30 |
| $M_2P_2$ | 0.31 |
| $M_2P_3$ | 0.37 |
| $M_2P_4$ | 0.32 |
| $M_3P_1$ | 0.31 |
| $M_3P_2$ | 0.39 |
| $M_3P_3$ | 0.36 |
| $M_3P_4$ | 0.32 |
| CD (0.01) | 0.03 |
| Treatment means | 0.33 |
| $C_1$ | 0.26 |
| $C_2$ | 0.26 |

Meanwhile $C_1$ and $C_2$ themselves did not show any significant variation in total phosphorus content of plant.

## 4.5 Nutrient content of pod

The mean values of nitrogen and phosphorus content presented in Table 13 revealed that bioinoculants, levels of phosphorus and their interaction effects had a significant influence on nitrogen content. Phosphorus content of pod was also significantly influenced by levels of phosphorus and interaction effects. However, bioinoculants had no significant effect on phosphorus content of pod.

Among the bioinoculants, $M_3$ recorded the maximum nitrogen content of pod (12.17 percent) and was significantly superior over $M_1$ and $M_2$ and latter two were on par.

All the different levels of P significantly influenced nitrogen content except for zero level of phosphorus application and the highest value (13.17 percent) was recorded by $P_3$. Treatment $P_3$ was statistically superior over other levels of phosphorus followed by $P_2$.

Of the twelve different factorial treatment combinations, $M_1P_3$, $M_2P_3$, $M_3P_2$ and $M_3P_3$ were statistically on par and significantly superior over the other treatment combinations.

**Table 13**

**Effect of microbial inoculants, phosphorus levels and interaction on nutrient content of pod.**

| Treatments | Nitrogen content (percent) | Phosphorus content (percent) |
|---|---|---|
| $M_1$ | 10.23 | 0.22 |
| $M_2$ | 10.76 | 0.23 |
| $M_3$ | 12.17 | 0.23 |
| CD (0.05) | CD (0.01) 0.91 | ns |
| $P_1$ | 9.07 | 0.21 |
| $P_2$ | 11.83 | 0.24 |
| $P_3$ | 13.17 | 0.23 |
| $P_4$ | 10.14 | 0.23 |
| CD(0.01) | 1.05 | 0.01 |
| $M_1P_1$ | 6.53 | 0.19 |
| $M_1P_2$ | 10.77 | 0.22 |
| $M_1P_3$ | 13.20 | 0.25 |
| $M_1P_4$ | 10.43 | 0.22 |
| $M_2P_1$ | 10.10 | 0.23 |
| $M_2P_2$ | 10.57 | 0.23 |
| $M_2P_3$ | 12.63 | 0.24 |
| $M_2P_4$ | 9.73 | 0.22 |
| $M_3P_1$ | 10.57 | 0.22 |
| $M_3P_2$ | 14.17 | 0.27 |
| $M_3P_3$ | 13.67 | 0.21 |
| $M_3P_4$ | 10.27 | 0.24 |
| CD (0.01) | 1.82 | 0.02 |
| Treatment means | 11.05 | 0.23 |
| $C_1$ | 6.03 | 0.17 |
| $C_2$ | 6.23 | 0.17 |

Phosphorus content of pod was significantly influenced by different levels of phosphorus and treatments $P_2$, $P_3$ and $P_4$ were statistically on par and significantly superior over no phosphorus application.

Of the treatment combinations, $M_1P_3$ and $M_3P_2$ were statistically on par and significantly superior over remaining treatment combinations.

Significant difference in nitrogen and phosphorus content of pod was observed between the mean of treatment combinations and mean of control treatments ($C_1$ and $C_2$), with highest value being observed by the mean of treatment combinations (11.05 and 0.23 percent respectively). $C_1$ and $C_2$ recorded lower mean values of 6.13 and 0.17 percent for nitrogen and phosphorus content of pod respectively. However, $C_1$ and $C_2$ did not differ significantly with regard to nitrogen and phosphorus content of pod.

## 4.6 Quality characters of pod

The average values of protein and fibre content of pod are furnished in Table 14

### 4.6.1 Protein content of pod

The protein content of pod was favourably influenced by bioinoculants, different levels of phosphorus and their interaction effects.

The maximum protein content (7.60 percent) was recorded by $M_3$ which was superior over $M_1$ and $M_2$ and latter two were on par.

Protein content was maximum (8.23 percent) at $P_3$ level which was significantly superior over other phosphorus levels followed by $P_2$.

Among the factorial treatment combinations, $M_1P_3$, $M_2P_3$, $M_3P_2$ and $M_3P_3$ were statistically on par and significantly superior over other treatment combinations.

The mean of the treatment combinations showed significantly higher protein content (6.91 percent) compared to the mean of control treatments (3.83 percent). However, among the two control treatments ($C_1$ and $C_2$) there was no significant variation. All the treatment combinations gave significantly higher protein content compared to $C_1$ and $C_2$.

**4.6.2 Fibre content of pod**

Data on fibre content furnished in Table 14 revealed that bioinoculants, varying levels of phosphorus and their interaction effects exhibited significant positive influence on fibre content of pod.

Application of $M_3$ has recorded the least fibre content (9.57 percent) which was superior to other bioinoculants. Maximum fibre content was recorded by $M_2$ (12.07 percent) which was on par with $M_1$.

Among the different phosphorus levels, $P_2$ and $P_4$ were on par and significantly superior over other treatments.

# Table 14

**Effect of microbial inoculants, phosphorus levels and interaction on quality characters of pod.**

| Treatments | Protein content ( percent ) | Fibre content ( percent ) |
|---|---|---|
| $M_1$ | 6.40 | 10.97 |
| $M_2$ | 6.72 | 12.07 |
| $M_3$ | 7.60 | 9.57 |
| CD (0.01) | 0.57 | 0.75 |
| $P_1$ | 5.67 | 10.82 |
| $P_2$ | 7.40 | 9.60 |
| $P_3$ | 8.23 | 12.80 |
| $P_4$ | 6.34 | 10.24 |
| CD(0.01) | 0.66 | 0.87 |
| $M_1P_1$ | 4.08 | 11.00 |
| $M_1P_2$ | 6.73 | 9.93 |
| $M_1P_3$ | 8.25 | 10.40 |
| $M_1P_4$ | 6.52 | 12.53 |
| $M_2P_1$ | 6.31 | 10.20 |
| $M_2P_2$ | 6.60 | 12.27 |
| $M_2P_3$ | 7.90 | 15.40 |
| $M_2P_4$ | 6.08 | 10.40 |
| $M_3P_1$ | 6.60 | 11.27 |
| $M_3P_2$ | 8.85 | 6.60 |
| $M_3P_3$ | 8.54 | 12.60 |
| $M_3P_4$ | 6.42 | 7.80 |
| CD (0.01) | 1.13 | 1.51 |
| Treatment means | 6.91 | 10.87 |
| $C_1$ | 3.77 | 12.53 |
| $C_2$ | 3.90 | 13.13 |

The treatment combinations $M_2P_2$ and $M_3P_4$ showed significant difference from other treatment combinations and were on par.

The factorial treatment combinations were found to record a significantly lower fibre content (10.87 percent) compared to the mean of control treatments ($C_1$ and $C_2$). However, $C_1$ and $C_2$ did not differ significantly with regard to the fibre content.

## 4.7 Soil nutrient status after harvest

The available nitrogen and available $K_2O$ content of soil after harvest is furnished in Table 15

### 4.7.1 Available nitrogen

Bioinoculants, levels of phosphorus and their interaction effects had no significant influence on the available nitrogen content of soil after harvest.

Though treatment differences were not statistically significant, $M_3$, $P_4$ and $M_3P_3$ recorded the highest mean nitrogen content of soil after harvest among bioinoculants, phosphorus levels and treatment combinations respectively.

The mean of the twelve treatment combinations showed a comparatively lower soil nitrogen value (165.20 kg $ha^{-1}$) over the mean of control treatments (180.84 kg $ha^{-1}$). No significant difference was observed

## Table 15

**Effect of microbial inoculants, phosphorus levels and interaction on soil nutrient status after harvest.**

| Treatments | Available N (kg ha $^{-1}$) | Available $K_2O$ (kg ha $^{-1}$) |
|---|---|---|
| $M_1$ | 160.57 | 23.80 |
| $M_2$ | 165.42 | 25.24 |
| $M_3$ | 169.61 | 24.34 |
| CD (0.05) | ns | 1.13 |
| $P_1$ | 160.11 | 26.35 |
| $P_2$ | 160.98 | 24.57 |
| $P_3$ | 166.90 | 24.40 |
| $P_4$ | 172.80 | 22.52 |
| CD(0.05) | ns | CD (0.01) 1.30 |
| $M_1P_1$ | 145.82 | 24.81 |
| $M_1P_2$ | 175.62 | 24.24 |
| $M_1P_3$ | 151.57 | 24.19 |
| $M_1P_4$ | 169.27 | 21.94 |
| $M_2P_1$ | 174.57 | 27.51 |
| $M_2P_2$ | 159.94 | 24.89 |
| $M_2P_3$ | 159.94 | 24.93 |
| $M_2P_4$ | 167.25 | 23.64 |
| $M_3P_1$ | 159.94 | 26.74 |
| $M_3P_2$ | 147.39 | 24.58 |
| $M_3P_3$ | 189.21 | 24.08 |
| $M_3P_4$ | 181.89 | 21.97 |
| CD (0.05) | ns | ns |
| Treatment means | 165.20 | 24.46 |
| $C_1$ | 174.57 | 22.36 |
| $C_2$ | 187.11 | 24.84 |

in the available nitrogen content in soil between $C_1$ and $C_2$, but comparatively a higher soil nitrogen value (180.11 kg $ha^{-1}$) being recorded by $C_2$.

### 4.7.2 Available $K_2O$

Available $K_2O$ content of the soil was favourably influenced by bioinoculants and phosphorus levels.

The highest potassium content in the soil (25.24 kg $ha^{-1}$) was noticed by the application of $M_2$ which was significantly superior over $M_1$ and $M_3$, the latter two being on par.

On phosphorus application, it was observed that treatment $P_1$ recorded the highest potassium content in the soil (26.35 kg $ha^{-1}$) and was significantly superior over other phosphorus levels. $P_2$ and $P_3$ were found to be significantly superior over $P_4$ and they were on par.

The mean value of the two control treatments ($C_1$ and $C_2$) did not show any significant variation from the mean of treatment combinations with regard to available $K_2O$ content. However, $C_1$ and $C_2$ showed significant difference with regard to available $K_2O$ content in soil, with the highest content being recorded by $C_2$ (24.84 kg $ha^{-1}$).

### 4.7.3 Available $P_2O_5$ content

The available $P_2O_5$ content of soil at three stages viz. vegetative flowering and harvest is presented in Table 16.

## Table 16

**Effect of microbial inoculants, phosphorus levels and interaction on available $P_2O_5$ content in soil.**

| Treatments | Available $P_2O_5$ content ( kg ha $^{-1}$ ) | | |
|---|---|---|---|
| | Vegetative stage | Flowering stage | Harvest stage |
| $M_1$ | 44.05 | 120.82 | 100.80 |
| $M_2$ | 50. 77 | 108.77 | 103.60 |
| $M_3$ | 59.58 | 147.19 | 107.15 |
| CD (0.05) | CD (0.01) 3.44 | CD (0.01) 20.01 | ns |
| $P_1$ | 46.54 | 114.81 | 114.74 |
| $P_2$ | 59.98 | 148.74 | 111.25 |
| $P_3$ | 55.25 | 116.61 | 88.36 |
| $P_4$ | 44.09 | 122.14 | 101.05 |
| CD(0.05) | CD (0.01) 3.97 | CD (0.05) 23.10 | CD (0.05) 18.16 |
| $M_1P_1$ | 41.07 | 110.01 | 110.51 |
| $M_1P_2$ | 49.28 | 139.72 | 119.47 |
| $M_1P_3$ | 43.31 | 92.59 | 77.65 |
| $M_1P_4$ | 42.56 | 140.96 | 95.57 |
| $M_2P_1$ | 44.05 | 85.17 | 100.80 |
| $M_2P_2$ | 56.75 | 127.89 | 112.00 |
| $M_2P_3$ | 53.76 | 116.46 | 98.56 |
| $M_2P_4$ | 48.53 | 105.55 | 103.04 |
| $M_3P_1$ | 54.51 | 149.24 | 132.91 |
| $M_3P_2$ | 73.92 | 178.75 | 102.29 |
| $M_3P_3$ | 68.69 | 140.83 | 88.85 |
| $M_3P_4$ | 41.18 | 119.92 | 104.53 |
| CD (0.05) | CD (0.01) 6.87 | ns | ns |
| Treatment means | 51.47 | 125.59 | 103.85 |
| $C_1$ | 20.16 | 75.92 | 66.45 |
| $C_2$ | 24.64 | 81.46 | 74.67 |

At vegetative stage, available $P_2O_5$ content was favourably and significantly influenced by application of bioinoculants, phosphorus levels and their interaction effects .

The highest available $P_2O_5$ content in soil (59.58 kg $ha^{-1}$) was obtained when $M_3$ was applied which was significantly superior over $M_2$ and $M_1$. The lowest value of available $P_2O_5$ content in soil (47.0 kg $ha^{-1}$) was recorded when $M_1$ was applied.

Regarding phosphorus application, $P_2$ recorded the maximum available $P_2O_5$ content in soil, which was significantly superior over other levels of phosphorus. The lowest available $P_2O_5$ content was obtained at the highest level of phosphorus application ie. $P_4$.

Among the treatment combinations, $M_3P_2$ and $M_3P_3$ were significantly superior over other treatment combinations and were on par. Moreover, $M_2P_2$, $M_3P_1$ and $M_2P_3$ were also found to be statistically on par.

The twelve factorial treatment combinations recorded a higher $P_2O_5$ content (51.45 kg $ha^{-1}$) compared to the mean (22.40 kg $ha^{-1}$) of two control treatments ($C_1$ and $C_2$). However, no significant differnce in available $P_2O_5$ content was observed between $C_1$ and $C_2$.

At flowering stage, available $P_2O_5$ content in soil was significantly influenced by bioinoculants and levels of phosphorus. However, the interaction effects did not exert any favourable influence on the available $P_2O_5$ content in soil.

Among the bioinoculants, $M_3$ recorded the maximum available $P_2O_5$ content in soil (147.19 kg $ha^{-1}$) and significantly superior over $M_1$ and $M_2$. The lowest available $P_2O_5$ content was obtained on application of $M_2$.

Phosphorus levels significantly influenced the available $P_2O_5$ content in soil, the highest value (148.78 kg $ha^{-1}$) was obtained at $P_2$ level which was significantly superior over other levels of phosphorus. However , $P_1$ was found to be on par with $P_3$.

The mean of the twelve treatment combinations recorded a significantly higher available $P_2O_5$ content (125.59 kg $ha^{-1}$) compared to the mean of the two control treatments ($C_1$ and $C_2$). Meanwhile $C_1$ and $C_2$ themselves did not show any significant variation in available $P_2O_5$ content, with a comparatively higher value (81.46 kg $ha^{-1}$) being recorded by $C_2$.

At harvest stage, phosphorus levels showed a significant influence on the availability of $P_2O_5$ content in soil. However, bioinoculants as well as interaction effects had no significant variation in the available $P_2O_5$ content in soil.

Regarding the levels of phosphorus $P_1$,$P_2$ and $P_4$ were on par and significantly superior over $P_3$.

The twelve factorial treatment combinations recorded a significantly higher available $P_2O_5$ content (103.85 kg ha $^{-1}$) compared to mean of control treatments ($C_1$ and $C_2$). However, $C_1$ and $C_2$ themselves did not show any significant variation in available $P_2O_5$ content in soil.

## 4.8. Economics of cultivation

Economics of production of twelve factorial treatment combinations and two control treatments are presented in Table 17 .

The data indicated that net returns and benefit-cost ratio (BCR) were higher with the treatment combination $M_3P_3$ . $M_3P_3$ gave the maximum net returns of Rs. 15 672.90 ha$^{-1}$ and BCR of 1.54. The absolute control ( $C_1$ ) gave the lowest net returns and BCR.

## Table 17

### Economics of cultivation ($ha^{-1}$)*

| Treatments | Net returns (Rs.) | B:C ratio |
|---|---|---|
| $T_1$ | 12352.70 | 1.01 |
| $T_2$ | 14238.50 | 1.34 |
| $T_3$ | 12987.85 | 1.21 |
| $T_4$ | 11995.35 | 0.76 |
| $T_5$ | 12115.70 | 0.96 |
| $T_6$ | 14238.50 | 1.34 |
| $T_7$ | 12357.50 | 1.06 |
| $T_8$ | 12000.65 | 0.82 |
| $T_9$ | 12005.50 | 0.84 |
| $T_{10}$ | 15529.35 | 1. 51 |
| $T_{11}$ | 15672.90 | 1.54 |
| $T_{12}$ | 11970.50 | 0.72 |
| $T_{13}$ ($C_1$) | 11480.80 | 0.52 |
| $T_{14}$ ($C_2$) | 11580.85 | 0.64 |

* Data statitistically not analysed

Wage rate - Rs.135.00 $day^{-1}$

Cost of inputs

Farm yard manure - Rs.4.50 $kg^{-1}$

N (Urea) - Rs.5.00 $kg^{-1}$

$P_2O_5$ (MRP) - Rs.3.00 $kg^{-1}$

$K_2O$ (MOP) - Rs.6.00 $kg^{-1}$

Cost of produce - Rs.9.00 $kg^{-1}$

# DISCUSSION

# DISCUSSION

The results of the experiment conducted to study the role of microbial inoculants viz. arbuscular mycorrhizal fungi (AMF) and phosphate solubilising micro organisms (PSM) in enhancing phosphorus use efficiency and productivity in vegetable cowpea are discussed below.

## 5.1 Growth characters

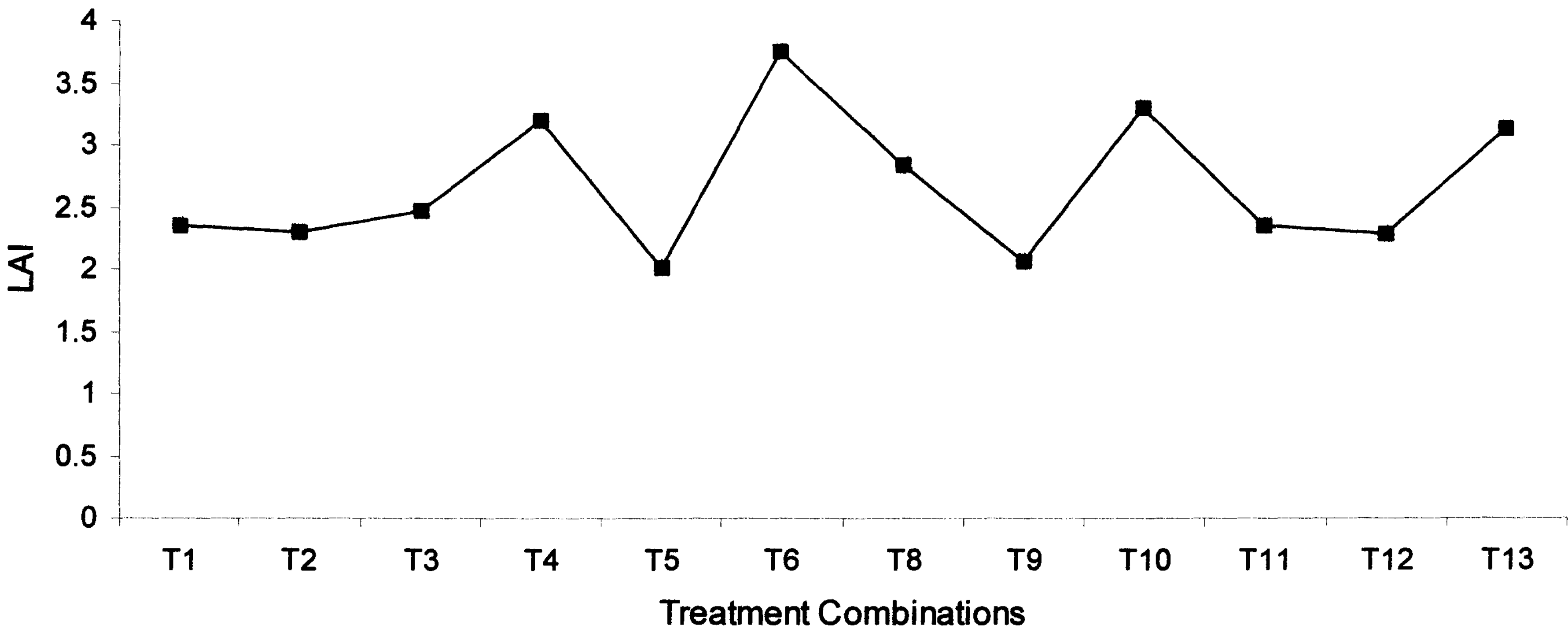
Among the different growth characters, bioinoculants could produce a significant influence on length of vine at the vegetative stage only. Height of plants increased under PSM ($M_2$) which was significantly superior over AMF($M_1$) and combined application of AMF + PSM($M_3$) during the vegetative stage. Even in this stage, the influence of combined application of AMF + PSM ($M_3$) and PSM alone($M_2$) were on par. It may be inferred that this is due to the effect of PSM in influencing the length of vine in the initial growth stage. These results corroborate with the findings of Khalafallah *et al.* (1982) who has reported increased plant height due to PSM inoculation in fava bean.The lack of influence of bioinoculants in later stages of growth with respect to all growth characters might be due to the medium status of phosphorus in soil. In general, these results are in confirmity the findings of Detroja *et al.*(1997) in ground nut.

Effect of graded levels of phosphorus and interaction between phosphorus levels and bioinoculants were not significantly different with respect to the growth parameters at all growth stages except leaf area index (LAI) at harvest stage wherein interaction effect was found to be significant. A declining trend in growth parameters at higher levels of phosphorus compared to lower levels was also reported by Verma and Saxena (1995) in french bean and Detroja *et al.*(1997) in ground nut. The poor response of higher levels of phosphorus might be due to the imbalance in application of major nutrients especially nitrogen as well as due to the medium phosphorus status of the experimental soil. In the absence of nitrogen, phosphorus has only a limited role in bringing about a favourable influence on vegetative characters. Mehta *et al.* (1996) elicited the non response of applied phosphorus due to the medium phosphorus status of soil. Addition of graded levels of phosphorus with out increasing the other major nutrients has not proportionately increased phosphorus availability considerably, as evident from the total phosphorus content in the plant (Table 12). These results are in close conformity with the findings of Kumar and Agarwal (1993).

Increased phosphorus application without adequate quantity of nitrogen and potassium results in poor meristematic activity, root growth and nutrient absorption leading to reduced growth (Brady, 1988).

Interaction effect due to graded doses of phosphorus and bioagents in influencing only the LAI at harvest stage might be attributed to the limited role of microbial inoculants in releasing the unavailable phosphorus in soil (Fig. 3). This was also evident from the increased total phosphorus content of the plant at harvest stage due to the main as well as interaction

**Fig.3 Interaction effect of microbial inoculants and phosphorus on leaf area index at harvest stage**



effects. Improved translocation of photosynthates by increased uptake of phosphorus may be another contributing factor for significant LAI at harvest stage (Verma and Saxena 1995).

The mean of the factorial treatment combinations did not differ significantly from the mean of the control treatments ($C_1$ and $C_2$) with respect to all growth parameters at all the three growth stages. It can be therefore inferred that microbial inoculants along with graded doses of phosphorus fail to excert a significant influence on growth parameters in acid soil with medium phosphorus status.

## 5.2 Root characters

The scrutiny of the data reveals the significant role of bioagents in improving the root characters except root mass.Phosphate solubilising microorganisms (PSM) alone as well as in combination with arbuscular mycorrhizal fungi (AMF) had a significant influence over AMF alone with respect to root volume. But, PSM alone could not produce a significant positive impact on root length. Significant increase in root length by the inoculation of AMF or *Rhizobium* alone or in combination was reported in chickpea by Chaturvedi *et al.*(1987).

The role of bioinoculants in improving root length and root volume during flowering stage is reflected in enhanced phosphorus content in the plant (Table 12). Stimulation in root growth by AMF concurred with the reports of Bagyaraj and Manjunath (1980).

With regard to phosphorus levels, positive influence on root characters were obtained at the lower level of phosphorus viz . 15 kg $P_2O_5$ $ha^{-1}$. It is quite evident that the bioinoculants have got a limited role in improving the root characters in a soil with medium phosphorus status. More over the infection of mycorrhiza seems to be inhibited by higher levels of phosphorus and lower pH. Earlier reports have shown that mycorrhizal infection was stimulated at low levels of applied phosphorus (Saif, 1986). The preference of fungi at low phosphorus concentration is because that at low levels the exudates from plants stimulate hyphal elongation of VAM fungi (Elias and Safir,1987).

Treatment combinations were found to be significant over the control treatments with respect to root length and root volume whereas insignficant with regard to root mass. In both the cases, bioinoculants along with lower dose of phosphorus viz. 15 kg $P_2O_5$ $ha^{-1}$ recorded the maximum root length and root mass. Moreover, it can be inferred that microbial inoculants along with lower dose of phosphorus is effective in improving the root characters in a soil with medium phosphorus status.

## 5.3 Number of effective nodules

Significant influence on nodulation was observed by the inoculation of bioagents. Maximum number of effective nodules was recorded in AMF treatment which was significantly higher than phosphate solubilising microorganisms as well as dual application of arbuscular mycorrhizal fungi and phosphate solubilising microorganisms. Increased availability of soil phosphorus in turn enhanced root nodulation. It is also to be noted that the same influence was effected in root length also. Phosphorus is a key element for root formation and nodulation. More over, phosphorus is a constituent of nucleic acids and phospholipids and act as "energy currency" within plants (Tisdale *et al.* 1995).

Among the bioinoculants, PSM has no pronounced effect in nodulation when compared to AMF. The reduced effect of PSM might be due to the acidic nature of soil since main mechanism of phosphorus release from insoluble and fixed forms in soil is through the secretion of organic acids whereas AMF transports phosphate over distances into the root cortical cells. These results regarding AMF are in agreement with the findings of Pearson and Tinker (1975). Combined application of AMF + PSM produced more number of effective nodules over PSM application alone. This implies that AMF has a definite role in enhancing nodulation. This can be attributed to the increased availability of soil phosphorus by AMF resulting in more nodulation in cowpea. These results corroborate the findings of several workers (Singh and Singh, 1986., Chaturvedi *et al.*, 1987., Khaliel and Elkhider, 1987., Godse *et al.*1988). Maximum number of effective nodules were produced at the lower level of phosphorus viz. 15 kg $P_2O_5$ $ha^{-1}$ which was significantly superior over all other higher levels. Reduction in nodulation at higher phosphorus levels may be attributed to the imbalance of nutrients in soil with medium phosphorus status. Application of phosphorus increases the concentration of phosphate ions in soil solution and ultimately helps in the formation of more nodules (Abbas *et al.* 1994).

On comparing with the control treatments, it is evident that all the treatment combinations produced more number of effective nodules. The results clearly revealed that bioinoculants along with graded doses of phosphorus had improved the nodulation character in the crop.

## 5.4 Days to 50 percent flowering

Bioinoculants could not exert a significant influence in number of days taken for 50 percent flowering . It can be inferred that AMF, PSM as well as their combined application could not appreciably increase the phosphorus availability in soil .

Increasing the level of phosphorus from 0 to 45 kg $P_2O_5$ $ha^{-1}$ induced the earliness and number of days taken for 50 percent flowering was minimum with the highest level of phosphorus viz. 45 kg $P_2O_5$ $ha^{-1}$ .

The plots which received no phosphorus has taken the maximum number of days for flowering which was found to be significant over other phosphorus treatments. Influence of phosphorus in hastening maturity is well documented. Balakumaran (1981) and Philip (1993) have reported the trend of early flowering at higher levels of phosphorus in cowpea. An adequate supply of phosphorus in the early stages of plant growth is necessary for the initiation primordia for the reproductive parts of plants. The stimulatory effect of phosphorus on nodulation leading to nitrogen fixation might have also been contributed to earliness in flowering .

On comparison with the control treatments ($C_1$ and $C_2$), it can be noted that application of bioinoculants along with graded doses of phosphorus had a definite role in inducing earliness in flowering. Dual inoculation of AMF and PSM along with 45 kg $P_2O_5$ $ha^{-1}$ had considerably reduced the number of days for 50 percent flowering.

## 5.5 Mycorrhizal colonisation percent.

Arbuscular mycorrhizal colonisation percent was observed for the various treatment combinations at flowering and harvest stages. The data reveals that maximum colonisation was observed with the treatment combination viz $M_3P_2$ ie., combined application of AMF and PSM with 15 kg $P_2O_5$ $ha^{-1}$ . These results clearly revealed the effectiveness of inoculants at lower level of phosphorus which might be due to the acidic nature and medium phosphorus status of soil. This may be another reason for poor response of bioinoculants in influencing growth characters. Bioinoculant treatments along with varying levels of phosphorus had significantly improved the colonisation percent which might have resulted in enhanced phosphorus uptake by the crop ( Table 12 ) compared to the control treatments ($C_1$ and $C_2$).

## 5.6 Yield and yield attributes

### 5.6.1 Yield attributes

In general, bioinoculants had no significant influence on the different yield attributes. The same trend was noticed in various growth parameters also. This may be due to the inadequate release of phosphorus from insoluble and fixed phosphorus forms by bioinoculants in a soil with medium phosphorus status as reported by Dubey and Gupta (1996).

Among the yield attributes, only the number of pods per plant was significantly influenced by graded doses of phosphorus . Maximum number of pods was produced by 30 kg $P_2O_5$ $ha^{-1}$ which was significantly superior to all other treatments and on par with 15 kg $P_2O_5$ $ha^{-1}$. The least number of pods per plant was recorded in plots where no phosphorus was applied.

The positive impact of phosphorus application on yield may be due to the better LAI (Table 5) and better uptake of nutrients. Moreover, adequate supply of phosphorus might have influenced the formation of primordia. Higher levels of phosphorus seems to have stimulated plants to produce more pods in grain cowpea (Philip, 1993).

Phosphorus, being a major constituent of nucleic acids and growing root tips, also helps in cell division thus enabling plants to absorb more nutrients from deeper soil layers (Tisdale *et al.* 1995). Phosphorus might have involved in photosynthesis and reproductive function which tend to increase the number of pods per plant (Jyothi, 1995). The medium phosphorus status of experimental field and its acidic soil reaction along with low nitrogen status might have resulted in nutrient imbalance leading to lack of response at higher phosphorus doses. These findings are in close conformity with the results of Abbas *et al.* (1994) in soybean,Phookan and Shadeque (1994) in pea, Sarkar *et al.* (1995) in chickpea and Mehta *et al.*(1996) in ground nut.

Phosphorus application above 30 kg $P_2O_5$ $ha^{-1}$ could not produce significant influence on yield attributes like number of pods per plant. This result corroborated the works of Kher *et al.* (1994) where in 40 and 80 kg $P_2O_5$ $ha^{-1}$ could not produce significant difference in length as well as number of seeds per pod in summer cowpea. This might be due to the unavailablity of insoluble phosphorus from a higher dose at a shorter period.

Interaction due to bioinoculants and phosphorus levels could not produce significant influence with respect to all yield attributes except on the number of pods per plant. Dual inoculation of AMF and PSM at 30 kg $P_2O_5$ $ha^{-1}$ gave the maximum number of pods per plant. This can be attributed to the poor response of bioinoculants at higher levels of phosphorus in acid soils with medium phosphorus status (Mehta *et al.*1996). Yield attributes in banana was favourably influenced by the application of phosphate solubilising bacteria along with lesser quanitity of phosphorus in a similar situation as reported by Shehana (1997). The treatments $C_1$ and $C_2$ recorded a higher mean pod number per plant compared to mean number of pods recorded by phosphorus levels.

### 5.6.2 Yield

The trend expressed by the bioinoculants in yield attributes was also reflected in the pod and haulm yield.

The difference in yield obtained by the application of AMF and PSM were insignificant., since the acidic reaction of experimental soil which provided an environment for relatively higher availability of phosphorus . The trend on pod and haulm yield might be the direct effect of their response on growth characters. Another reason attributed for minimal response of bioinoculants is the low nitrogen status of soil coupled with fixed dose of nitrogen application (30 kg ha $^{-1}$ ) resulting in imbalance of major nutrients along with higher level of $P_2O_5$. These results are in close conformity with the reports of Dubey and Gupta (1996) who observed a positive response of phosphate solubilising microorganisms only in soil with less available phosphorus and high organic matter content.

It may be noted that the release of phosphorus by the action of AMF, PSM and their combined application was less pronounced. It is quite evident from the total phosphorus content of plant at the time of harvest (Table 12). Though the bioinoculant treatments significantly influenced the total phosphorus content of plant, the response of these bioagents was found to be on par.

Moreover, the available $P_2O_5$ content in the soil at harvest stage was not significantly influenced by the application of bioinoculants. The experimental soil being acidic and with medium phosphorus status, might have contributed for the poor response of bioinoculants in this study. The main mechanism of phosphorus release by PSM is through the secretion of organic acids leading to dissolution of insoluble and fixed forms of phosphorus (Gaur *et al.* 1973), Khan and Bhatnagar, 1977).

Significant response on number of pods per plant obtained by the application of 30 kg $P_2O_5$ $ha^{-1}$ might have contributed to maximum yield at 30 kg $P_2O_5$ $ha^{-1}$ . But improved root characters were observed at 15 kg $P_2O_5$ $ha^{-1}$ and no significant difference was noticed among the remaining phosphorus levels viz. 30 and 45 kg $P_2O_5$ $ha^{-1}$ . This implies that there was no role for graded doses of phosphorus application in influencing the root characters and only lower doses could influence the root characters.

In green gram, Thakuria and Saharia (1990) observed the highest grain yield with 20 kg $P_2O_5$ $ha^{-1}$ which was on par with higher doses. The results obtained in the present study confirm the findings of Singh *et al.* (1994) who observed an increase in seed yield by phosphorus application 30 kg $ha^{-1}$ and the effect of a higher dose was not significant in green gram.

Results revealed that the yield obtained at 30 kg is on par with the application of 15 kg $P_2O_5$ $ha^{-1}$ ( Fig.4,5,6 ). This indicates that though the present package of practice (POP) recommendation to grain cowpea is 30 kg $P_2O_5$ $ha^{-1}$, 15 kg P2O5 ha-1 is found to be sufficient for vegetable cowpea in soil with medium phosphorus and acid reaction with a nitrogen level of 30 kg $ha^{-1}$.

**Fig.4 Effect of phosphorus levels on pod yield per plant (g)**

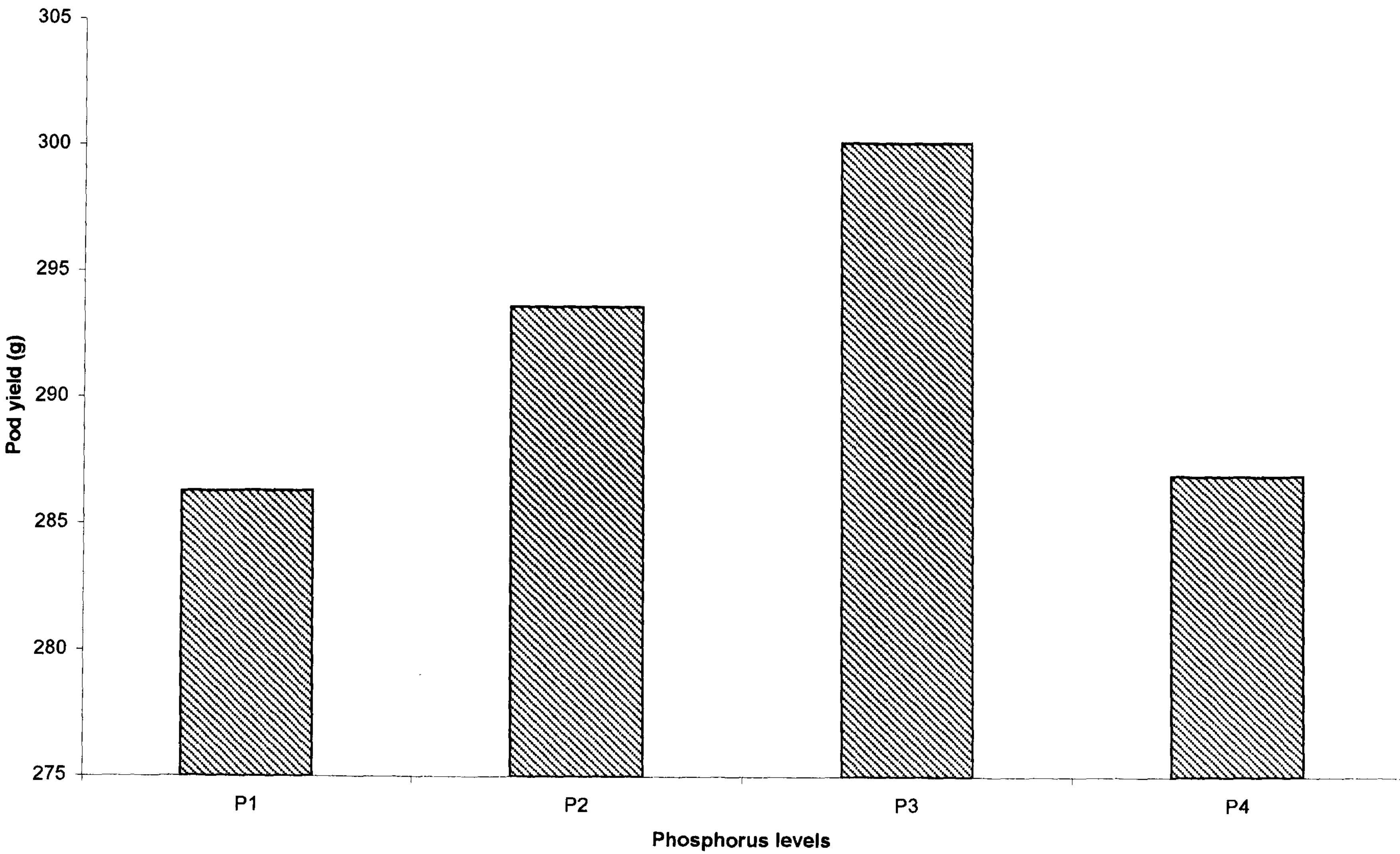


**Fig.5 Interaction effect of microbial inoculants and phosphorus on pod yield per plant (g)**

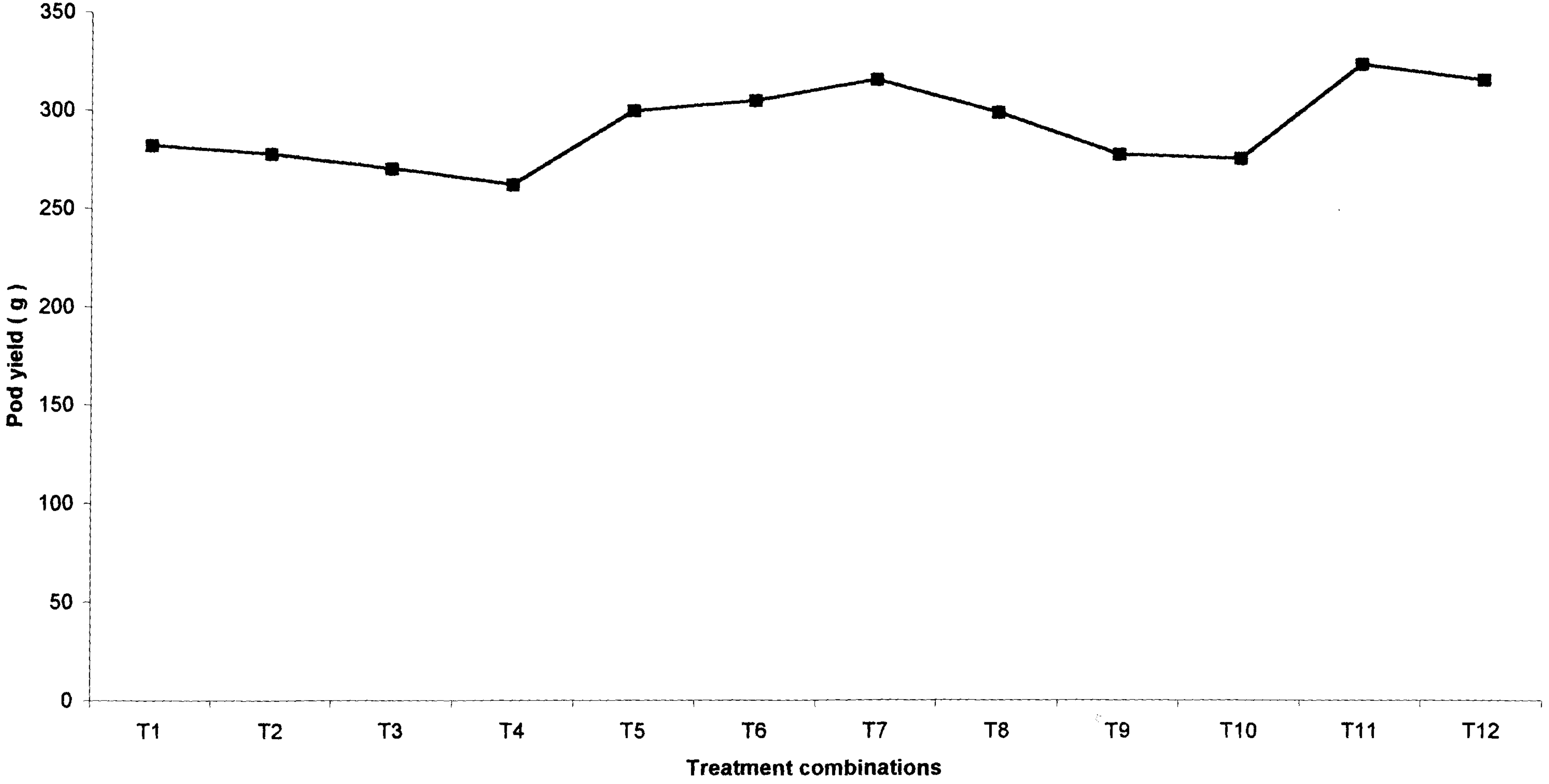
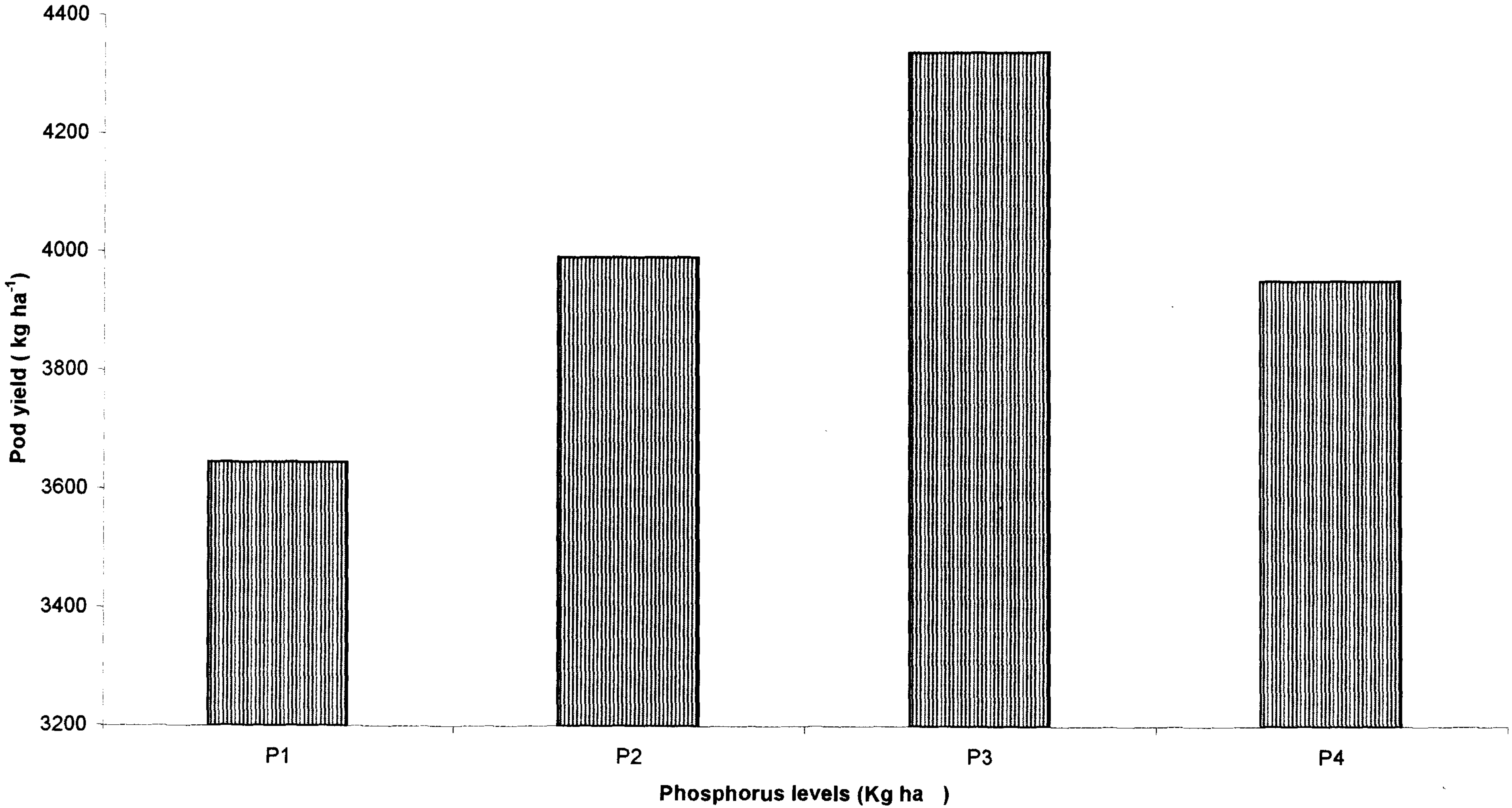


Fig.6 Effect of phosphorus levels on pod yield ( kg ha$^{-1}$ )



In acid soil condition, phosphorus is relatively more available and the response of added phosphorus seems to be reduced. At 30 kg P2O5 ha-1 uptake is positively influenced and significantly superior over 45 and 0 kg P2O5 ha-1 ( Table 12 ). It may be inferred that the role of miocrobial inoculants in releasing unavailable phosphorus is limited at higher phosphorus levels. These results are in agreement with the reports of Abbott and Robinson (1984), Smith and Gianinazzi-Pearson,(1988).The low available nitrogen status of the experimental field along with the fixed dose of nitrogen application (30 kg ha-1) have resulted in poor nitrogen availability throughout the crop growth stage. This might have resulted in an imbalance of major nutrients and poor response at 45 kg P2O5 ha-1.

Phosphorus application was reported to increase the grain, straw and biological yields in blackgram upto 30 kg ha-1 beyond which the increase was not significant.(Shah et al.1994).

The staggered harvesting of the crop during the period of two months might have increased their nitrogen requirement and the lower levels along with the initial phosphorus status of soil might have met the phosphorus requirement of plants. These results are in strong agreement with the findings of Phookan and Shadeque (1994) in pea, Abbas et al.(1994) in soybean. They reported poor response at higher doses of phosphorus in acidic soil with low nitrogen status leading to nutrient imbalance. Moreover, application of phosphorus increases the concentration of phosphate ions in soil solution and ultimately affects the formation of more nodules, vigorous root development and nitrogen fixation (Abbas et al. 1994).

The interaction effect due to bioagents and graded doses of phosphorus was also found to be significant ( Fig. 7,8,9 ). The treatment combination M3P3 has recorded the maximum yield. This reveals that the dual inoculation of AMF and PSM at 30 kg ha-1 was most effective. This is the direct consequence of significant LAI recorded at harvest stage due to interaction effect. The LAI is a critical factor for determining the photosynthetic efficiency of plants which in turn determines the dry matter production and ultimately the yield. The control treatments C1 and C2 gave a higher mean pod yield compared to the mean yield recorded by graded doses of phosphorus. This clearly indicates that the role of PSM in releasing unavailable phosphorus forms is limited in the soil due to medium phosphorus status.

## 5.7 Nutrient content

Though significant influence on nutrient content was noticed by the application of bioinoculants, they are found to be on par with respect to total phosphorus content of plant while there was no significant difference in the phosphorus content of pods ( Fig. 10 ).

**Fig.7 Interaction effect of microbial inoculants and phosphorus on pod yield ( kg ha$^{-1}$ )**

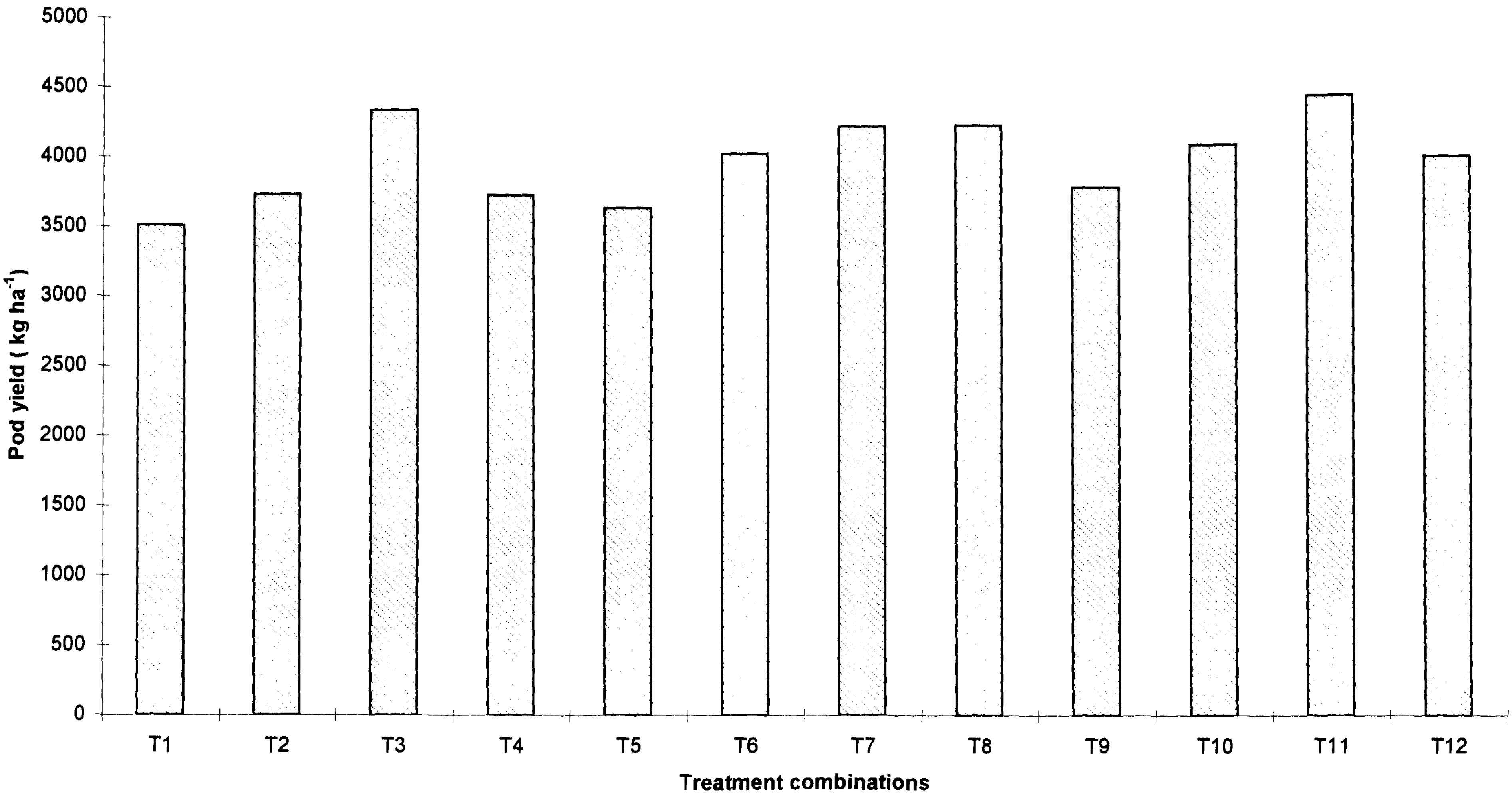


**Fig.8 Effect of phosphorus levels on haulm yield ( kg ha$^{-1}$)**

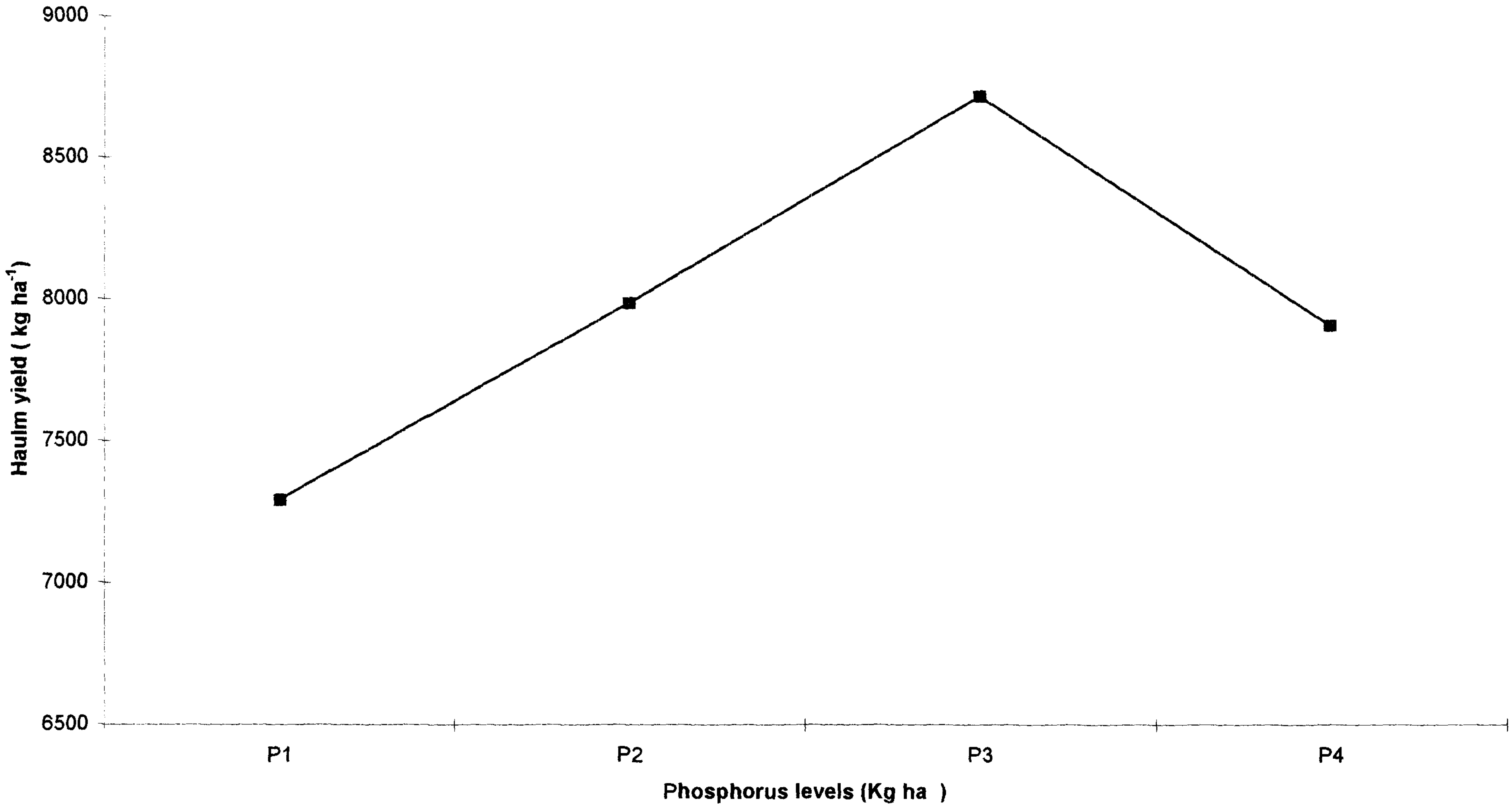


**Fig.9 Interaction effect of microbial inoculants and phosphorus on haulm yield ( kg ha$^{-1}$ )**

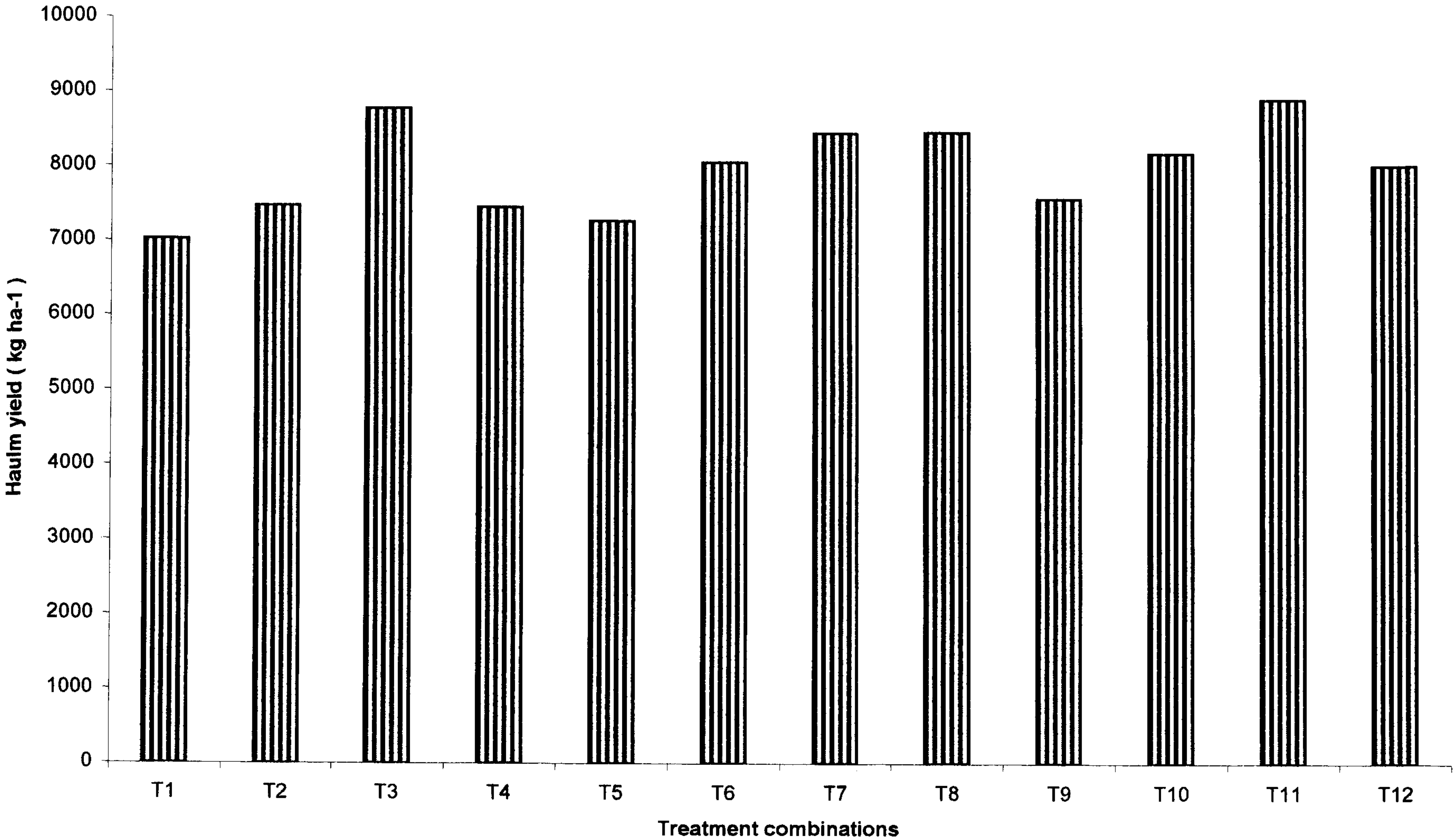
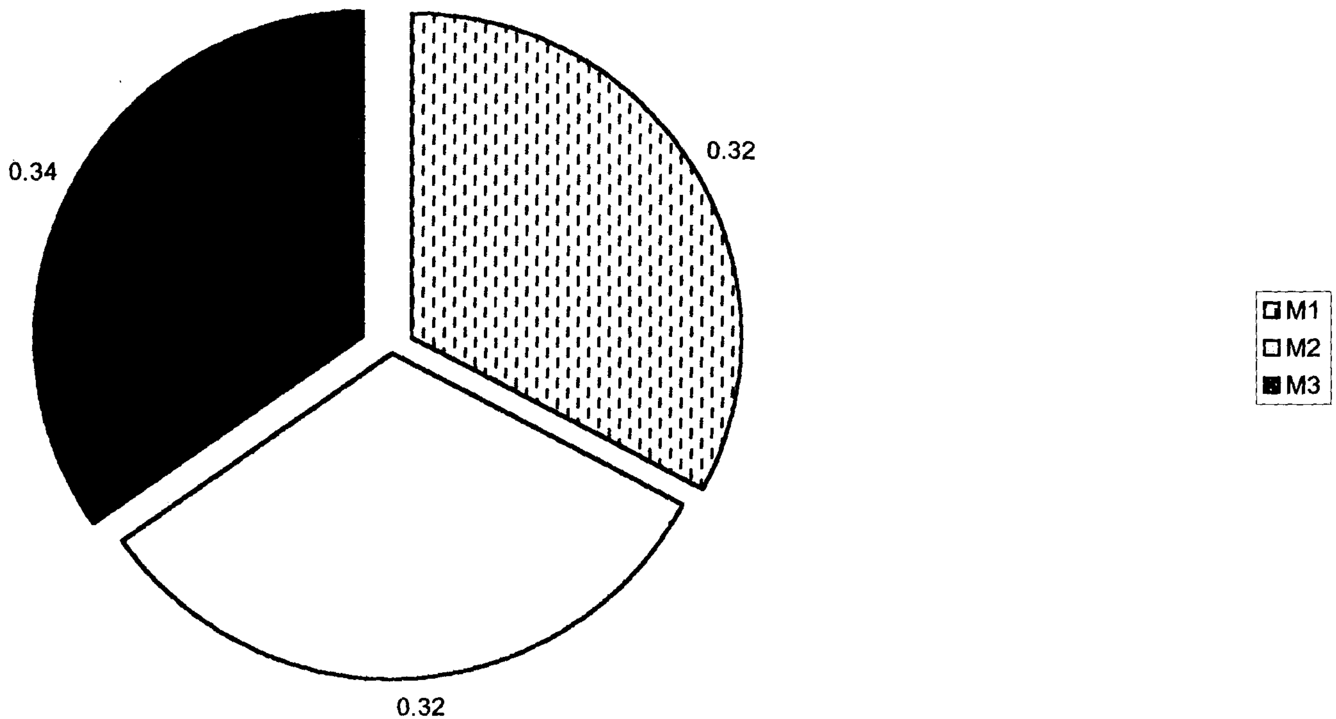


**Fig. 10 Effect of microbial inoculants on total phosphorus content of plant (percent)**



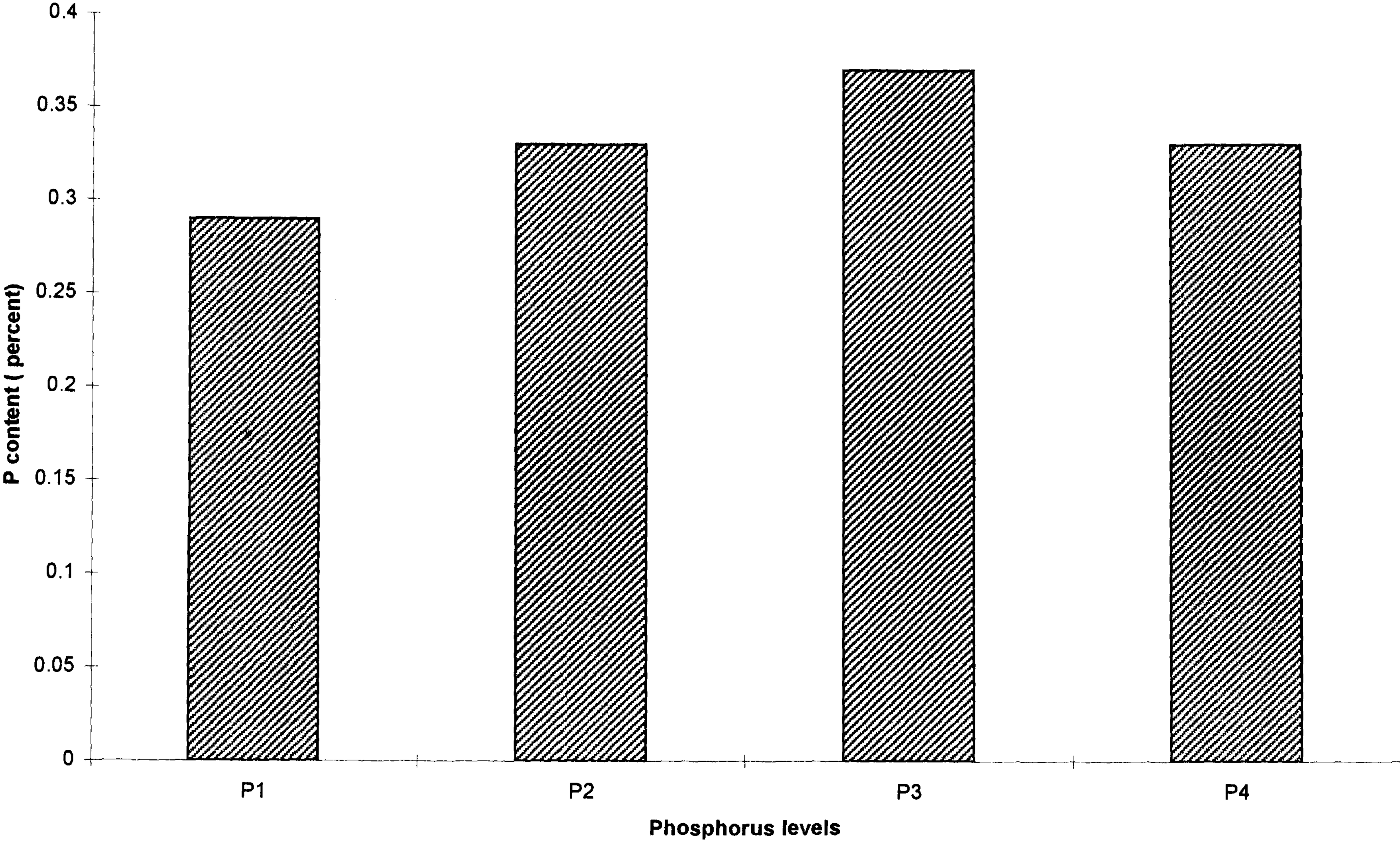
As discussed earlier, the difference in phosphorus uptake was not high owing to the high phosphorus status of soil with increased phosphorus application. This might be the reason for the poor translocation of phosphorus to pods.

The ability of VAM hyphae to take up phosphorus from soil with low phosphorus concentration than normal roots is well documented by Barea (1991). The response of microbial inoculants is found to be very much limited due to high phosphorus status and low pH of soil. These results are in conformity with the findings of Sperber (1958), Katznelson and Bose (1959), Abbott and Robinson (1984).

The maximum nitrogen content in pod was recorded by 30 kg P2O5 ha-1 which implies that at moderate level of P2O5 nitrogen uptake was more and it was reflected in number of pods per plant and pod yield.

The maximum phosphorus content of the plant was noticed at 30 kg P2O5 ha-1 which was significantly superior over all other treatments (Fig.11). The role of phosphorus in proper root development, nodulation, nitrogen fixation, meristematic activity and translocation is well known and this explains its influence on the uptake of nutrients. Higher uptake of phosphorus and potassium following phosphorus application might be a cumulative effect of

**Fig.11 Effect of phosphorus levels on total phosphorus content of plant**



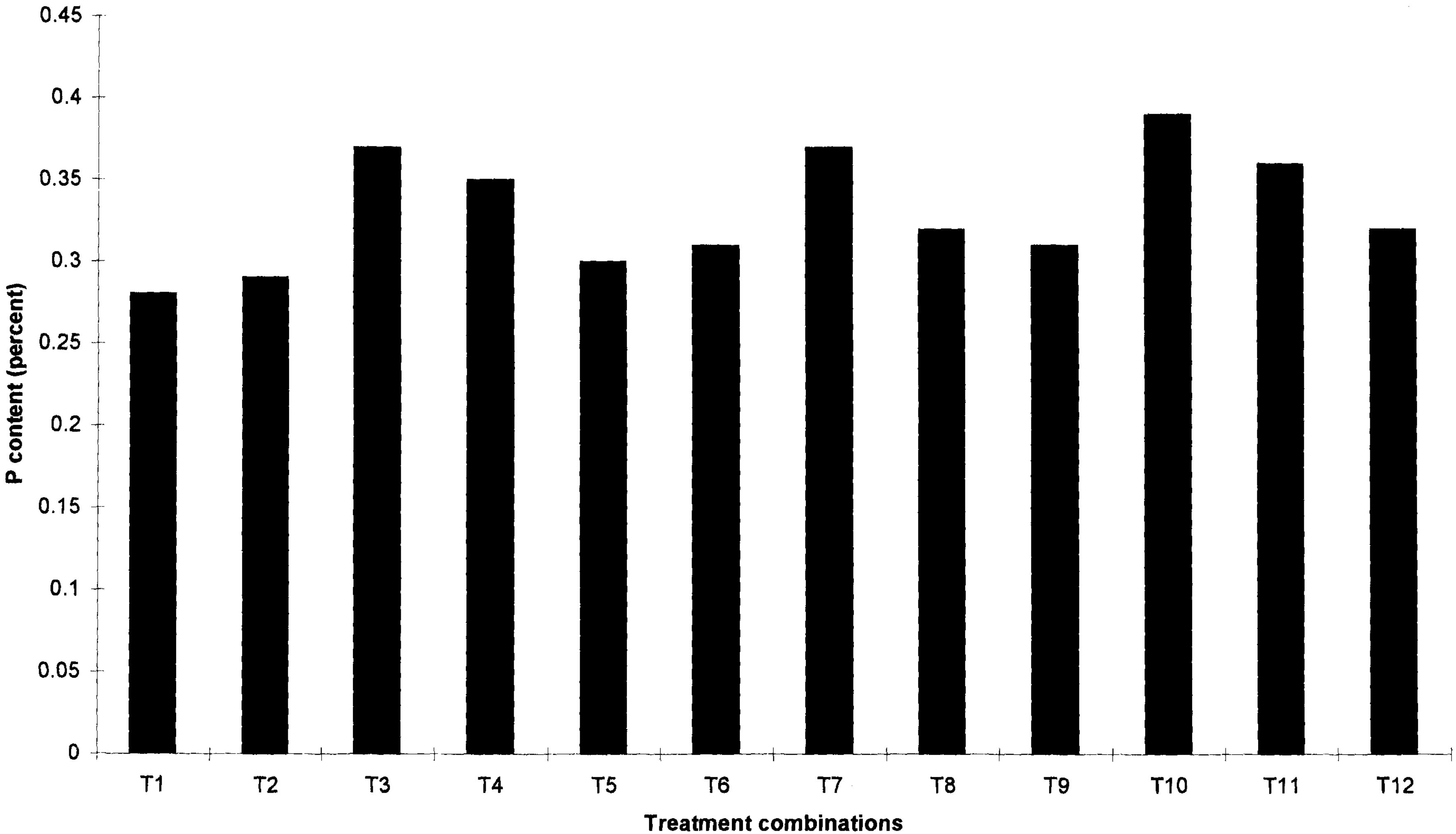
increased dry matter production and nutrient content on account of higher availability of nutrients ( Dashora and Jain, 1994).

Interaction due to graded levels of phosphorus and bioinoculants was also found to be significant with respect to total phosphorus content of plant. Maximum phosphorus content was noticed with M3P2 i.e., combined application of AMF+PSM with 15 kg $P_2O_5$ $ha^{-1}$ ( Fig. 12 ).

The improved phosphorus content of the plant might be mainly through the action of mycorrhizal association which was indicated in the mycorrhizae treated plots and was more pronounced in moderate levels of phosphorus application as the inherent phosphorus status of soil itself is medium. In general, nutrient uptake was higher due to mycorrhizal inoculation. The development of an extramatrical hyphae by the VAM in soil surrounding the root, together with the capacity of hyphae for nutrient absorption and transport to the cortical root cells, indicate that VAM modify nutrient uptake properties of root system (Harley and Smith, 1983).This might be reason for relative efficiency of AMF in increasing phosphorus availability there by enhancing the total phosphorus content of plant.

The treatment combinations recorded significantly higher phosphorus content of plant compared to the control treatments. It is clearly

**Fig.12 Interaction effect of microbial inoculants and phosphorus on total phosphorus content of plant**



evident from the results that the bioinoculants along with varying levels of phosphorus had improved the root characters, which ultimately led to more phosphorus uptake and is reflected in the phosphorus content of plant compared to the control plots.

## 5.8 Quality characters of pod

### 5.8.1 Protein content

Combined application of AMF + PSM and AMF alone with better AMF colonisation (Table 9) has exhibited the ability of improving the root characters (Table 7) and nodulation (Table 8) which might increase the nitrogen fixation and uptake and this resulted in higher nitrogen and protein content of pod.

A reduction in protein content at phosphorus level exceeding 30 kg P2O5 $ha^{-1}$ may be attributed to the imbalance between high phosphorus and low nitrogen availability in the soil. This is more revealed in the fact that the protein content recorded by 45 kg is less than 30 kg $P_2O_5$ $ha^{-1}$. Phosphorus being the "energy currency" is highly essential for amino acid and protein synthesis (Tisdale *et al.*1995). This may be another contributing factor for more total P content in the plant at 15 and 30 kg $P_2O_5$ $ha^{-1}$ in a soil with medium phosphorus status. The interaction effect due to graded doses of phosphorus and bioinoculants was also found to be significant. AMF and PSM application along with 30 kg $P_2O_5$ as well as dual inoculation with 15 and 30 kg $P_2O_5$ recorded the maximum protein content and they were on par. This might be due to the increased availability of phosphorus in the soil leading to more uptake when applied along with lower doses of phosphorus ( Table 12 ). The control treatments ( $C_1$ and $C_2$) recorded lower protein content compared to the twelve treatment combinations. This might be due to fact that bioinoculants along with phosphorus application had improved the nitrogen uptake and ultimately increased the protein content of pods.

### 5.8.2 Fibre content

As in the case of protein content of pod, combined application of AMF + PSM significantly reduced the fibre content over other treatments. This result corroborated the findings of Sathi (1987). Similarly, 15 and 30 kg $P_2O_5$ $ha^{-1}$ has considerably reduced the fibre content of pod and was found to be on par.

Interaction effect due to varying levels of phosphorus and bioinoculants was also significant and $M_3P_2$ has recorded the least fibre content (6.60 percent). This might be due to the maximum phosphorus content of plant observed at $M_3P_2$ (Table 12). Better quality pods are produced at moderate amount of $P_2O_5$ application. This is more evident from the fact that the two control treatments ($C_1$ and $C_2$) recorded higher fibre content compared to the treatment combinations.

## 5.9 Soil nutrient status

The significant influence of bioinoculants and phosphorus application on available $K_2O$ content in soil is evident from the data presented in Table 15. The application of phosphate solubilising microorganisms has registered the maximum content of available potassium in soil. This may be due to the reason that action of phosphate solubilising microorganisms (PSM) in releasing phosphorus from fixed forms is limited in an acidic soil with medium phosphorus status (Dubey and Gupta, 1996). The mode of release of phosphorus by PSM is through organic acids secreted by them (Venkateswarlu *et al.* 1984) while AMF trnasports phosphate ions from deeper layers to the root zone, thus enhancing nutrient uptake (Pearson and Tinker, 1975). The same trend is reflected yield attributes and yield (Tables 10 and 11 respectively). AMF alone and dual inoculation of AMF and PSM have improved the availability of phosphorus in soil which might have resulted in low residual $K_2O$ content by these treatments. It may be inferred from the results that phosphorus released by PSM is restricted in acid soils while phosphorus availability and uptake is considerable by the presence of AMF ($M_1$ and $M_3$). Hence better uptake of phosphorus results in better infilteration of $K_2O$ and this resulted in low $K_2O$ content in AMF applied plots and more $K_2O$ in PSM applied plots.

At higher levels of phosphorus, the available $K_2O$ content in soil is reduced. Residual potassium content in soil was maximum at $P_1$ level.

Phosphorus application improves root development which might have contributed to better uptake of potassium by the crop. This can be again attributed to higher yield recorded with increased P application.

The non significant influence of bioinoculants and phosphorus levels on available nitrogen content in soil might be due to fixed dose of nitrogen applied (30 kg N $ha^{-1}$) and the low initial status of nitrogen in the soil. The nitrogen applied through fertilizer is insufficient to meet the requirement of the crop.

The available phosphorus content in soil was found to increase up to $P_2$ level at vegetative and flowering stages after which a decline was noticed ( Fig. 13, 14, 15, 16, 17, 18 ). At $P_1$ and $P_2$ levels, the phosphorus requirement of the crop is already met from the native soil phosphorus. But at 30 kg $P_2O_5$ level, native as well as some applied phosphorus was utilised by the crop which might be the reason for low residual $P_2O_5$ in soil at all the three crop growth stages. Moreover, at $P_3$ level, applied phosphorus might have released some fixed phosphorus which resulted in a balanced state of major nutrients. This is reflected in the phosphorus content of plant at harvest stage. Phosphorus content of plant was maximum at $P_3$ level (Table 12). At higher phosphorus levels, native phosphorus along with a portion of applied phosphorus released exceeds the requirement of the crop and due to imbalance of nutrients a low yield inspite of more phosphorus content in plant at harvest was recorded. George (1980) also reported more available $P_2O_5$ in soil at lower doses of phosphorus application. At higher

**Fig.13 Effect of microbial inoculants on available $P_2O_5$ content in the soil at vegetative stage**

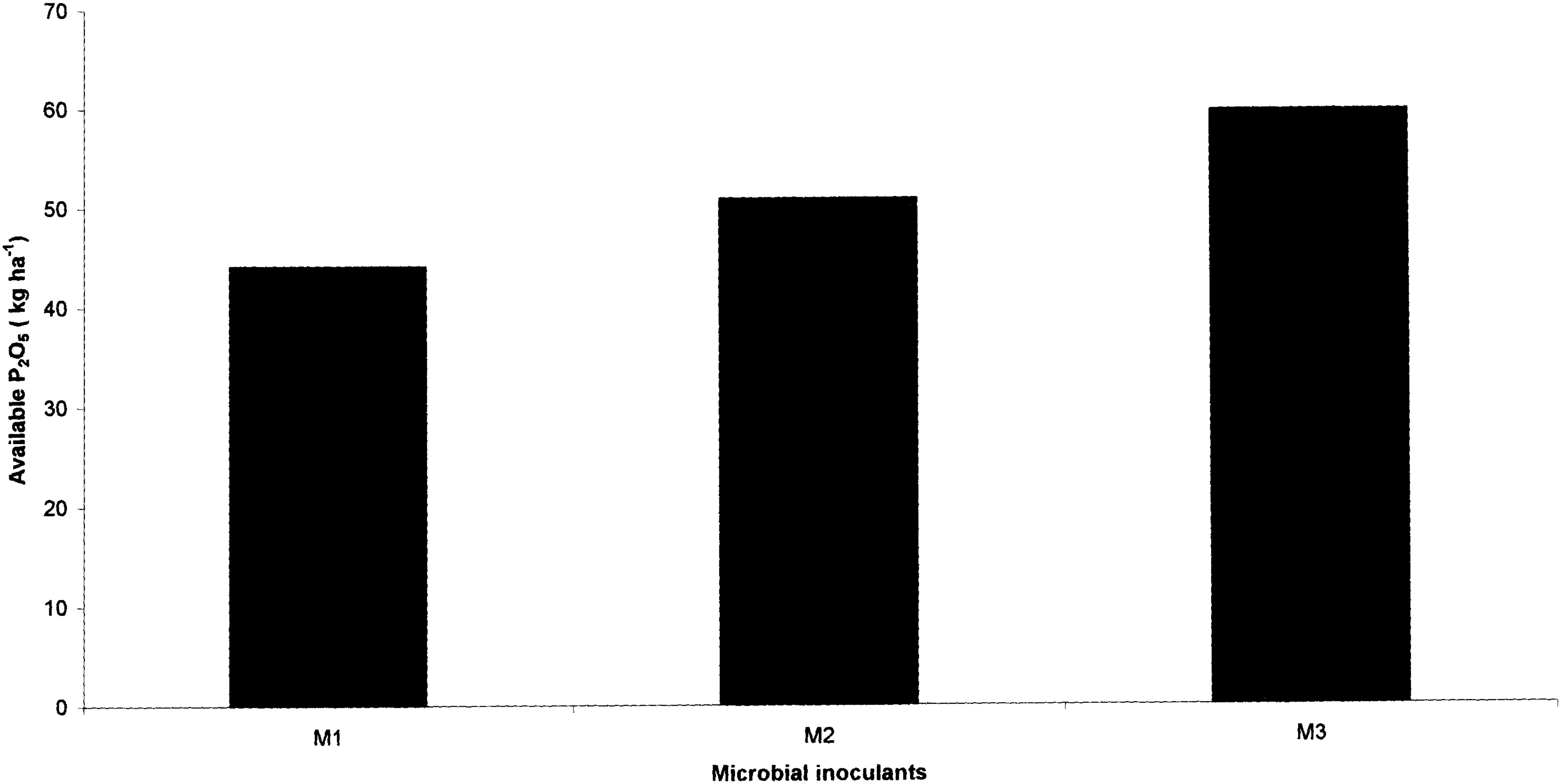


**Fig.14 Effect of phosphorus levels on available $P_2O_5$ content in the soil at vegetative stage**

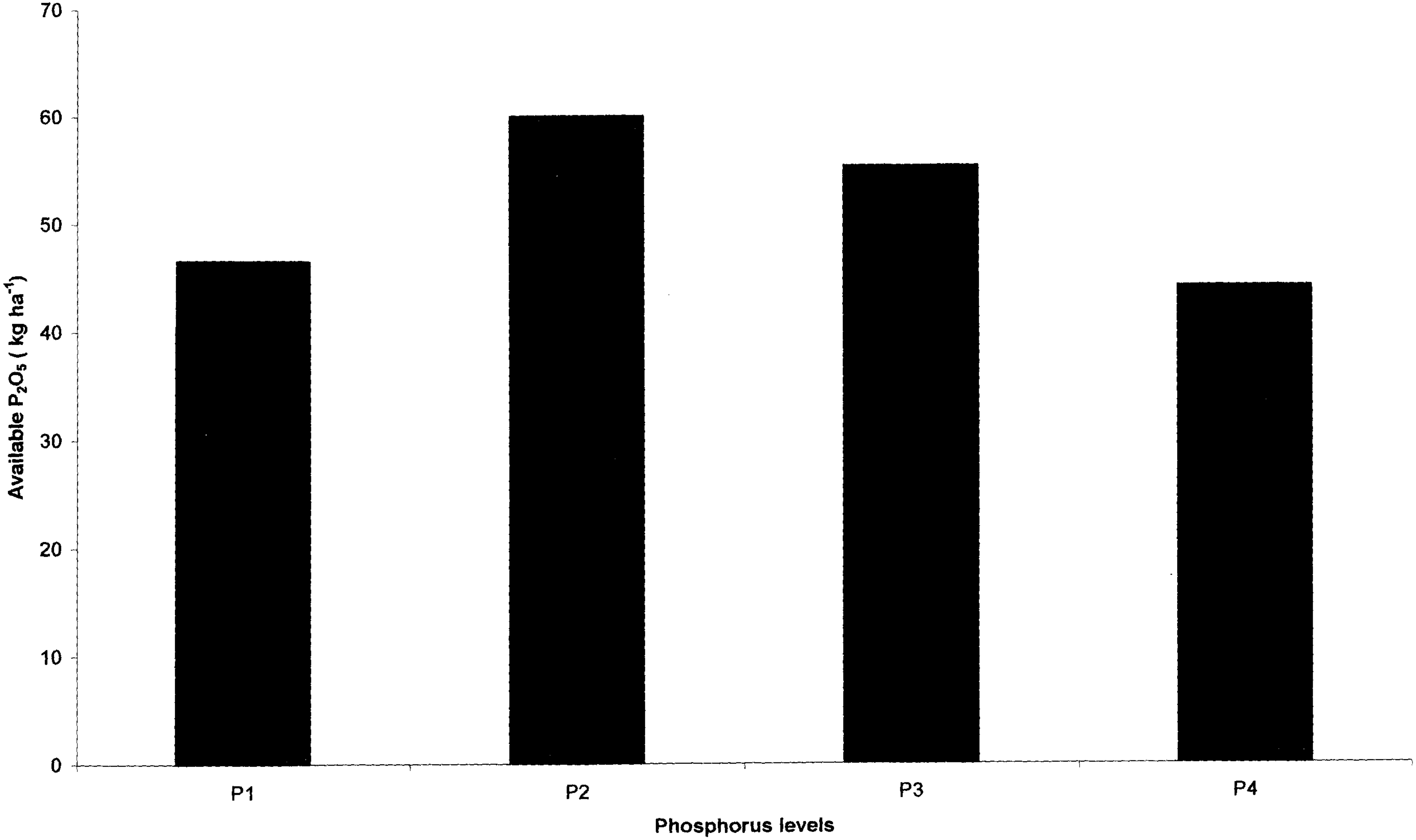


**Fig.15 Interaction effect of microbial inoculants and phosphorus on available $P_2O_5$ content in the soil at vegetative stage**

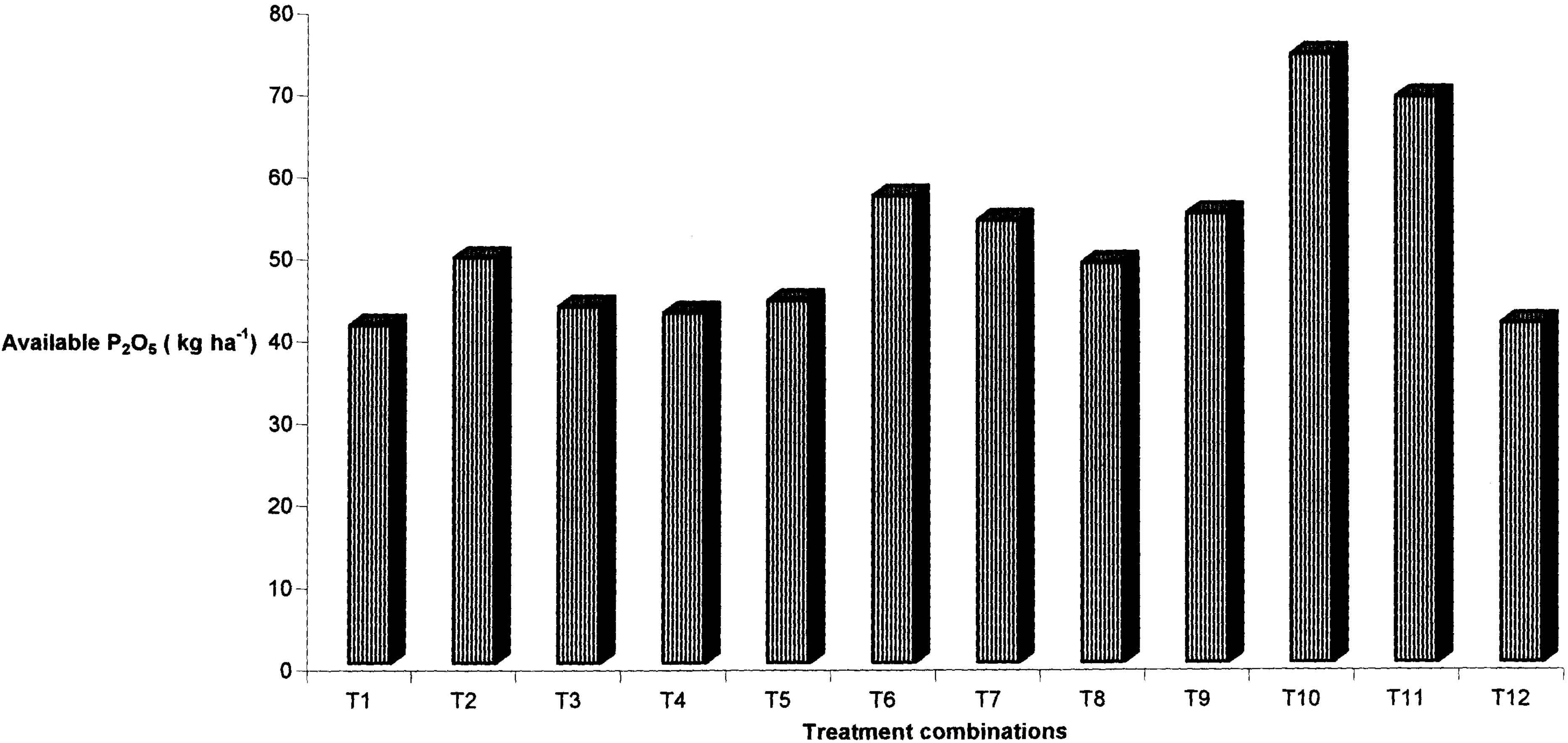


**Fig.16 Effect of microbial inoculants on available $P_2O_5$ content in the soil at flowering stage ( kg $ha^{-1}$)**

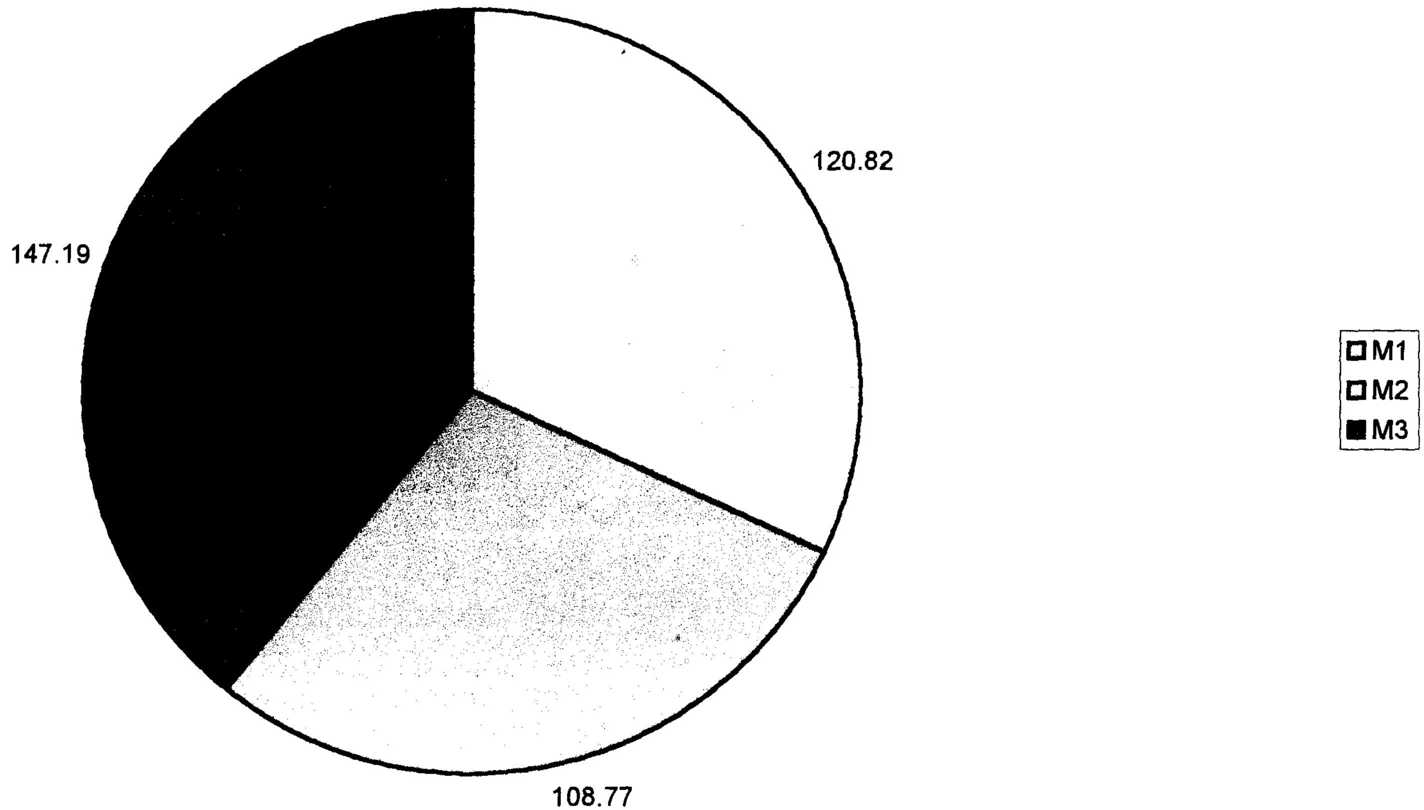


**Fig.17 Effect of phosphorus levels on available $P_2O_5$ content in the soil at flowering stage**

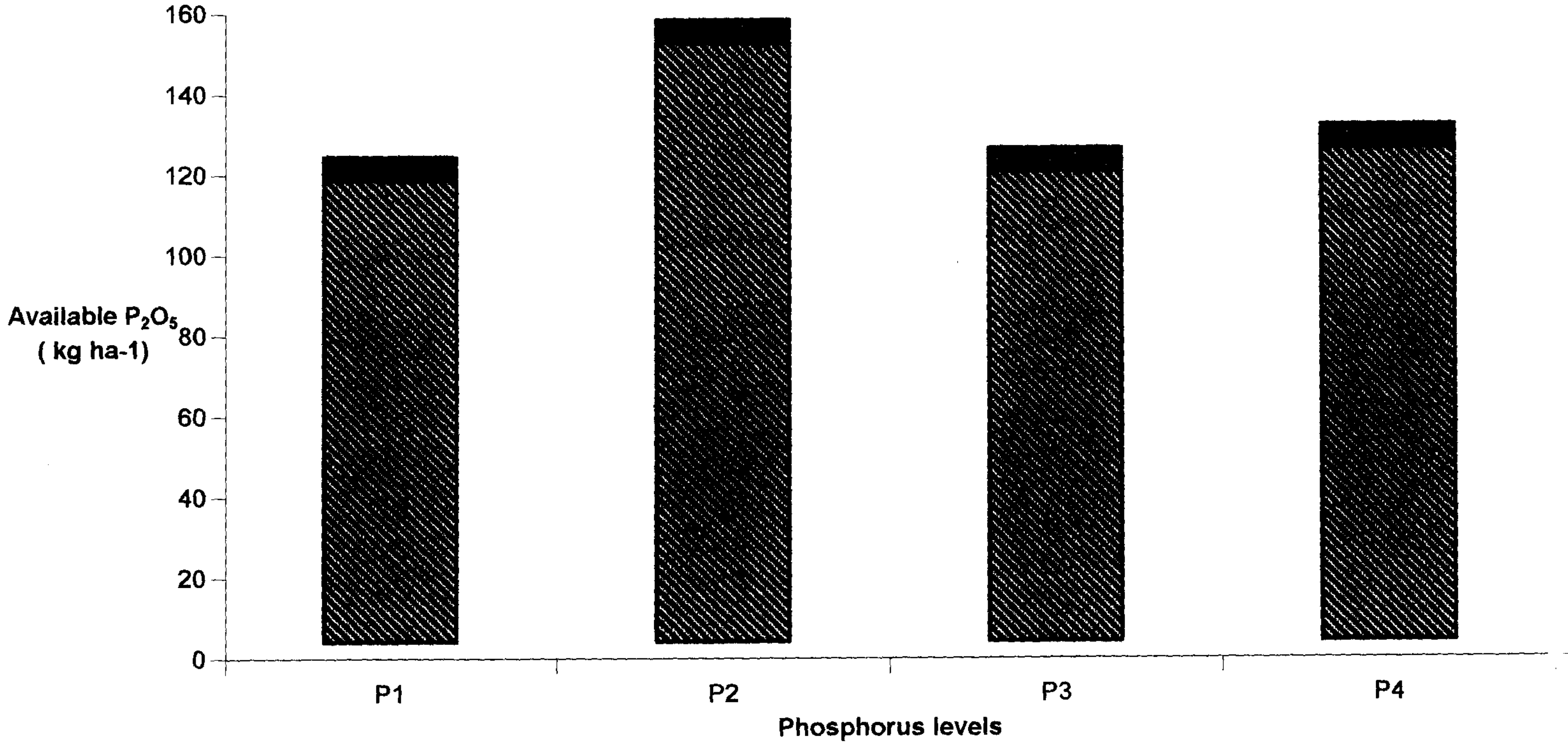
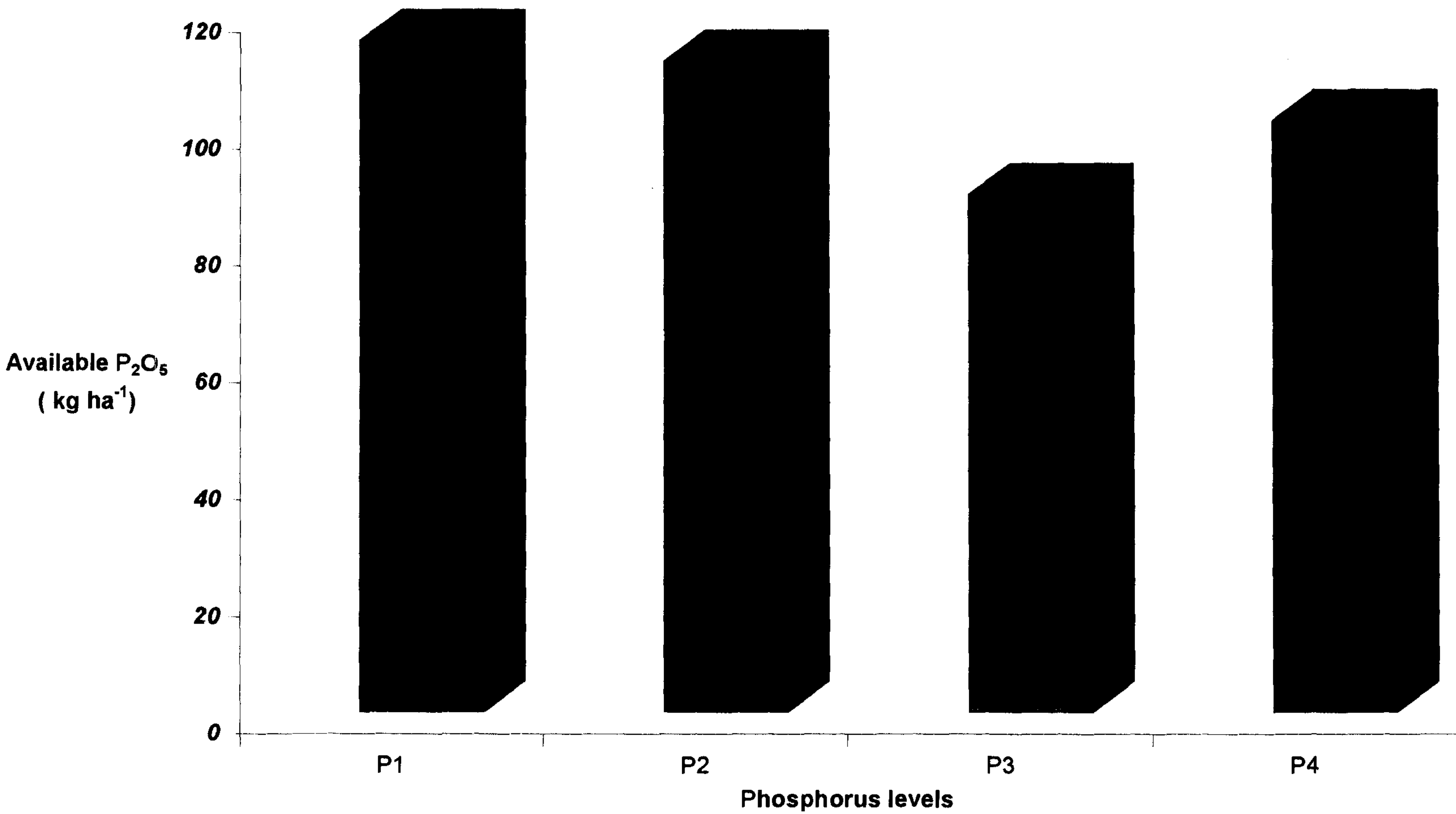


**Fig.18 Effect of phosphorus levels on available $P_2O_5$ content in the soil at harvest stage**



levels of applied phosphorus, more $P_2O_5$ is rendered unavailable because of phosphorus fixation and less response of bioinoculants at high phosphorus levels.

The significant influence of bioinoculants in enhancing phosphorus availability in soil is well documented. By dual inoculation of AMF and PSM, available $P_2O_5$ content in soil has improved, which is due to their synergistic interactions. This finding corroborates the results of many scientists (Mohod *et al.*, 1989; Heggo and Barakah, 1993 and Viswambaran, 1997). The ability of microbial inoculants in enhancing phosphorus availability is reduced at higher doses of applied phosphorus.

The treatment combinations when compared to the control treatments recorded higher residual phosphorus content in soil at all the three growth stages which reveals that microbial inoculants had definitely improved the phosphorus availability in the soil, but their role is limited in acid soil with medium phosphorus status.

## 5.10 Economics of cultivation

It was evident from the economic analysis that the net returns and benefit-cost ratio (BCR) were higher with the treatment combination $M_3P_3$. Dual inoculation of AMF and PSM with 30 kg $P_2O_5$ $ha^{-1}$ of phosphorus was found to be the most profitable. The highest pod yield recorded by $M_3P_3$ resulted in maximum net returns and BCR compared to other treatment combinations. Eventhough, lowest yield was obtained with the treatment combination $M_1P_1$, it was not computed as least economic. The absolute control treatment ($C_1$) was found to be least economic as it gave the lowest net returns and BCR.

# SUMMARY

# SUMMARY

A field experiment was conducted at the Instructional Farm, attached to the College of Agriculture, Vellayani during December 1998 to April 1999 to evaluate the role of microbial inoculants viz. arbuscular mycorrhizal fungi (AMF) and phosphate solubilising microorganisms (PSM) in enhancing the phosphorus use efficiency and productivity of vegetable cowpea. The soil of the experimental field was sandy loam in texture, acidic in reaction, low in available nitrogen, potassium and medium in available phosphorus. The experiment was laid out in factorial randomised block design with three replications. The treatments comprised of three levels of microbial inoculants and four levels of phosphorus

Microbial inoculants:

$M_1$ - Arbuscular mycorrhizal fungi (AMF)

$M_2$ - Phosphate solubilising micro organisms (PSM)

$M_3$ - AMF + PSM

Phosphorus:

$P_1$ - 0 kg $P_2O_5$ ha $^{-1}$

$P_2$ - 15 kg $P_2O_5$ ha $^{-1}$

$P_3$ - 30 kg $P_2O_5$ ha $^{-1}$

$P_4$ - 45 kg $P_2O_5$ ha $^{-1}$

In addition , there were two control treatments ($C_1$ and $C_2$)

$C_1$ – No bioinoculants + No NPK (Absolute control)

$C_2$ - No bioinoculants + N and K fertilizers + No $P_2O_5$

Observations were made on growth, root, yield and quality characters of the crop. Data were statistically analysed and the results of the study are summarised below:-

1. It was observed that among the growth parameters, only length of vine at vegetative stage was significantly influenced by bioinoculants. The treatments $M_2$ and $M_3$ were on par and showed a marked response on length of vine over $M_1$ . Graded doses of phosphorus as well as effect of interaction due to phosphorus levels and bioinoculants failed to exert a significant influence on growth parameters at all stages except LAI at harvest stage where in interaction effect was found to be significant.
2. The days for 50 percent flowering was not significantly influenced by bioinoculants. Phosphorus application at all levels induced earliness in flowering. $P_3$ which was on par with $P_4$ gave earliest flowering. However, interaction effect due to bioinoculants and phosphorus levels showed no significant response on earliness in flowering.
3. Among the root characters at flowering stage, root length and root volume were substantially improved by bioagents. Bioinoculant treatments $M_1$ and $M_3$ showed significant improvement in root length and superiority over $M_2$ . $M_2$ and $M_3$ were on par and exerted a significant response on root volume. Phosphorus application at $P_2$ level recorded the maximum root length and root volume. Phosphorus application at all levels increased root mass than no application ; $P_2$ , $P_3$

and $P_4$ were on par. Interaction effect showed a significant response on root volume and root mass but insignificant with respect to root length.

4. Bioinoculant treatment $M_1$ produced the maximum number of effective nodules over $M_2$ and $M_3$ . Among phosphorus levels and treatment combinations , $P_1$ level and $M_1P_4$ recorded the maximum number of effective nodules respectively.

5. Arbuscular mycorrhizal colonisation was higher with the treatment combination $M_3P_2$ at both flowering and harvest stages.

6. Bioinoculants had no significant influence on yield and yield attributes. Of the different yield attributes, maximum number of pods per plant was produced at $P_3$ level and least number by $P_1$. Maximum pod and haulm yield were also recorded at $P_3$ level and was on par with $P_2$. The treatment combination $M_3$ $P_3$ recorded the highest number of pods per plant, maximum pod and haulm yield.

7. All the three bioinoculant treatments showed a marked response on total phosphorus content of plant and were on par. Highest phosphorus content was recorded at $P_3$ level and significantly superior over other phosphorus levels. The phosphorus content of pods was not at all influenced by bioinoculants. Phosphorus application at all levels increased phosphorus content of pod over no phosphorus application. Interaction effect had a significant influence on phosphorus content of plant and pod.

8. Quality characters of pod were significantly improved by bioinoculants, phosphorus levels and interaction effect. Highest protein and least fibre

content were recorded with $M_3$ which was significantly superior over $M_1$ and $M_2$. Phosphorus application at $P_3$ level gave the maximum protein content where as $P_2$ and $P_4$ were on par and recorded low fibre content.

9. Available nitrogen content in soil after harvest was not influenced by bioinoculants, phosphorus levels and their interaction effect. However, among the bioinoculants and phosphorus doses, $M_2$ and $P_1$ recorded the highest residual potassium content in soil respectively.

10. Residual available phosphorus content in soil at vegetative & flowering stages was significantly influenced by bioinoculants and graded doses of phosphorus. $M_3$ and $P_2$ recorded the maximum available $P_2O_5$ content respectively. At harvest stage, bioinoculants had no significant influence where as phosphorus application significantly influenced available phosphorus content in the soil.

11. It was evident from the results that dual inoculation of microorganisms viz. arbuscular mycorrhizal fungi and phosphate solubilising microorganisms along with 30 kg $P_2O_5$ $ha^{-1}$ ($M_3P_3$) was most economic with the highest net returns and BCR. The treatment combination $M_3P_3$ gave the maximum net returns of Rs.15 672.90 $ha^{-1}$ with BCR of 1.54.

The findings of the present investigation revealed that microbial inoculants viz. AMF and PSM have only a limited role in enhancing phosphorus availablity in acidic soils with medium phosphorus status. Higher doses of phosphorus along with fixed doses of nitrogen and potassium will lead to nutrient imbalance resulting in lack of crop response to added phosphatic fertilizers. It is highly necessary to develop a clear cut fertilizer recommendation for vegetable cowpea under Kerala condition depending upon the phosphorus status of soil, fertilizer applied to previous crop and climatic factors. Present study suggests that a lower level of 15 kg $P_2O_5$ $ha^{-1}$ is sufficient for vegetable cowpea at medium phosphorus status of soil. Further trials have to be conducted with AMF and PSM along with lower doses of phosphorus with a view to get a realistic result.

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*** Originals not seen.**

# APPENDIX

# APPENDIX

## Weather data during the cropping period

| PERIOD | MAXIMUM TEMPERATURE (°C) | MINIMUM TEMPERATURE (°C) | RAINFALL (mm) (weekly total) | EVAPORATION (mm) (weekly total) | RELATIVE HUMIDITY (percent) |
|---|---|---|---|---|---|
| 1998-99 | | | | | |
| December 15 — December 21 (1) | 30.90 | 23.43 | 19.30 | 18.20 | 83.07 |
| December 22 — December 28 (2) | 29.20 | 23.11 | 38.18 | 13.30 | 87.09 |
| December 29 — January 4 (3) | 30.79 | 23.08 | 48.02 | 20.09 | 85.0 |
| January 5 — January 11 (4) | 31.34 | 21.14 | 6.02 | 19.53 | 85.5 |
| January 12 — January 25 (5) | 30.93 | 22.63 | 3.22 | 14.77 | 92.93 |
| January 26 — February 1 (6) | 31.49 | 22.27 | 0 | 42.98 | 94.71 |
| February 2 — February 8 (7) | 31.34 | 22.53 | 0 | 25.13 | 92.50 |
| February 9 — February 15 (8) | 31.36 | 21.27 | 0 | 15.89 | 77.43 |
| February 16 — February 22 (9) | 30.63 | 21.37 | 2.0 | 24.71 | 76.29 |
| February 23 — March 1 (10) | 30.94 | 22.27 | 78.60 | 27.79 | 83.0 |
| March 2 — March 8 (11) | 31.40 | 23.06 | 0 | 26.39 | 81.64 |
| March 9 — March 15 (12) | 31.80 | 23.14 | 0 | 26.39 | 84.39 |
| March 16 — March 22 (13) | 31.93 | 23.11 | 0 | 27.72 | 80.0 |
| March 23 — March 29 (14) | 32.20 | 23.09 | 0 | 30.17 | 78.79 |
| March 30 — April 5 (15) | 32.70 | 24.31 | 1.80 | 30.38 | 80.71 |
| April 6 — April 12 (16) | 32.53 | 25.23 | 54.80 | 31.57 | 81.21 |
| April 13 — April 19 (17) | 32.73 | 25.34 | 2.20 | 28.21 | 82.0 |

# PHOSPHORUS USE EFFICIENCY AND PRODUCTIVITY AS INFLUENCED BY MICROBIAL INOCULANTS IN VEGETABLE COWPEA

*(Vigna unguiculata sub sp. sesquipedalis* (L.) Verdcourt) var.Sharika


BY

**MEENA MARY MATHEW**


ABSTRACT OF THESIS
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1999

# ABSTRACT

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An experiment was conducted at the Instructional Farm attached to the College of Agriculture, Vellayani during December 1998 - April 1999 with the objectives of finding out the role of bioinoculants viz. arbuscular mycorrhizal fungi (AMF) and phosphate solubilising microorganisms (PSM) in improving the phosphorus use efficiency and productivity in vegetable cowpea var. Sharika. The experiment was laid out in 3 x 4 + 2 factorial randomised block design with three replications. The treatments included three levels of microbial inoculants and four levels of phosphorus along with two control treatments.

The study revealed that crop failed to show a significant response to the use of bioinoculants and phosphorus levels in a soil with low available nitrogen and medium phosphorus status. Biometric characters except length of vine at vegetative stage was influenced by phosphate solubilising microorganisms as well as dual application of PSM and AMF. Phosphorus application as well as interaction effect did not show a positive response on growth parameters except LAI at harvest stage where in interaction effect was significant.

Bioinoculants and phosphorus application exerted a profound influence on root length and volume. Dual inoculation of AMF and PSM significantly improved root length and volume . Phosphorus application at all

levels improved root mass where as maximum root length and volume were recorded at $P_2$ level. Interaction effects were significant only with respect to root volume and root mass. Mycorrhizal colonisation percent was highest with $M_3P_2$ (AMF + PSM + 15 kg $P_2O_5$ $ha^{-1}$) and showed a decreasing trend with higher doses of phosphorus.

Microbial inoculants showed only limited role in improving yield and yield attributes. In general, crop responded positively to phosphorus application only up to 30 kg $P_2O_5$ $ha^{-1}$ but it was on par with 15 kg $P_2O_5$ $ha^{-1}$. Among the interaction effects, dual application of AMF + PSM along with 30 kg $P_2O_5$ $ha^{-1}$ gave the highest yield. The effect of microbial inoculants in promoting growth and yield of crop was found to decline in the presence of higher doses of applied phosphorus.

Quality characters of pod viz. protein and fibre content were significantly improved by bioinoculants and graded doses of phosphorus. Dual inoculation of AMF and PSM significantly increased protein content as well as reduced fibre content of pod.

Available nitrogen content in soil after harvest did not show any significant variation among treatments but bioinoculants significantly improved residual $K_2O$ content in soil. Available $P_2O_5$ content at vegetative, flowering and harvest stages recorded higher values compared to initial status. Treatments $M_3$ and $P_2$ recorded the maximum available $P_2O_5$ content at vegetative and flowering stages. But at harvest stage, lowest residual $P_2O_5$

content was recorded at $P_3$ level indicating higher uptake by the crop at later stages. Interaction effects were significant with respect to $P_2O_5$ content only at vegetative stage.

The results of economic analysis revealed that the net income and benefit-cost ratio was maximum by dual inoculation of arbuscular mycorrhizal fungi and phosphate solubilising microorganisms along with a phosphorus level of 30 kg $P_2O_5$ $ha^{-1}$.