INCREASING PHOSPHORUS USE EFFICIENCY IN BANANA cv. NENDRAN

By

SHEHANA, R. S.

THESIS

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1997

DECLARATION

I hereby declare that this thesis entitled **"Increasing phosphorus use efficiency in banana cv. Nendran"** 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 of any degree, diploma, associateship, fellowship or other similar title of any other University of Society.

Vellayani,
25 - 8 - 1997.

SHEHANA, R. S.

CERTIFICATE

Certified that this thesis entitled **"Increasing phosphorus use efficiency in banana cv. Nendran"** is a record of research work done independently by Smt. Shehana, R. S. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship.

Vellayani,
25-8-1997.

Dr. (Mrs.) Alice Abraham
(Chairman, Advisory Committee)
Professor,
Department of Soil Science and
Agricultural Chemistry,
College of Agriculture, Vellayani.

Approved by

Chairman :

Dr. (Mrs.) Alice Abraham Alice Abraham 5.10.97

Members :

1. **Dr. Thomas Varghese**

2. **Dr. (Mrs.) P. Saraswathi**

3. **Dr. K. Vasanthakumar**

4. **Dr. L. Rajamony**

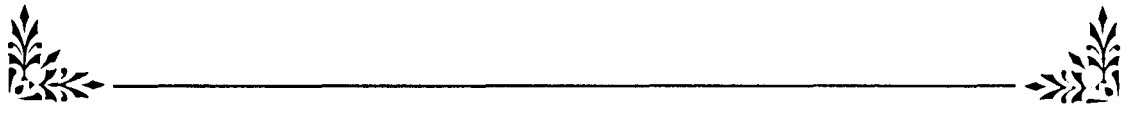
External Examiner :

Dr. A. Rajamannar A. Raj D.

Dedicated

to my

Parents & Husband



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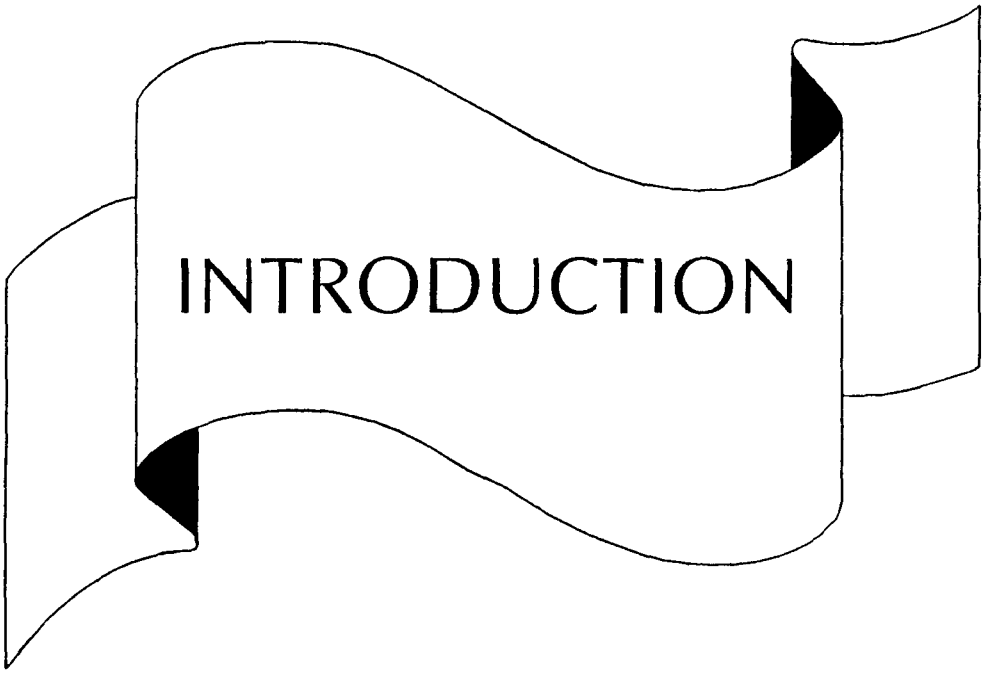
ABBREVIATIONS USED

g	-	gram
%	-	percentage
m	-	metre
N	-	Nitrogen
P	-	phosphorus
K	-	Potassium
PB	-	Phosphobacterin
mg	-	milligram
me	-	milliequivalent
DS	-	Deci Siemens
cm	-	Centimetre
SP	-	Super phosphate
EC	-	Electrical Conductivity
CV	-	Cultivar
Fe	-	Iron
Al	-	Aluminium
^{o}C	-	degree celcius
PSM	-	Phosphorus solubilising Microorganism
FYM	-	Farm Yard Manure
MRP	-	Mussorie Rock Phosphate
SSP	-	Single super phosphate
POP	-	Package of Practices
KAU	-	Kerala Agricultural University
HCH	-	Hexa Chloro Cyclo Hexane
Fig.	-	Figure
LAI	-	Leaf Area Index
DAP	-	Days After Planting
MAP	-	Months After Planting
C mol	-	Centi mole
CEC	-	Cation exchange capacity
kg ha^{-1}	-	kilogram per hactare
PSB	-	Phosphorus Solubilising Bacteria
PDB	-	Phosphorus Dissolving Bacteria
TNAU	-	Tamil Nadu Agricultural University
FSRS	-	Farming Systems Research Station


INTRODUCTION

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Fertilizer is considered as the most effective and expensive input in agriculture. It is the primary concern of soil scientists to help the farmer to derive maximum benefit out of this costly input by increasing the fertilizer use efficiency by appropriate methods.

Management of P fertilizers for various crops has been a favourite topic of research for many a soil scientist in India as well as in Kerala. It is widely known that the different soil types of India supporting a variety of crops and cropping systems show only a very poor response to the use of phosphate fertilizers. The consumption of P fertilizers in India as well as in Kerala is not as high as that of N and K fertilizers evidently due to the lack of a spectacular crop response to P as in the case of N and K.

While the efficiency of applied N and K fertilizers is adversely affected by their high water solubility and resultant losses from soil, the effectiveness of P fertilizers is decreased due to their reaction with soil components forming insoluble products which diminish their availability to plants. An efficient P fertilizer management programme, therefore, should take care of these aspects and practice all methods feasible to maintain an optimum level of available P in soil to meet continued plant demand.

Needless to mention, much of this phenomenon depend upon the nature of P fertilizers and the soil type in which they are used.

Since the production of water soluble phosphate fertilizers is energy intensive and likely to be limited by regulation of foreign exchange for the import of raw materials, direct application of mined rock phosphates as such is encouraged as a feasible proposition, as a national fertilizer policy.

The utilisation of about 260 million tons (Jaggi, 1989) of Rock Phosphate distributed in the States of MP, UP, AP and Rajasthan as a direct source of P fertilizer is considered as an easy and simple way of exploring a natural resource in a most economical way.

Indigenous and cheaper rock phosphates have already replaced the costlier water soluble phosphate fertilizers in the fertilizer market in Kerala. Different types of rock phosphates like Rajasthan Rock phosphate, Udaipur Rock Phosphate, Mussoorie Rock Phosphate etc. are currently used on a large scale for various long and short duration crops, both under upland and wetland soil conditions.

The midland region of Kerala, accounting for about 41.76% of the geographical area of the state is predominated by typical laterite soils, notorious for high P fixing capacity and lack of response to P fertilizers. The area nurtures a cafeteria of crops, all of which invariably show a poor response to phosphate fertilizers. Along with other field crops like coconut,

is considered to be a very effective method (Singh *et al.* 1979 and Ushakumari, 1991).

Priming of RP in moist soil for two weeks before field application has been acclaimed to increase its efficiency especially for short duration crops (Nair, 1977 and Nair, 1978).

Utilisation of soil microorganisms as agents for mediating solubilisation of P from RP is yet another technique promulgated by microbiologists. Reports on the successful use of phosphobacterin cultures in the USSR have prompted many Indian Scientists and since 1960, a huge volume of research has been carried out on the usefulness of PSM in boosting P use efficiency in various crops. Encouraged by the results, cultures of different types of PSM are recommended for use along with RP in most of the Indian states. However, it has never been a recommended practice in Kerala, although some progressive farmers are using PSM cultures supplied by private agencies promoting the use of biofertilizers.

The use of phosphobacterin cultures open up a new avenue for better P management in banana in Kerala. A number of trials have been conducted in KAU on the nutritional requirement of banana varieties, the major stress being given to the management and levels of N and K fertilizers. In this context, a study on "increasing the P use efficiency in banana cv. Nendran" was considered imperative to achieve the following objectives.

i. To study the pattern of P solubilisation from MRP under the influence of PB and other inputs.

ii. To compare the influence of PB on the release of available P from graded levels of MRP applied to banana in the field.

iii. To study the influence of MRP applied along with PB on the growth and yield of banana.

iv. To find out the possible extent of reduction in the use of fertilizer P for banana when used in conjunction with PB.

v. To identify the best plant part in banana as an index of P status with a bearing on yield.

It is hoped that the results from the study will enlighten on these aspects, based on which P management strategies in banana cultivation can be improved.


REVIEW OF
LITERATURE

REVIEW OF LITERATURE

One of the major fertility constraints in tropical soils is phosphorus deficiency resulting from low available P status in soil, low crop recovery of added P fertilizers due to chemical fixation in the soil coupled with the unavailablity of native soil P which exists in both organic and inorganic forms.The long term use of phosphatic fertilisers and organic manures leads to the build up of insoluble phosphates which can become useful to crops under proper management.

For an efficient P management, several agronomic, chemical, and biological methods are widely used. Use of biofertilisers or microbial inoculants to increase the efficiency of applied and native P sources is currently recognised and practised as an efficient method of P management.

Literature on the use of several types of bioagents and the resultant effect on increasing P use efficiency in various crops in India and abroad are briefly reviewed in this chapter.

Development of P solubilizing microbial cultures

Biofertilizers under the name 'Phosphobacterin' which contain the P solubilising bacteria, *Bacillus megatherium var. phosphaticum*, isolated by

Menkina in (1950) was commercially prepared on a peat base in the former USSR. This was widely used in the collective farms of USSR for seed and soil inoculation for several crops and was reported to give increase in crop yields by 5-10%.

The effectiveness of phosphobacterin has been investigated by staff of the US Department of Agriculture, and they reported that the culture can readily decompose organic phosphates like glycerophosphates. It was also found that the yield of tomatoes grown in green house was increased by 7.5%. However, there was no increase in the yield of wheat and neither total P uptake nor phosphorus concentration was reported to be favourably influenced by phosphobacterin (Tisdale *et al.*, 1975).

Introduction of PS microbial cultures in India

Phosphobacterin culture was introduced in India by IARI, New Delhi, in 1959 and the first field trial with the imported material was conducted in wheat during 1960-61 by Rao and associates (Rao *et al.*, 1963). However, no significant increase in wheat yield due to inoculation was observed. Subsequently, several field trials with imported strains of P solubilising microorganisms as well as with local isolates on various crops were conducted by the Institute under different agro-climatic conditions in India. Results showed significant increase in yield over uninoculated control in ten out of thirty seven locations.

At present, efficient strains of bacteria like *Pseudomonas* and *Bacillus sp.* as well fungi like *Aspergillus*, and *Penicillium sp.*, either separately or as a mixture have been cultured and used as inoculants for improving P solubilisation. These commercial cultures under various trade names like "IARI Microphos", "Fosfo-24", "Superphos" etc. are now being made available to farmers through National Biofertilizer Development Projects operating at different Regional Centres, as well as by Agricultural Universities all over India. In addition, several private organisations are also active in the preparation and distribution of PS cultures to farmers.

PS organism in soil

Banik and Dey (1982) observed that PS bacteria out numbered PS actinomycetes and fungi in Indian soils. According to Kucey (1983), PS bacteria and fungi constituted 0.5 and 0.1 per cent respectively of the general soil microbial population in Prairie soils with PS bacteria out numbering PS fungi two fold and one hundred and fifty fold. He also found that most of the PS fungal isolates from Prairie soils were either species of *Penicillium* or *Aspergillus* which shows that PS ability is not common to soil fungi in general.

Venkateswarlu *et al.* (1984) detected the occurrence of PS organisms in desert soils of India and reported that they were present in varying numbers in these soils. But their population was relatively low as compared to other

tropical soils, probably because of high temperature and poor status with respect to organic matter and nitrogen.

Thomas *et al.* (1985) found that PS fungi isolated from coconut plantation soils of Kerala belonged to the *Aspergillus* and *Penicillium* genera and that the alluvial, laterite and clayey soils were found to contain more PS fungi than sandy soils.

The occurrence of PSM in soils as reported by various scientists all over the world was reviewed by Kucey *et al.*, (1989). It is reported that PSM are present in almost all soils, although their numbers vary with the soil climate and history.

Antarikanonda *et al.* (1990) isolated 102 P solublising microorganisms comprising 76 strains of fungi and 26 strains of bacteria. They found that fungi were more active in solubilising phosphate than bacteria.

Yadav and Singh (1991) studied the occurrence of PSM in a calcifluent and reported that the population depend upon the content of organic matter in the soil.

PS organisms in the rhizosphere

The increased availability of P to crop plants has been reported by various workers as due to the presence of P solubilising microorganisms in the rhizosphere soils.

Sperber (1958) found that PS organisms in the rhizosphere of subterranean clover, rye grass and wheat roots constituted 26 to 39 per cent of the total microbial population.

Katznelson and Bose (1959) have observed that approximately one third of the bacteria from the rhizoplane possessed P solubilising abilities.

The number of dicalcium phosphate dissolving bacteria was reported by Louw and Webley (1959) to be greater in the rhizosphere of oat plants than in the surrounding environment. A greater number of P dissolving bacteria in the rhizosphere of chick pea and mustard in comparison to non-rhizosphere soils was also reported by Podyapolskaya (1960).

Golebiowska *et al.* (1964) observed increased P availability in the rhizosphere of lucerne due to the presence of a higher number of bacteria and streptomyces.

Chhonkar and Subba Rao (1967) isolated a few fungi associated with root nodules of leguminous plants which were capable of solubilising TCP.

P solubilising bacteria like *Bacillus megatherium*, *Bacillus subtilis*, *Bacillus brevis*, *Bacillus pulvifaciens* and others were isolated by Paul and Sundera Rao (1971) from the rhizosphere of berseem and green gram.

The predominant group of inorganic P solubilising bacteria in the rhizosphere of broad beans were identified by Mahmoud *et al.* (1973) as spore formers and streptomyces.

Khan and Bhatnagar (1977) concluded that there was no preferential effect of rhizospheric condition on the incidence of PS organisms, since the general rhizospheric microbial population also increased in proportion to the increase in the number of PS organisms.

Khan (1977), while studying the solubilisation of insoluble phosphates by microorganisms found that their number was greater in the rhizosphere than in the non rhizosphere soils. The rhizosphere of maize plants contained the maximum number of microorganisms and among the fungi, *Aspergillus niger* and *Penicillium* sp. were found most active. But their ability to solubilise P varied with the type of rock phosphate obtained from different sources.

Nair and Rao (1977) found that the rhizosphere of coconut and cacao were inhabited by many P solubilising bacteria of the genus *Pseudomonas* and PS fungi of the genus *Aspergillus*. They were able to solubilise about 50 per cent inorganic P from insoluble phosphates.

Barthakur (1978) tested different fungi from the rhizosphere of rice for their capability to dissolve Fe-P, Al-P and Ca-P in a synthetic medium containing 5 mg P /50 ml. He found that *Aspergillus niger* could produce on an average 2.18-2.60 mg of water soluble P.

Ghazvinizadeh *et al.* (1980) observed that the most active P dissolving microorganisms in the rhizosphere soil of fertilised maize were *Bacillus megatherium* var. *phosphaticum* and *Bacillus cereus*.

It has been reported that rhizospheric P solubilising bacteria were more active than those isolated from non rhizosphere soils, (Baya *et al.*, 1981) and even in the salt marsh and desert soils of Kuwait, the occurrence of acid producing PS bacteria was reported (Diab and Al-Gounaim, 1984). Active population of PSM was reported in the rhizosphere of rye grass and wheat and PS bacteria of genus *Bacillus*, *Pseudomonas* and fungi of genus *Aspergillus* and *Penicillium* were isolated from the rhizosphere of arecanut palms (Molla *et al.*, 1984 and Bopaiah, 1985).

Vlassak *et al.* (1992) examined the bacterial population in different parts of the rhizosphere of rice and banana in Sri Lanka and found that the percentage of fluorescent bacteria was significantly greater in the rhizosphere of banana (10.8%).

Narsian *et al.* (1994) isolated 35 PS fungi from the rhizosphere of 24 crop plants.

Organic P mineralisation by soil microorganisms

The main source of organic P compounds in soil is organic residues of plants and animal excreta, where it is found mostly in three forms such as phytin, phospholipids and nucleic acids. As early as in 1911, Dox and

Golden identified three species of *Aspergillus* which contained the enzyme that can dephosphorylate phytin and release inorganic P. Sen and Paul (1957) reported the mineralisation of lecithin by *Bacillus mycoides* and *Bacillus subtilis*. Szember (1960) isolated soil microorganisms capable of breaking down lecithin or phytin which served as a good source of P for radish plants under sterilised condition.

Smith *et al.* (1961) found that a strain of *Bacillus megatherium* var. *phosphaticum* decomposed glycerophosphates.

Several workers have reported the mineralisation of organic P by bacteria such as *Bacillus mycoides, Bacillus cereus, Bacillus megatheria, Aerobacter aerogenes, Pseudomonas fluorescens* etc. (Duff *et al.*, 1963, Greaves *et al.*, 1963, Janossy, 1963).

Sethi and Subba Rao (1968) studied the ability of fungi of different species and found that *Penicillium* and *Aspergilli* were most active in mineralising calcium phytate.

Gaur (1972) reported that calcium phytate and lecithine in Pikovskaya's medium were rendered soluble by several sps. of *Pseudomonas, Penicillium* and *Aspergillus*.

Gaur *et al.* (1973) reported that the bacterial and fungal isolates obtained from alluvial soils as well as rock phosphate deposits, mineralised calcium phytate more effectively and lecithin less effectively.

EL-Sawah *et al.* (1995) studied the effect of applying phytate biofertilizers to soil on the production of soluble phosphate, plant growth and N and P uptake by maize. Water soluble phosphate released from phytic acid, sodium phytate and calcium phytate by the action of tested bacteria, *Pseudomonas* sp., *Bacillus megatherium* etc. were studied and after two weeks of incubation at 30°C, *Bacillus subtilis* was identified as the most efficient strain in P mineralisation.

Inorganic P solubilising microorganisms

Solubilisation of phosphates in pure culture

Solubilisation of inorganic P by microbes under pure culture conditions has been reported by several Russian workers (Menkina, 1950 and Muromtsev, 1958). Solubilisation of precipitated calcium phosphate in agar medium has been used as the initial criterion for isolation and enumeration of P solubilising (PS) microorganisms. (Sperber, 1958, Katznelson and Bose, 1959). Organisms growing on such media are also able to solubilise P and produce a clear zone around them due to the solubilisation of the fine particles of calcium phosphate.

Moreau (1959) observed that in a liquid medium containing TCP, the liberation of P was done mainly by bacteria and only by some fungi isolated from forest soils. Most strains liberated about 3-17 % and some strains solubilised as high as 20-40 % of the total P within about ten days.

A variation in the rate of P solubilisation with various inorganic P sources has been reported. However, Louw and Webley (1959) observed equal levels of solubilisation from tricalcium phosphate and hydroxy apatite in liquid media by PS organisms isolated from the rhizosphere of oat plants.

Goswami and Sen (1962) studied the solubilisation of TCP in liquid medium by *Bacillus megatherium* var. *phosphaticum*, and reported that maximum solubilisation of P under cultured conditions occurred within a week. *Pseudomonas* sp. isolated from Maharashtra soils could solubilise 13-58% of TCP in liquid medium. (Ostwal and Bhide, 1972).

Banik and Dey (1981) isolated species of *Bacillus*, *Streptomyces*, *Aspergillus* and *Penicillium* from laterite soils and observed that TCP was solubilised to the maximum extent followed by aluminium and iron phosphates. *Bacillis* were found most active followed by *Penicillium* and *Aspergillus* sp. Iron and aluminium phosphates also have been shown to be solubilised in liquid media, but levels of P released were less than that released from calcium phosphate.

Agnihotri (1970) studied the ability of fungi occurring in nursery seed beds to solubilise apatite and fluorapatite in solution culture. Khan and Bhatnagar (1977) observed that *Aspergillus niger* could solubilise P from rock phosphate mined from eight different sources.

The results of investigation on the periodic solubilisation of ferric and aluminium phosphates in liquid medium (Gaur and Gaind, 1983) showed

that maximum solubilisation of aluminium and iron phosphate by *Aspergillus awamori* was achieved on the tenth and eleventh days respectively. The maximum amount of P_2O_5 (%) released by *Pseudomonas striata*, from dicalcium, tricalcium, Al and Fe phosphates were 30.8, 58.4, 24.0 and 25.6 respectively.

Thomas *et al.* (1985) found that the PS fungi isolated from coconut plantation soils of Kerala belonged to the *Aspergillus* or *Penicillium* genera.

Narsian *et al.* (1993) studied the solubilisation of natural rock phosphate and pure insoluble inorganic phosphate by six strains of *Aspergillus awamori* and found that DCP is preferred by four strains and TCP by two strains.

Thakkar *et al.* (1993) reported that *Enterobacter aerogenes* was the most effective TCP and RP solubiliser which liberated 80.7 and 20.6 mg P_2O_5 respectively.

Singh and Kapoor (1994) isolated 27 species of bacteria capable of producing clear zones of solubilisation on TCP plates from the rhizosphere and non-rhizosphere soils under various crops in Hissar, India. These were screened for solubilisation of TCP and MRP. Increasing level of glucose in the medium from 1 to 2% led to an increase in the degree of solubilisation of both TCP and MRP. The effect of incubation period varied depending upon the isolates and some isolates showed maximum solubilisation of TCP in seven days while in others, it increased up to 15 days.

Narsian *et al.* (1994), isolated PS fungi from the rhizosphere of 24 plants from compost and garden soils using tricalcium phosphate in Pikovskaya's medium. From these, eight fungi with highest PS activity were selected and tested against the natural sources of P (P fertilisers), dicalcium phosphate, Al-P, Fe-P, rock phosphate P (four types) and bone meal. *Aspergillus aculaetus* was best in solubilising tricalcium phosphate (94 %) followed by dicalcium phosphate (54.5%) and Al-P (31.8 %). Iron phosphate was best solubilised (36.8%) by *Aspergillus niger* which also solubilised rock phosphate (56.6%) more effectively than bone meal.

Illmer and Schinner (1995) found that *Penicillium aurantiogriseum* and *Pseudomonas* species have high abilities in solubilising phosphate from hydroxy apatite and brushite.

Rock Phosphate solubilisation by PSM

In India out of 259.47 million tonnes of rock phosphate estimated to be available, (Jaggi, 1989) only 15.3 million tonnes are of high grade and useful for the manufacture of commercial P fertilizers. The balance is of low grade, and can be used as a direct and cheaper source of P fertilizer.Several RP dissolving microorganisms have been isolated and the research work done on the solubilisation of RP by PSM are reviewed here.

From studies on the solubility of rock phosphate in liquid medium with various mixed inoculants, Bromfield (1959) has shown that P

solubility was closely related to the magnitude of acidity produced in the medium.

On the other hand, Louw and Webley (1959) showed that many isolates which did not show any zone of solubilization on agar plates, released phosphate from rock phosphate which was inoculated in liquid medium. A similar observation was made by Ahmad and Jha (1968) also.

Meyer and Konig (1960) studied the effect of 24 strains of fungi and three strains of Streptomyces on the solubilisation of rock phosphate and reported that solubilisation of rock phosphate proceeds through the utilisation of small amounts of initial P available in the medium followed by the use of soluble P dissolved by organic acids secreted by the growing mycelia.

Ahmad and Jha (1968) published 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) tested the bacterial and fungal isolates obtained from rock phosphate mines for solubilisation or mineralisation of TCP, Mussorie, Jhamarkotra and Maton rock phosphate as well as organic phosphates and found that among the isolates, *Aspergillus carbonum* proved to be the best culture since it solubilised all the three types of phosphates tested.

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 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.

The solubilisation of ^{32}P tagged hydroxy apatite by *Pseudomonas striata*, *Bacillus polymyxa* and *Aspergillus awamori* was studied in liquid medium (Arora and Gaur 1978). They have found that the extent of P solubilisation increased progressively and reached a maximum in the sixth week of incubation.

The microbial solubilisation of rock phosphates of varying origin was investigated in liquid medium by Singh *et al.* (1984) and the results showed that *Pseudomonas striata* solubilised Jordan rock phosphate to a maximum extent followed by the rock phosphates of 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. Singal *et al.* (1994) have reported that *Aspergillus Japononicus* and *Aspergillus foetida* were able to solubilise five types of rock phosphates at pH 8 and 9.

Mechanism of P solubilisation

Sperber (1958) and Katznelson and Bose (1959) have reported that the P solubilising ability of PS organims is due to the excretion of organic acids which directly dissolved inorganic phosphatic materials or by chelation of the cationic partners of the P ion.

Analysis of culture filtrates of pure isolates of PS microorganisms by several scientists has revealed the presence of a number of organic acids like lactic, glycolic, citric, keto gluconic, malic, oxalic, malonic, tartaric and succinic acids. All these acids have chelating properties and serve as active components in promoting P solubilisation (Louw and Webley, 1959; Duff *et al.*, 1963; Taha *et al.*, 1969 and Banik and Dey, 1981).

Duff *et al.* (1963) observed that 2 - keto gluconic acid produced by several PS bacteria and fungi released several phosphates and silicates in solution.

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.

Moghimi and Tate (1978) have opined that upto 20 % of the root exudates released into the rhizosphere of a plant may be converted to keto gluconate by the PS organisms, the main function of 2 - keto gluconic acid being to serve as a source of H ions in the dissolution of calcium phosphate.

The quantity of organic acids produced by the PS organisms has been reported in some cases to be equal to more than 5 % of the carbohydrates consumed by them (Banik and Dey, 1982).

The capacity of PS organisms to produce effective chelating materials in a microenvironment such as in the immediate vicinity of rock phosphate or phosphatic materials or in the rhizosphere has been noted by Moghimi *et al.* (1978) and Tinker (1980). According to Kucey (1988), under these conditions, P could be solubilised and be present in an available form in concentrations sufficient to be plant available.

Penicillium bilaji has been reported (Asea *et al.*, 1988) to be able to release more soluble P from Idaho rock phosphate than that released by the additiona of 0.1 N HCl to achieve equivalent media pH levels.

In vitro evaluation of the cultures of *Bacillus, Psuedomonas, 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.

Kucey *et al.* (1989) were of the opinion that the ability of PS microorganisms appears to be manifested *via* mechanisms other than strict acidification of the surrounding environment. This view is supported by a lack of correlation between the ability to reduce media pH and ability of the isolates to solubilise P as observed by Chhonkar and Subba Rao (1967), Gaur *et al.* (1973) and Surange (1985).

Illmer and Schinner (1992) reported that no direct contact between the PS organisms and insoluble phosphate was necessary for effective solubilisation. The P concentration in a solution did not increase according to a sigmoid type curve suggesting that sampling time is of particular importance for estimating P mobilisation. They conceived the most probable reason for P solubilisation without acid production as the release of protons accompanying respiration or NH_4^+ assimilation by the concerned organisms.

Kumar and Dube (1993) studied the production of siderophores by a plant growth promoting fluorescent *Pseudomonas*. Siderophores are reported to be iron chelating compounds secreted by bacteria on or around the roots and affect the growth of the plants. The strain was isolated from the rhizoplane of tomato and it produced siderophores in succinate medium deficient in iron. They have reported that the study of siderophore production by RBT 13 is highly significant because this strain showed potentiality to enhance plant growth which was due to the siderophore production.

Illmer *et al.* (1995) have also stated that while *Aspergillus niger* produced citrate, oxalate and gluconate, the other species of PS microorganisms did not produce any organic acids in detectable amounts. This was considered as an indication of the lack of correlation between production of organic acids and solubilisation of aluminium phosphate. They re affirmed the view that proton excretion accompanying NH_4^+ assimilation is the most probable explanation for microbial solubilisation without acid production.

Role of PS organisms in increasing 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 the organisms increased the available P_2O_5.

Rangasamy and Morachan (1974) reported that application of phosphobacterin increased the available P content in soil. The P content in the crop was found to be highly influenced by phosphobacterin at all stages of growth.

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* species were added.

The level of Na HCO_3 extractable P in soil was found to increase after the addition of *Penicillium bilaji* both with and without rock phosphate (Kucey, 1988).

The use of P solubilising culture alone or in combination with phosphatic fertilizers in rice has been reported (Mohod *et al.*, 1989) to increase the root CEC and available P in soils and P uptake in rice.Use of P solubilising culture alone produced 1.3 times increase in the root CEC during the period from maximum tillering stage to maturity. The beneficial effects of P solublising organisms on these parameters were greater with rock phosphate than with single super phosphate. The culture increased the P release efficiency of rock phosphate and made it equivalent to single super phsophate with respect to avialable P status in soil.

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 thirty days of crop growth and declined after 120 days.

From the results of a laboratory experiment conducted to test whether phosphorus dissolving fungi are capable of increasing the amount of available P in a calcareous soil treated with rock phosphate or TSP and it's 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. Positive and significant correlation coefficients between available P, P uptake and dry matter production at different periods of growing season were observed following inoculation.

Patgiri and Bezhauruah (1990) have reported that out of the 46 strains of aerobic heterotrophic bacteria isolated from tea soils of Assam, *Bacillus* sp. and *Pseudomonas* sp. possesed significant P solubilising and phosphatase activity. Inoculation increased the available phosphorus content of soil during a 22 day period in the presence or absence of leaf litter or SSP.

Heggo and Barakah (1993) observed that the available P status in a calcareous soil increased significantly through the application of MRP and superphosphate in combination with P dissolving bacteria or VAM inoculants.

A very high level of available P was reported in the rhizosphere soil (Datta and Banik, 1994) when *Bacillus firmus* was applied along with poultry manure and Mussorie rock phosphate to rice in an acid sandy clay loam soil of Lembucherra, Tripura.

Effect of PS organisms on P uptake of crops

A number of reports are available to affirm that inoculation of PS organisms promoted P uptake of crops. Kavimandan and Gaur (1971) reported that inoculation of PDB increased P uptake and yield of maize. From a study conducted to evaluate the effect of seed treatment of bengal

gram with *Bacillus circulans* on P uptake, Subramaniam and Purushothaman (1974) reported that the crop absorbed more P after inoculation with *Bacillus circulans*.

The results of a pot experiment conducted by Osman (1975) indicated that P uptake in sudan grass was increased due to inoculation with P dissolving bacteria. They have also reported that combined inoculation and fertilization had the greatest effect, although inoculation decreased the proportion of plant P that was derived from the fertilizer.

Similarly, Gaur *et al.* (1980) reported on increase in growth and P uptake by wheat in response to addition of rock phosphate and PSM cultures consisting of *Pseudomanas striata* and *Aspergillus awamori*.

Asea *et al.* (1988) using ^{32}P isotope dilution method found that wheat when inoculated with *Penicillium bilaji* was able to obtain 18 per cent of its P from sources unavailable to the uninoculated plants and was also able to solubilise added rock phosphate.

Dry matter production and P uptake in wheat has been reported (Kucey, 1988) 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 dry matter production. Vaishya *et al.* (1996) have reported that the use of PSM along with RP for bengal gram in a vertisol resulted in a significantly higher P uptake.

Crop response to P Biofertilizers

Inoculation of seedlings with PS organisms resulting in increased uptake of P and crop yields was first shown in 1948 by Gerretsen in the USSR. Since then, the beneficial influence of artificial inoculation with PS organisms has been reported by many for different crops under diverse agro climatic conditions.

Response in cereals

Bajpai (1965), using radio active isotope ^{32}P conducted pot experiments to examine the effect of phosphobacterin and *Bacillus circulans* on the uptake of P from super phosphate and apatite by wheat and cowpea. The results showed that the percentage of P uptake by the wheat crop was significantly greater from super phosphate in the presence of FYM and ammonium suplhate. The results obtained with cowpea also showed that the bacteria were effective in augmenting P uptake from either source of phosphorus when the soil was amended with FYM. In the absence of FYM, *Bacillus circulans* was not found effective.

Taha *et al.* (1969) demonstrated that inoculating soil with phosphate dissolving microorganisms increased the P uptake and yield of wheat and broad beans grown in Egyptian soils. From the results of a green house experiment in barley, these authors have reported that inoculation with *Bacillus megatherium* increased plant weight, P uptake and P concentration in plant tissues.

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 bone meal. The same authors also conducted field trials with maize and concluded that phosphobacterin culture enhanced the efficiency of phosphatic fertilizers particularly super phosphate.

The response of rainfed sorghum to phosphobacterin with and without N and P was studied in TNAU, Coimbatore and Rangasamy (1972) has reported that phosphobacterin increased plant height, girth, root weight and uptake of P and K at all stages of growth of the crop.

Vinayak and Patil (1978) observed better root development in corn, cabbage, millet and oats and reported 33 % increase in yield of tomato due to combined inoculation phosphobacterin and *Azotobacter* sp.

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}.

Datta *et al.* (1982) conducted field experiments in acid soils of Nagaland cultivated to rice by using a super strain of *Bacillus firmus* (NCIM-2636) producing a phyto hormone Indole-3- acetic acid, in addition to its

high ability to solubilise insoluble inorganic phosphate. They have reported that the yield of rice in both years increased significantly due to bacterial inoculation. Similar yield increase and P uptake in the case of canola (Brassica napus. L), field beans and wheat have been reported by Kucey (1987) and Kucey and Leggette (1989).

The positive effect of P solubilising organisms (*Pseudomonas striata* and *Bacillus polymyxa*) on yield components, yield and N uptake by rice in laterite soil under field conditions was evaluated in Maharashtra during 1986. Based on the data Mohod *et al.* (1989) revealed that the use of P solubilising culture significantly increased the number of grains per panicle, weight of 1000 grains, grain weight per panicle, grain yield, straw yield and nitrogen uptake in rice and the beneficial effects were greater with rock phosphate than SSP.

From the studies at three sites in Manitoba, Canada,Chambers and Yeomans (1990) showed that inoculation with a P solublising organism (*Pencillium bilaji*) in absence of fertilization resulted in an increase of wheat grain yield of about 100 kg ha^{-1}.

Gaur (1990) conducted field trials with 'microphos' cultures in wheat during 1979-84. He has reported that the grain yield was significantly increased (3070 kg/ha) due to inoculation of seed with *Pseudomonas striata, Bacillus polymyxa and Aspergillus awamori* as compared to un inoculated

control (2650 kg/ha). The P uptake was also augmented due to the use of inoculants.

Gaur (1990) has summarised the response of wheat to carrier based *Pseudomonas striata* culture under field conditions and the results showed the favourable effect of the culture in augmenting yield. A great response of the crop to seed inoculation both with and without phosphatic fertilizers was also evident.

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 P fertilizers gave an average increase in yield of 76 kg wheat per hectare. However, yield response to *Penicillium bilaji* declined with the use of P fertilizer.

From the results of a green house study in Egypt during 1985-86, Saber and Kabesh (1990) reported that fertilizing lentil plants with increasing rates of rock phosphate in association with either sulphur or P biofertilizers increased dry weight and nutrient uptake. They found that both treatments mobilised the fixed phosphate in the soil to a form available to the lentil plants.

Rachewad *et al.* (1991) have reported that seed inoculation with *Bacillus polymyxa* and / or 75 kg P ha^{-1} increased the biomass production

and P content in maize grown in a P deficient soil compared to the untreated control.

Rathore *et al.* (1992) conducted field trials during 1985-86 using lentils inoculated with *Bacillus megatherium* and reported that seed inoculation significantly increased yield over the uninoculated control.

Datta *et al.* (1992) studied the effect of *Bacillus firmus* on rice in Tripura during 1989-90 and concluded that *B. firmus* in combination with MRP and poultry manure served as an excellant biofertilizer superior to SSP in acid soils. Similar results in rice have been reported by Datta and Banik (1994) also.

Sushama *et al.* (1993) used different sources of P such as SSP, MRP, partially acidulated RP and MRP along with PS fungi in rice and reported that the grain yield was highest with MRP and fungi when applied in conjunction with green manure or FYM. The fertilizer use efficiency was highest for the combination of MRP and fungi with green manure indicating that MRP is a better alternative to other expensive WSP source for use in coastal laterites.

Goos *et al.* (1994) have reported that in the absence of P fertilization, *Penicillium bilaji* inoculation increased the grain yield in spring wheat by an average of 66 kg ha^{-1}.

Hegde and Dwivedi (1994) reviewed the field studies carried out under ICAR during 1969 - 71 and reported significant effect of inoculation with *Bacillus megatherium* and *Bacillus circulans* in rice and wheat which was equivalent to the yield increase obtained with the use of 50 kg P_2O_5 ha^{-1}.

From field experiments with soybean in a Vertisol, Dubey (1996) has reported that total dry matter, P content in different plant parts at various stages and yield increased with the use of *Pseudomonas striata* either alone or in conjunction with SSP and MRP.

Response in pulses

Kabesh (1957) reported that P uptake was significantly increased by inoculation with PDB and P fertilization either singly or in combination. Application of PDB, SSP or basic slag alone increased P uptake (%) by 14.3, 19.1 and 6.7 over the control treatment while the combined application of PDB and P fertilizers raised P uptake by 44.1%.

Bajpai and Sundara Rao (1971) conducted pot culture experiments in cow pea using SSP and apatite with and without FYM using *Bacillus* sp. It was seen that under specific conditions, these organisms increased crop yield, P as well as nitrogen uptake. This finding was further supported from the data in a field trial on a soil with low available P status.

Yousry *et al.* (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. Inoculation of fava bean with *Bacillus megatherium* var. *phosphaticum* was reported by Khalafallah *et al.* (1982) to have resulted in increased plant weight, P uptake and P concentration.

In a pot experiment to study the effect of PS fungi on the availability of P from RP on the growth of chick pea, Rasal *et al.* (1988) noticed that inoculation with *Aspergillus awamori* increased the availability of P in soil leading to a significant improvement in nodulation.

Dubey and Billore (1992) reported that microbial inoculation and fertilisation of P and their interaction significantly influenced grain and straw yield of chickpea. Favourable effect of *P. striata* on chickpea has been reported by Prabhakar and Saraf (1990) and Kumar *et al.* (1993). Inoculation with P solubilising bacteria alone as well as with either rhizobia or VAM in sub tropical acid soils of China increased peanut yield to 20 - 73% as evident from field trials conducted by Chiu-Chung-Young (1994).

Podile (1995) reported the effect of seed bacterisation of pigeon pea with *Bacillus subtilis* in enhancing the percentage emergence of seedlings.

Srivasthava and Ahlawat (1995) have also confirmed that seed inoculation with rhizobium or PSB alone or in combination resulted in a

conspicuous increase in nodulation, nitrogenase activity, growth, yield, and nutrient uptake by cowpea over uninoculated control.

Viswambaran (1995) has reported that the use of 100% P as RP along with VAM and PB resulted in the highest available P content in cowpea (var. C-152) in a redloam soil and the combined application of VAM and PB was found to be better than the individual application of either VAM or PB.

Response in other crops

Several crops have been reported to show positive response to the use of PB organisms alone and in combination with VAM.

Increase in crop yield of tomato due to inoculation with phosphobacterin has been reported by Rao and Sinha (1963). Kundu and Gaur (1980) stated that the combined inoculation of *Bacillus polymyxa* and *Pseudomonas striata* on potato increased the yield upto 35.2 % and P uptake over individual inoculation.

Chang and Young (1994) showed that incoulation of tea cuttings with P solubilising bacteria or VAM resulted in an enhanced growth of seedlings.

The response of biofertilizers to forage and fodder crops was studied by Hazra (1994) and he reported that phosphobacterised seeds produced

31% yield increase in oats. In another study he observed that seeds coated with *Bacillus polymyxa* gave higher forage yield than non bacterised seeds.

Huggag *et al.* (1994) have conducted pot experiments to study the P content and dry matter of Guava seedlings inoculated with Phosphorine and reported an increased P uptake and dry matter compared to un inoculated seedlings. Phosphorin culture was found to be more effective in increasing available P supply to seedlings.

From the results of a field experiment with sugarcane a sandy loam soil with high available P in Tamil Nadu, Kathiresan *et al.* (1995) have reported that soil inoculation with phosphobacterin (10 kg/ha) increased cane yield and it's quality. 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.

Role of P in the nutrition of banana

A review of the research work conducted in the KAU reveals that although much work has been done on rock phosphate fertilisation of rice and other vegetable crops, systematic studies on increasing the efficiency of this fertilizer for banana cv. Nendran has not so far been undertaken.

There is a general agreement among the scientists that when used in combination with readily decomposable organic residues, rock phosphate increases the yield of crops much more than rockphosphate alone.

Pillai *et al.* (1977) in an experiment to study the response of banana cv. Nendran to different levels of N, P and K have reported that the effect due to P was positive upto 114 g plant on the number of fruits and it showed a declining trend beyond that level.

According to Shankar (1980), the bunch weight in banana was influenced significantly by N and P application.

Mathew (1980) has observed that the uptake of P by banana cv. Palayankodan was high both at shooting and harvest stages and the uptake of P increased with the advancement of growth of plants. He has also reported that as in the case of N, P uptake was more in the vegetative phase of the crop and its content was more prominent in the lamina.

Sheela (1982) in a study on rainfed banana cv. Palayankodan has reported that the uptake of P continued to increase through out the crop growth and the maximum uptake of P was recorded during the period between late vegetative phase and shooting. It was also observed that the content of P was maximum in the lamina at early and late vegetative phase and also at shooting.

Chathopadhyay and Bose (1986) coducted studies with banana cv. Giant Governor, with 0, 120 and 240 g N; 0, 45 and 90 g P and 0, 240 and 480 g K plant^{-1} and reported that application of these nutrients significantly increased the plant height, girth, leaf number and sucker production.

From studies on the nutritional requirement of banana (Nendran) under rice fallows Geetha (1988) has concluded that a treatment combination of 400 g N, 100 g P_2O_5 and 600 g K_2O plant^{-1} applied in six equal splits gave the best yield and maximum net profit.

Natesh (1987) studied the effect of split application of fertilizers in banana cv. Nendran and reported maximum bunch weight of 11.13 kg for plants treated with 140 kg P_2O_5 plant^{-1} in two splits.

From studies conducted at the College of Agriculture, Vellayani (KAU Research Reports, 1987-1990) using Mussoorie and Rajasthan rock phosphates in comparison with superphosphate for different crops, no significant difference between different sources of phosphorus has been observed indicating that these indigenous rockphosphates can substitute superphosphate as a source of phsophorus.

Ray *et al.* (1988) reported that increased levels of P reflected in an increased content of P in leaves and a leaf content of 0.52% P at shooting was considered as a good indication for good productivity.

Sheeja (1990) has reported that when different phosphatic fertilizers were applied to banana, there was no significant variation in the uptake of phsophorus and the effect of superphosphate and rockphosphate were on par.

Lin and Fox (1992) studied the agronomic effectiveness of three rock phosphates (Idaho, Florida and North Carolina) as influenced by mycorrhizal inoculation with *Glomas aggregatum* using small banana (*Musa paradiciaca*. L.) and found that plant dry weight, P% in the third leaf and total P uptake were increased in the plants fertilized with insoluble RP and inoculated with mycorrhizae fungi.

Prema (1992) observed that at the time of shooting and harvest, the P% in leaf was found positively correlated with vegetative characters. At the time of shooting, a positive correlation was obeserved between available P and P content of leaf. She has also reported that there was a positive correlation between available P and height of plants at the time of harvest.

P content in leaf

Ashok kumar (1977) reported that thr leaf concentration of P at shooting ranged from 0.11 - 0.37% in Robusta banana. Ramirez *et al.* (1978) analysed the first and third leaf of Dwarf Cavendish banana at various stages of growth viz., before flowering and at bunch formation and found that the concentration of P was lower in the third leaf than in the first leaf and was occasionally below 0.19 %.

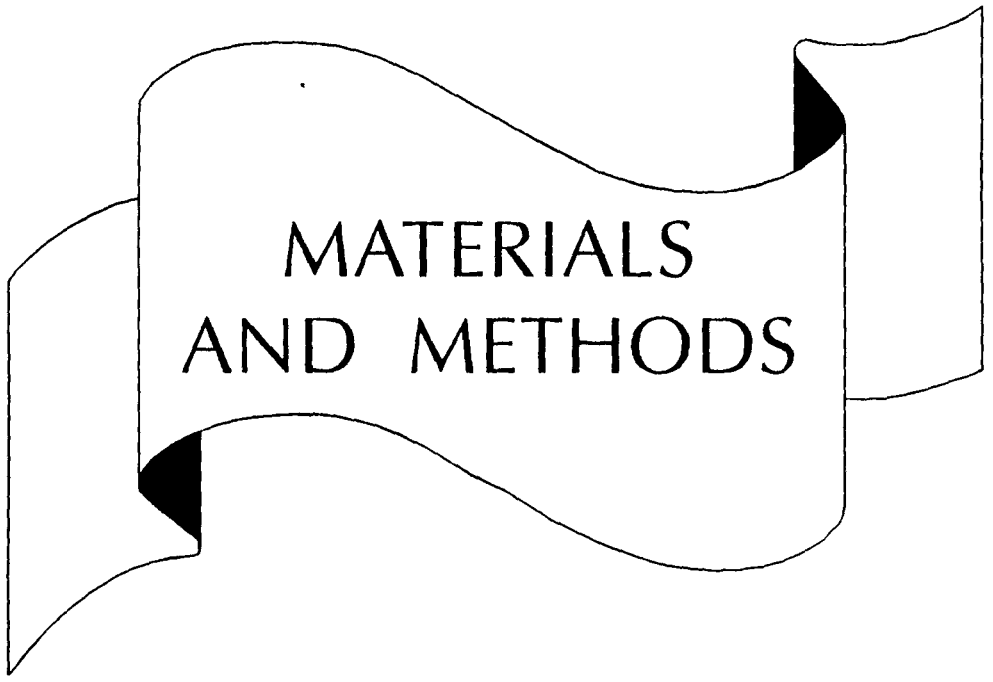
Bala krishnan (1980) reported that the distribution pattern of P in different parts of the plant was similar over different sites in Robusta banana.

At all stages, leaves and pseudostem contained substantial amount of P, while at vegetative phase, corm contained maximum P.

Krishnan and Shanmughavelu (1980) in a study on the water requirement of banana, analysed leaf nutrient concentration and total uptake of nutrients and observed that the critical leaf concentration of N, P and K ranged at shooting from 2.32 - 2.44, 0.22 - 0.25 and 3.97 - 4.19% respectively.

Mathew (1980) observed that P content in the third leaf at shooting ranged from 0.14 - 0.17 % in palayankodan. Turner (1980) suggested that the flowering stage is the best for sampling in leaf anlysis.

The petiole, midrib and lamina of fully opened leaf in position III of banana has been adopted as the International Standard for testing mineral elements in non flowering banana and banana in flower (Prevel, 1986).


MATERIALS
AND METHODS

MATERIALS AND METHODS

Increasing phosphorus use efficiency in banana by the use of phosphobacterin (PB) culture was evaluated by conducting a laboratory incubation study and a field experiment at the Farming System Research Station, Kottarakkara during the period 1993-96. The materials used and the methods followed for the studies are described in this chapter.

Incubation study

The effect of PB inoculation on the solubilisation of phosphorus from Mussorie rock phosphate (MRP) and the maintenance of available P status in soil was monitored by carrying out an incubation study using five kg soil from the experimental field of the FSRS, Kottarakkara. Details of the experiment are given below:

Design : Completely Randomised Design

Treatments : 7

Replications : 3

Treatments	Notation
Soil alone	T_1
Soil + MRP to get 100 ppm P	T_2
Soil + PB in (4 g pot^{-1})	T_3
Soil + FYM (50g pot^{-1})	T_4
Soil + MRP + PB	T_5
Soil + MRP + FYM + PB	T_6
Soil + MRP + FYM	T_7

The soil after thoroughly mixing with the different materials was incubated in plastic containers at a moisture content of 60 % water holding capacity for a continuous period of 90 days.

Chemical analysis of soil

Soil samples were collected for analysis from the incubated soil after 3, 6, 8, 10, 15, 20, 25, 30, 45, 60, 75 and 90 days. The moisture content, pH and available P content of the samples were estimated.

Moisture content

To estimate the moisture content, 5 g soil sample was taken in a previously weighed porcelein dish and dried in an electric oven at 105°C, cooled and weighed. The loss in weight was calculated as the percentage of moisture of the sample.

pH

pH of the sample was measured in the freshly collected soil samples using a pH meter (1 : 2.5 soil- water ratio)

Available phosphorus

The weight of soil to be taken for analysis at each interval was determined based on its moisture status. Available P was extracted with Bray No. 1 reagent (Jackson, 1973) and the blue colour developed in HCl system was measured in a photoelectric colorimeter and P content calculated.

Field experiment

Experiment site and soil

The field experiment was laid out in Area II of the FSRS, Kottarakkara. Geographically the area is situated at 9° 16' North latitude and 76° 37' East longitude and at an altitude of 91.44 M above MSL.

Soil

Soil of the experiment site belongs to the taxonomical class Plinthic Kandiustult. On fertility basis it was high in organic carbon, medium in available N and low in available P and K. The soil reaction was acidic and the electrical conductivity of the soil solution was within safe limits. The important physico-chemical properties of the soil are presented below

Table 1. Physio-chemical properties of soil

Physical properties

1.	Apparent specific gravity	-	1.00 g^{-cm3}
2.	Absolute specific gravity	-	1.89 g^{-cm3}
3.	Maximum water holding capacity	-	43.7%
4.	Pore space	-	47.7%
5.	Mechanical analysis		
	Coarse sand	-	42.00 %
	Fine sand	-	9.50 %
	Silt	-	13.00 %
	Clay	-	35.35 %

Chemical properties

1.	pH (water)	-	5.7
2.	EC	-	0.04 $dS/^{-m2}$
3.	Organic carbon	-	0.91%
4.	CEC	-	3.9 C mol^{-kg}
5.	Total N	-	0.052%
6.	Total P	-	0.052%
7.	Total K	-	0.180%
8.	Available N	-	280 kg ha^{-1}
9.	Available P	-	6.21 kg ha^{-1}
10.	Available K	-	71.68kg ha^{-1}
11.	Exchangeable bases	-	$(me^{-100}g$ soil)
	K	-	0.007
	Na	-	0.060
	Ca	-	0.125
	Mg	-	0.018
12.	Percent Base Saturation	-	5.27
13.	P fixing capacity	-	47.87%
14.	Total sesqui oxides	-	27.5%

Lay out of the experiment

Design - Randomised Block Design

Treatments - 9

Replication - 3

Variety - Banana cv. Nendran

Plot size - Pits of size 50 x 50 x 50 cm at a spacing of 2 x 2 m

No. of plants per / plot - 10

Treatments	Notation
NPK to supply 190 g N + 115 g P_2O_5 + 300 g K_2O + FYM + mulch (POP recommendation)	T_1
NPK to supply 190 g N + 3/4 P + 300 g K_2O + FYM + mulch	T_2
NPK to supply 190 g N + 1/2 P + 300 g K_2O + FYM + mulch	T_3
NPK to supply 190 g N + 3/4 P + 300 g K_2O + Phosphobacterin + FYM + mulch	T_4

Treatments	Notation
NPK to supply 190 g N + 1/2 P + 300 g K_2O + Phosphobacterin + FYM + mulch	T_5
NPK to supply 190 g N + 3/4 P + 300 g K_2O + Phosphobacterin + mulch	T_6
NPK to supply 190 g N + 1/2 P + 300 g K_2O + Phosphobacterin + mulch	T_7
NPK to supply 190 g N + 3/4 P + 300 g K_2O + Phosphobacterin + FYM	T_8
NPK to supply 190 g N + 1/2 P + 300 g K_2O + Phosphobacterin + FYM	T_9

The layout plan of the experiment is presented in fig. 1.

Weather parameters

The major weather parameters during the season were monitored (Fig. 2 and Appendix 1).

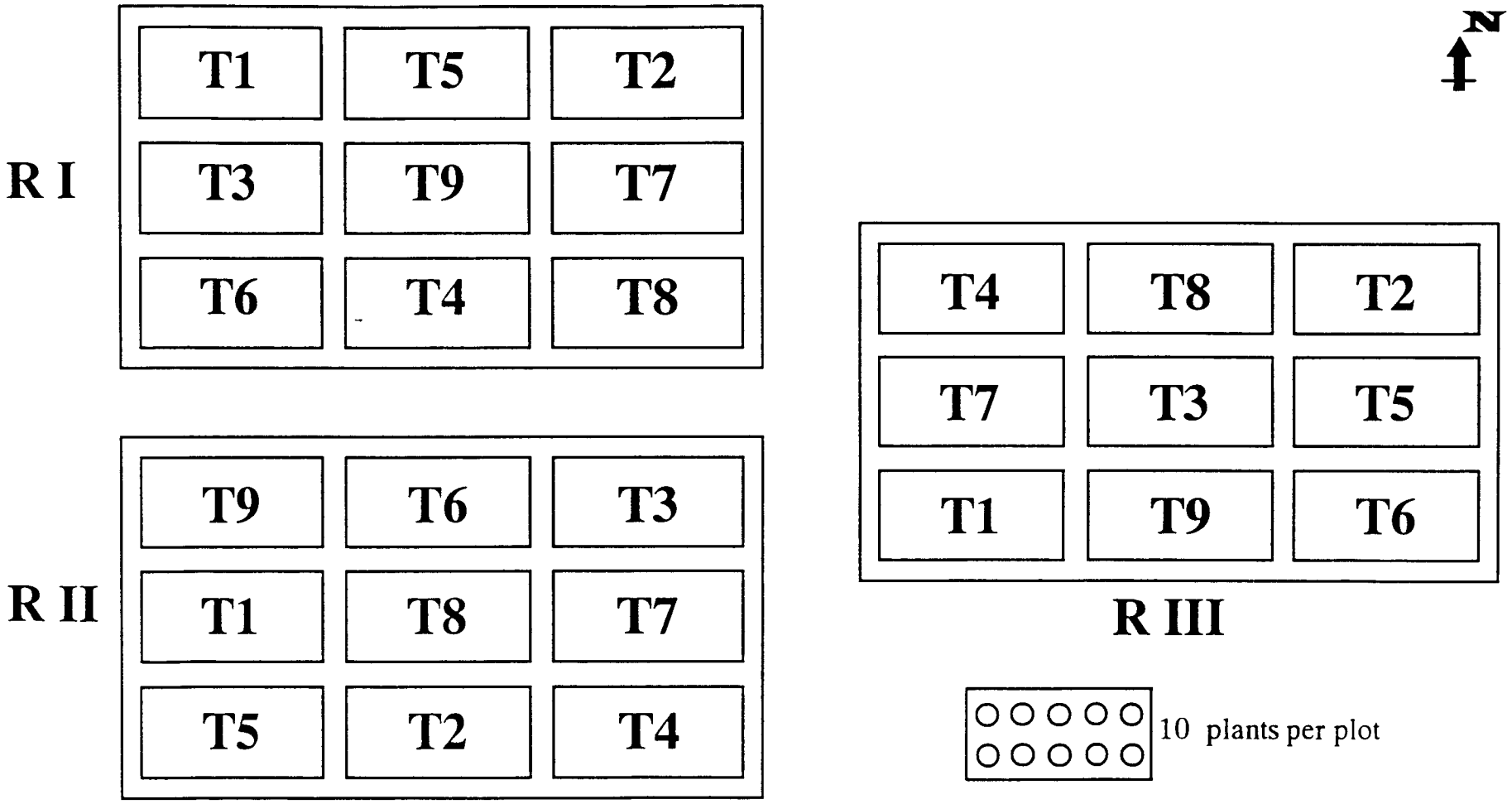


Fig. 1. Layout plan of the experiment

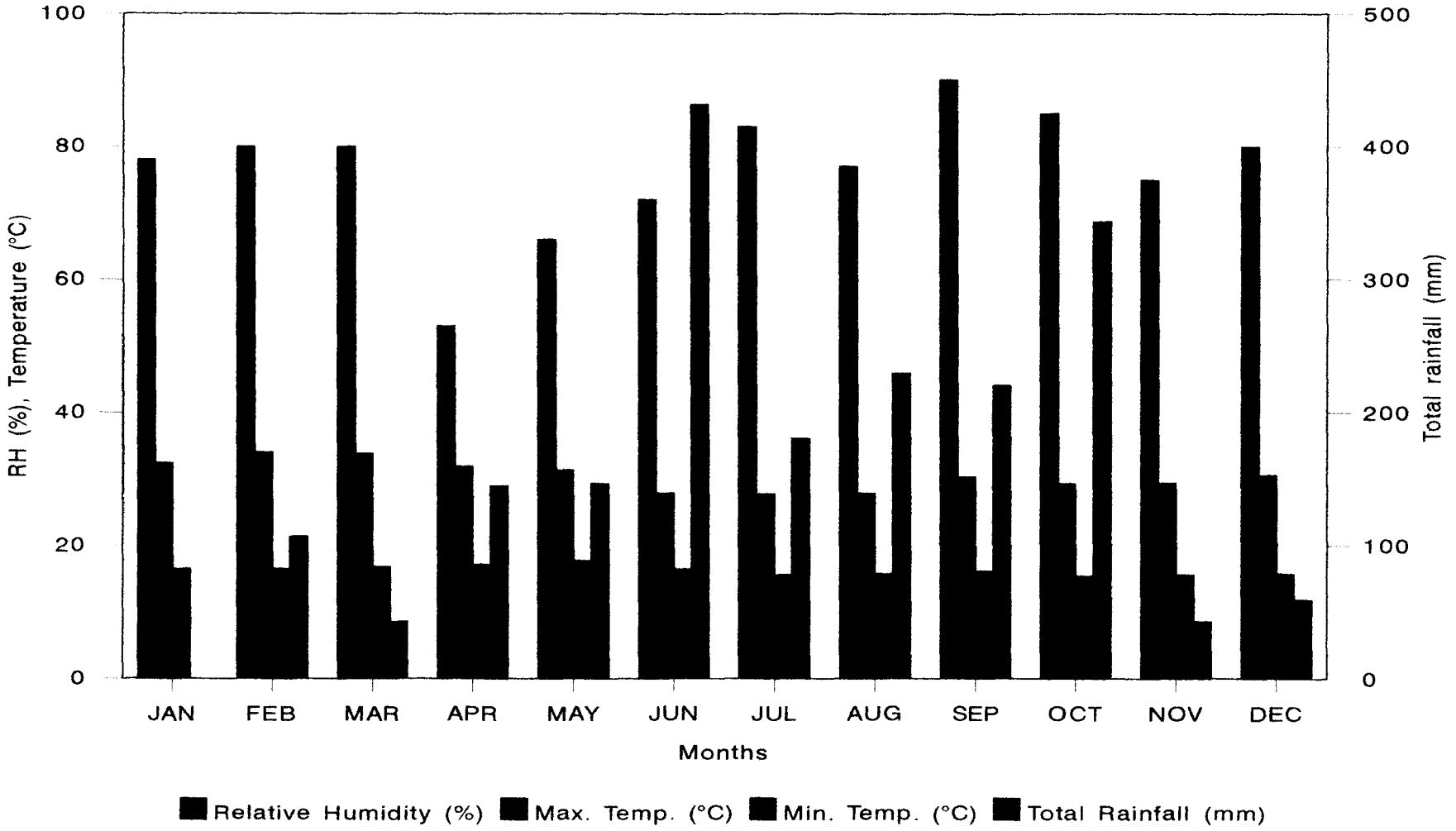


Fig. 2. Main meteorological parameters during the cropping season (January 1994 to December 1994)

Maximum temperature	-	27.8 to 34.0°C
Minimum temperature	-	15.4 to 17.7°C
Relative humidity	-	53 - 90 %
Total rainfall	-	0 - 432 mm

Season

The period of crop growth was from January 1994 to November 1994.

Planting materials

Three months old, disease free suckers obtained from farmers field at Kottarakkara were selected for planting. The rhizomes were dipped in cow dung slurry, smeared with 0.2% HCH and wood ash, dried in the sun for four days and stored for 15 days in shade before planting.

Planting

The rhizomes were planted in pits of 50 x 50 x 50 cm at a spacing of 2 x 2 m during January 1994.

Liming

Burnt lime @ 500 g plant^{-1} was applied in the pits two weeks before the application of fertilizers.

Fertilizer application

Nitrogen was applied as Urea (45 % N), Phosphorus applied as Mussorie rock phosphate analysing 0.059% citrate soluble P_2O_5 and 20.1% total P_2O_5 and potassium as Muriate of Potash(60 % K_2O). FYM analysing 0.5% N, 0.3% P_2O_5 and 0.5% K_2O was applied @ 10 kg plant^{-1} . The levels of N and K were kept constant for all treatments. 190 g N plant^{-1} was applied in six equal splits, first as basal and the remaining at one, two, four, five and six months after planting. 300 g K_2O plant^{-1} was also applied in five equal splits, first as basal and rest at one, two, four, and five months after planting. Phosphorus was applied in two splits only; first as basal and second one month after planting.

Phosphobacterin

Phosphobacterin culture consisting of a mixture of bacteria (*Pseudomonas* and *Bacillus* sp.) and fungi (*Aspergillus* sp.) purchased from the microbiology department of the TNAU, Madurai campus was used @ 40 g plant^{-1}.

Application of phosphobacterin

The required weight of phosphobacterin for a plant was mixed with equal quantity of river sand and applied uniformly in the pits two weeks after the basal application of fertilizers.

Mulching

Coconut husk was used as the mulch. Husks of five coconuts were packed with their concave surface downwards around the plants in each pit.

Maintenance of the crop

Ten plants were maintained in each plot.

Irrigation

Irrigation was given at weekly intervals @ 20 litres water plant^{-1} upto third month and 40 litres plant^{-1} up to harvest.

Weeding

Hand weeding was resorted to as and when required.

Plant protection measures

Phorate (10% G) was applied uniformly to all plants @ 25 g plant^{-1} 20 DAP in the soil and 12.5 g each 75 and 165 DAP in the leaf axils as a prophylactic measure against the bunchy top insect vector, *Pentalonia nigronervosa*. A spray of Indofil M-45 was given to all plants for controlling the yellow spot disease.

Incidence of Pests and diseases

No serious problem was noticed.

Observations on plant characters

Observation on vegetative characters such as height of plant, girth of pseudostem, total number of leaves, leaf area index and total dry matter content were made by destructive sampling of individual plants at three stages as shown below:

Three months after planting - Vegetative stage

Six months after planting - Shooting / flowering stage

Nine months after planting - Harvest stage

Growth characters

The growth characters of the crop were recorded as detailed below:

Height of plant

Height of the plant was measured from the base of the pseudostem at the soil level to the axil of the youngest un opened leaf at vegetative, shooting and harvest stages.

Girth of pseudostem

Girth of the pseudostem at the soil level and at 20 and 100 cm above the soil level was measured using a flexible measuring tape at vegetative, shooting and harvest stages.

Number of leaves plant^{-1}

The total number of functional leaves per plant was recorded at the three stages mentioned above.

Leaf area index

Leaf area index was computed from the values of the total leaf area of the plant and the geographical area occupied by it using the formula

$$LAI = \frac{\text{Total leaf area of the plant}}{\text{Geographical area occupied by the plant}}$$

The leaf area of the functional leaves was calculated adopting the formula proposed by Murray (1960).

$$\text{Leaf area} = L \times B \times 0.8 \quad \text{(a constant)}$$

where L = Length of lamina

B = Width of lamina

The length of lamina was measured from the base of leaf to the tip and the width at the broadest point of the leaf in the middle region. The sum of the area of all the functional leaves in a plant was then calculated. These observations were recorded at all the three stages.

Total dry matter

Determination of dry matter content of each part of the banana plant uprooted for destructive sampling was made according to the methods suggested by Piper (1967). The uprooted plant was separated into lamina, petiole, midrib, pseudostem and rhizome with roots and fresh weight of each was recorded. The flower at shooting stage and fruit at the harvest stage were also included in sampling. 500 g of fresh sample from each plant part was washed, air dried and then oven dried at 65 to 70°C to constant weight for calculating the moisture content. Using the values for per centage moisture and fresh weight of each part, total dry matter content was computed.

Yield and yield attributes

Bunch characters

The following characters of the bunch contributing to yield were recorded immediately after harvest of the fully matured bunch. The disappearance of ridges followed by rounding of the fruit angles was taken as the indication of maturity (Stover and Simmonds, 1987).

Weight of bunch

The weight of bunch including the peduncle was recorded.

Number of hands per bunch

The number of hands in a bunch for each treatment was counted.

Length of bunch

Length of bunch was measured from the point of attachment of the first hand to that of the last hand.

Weight of hand (kg)

Each hand on a bunch was detached and weighed separately. The mean value of the weight of different hands on a bunch was calculated and recorded as the weight of a hand for each treatment.

Distance between hands in a bunch

The distance between adjacent hands in a bunch was recorded and the mean value calculated for a bunch.

Number of fingers per bunch

The total number of fingers in a bunch was counted.

Finger characters

Following characters of the middle finger in the top row of the second hand, designated by Gottriech *et al.* (1964) as the index finger were recorded.

Length of finger

The length of finger was measured from the top of the finger to the point of attachment to the peduncle.

Girth of finger

The girth of finger was measured at the mid portion of the finger.

Weight of finger

The weight of finger was determined after detaching it from the peduncle.

Harvest index

Harvest Index was calculated using the formula

$$HI = \frac{\text{Total economic yield}}{\text{Total biological yield}}$$

Fullness index

Fullness index was calculated as the ratio of the weight of finger to its convex length (Stover and Simmonds, 1987).

Chemical analysis of plant parts and fruits

The individual plant parts such as the lamina, petiole, midrib, pseudostem, rhizome flower and fruit collected at the respective stages of sampling were finely chopped, air dried and then oven dried at a temperature of 65 to 70°C in a hot air oven. The dried material was powdered uniformly and stored in air tight containers for chemical analysis.

Phosphorus

Tri acid extract of the samples(Piper, 1967) was taken and P estimated colorimetrically following the procedure outlined by Jackson (1973).

Protein

The protein content of the fruits was calculated by multiplying the estimated nitrogen (Kjeldahl method) with the factor 6.25.

Phosphorus uptake

Uptake of P was calculated by multiplying the total dry matter of the respective plant part with its P content.

Analysis of ripe fruits

Quality of fruits

The ripe fruits after removing the skin were made into a pulp in a homogeniser, filtered and made up to known volume. Aliquots from this were used for the analysis of the following characters as detailed below.

	Method adopted	Reference
Total soluble solids	Direct reading using hand refractometer	Ranganna (1977)
Titrable acidity	Titration against 0.1 N Na OH	Ranganna (1977)
Reducing sugars	Copper reduction method using Fehling's solution	Chopra and Kanwar (1976)
Total sugars	Copper reduction method using Fehling's solution after HCl digestion	Chopra and Kanwar (1976)

Non reducing sugars

This was computed using the values for total and reducing sugars adopting the formula,

Non reducing sugars = (Total sugar – reducing sugars) x 0.95

Sugar-acid ratio

Sugar-acid ratio was determined by dividing the value of total sugar by the value for acidity of the corresponding sample.

Indexing of plant part

For indexing the best plant part or reflect in banana for P, the third leaf was collected (Hewitt, 1955) at monthly intervals from the third month onwards upto harvest and separated into petiole, lamina and midrib portion as given below (Prevel *et al.*, 1986) (Fig. 3).

Petiole - distal half portion

Midrib - Five cm long piece of midrib exactly half way along the leaf

Lamina - Five cm wide strip across the leaf on either side of the midrib sample

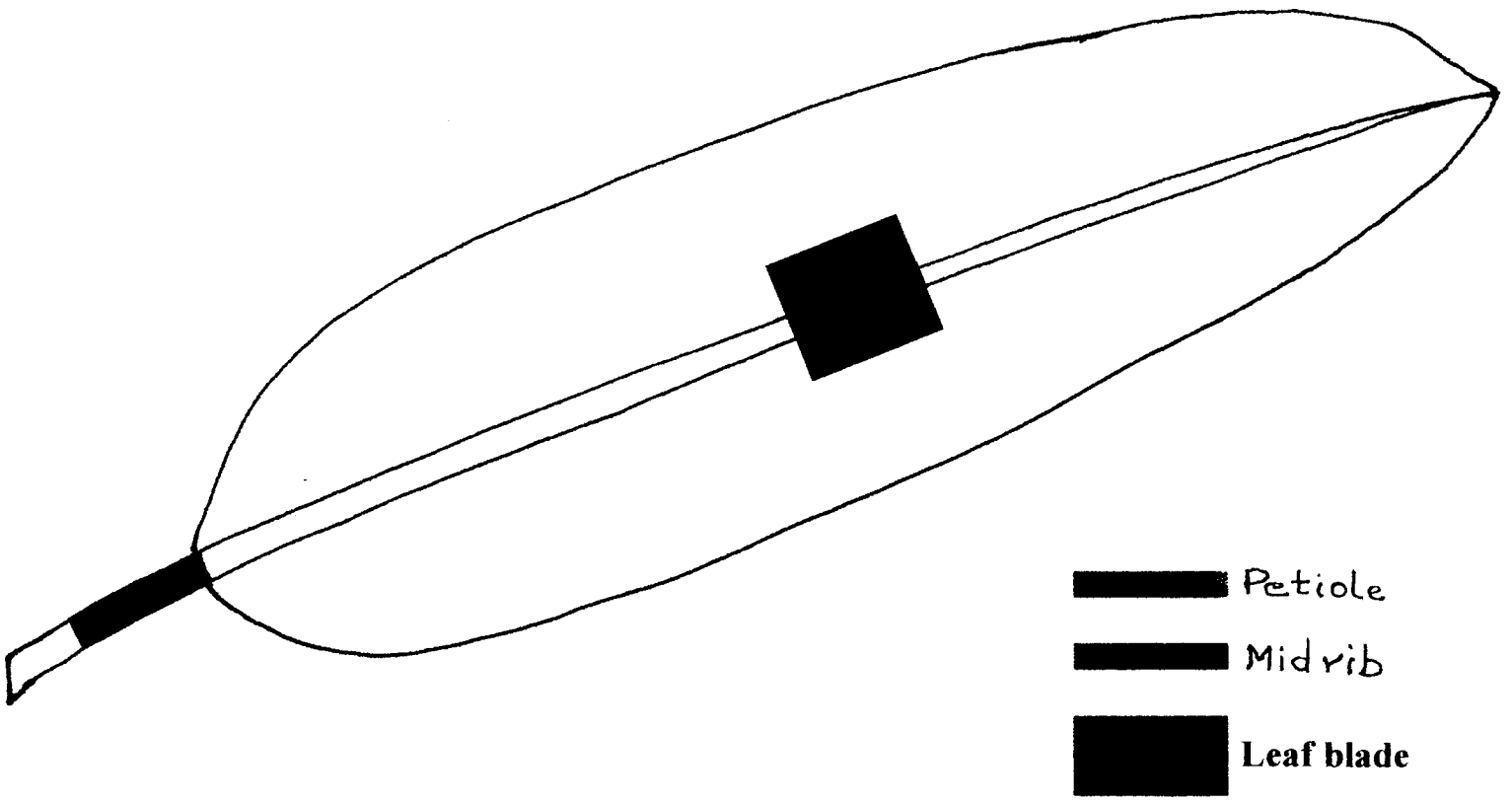


Fig. 3. Selection of sections of third leaf for indexing P status in banana cv. Nendran

The samples were dried at 65 to 70°C, powdered and analysed for P content as described earlier.

Soil analysis

Soil samples were collected from the pits at the three growth stages on the day previous to the application of fertilizers. Four points around the plants within a lateral distance of 0 - 30 cm were located and soil was collected from a depth of 0 - 30 cm (Mohan and Madhava Rao, 1985). The composite sample drawn from each pit was air dried, powdered, sieved through a 2 mm sieve and analysed for pH and available P content following standard procedures (Jackson, 1973).

Statistical analysis

The data generated from the laboratory incubation study and field experiment was subjected to statistical analysis by applying the technique of analysis of variance using RBD for field experiment and CRD for incubation study (Panse and Sukhatme, 1967). Pooled analysis was conducted for P content, P uptake and dry matter content of the different plant parts.

Correlation studies

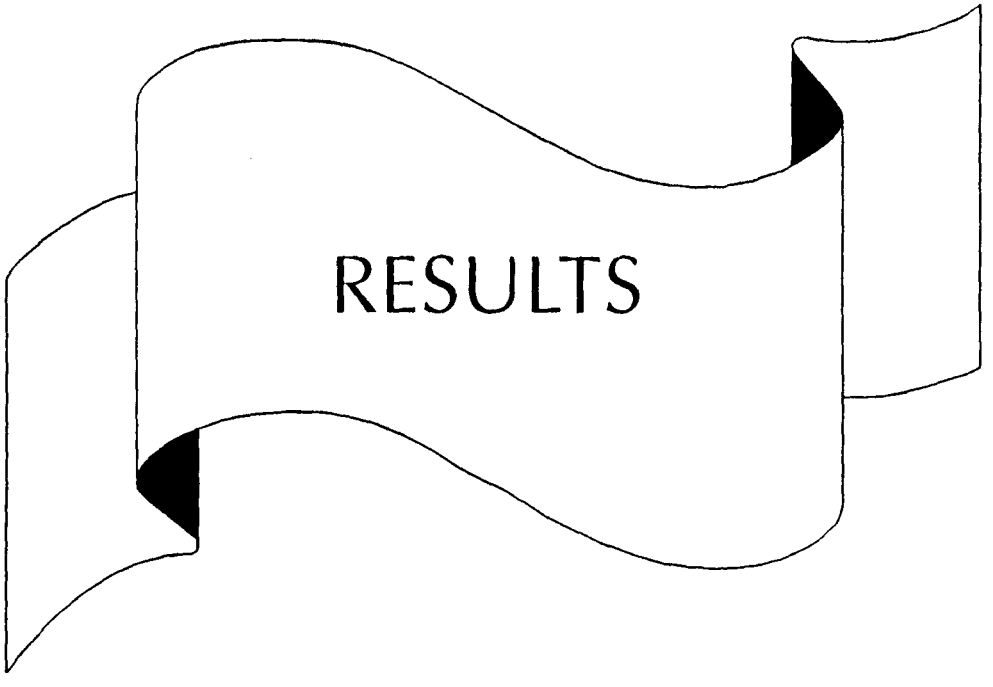
Simple linear correlations were worked out (Snedecor and Cochran, 1967) to study the relationship between vegetative characters at different stages, soil available P status and yield attributes and yield of banana.

Multiple regression analysis

Multiple regression relationship between various factors and yield were also worked out.

Path coefficient analysis

Path analysis was conducted to study the direct and indirect effects of vegetative characters and yield parameters with yield (Singh and Choudhary, 1985).


RESULTS

RESULTS

The efficiency of phosphobacterin cultures to increase the solubility of phosphorus from rock phosphate and maintaining a high status of available P in soil was evaluated by carrying out an incubation study in the laboratory. The resultant effect on the growth and yield of banana was assessed by conducting a field experiment at Farming Systems Research Station, Kottarakkara. The results of these two experiments are presented in this chapter.

Incubation study

The pH and available P status of the differently treated soil samples incubated in the laboratory for a period of ninety days are presented in tables 2 and 3 and Fig. 4.

Soil pH

The results presented in table 2 reveal that there existed only a non significant variation between the pH values of soils treated with different inputs. The untreated soil recorded the lowest pH (5.5) which however was not significantly different from the pH of the soils in other treatments.

Table 2. Incubation study - Soil pH at different periods

Treatments	Period (days)													
	0	3	6	8	10	15	20	25	30	45	60	75	90	Mean
T_1	5.7	5.6	5.8	5.8	5.7	5.5	5.7	5.2	5.2	5.4	5.1	5.3	5.3	5.5
T_2	5.6	5.7	5.6	5.8	6.1	5.7	5.4	5.4	5.9	5.3	5.2	5.3	5.3	5.6
T_3	5.6	5.8	5.8	5.9	6.1	5.9	5.8	5.5	5.1	5.8	5.7	5.5	5.8	5.7
T_4	5.7	5.4	5.8	5.6	5.8	5.6	6.0	6.0	6.0	6.1	6.1	6.1	5.9	5.9
T_5	5.7	5.5	5.5	5.6	5.6	5.0	5.7	5.8	6.0	5.3	5.3	5.3	5.4	5.6
T_6	5.8	5.4	5.7	5.2	5.3	5.8	6.0	6.0	6.1	6.0	6.1	5.9	5.8	5.7
T_7	5.6	5.9	5.7	5.7	5.7	5.7	5.7	5.9	5.5	5.4	5.6	5.5	5.6	5.6
Mean	5.7	5.6	5.7	5.7	5.8	5.7	5.8	5.7	5.7	5.6	5.6	5.6	5.6	

	T	P	TP
F	2.28^{ns}	7.66**	1.195**
SE	0.189	0.066	0.176
CD	—	0.185	0.489

** Significant at 1% level ns not significant T Treatments
P Period TP Treatment x Period

After 20 days, the values became lesser in most of the treatments indicating a tendency for the soil to become slightly acidic with progressive incubation. The interaction between treatments and period of incubation on changes in pH was significant. The pH values in the treatments ranged between 5.1 to 6.1 with a mean of 5.5 to 5.9.

Available Phosphorus

The data as seen from table 3 reveal that the status of available P in the soil showed a significant increase due to the effect of treatments as well as with increasing periods of incubation. The mean values indicated that maximum amount of available P (12.54 ppm) was extracted from soil receiving treatment T_6, where a combination of MRP, FYM and PB was used. This was followed by T_5 where, though inoculated with PB, no FYM was applied.

All the other treatments maintained significantly higher values for available P compared to the untreated soil.

The quantity of available P in soil due to the different treatments progressively increased with increasing period of incubation and reached a maximum value of 19.31 ppm in T_6 on the 90th day. This was closely followed by T_5 (15.73 ppm) and T_7 (14.56 ppm) which, though significantly lower than T_6, was higher than the other treatments including the control.

Table 3. Incubation study - Available P (ppm) in soil at different periods

Treatments	Period (days)													
	0	3	6	8	10	15	20	25	30	45	60	75	90	Mean
T_1	2.48	2.49	2.56	2.80	2.81	2.90	2.94	2.95	2.95	3.48	3.78	3.79	3.90	3.07
T_2	2.27	2.79	2.95	3.35	5.20	7.48	7.71	7.90	8.62	10.23	11.76	13.71	14.23	7.58
T_3	2.46	2.75	2.91	4.40	5.52	8.42	8.75	8.78	8.74	9.20	10.02	11.51	11.64	7.32
T_4	2.37	2.63	3.15	3.64	4.97	6.40	6.70	6.89	7.63	8.79	8.89	9.17	9.21	6.19
T_5	2.32	3.47	4.90	9.52	10.13	11.30	11.93	12.50	12.92	14.27	15.50	16.53	16.73	10.93
T_6	2.64	4.68	5.67	10.58	11.21	12.41	12.91	13.50	13.88	18.09	18.99	19.11	19.31	12.54
T_7	2.39	2.63	2.80	5.85	6.26	8.74	8.93	9.08	9.52	11.59	13.66	14.08	14.56	8.44
Mean	2.42	3.06	3.56	5.74	6.6	8.24	8.6	8.80	9.18	10.81	11.80	12.56	12.80	

	T	P	TP
F	2203.89**	3168.76**	116.46**
SE	0.066	0.063	0.167
CD	0.200	0.175	0.462

** Significant at 1% level T Treatment

P Period TP Treatment x Period

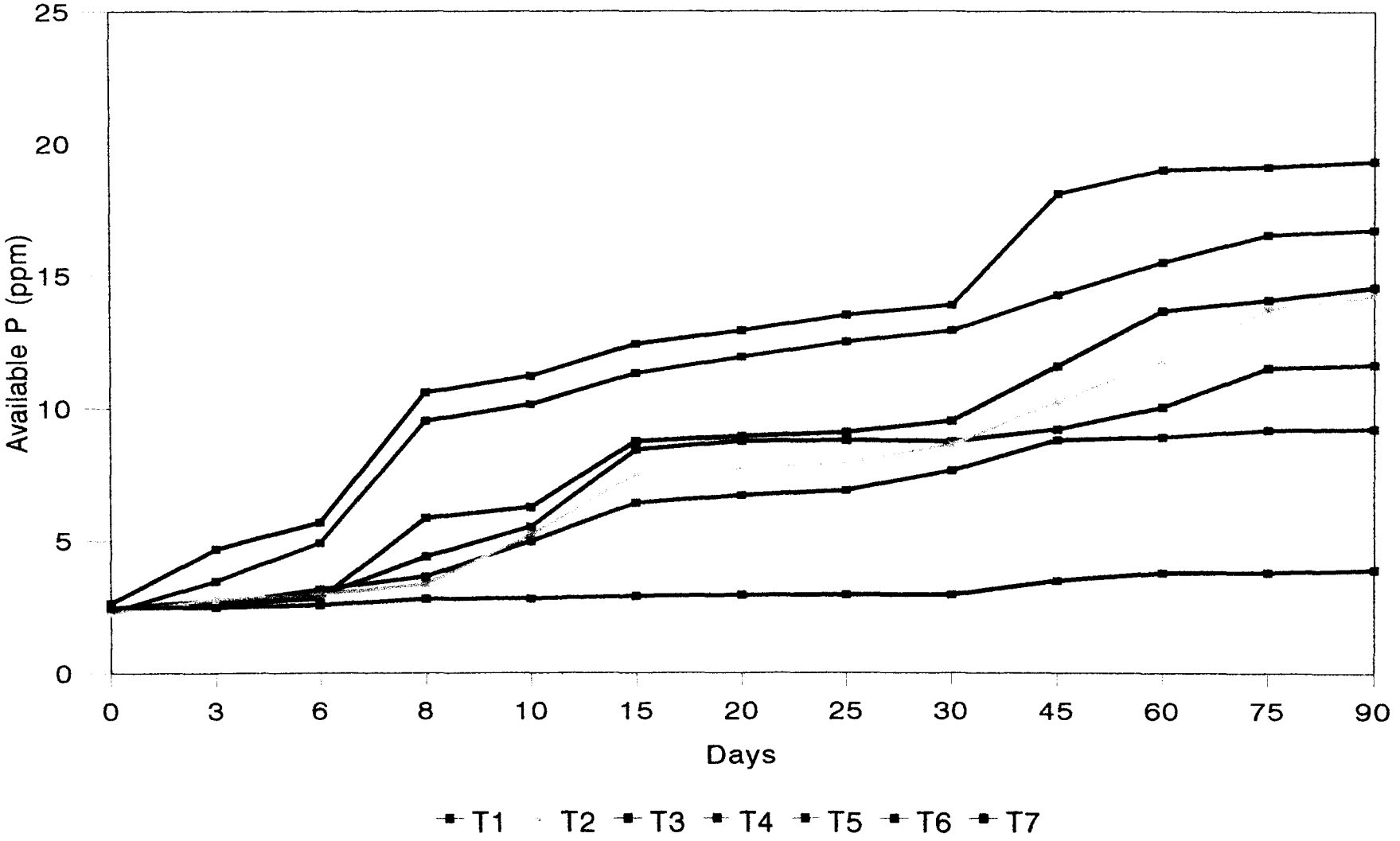


Fig. 4. Available P (ppm) in soil on incubation for a period of 90 days

The available P in different treatments showed a mean value of 3.07 to 12.54 ppm and the average values of available P ranged from 2.42 to 12.80 ppm for the periods.

FIELD EXPERIMENT

Results of the field experiment to study the effect of PB inoculation on growth, yield, P content in soil and plant and P uptake of banana are presented in tables 4 to 35.

Growth of banana was evaluated by taking observation on vegetative characters such as height, girth, total number of leaves, leaf area index and total dry matter production. The observations recorded at the vegetative (three months after planting), shooting (six months after planting) and harvest (nine months after planting) stages are presented in tables 4 to 7 and figures 5 to 11.

Vegetative characters

Height of Pseudostem

The mean values for the height of pseudostem in the differently treated banana plants at the three stages of observation are given in table 4 and figures 5 to 7.

Significant difference in plant height was noticed due to the effect of different treatments. Maximum height at the vegetative (169.0 cm) and harvest stages (312.3cm) was recorded by the plants in treatment T_4, where MRP was applied at 3/4 of the recommended level of P, combined with PB, FYM and mulch.

It may be seen that at the shooting stage, the maximum plant height of 302.3 cm was recorded in T_1 where P was applied as MRP at the full recommended level. But, this was on par with the treatment T_4 (298.7cm) showing that 3/4 of the P applied along with PB was equally good in promoting plant height.

The treatments T_4 and T_5 receiving PB inoculation recorded significantly higher values for plant height when compared to T_2 and T_3, the treatments with the same level of P, but without PB inoculation.

The treatments where PB was applied without FYM (T_6 and T_7) however have recorded only a significantly lower plant height at all stages when compared to the treatments T_4, T_5, T_8 and T_9 where FYM was applied along with PB.

It may be also seen from table 4 that the treatments T_8 and T_9 where PB was applied along with FYM but without mulch showed a significantly lower plant height compared to treatments T_4 and T_5 where mulching was done.

Table 4. Height of pseudostem at different stages (cm)

Treatment	Vegetative stage	Flowering stage	Harvest stage
T_1	163.7	302.3	310.7
T_2	162.7	296.7	300.0
T_3	160.0	276.3	290.7
T_4	169.0	298.7	312.3
T_5	164.0	294.7	297.3
T_6	160.0	285.0	291.0
T_7	145.3	263.3	280.0
T_8	155.0	290.7	299.0
T_9	158.7	283.3	295.7
Mean	159.8	287.4	297.4
F	22.48**	53.57**	120.06**
SE	1.413	1.649	0.913
CD	4.237	4.944	2.737

** Significant at 1% level

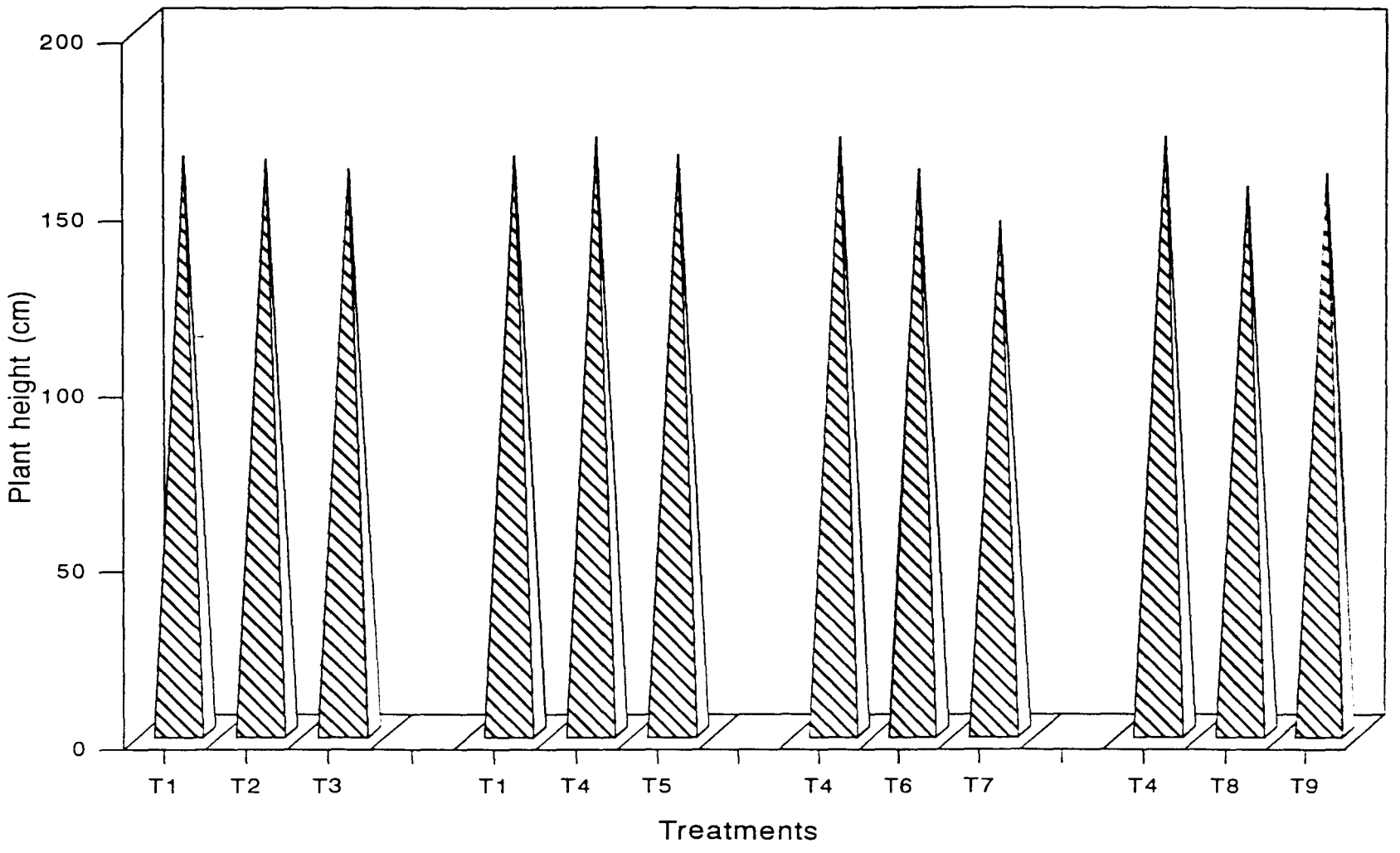


Fig. 5. Plant height (cm) at vegetative stage

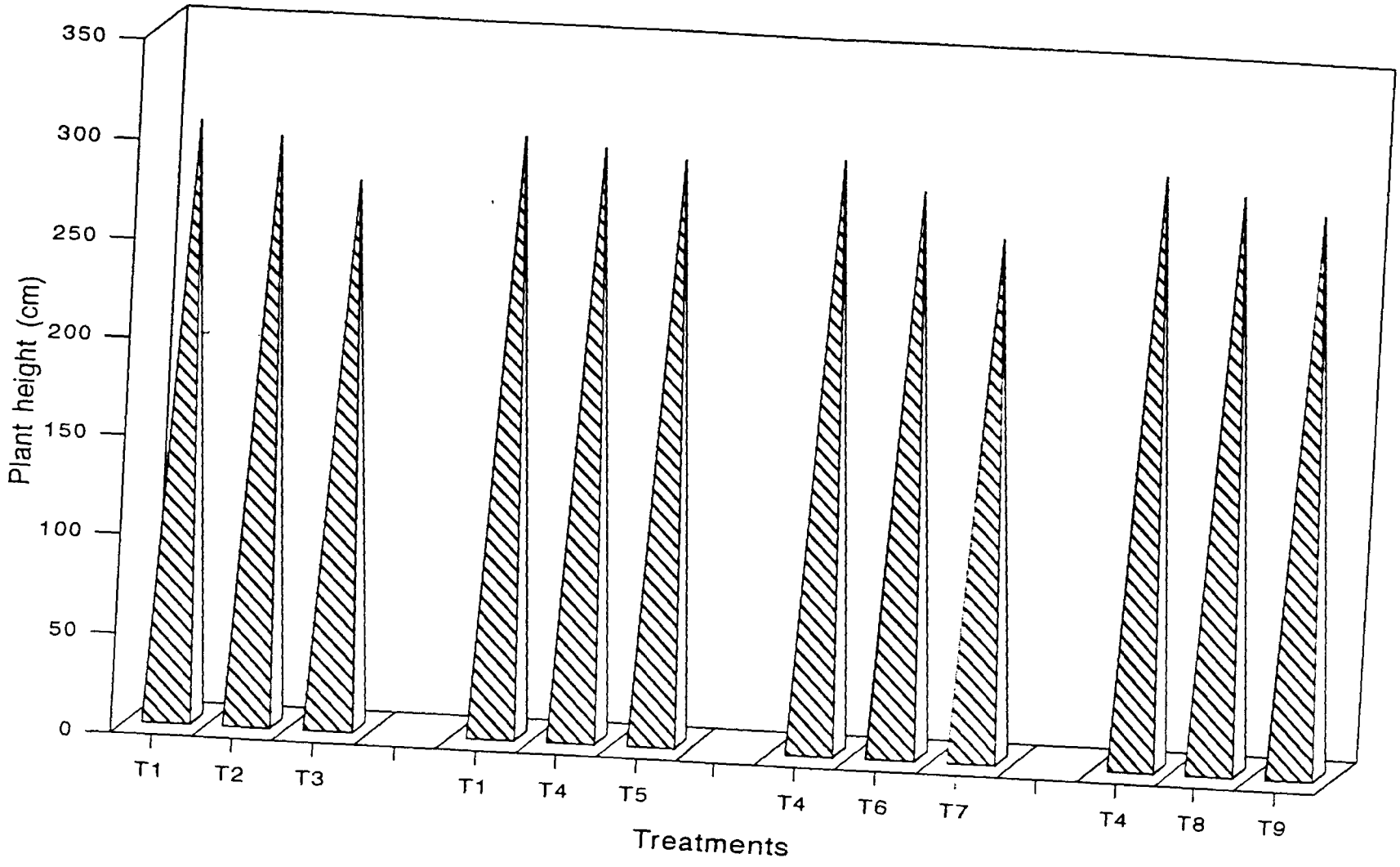


Fig. 6. Plant height (cm) at flowering stage

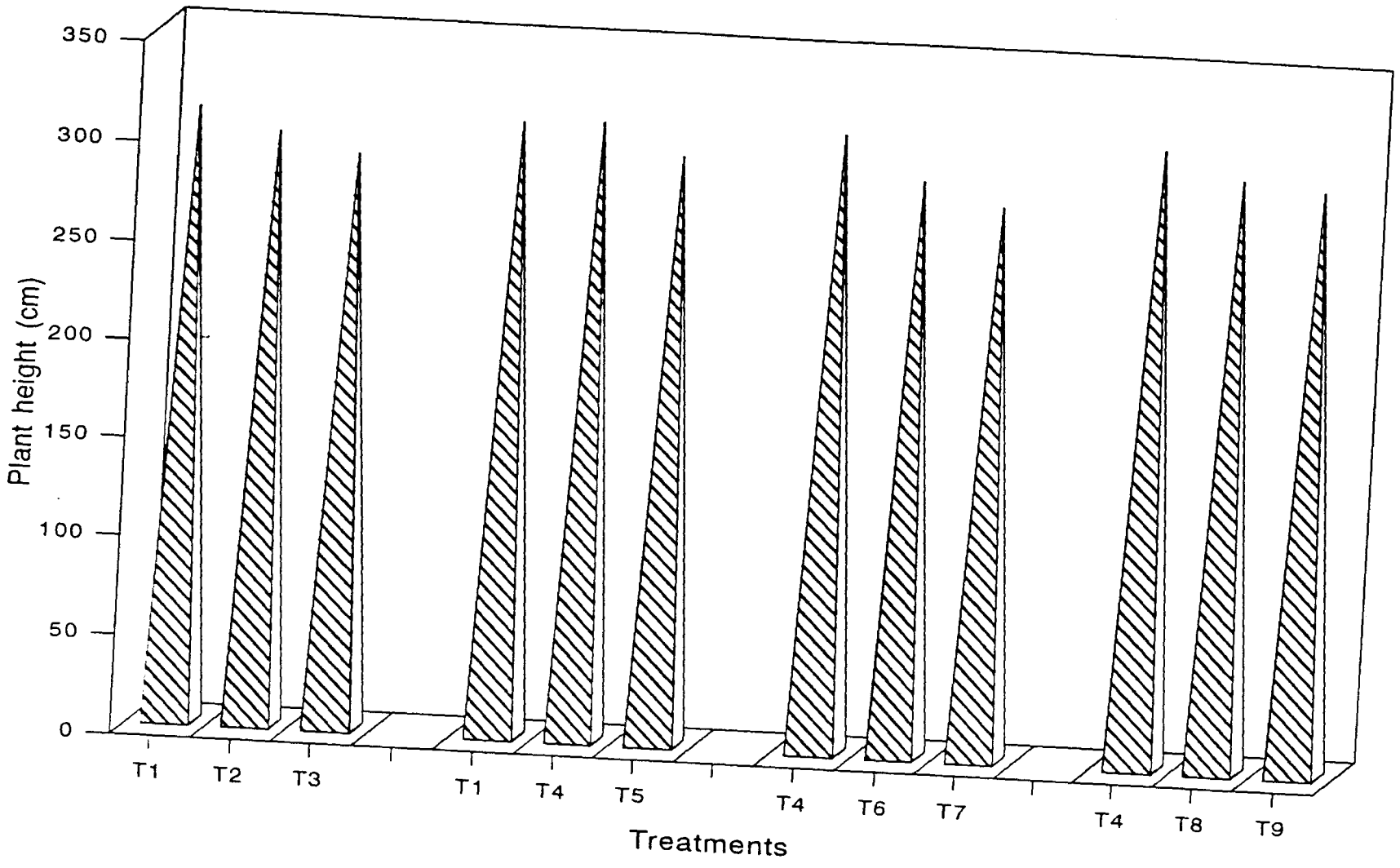


Fig. 7. Plant height (cm) at harvest stage

However the plant height in these treatments was significantly higher than that in the treatments T_6 and T_7 where the same levels of P, PB and mulching were given but without the addition of FYM.

Height of the plants in treatments T_2 and T_5 which was on par at all stages indicated that 1/2 level of P with PB, FYM and mulch (T_5) was as effective as the treatment with 3/4 level of P applied without PB (T_2) in maintaining plant height.

Girth of pseudostem

The girth of pseudostem at the base, 20 and 100 cm above the ground level recorded at the three prescribed stages mentioned above are presented in table 5.

Significant difference in the girth of pseudostem of banana in different treatments was noticed only at the vegetative stage as seen from table 5 and figure 8.

Maximum girth of pseudostem (41 cm) at the base was recorded at the vegetative stage in T_4 which was on par with the girth of plants in treatments T_1, T_2, T_3, T_5 and T_8. In the case of treatments T_8 and T_9 where FYM was applied with PB and mulching, a higher girth was recorded compared to those where no FYM was applied, indicating the superior effect of FYM to mulching in promoting girth of pseudostem.

Table 5. Girth of pseudostem at different stages (cm)

	Girth at base			Girth at 20 cm			Girth at 100 cm		
	Vegatative stage	Flowering stage	Harvest stage	Vegatative stage	Flowering stage	Harvest stage	Vegatative stage	Flowering stage	Harvest stage
T_1	40.0	61.7	58.0	38.3	57.7	57.0	27.7	50.0	47.0
T_2	40.3	58.0	58.7	37.3	54.7	55.7	29.0	47.0	47.3
T_3	40.7	60.0	56.3	37.0	56.0	53.7	28.0	48.0	46.0
T_4	41.0	60.7	56.3	39.3	57.0	57.7	29.3	47.7	47.0
T_5	39.7	60.7	56.7	38.0	57.7	59.0	28.3	49.3	48.3
T_6	34.0	57.7	54.7	33.3	55.3	54.0	24.7	47.3	44.3
T_7	33.0	57.3	55.7	32.3	54.3	54.3	23.0	45.7	43.3
T_8	39.0	57.7	56.0	34.7	54.0	56.3	25.7	45.7	46.3
T_9	38.0	58.3	55.0	34.0	54.7	55.0	24.3	45.7	46.3
F	18.10^{**}	2.38^{ns}	0.94^{ns}	11.90^{**}	2.41^{ns}	1.24^{ns}	24.13^{**}	1.28^{ns}	2.22^{ns}
SE	0.689	1.059	1.334	0.722	1.162	1.292	0.466	1.401	1.032
CD	2.067	—	—	2.165	—	—	1.399	—	—

ns not significant

** Significant at 1% level

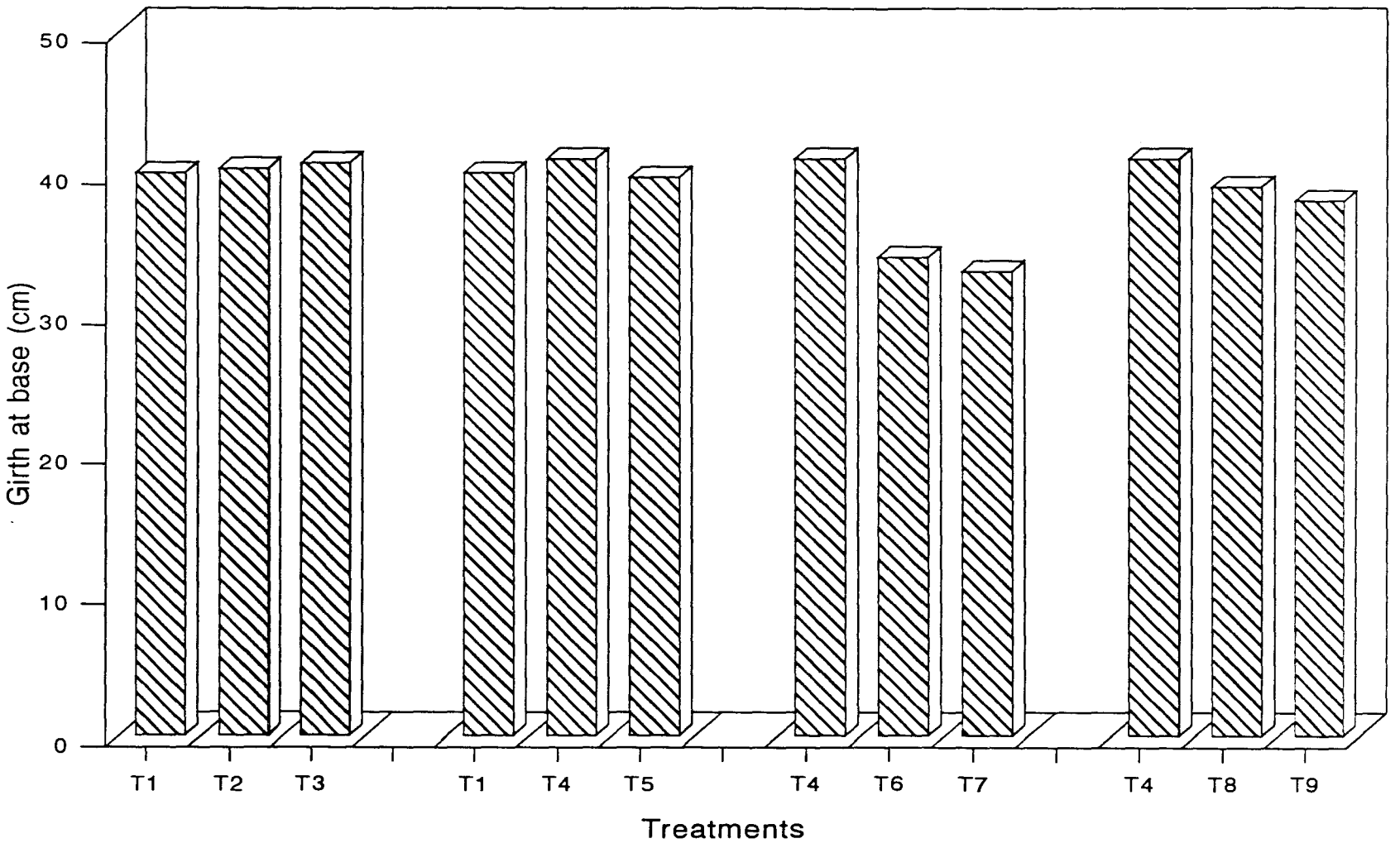


Fig. 8. Plant girth (cm) at vegetative stage

Table 6. Total number of leaves plant^{-1} at different stages

Treatments	Vegetative stage	Flowering stage	Harvest stage
T_1	11.0	8.3	3.0
T_2	10.0	8.0	3.0
T_3	9.7	8.3	3.0
T_4	11.0	8.7	3.3
T_5	10.3	8.7	3.0
T_6	9.3	8.3	4.3
T_7	9.7	9.0	4.0
T_8	10.7	9.0	3.7
T_9	10.7	9.0	3.7
Mean	10.2	8.6	3.4
F	1.540^{ns}	0.614^{ns}	4.91^{**}
SE	0.498	0.465	0.226
CD	—	—	0.677

ns not significant

** Significant at 1% level

Table 7. Leaf area index plant^{-1}

Treatments	Vegetative stage	Flowering stage	Harvest stage
T_1	0.84	1.57	0.43
T_2	1.00	1.52	0.32
T_3	0.95	1.46	0.46
T_4	0.90	1.88	0.64
T_5	0.77	1.68	0.68
T_6	0.56	1.37	0.70
T_7	0.65	1.85	0.44
T_8	0.92	1.93	0.52
T_9	0.95	1.77	0.43
Mean	0.84	1.67	0.51
F	3.58*	1.03ns	12.97**
SE	0.078	0.198	0.036
CD	0.236	—	0.109

* Significant at 5% level

** Significant at 1% level

ns not significant

Girth of plants at 20 and 100 cm from the base was also significant only at the vegetative stage. The maximum girth of 39.3cm at 20 cm and 29.3cm at 100cm from the base were recorded in the treatment T_4. The treatments without FYM (T_6 and T_7) recorded rather low plant girth compared to the treatments with FYM.

Total number of leaves

Total number of leaves was maximum at the vegetative stage with an average of 10.3 leaves per plant which decreased to 8.6 at shooting stage and reached a very low value of 3.4 leaves per plant at harvest stage. Even though a slight variation in the number of leaves at various stages was noticed, it did not show any appreciable difference suggesting the lack of treatment effect on this character.

Leaf area index

Leaf area index was highest during the shooting stage (1.67) compared to the other two stages. At this stage, plants in T_8 had the highest LAI (1.93) followed by T_4 (1.88) and T_7 (1.85). LAI was minimum at the harvest stage with a mean value of 0.51. Plants in treatment T_6 had the maximum LAI at this stage followed by T_5 and T_4. However, significant effect of treatments was evident only at the vegetative and harvest stages.

Dry matter content of different plant parts and total dry matter

Dry matter content of different plant parts and the total dry matter content of the plant at the different stages of growth are presented in tables 8 to 15 and figures 9 to 11.

Dry matter content of plant parts

Petiole

There was significant difference between treatments at the three stages on the dry matter content of petiole.

As seen from table 8, the maximum dry matter for petiole at the three stages was recorded in the treatment T_4 (95.4, 240.8 and 52.7 g plant^{-1} respectively) which was significantly superior to all the other treatments.

Treatments with lower levels of P along with PB and FYM produced higher dry matter than the corresponding treatments without PB. At the shooting stage T_8, T_9, T_1 and T_5 were on par showing that 3/4 P and 1/2 P without mulch but with PB and FYM has the same effect as that of full and half level of P applied along with PB, FYM and mulch.

The pooled analysis of the data showed the superior effect of T_4 over the other treatments in influencing the dry matter content of petiole.

Midrib

It can be seen from table 8 that at the vegetative stage, the highest dry matter content of 84.7 g was recorded in T_1 which was on par with T_4 (83.6g). But both at shooting and harvest stages T_4 recorded the maximum dry matter content of 238.0 and 75.1 g per plant respectively.

The highest dry matter content of 238.0 g was recorded at the shooting stage in T_4. The superiority of T_4 was confirmed in pooled analysis also.

The effect of FYM was pronounced in T_8 and T_9 when compared to treatments receiving no FYM (T_6 and T_7) which recorded only a significantly lower dry matter content. Mean values for dry matter content in the different treatments was significantly high and maximum during shooting stage compared to vegetative and harvest stages .As far as the effect of individual treatments is concerned, T_4 produced the maximum dry matter content (132.3) followed by T_8, (128.0) and T_1 (125.1g plant^{-1}). All the other treatments resulted in comparatively lower values, T_7 recording the minimum value of 88.2 g per plant.

Leaf blade

The dry matter content of leaf blade is presented in table 10

Table 8. Drymatter content in petiole (g plant^{-1})

Treatments	Vegetative stage	Flowering stage	Harvest stage	Pooled data
T_1	72.5	226.7	46.3	115.2
T_2	69.8	198.5	35.3	101.2
T_3	66.5	213.1	32.0	103.9
T_4	95.4	240.8	52.7	129.6
T_5	75.4	223.8	43.3	114.2
T_6	56.4	221.2	42.0	106.5
T_7	52.6	192.7	31.7	92.3
T_8	74.7	232.3	50.0	119.0
T_9	67.8	232.3	36.0	112.0
Mean	70.1	220.2	41.0	
F	305.04**	21.08**	715.01**	
SE	0.704	3.492	0.561	
CD	2.112	10.470	1.683	

	Pooled ANOVA	
	F	CD
Treatment	1510.70**	3.498
Stage	6.50**	6.058
Treatment x stage	12.53**	10.493

** Significant at 1% level

Table 9. Dry matter content in midrib (g plant^{-1})

Treatments	Vegetative stage	Flowering stage	Harvest stage	Pooled data
T_1	84.7	219.3	71.3	125.1
T_2	81.3	196.0	70.1	115.8
T_3	81.3	206.0	53.2	113.5
T_4	83.6	238.0	75.1	132.3
T_5	78.0	219.3	72.7	123.3
T_6	52.0	196.0	67.7	105.2
T_7	43.8	170.3	50.4	88.2
T_8	82.1	228.7	73.3	128.0
T_9	69.6	205.3	55.1	110.0
Mean	72.9	208.8	65.4	
F	715.01**	46.51**	28.29**	
SE	0.561	2.976	1.823	
CD	1.683	8.923	5.466	

	Pooled ANOVA	
	F	CD
Treatment	662.33**	4.433
Stage	6.27**	7.679
Treatment x stage	21.24**	13.302

** Significant at 1% level

Table 10. Dry matter content in leaf blade (g plant^{-1})

Treatments	Vegetative stage	Flowering stage	Harvest stage	Pooled data
T_1	201.9	583.2	168.0	317.7
T_2	180.0	550.0	165.3	298.4
T_3	170.7	500.0	115.0	261.9
T_4	186.0	691.7	198.0	358.6
T_5	177.0	517.5	180.0	291.5
T_6	120.0	566.7	122.0	269.6
T_7	107.7	550.8	113.7	257.4
T_8	188.6	601.7	177.3	322.5
T_9	168.0	575.0	171.0	304.7
Mean	166.7	570.7	156.7	
F	150.78**	129.96**	194.82**	
SE	2.585	4.848	2.248	
CD	7.751	14.534	6.740	

Pooled ANOVA

	F	CD
Treatment	540.99**	14.362
Stage	3.43*	24.876
Treatment x stage	79.03**	43.087

* Significant at 5% level

** Significant at 1% level

There was significant difference between treatments in the dry matter content of leaf blade. At the vegetative stage, the highest dry matter content of 202.0 g was recorded in T_1 which received the highest amount of P, followed by T_8 and T_4 which were on par. The lowest dry matter content was recorded in T_6 and T_7 which received only 3/4 and 1/2 level of P respectively along with PB, but without FYM.

At shooting and harvest stages the maximum dry matter content was recorded in the treatment T_4. At the shooting stage, T_4 was followed by T_8, which received MRP, PB, and FYM but without mulch. At the harvest stage, the dry matter content of leaf blade was drastically reduced to an average value of 156.7g per plant only compared to 570.7g at the shooting stage. At the harvest stage also, leaf blade in T_4 recorded the highest dry matter content of 198.0g per plant which was significantly higher than the rest of the treatments. This was followed by T_5 where 1/2 level of recommended P was applied along with PB.

On pooled analysis of the data, T_4 showed superiority over other treatments in maintaining a higher dry matter content.

Pseudostem

Data presented in table 11 shows that there was significant difference between treatments in the dry matter content of pseudostem. At all the three stages, highest dry matter content was recorded in T_4.

Table 11. Dry matter content in pseudostem (g plant^{-1})

Treatments	Vegetative stage	Flowering stage	Harvest stage	Pooled data
T_1	415.3	1740.0	1810.0	1321.8
T_2	415.3	1664.0	1690.0	1256.5
T_3	410.7	1540.0	1640.0	1196.9
T_4	466.3	1748.0	1840.0	1351.5
T_5	413.0	1738.0	1620.0	1257.0
T_6	289.3	1620.0	1620.0	1176.5
T_7	263.7	1552.0	1553.3	1123.0
T_8	373.3	1612.0	1734.0	1239.8
T_9	326.7	1578.0	1510.0	1138.2
Mean	374.9	1643.6	1668.6	
F	52.95**	9.526**	16.784**	
SE	9.268	26.742	27.027	
CD	27.786	80.178	81.033	

	Pooled ANOVA	
	F	CD
Treatment	1818.59**	24.555
Stage	6.71**	42.530
Treatment x stage	169.573**	73.664

** Significant at 1% level

At the vegetative and flowering stage, the treatments T_1, T_2 and T_5 were on par indicating the equal effect of full and 3/4 level of P without PB and 1/2 level of P with PB, FYM and mulch. In pooled analysis also T_1 recorded the highest dry matter content.

Rhizome

Table 12 reveals that there was significant difference between treatments in the dry matter content of rhizome at the three stages. It increased with growth and reached the maximum value of 1062.5g at harvest. The highest value of dry matter at all stages was recorded in T_4. The rhizome yield was on par with T_1 at the vegetative and shooting stages. But at harvest stage, T_4 was significantly superior to the rest of the treatments. At this stage T_5, T_1, T_8 and T_2 were on par suggesting the effect of full level of P as equivalent to the effect of treatments with 3/4 and 1/2 level of P, PB and FYM. Pooled analysis of the data also showed the superiority of T_4 in increasing the dry matter content in rhizome compared to other treatments.

Flower

The dry matter content of flower and fruit presented in table 13 revealed that there was significant difference in the dry matter content of flower due to treatments. The maximum dry matter of 246.7 g was recorded in T_4 and T_8.

Table 12. Dry matter content in rhizome (g plant^{-1})

Treatments	Vegetative stage	Flowering stage	Harvest stage	Pooled data
T_1	512.0	1036.7	1155.0	901.2
T_2	480.0	926.7	1118.3	841.7
T_3	472.0	820.0	1032.0	774.7
T_4	518.0	1036.7	1238.7	931.1
T_5	480.0	943.3	1173.3	865.6
T_6	464.0	860.0	944.3	756.1
T_7	416.0	740.0	902.0	686.0
T_8	480.0	916.7	1155.0	850.6
T_9	438.0	800.0	843.3	693.8
Mean	473.3	897.87	1062.5	
F	10.12**	31.72**	29.61**	
SE	10.091	18.169	25.349	
CD	30.254	54.474	76.000	

Pooled ANOVA

	F	CD
Treatment	225.41**	28.631
Stage	6.28**	49.590
Treatment x stage	10.30**	85.890

** Significant at 1% level

Table 13. Dry matter content in flower and fruit (g plant^{-1})

Treatment	Flower	Fruit
T_1	166.7	3268.3
T_2	200.0	3169.7
T_3	200.0	2966.3
T_4	246.7	3305.3
T_5	220.0	3293.0
T_6	220.0	2935.3
T_7	146.7	2528.3
T_8	246.7	3043.0
T_9	230.0	2627.0
F	291.68**	11.77**
SE	2.00	82.88
CD	6.00	248.48

** Significant at 1% level

Fruit

T_4 recorded the highest dry matter of 3305.3 g plant^{-1}. which was on par with T_5 and T_1. The absence of FYM was pronounced in T_6 and T_7 which recorded comparatively lower values than T_4 and T_5 receiving FYM along with MRP and PB.

Total dry matter content

Vegetative stage

The data presented in tables 14 and 15 and figures 9 to 11 revealed that the total dry matter was significantly higher for the treatment T_4 when compared to the other treatments. The treatments where PB was applied without FYM produced the lowest dry matter. Application of 3/4 and 1/2 level of recommended P along with PB, FYM and mulching(T_4 and T_5) were found to be significantly superior to the corresponding treatments without FYM (T_6 and T_7).

Shooting stage

During this stage also, plants in treatment T_4 recorded the highest dry matter content (4201.8g), which was significantly superior to T_1 (3972.7g). Treatments T_5 and T_8 produced equal amounts of dry matter which was higher than the dry matter produced by similar levels of P applied without PB and FYM.

Table 14. Total dry matter content (g plant^{-1})

Treatments	Vegetative stage	Flowering stage	Harvest stage	Pooled data
T_1	1286.5	3972.7	6518.9	3926.1
T_2	1226.0	3735.0	6248.7	3736.6
T_3	1210.4	3559.1	5838.5	3536.0
T_4	1405.7	4201.8	6677.6	4095.1
T_5	1223.4	3848.8	6383.8	3818.7
T_6	982.1	3673.8	5731.3	3462.4
T_7	887.0	3408.3	5179.4	3158.3
T_8	1198.5	3848.8	6383.8	3818.7
T_9	1063.3	3620.7	5242.4	3308.8
Mean	164.8	3762.0	6035.6	
F	89.70**	30.89**	18.46*	
SE	16.865	42.474	130.660	
CD	50.562	127.341	391.736	

Pooled ANOVA

	F	CD
Treatment	942.85**	112.248
Stage	4.99**	194.42
Treatment x stage	8.88**	336.745

* Significant at 5% level

** Significant at 1% level

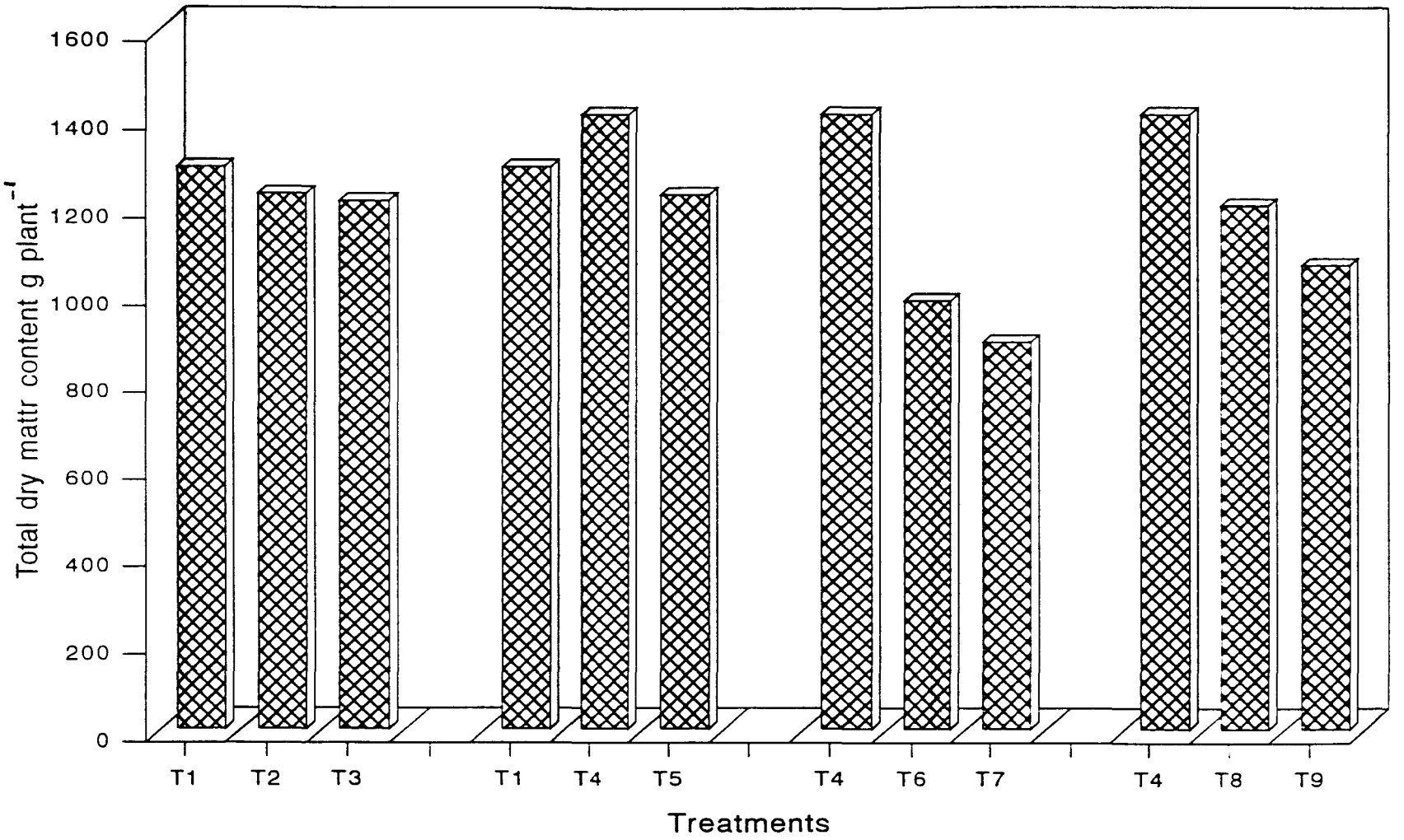


Fig. 9. Total dry matter content at vegetative stage

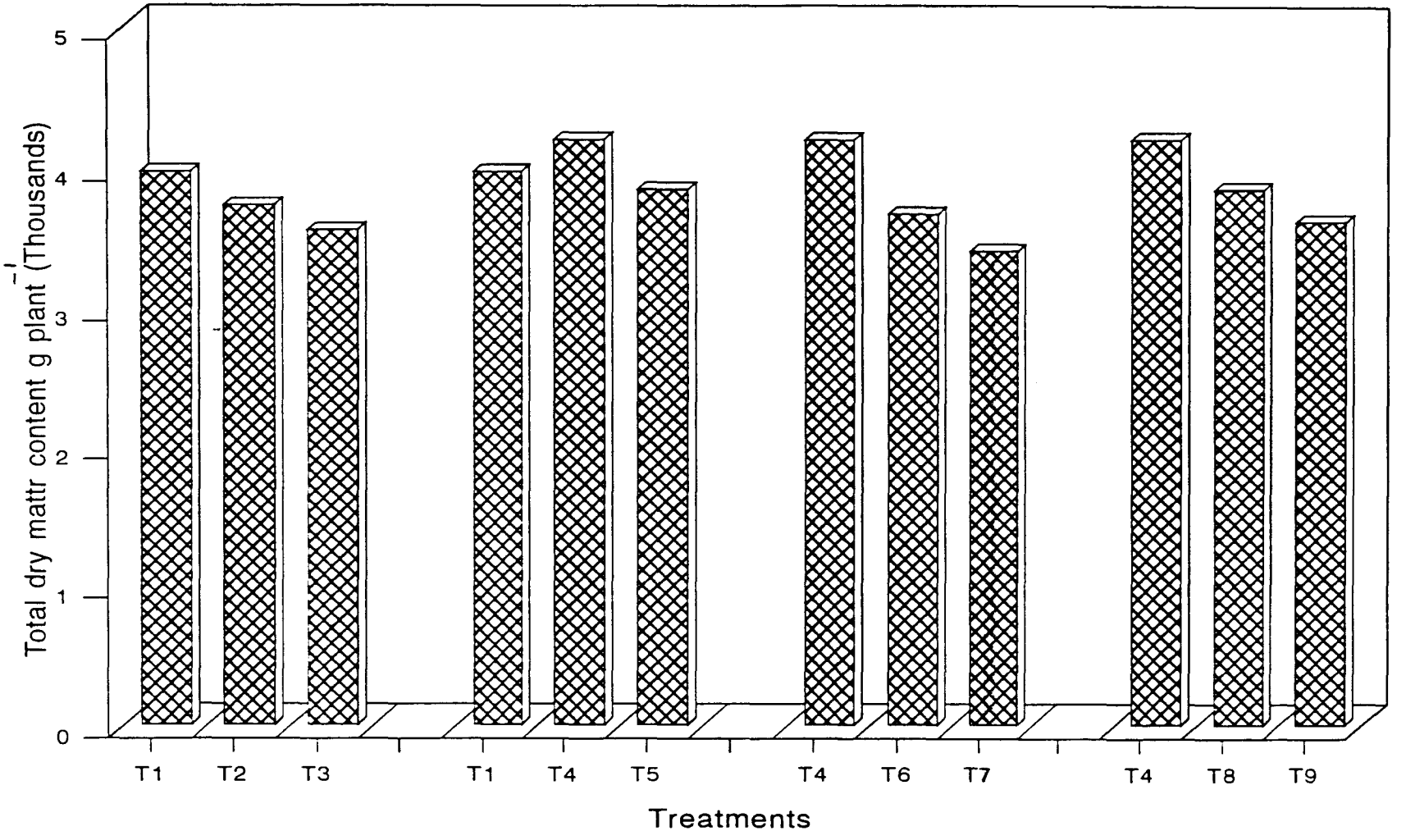


Fig. 10. Total dry matter content at flowering stage

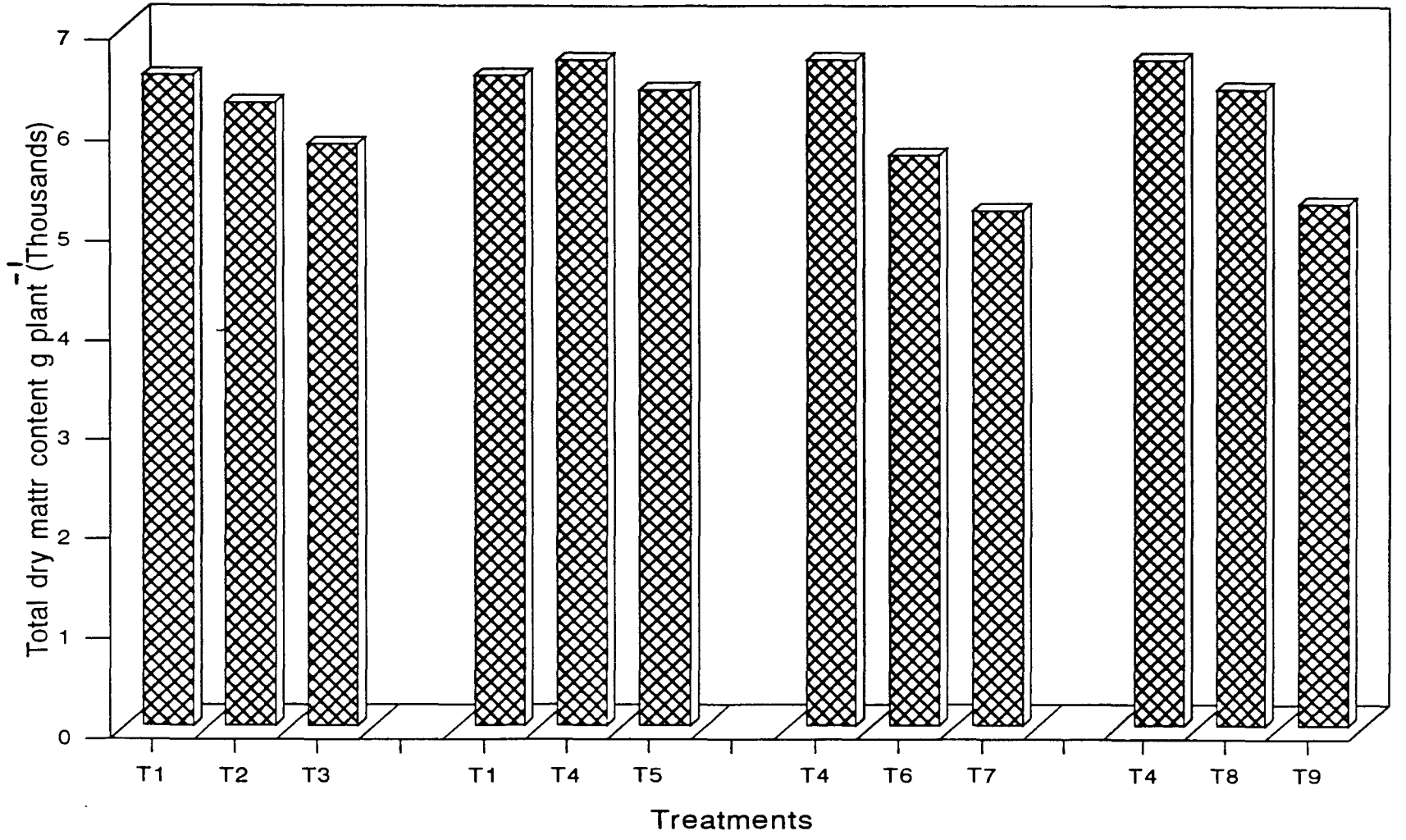


Fig. 11. Total dry matter content at harvest stage

Table 15. Total dry matter content (kg ha^{-1})

Treatments	Vegetative stage	Flowering stage	Harvest stage	Pooled data
T_1	3216.36	9931.67	16297.45	9815.16
T_2	3065.40	9337.50	15621.83	9341.58
T_3	3025.96	8897.67	14596.33	8839.99
T_4	3514.29	10504.58	16694.00	10237.63
T_5	3058.42	9622.08	15959.50	9546.67
T_6	2425.29	9184.58	14328.33	8646.07
T_7	2217.67	9072.50	12948.50	7895.81
T_8	2996.29	8897.67	16248.17	9613.15
T_9	2658.29	8521.25	13106.00	8278.93
Mean	2908.67	9407.43	15088.90	
F	80.76*	30.47**	15088.90**	
SE	44.922	106.633	326.615	
CD	134.683	319.701	979.235	

Pooled ANOVA

	F	CD
Treatment	939.77**	281.16
Stage	4.97**	486.99
Treatment x stage	8.88**	843.48

* Significant at 5% level

** Significant at 1% level

Harvest stage

Though the highest dry matter (including banana bunch) at this stage was shown in T_4 (6677.6 g) followed by T_1, T_8 and T_5, no significant difference was noticed between these values. The treatments without PB produced only lower dry matter compared to those which received PB along with FYM and mulching. The pooled analysis of the data at the three different stages of growth has revealed the superior effect of T_4 over the rest of the treatments.

b. Yield and yield attributes

The data on yield and yield attributes of banana plant are presented in table 16 and figures 12 to 15. There was significant difference in the yield of banana, due to the effect of treatments.

Yield

The highest mean bunch weight of 10.68 kg plant^{-1} was recorded in the treatment T_4, where only 3/4 of the recommended level of P was applied along with PB, FYM and mulch. This yield was significantly superior to all the other treatments and was followed by T_1 (9.93 kg plant^{-1}), which was on par with T_5 (9.25 kg plant^{-1}). The results show that the application of full P without PB could produce only a similar yield as that obtained by using 1/2 P with PB.

Table 16. Yield and yield attributes

Treatments	Weight of bunch (kg)	Number of hands bunch^{-1}	Length of bunch (cm)	Average weight of hand (kg)	Average distance between hands (cm)	Number of fingers bunch^{-1}	Length of finger (cm)	Girth of finger (cm)	Weight of finger (g)	Weight of peduncle (kg)
T_1	9.93	5.00	27.33	1.78	6.67	49.67	27.00	13.67	179.33	1.02
T_2	8.57	4.81	26.67	1.60	7.50	46.33	26.67	13.67	173.33	0.83
T_3	6.79	4.67	24.33	1.22	6.17	41.00	25.67	13.67	170.67	0.79
T_4	10.68	5.33	27.00	1.89	8.00	48.00	26.33	14.00	180.00	0.93
T_5	9.25	5.33	25.67	1.53	7.17	44.33	25.00	13.00	178.33	0.97
T_6	7.25	5.00	28.67	1.09	6.83	43.33	24.00	12.33	130.00	1.80
T_7	6.79	5.00	28.00	1.05	6.67	41.00	23.67	12.33	129.00	1.54
T_8	8.95	5.00	27.33	1.57	6.67	49.00	26.00	12.33	163.00	0.57
T_9	7.12	5.00	26.00	1.20	6.17	40.67	25.67	12.33	147.67	1.12
F	11.58**	0.55ns	3.21*	31.23**	1.53ns	14.11**	1.25ns	5.36**	315.61**	3.54*
SE	0.230	0.269	0.726	0.055	0.425	0.952	0.752	0.309	1.162	0.204
CD	0.690	—	2.178	0.164	—	2.853	—	0.927	3.483	0.610

ns not significant * Significant at 5% level ** Significant at 1% level

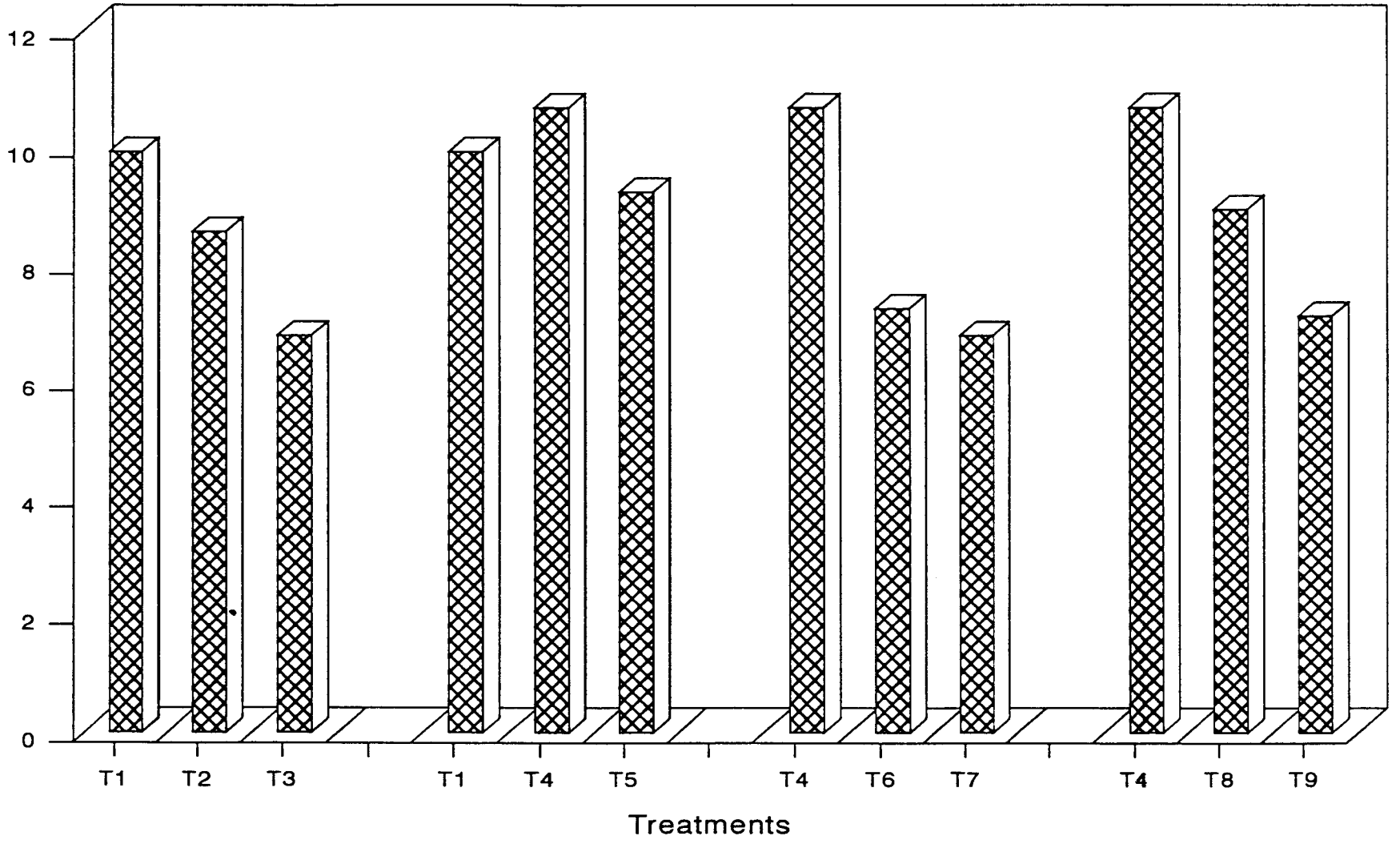


Fig. 12. Weight of bunch (kg plant^{-1})

The treatments T_2 and T_3 where P was applied at 3/4 and 1/2 recommended level but without PB, recorded only a lower yield of 8.57 and 7.68 kg per plant respectively when compared to the treatments T_4 and T_5. The same quantity of P was applied for these treatments along with PB, FYM and mulch and the yield was 10.68 kg and 9.25 kg plant^{-1} respectively. Treatments T_6 and T_7, which received MRP, PB and mulch but without FYM showed a reduced yield of 7.25 and 6.79 kg plant^{-1}, indicating the necessity for the use of FYM along with PB and mulching. However, the treatments T_8 and T_9, where mulch was not included, but FYM was applied, recorded a higher yield of 8.95 and 7.12 kg respectively revealing the greater influence of FYM when compared to mulching.

Number of hands

As seen from table 16, there was no significant difference between the treatments on the number of hands produced per bunch. The average number varied from 4.67 in T_3 to 5.33 in T_4 and T_5.

Length of bunch

Maximum and significantly higher length of bunch was recorded in T_6 (28.67cm). Length of bunch in treatments T_7, T_1, T_8 and T_2 were on par indicating that the treatments had no specific influence on this character.

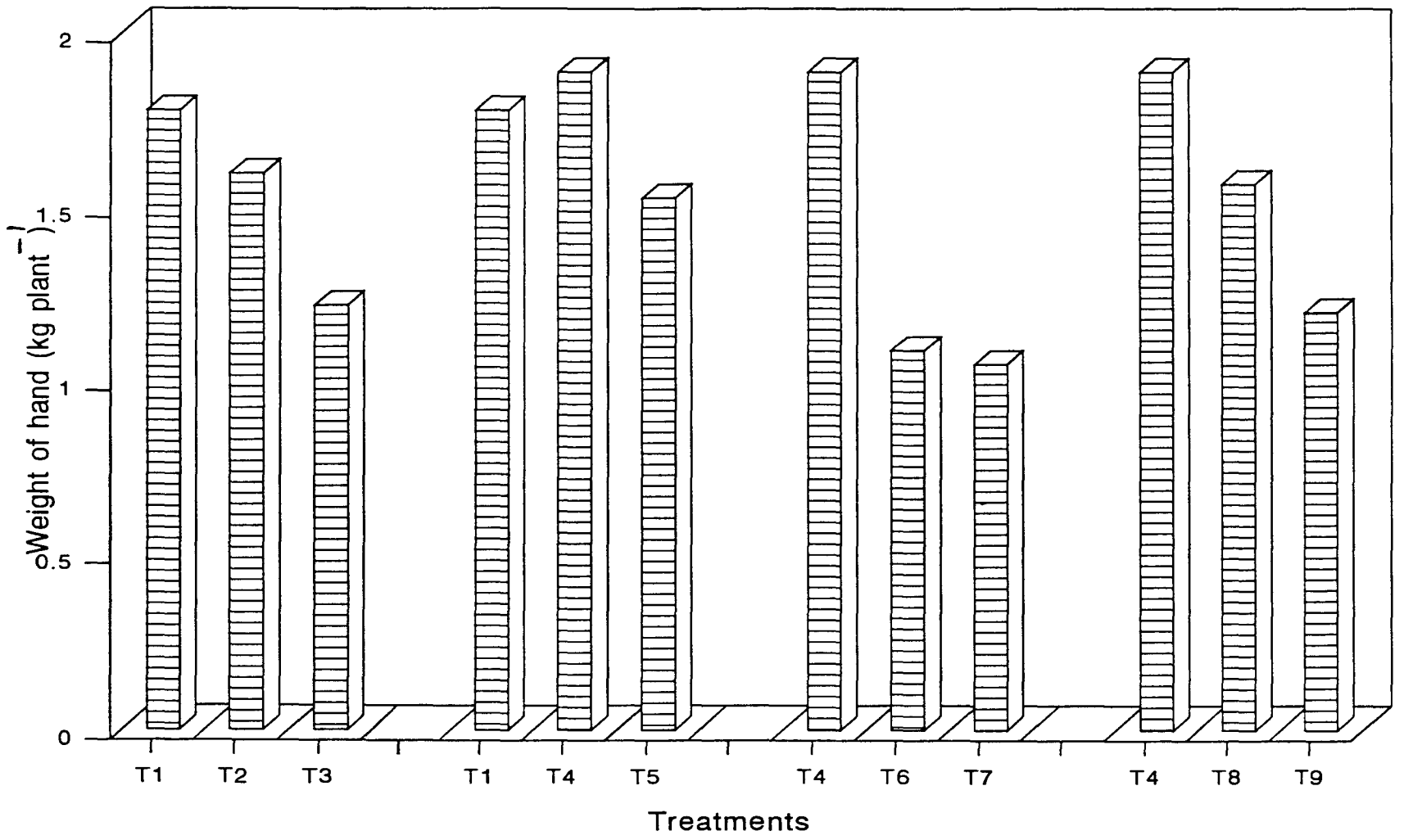


Fig. 13. Average weight of hand (kg plant^{-1})

Weight of hands

There was significant difference between the weight of hands due to the different treatments. The maximum weight of 1.89 kg per hand was recorded in T_4 followed by T_1 (1.78 kg). The weight of hands in T_2, T_8 and T_5 was on par. Treatments where FYM was not applied along with PB resulted in a significantly lesser weight only (1.05 kg) compared to the other treatments.

Average distance between hands

The average distance between hands as evident from table 16 was not significantly affected due to the treatments.

Number of fingers

Significant difference in the number of fingers in the various treatments was noticed. Maximum number of fingers per bunch (49.67) was recorded in T_1 which was on par with T_8 (49.00). The number of fingers in T_4 (48.00), though less than that in T_1 was not significantly lower. This shows that 3/4 level of P applied along with PB and FYM and full level of P without PB had more or less equal effect on the production of fingers in banana.

Length of fingers

As seen from table 16, there was not any significant effect of treatments on the length of fingers in the bunch. It varied from 23.67 in T_2 to 27.00 cm in T_1.

Girth of finger

As evident from table 16, the treatment effect was significant on the girth of fingers. The difference between individual treatments was very small and the values ranged from 12.33 in T_6 and T_9 to 14.00 cm in T_4.

Weight of finger

Significant difference between treatments was noticed for this character (Table 16). The maximum finger weight of 180.00g was recorded in T_4 which was on par with T_1 (179.33 g) and T_5 (178.33 g). The treatments with MRP and PB without FYM however showed a significant reduction in the weight of fingers. The weight of fingers was 130.00g in T_6 and 129.00g in T_7.

Harvest index

From table 17, it may be seen that there was no significant difference in harvest index due to the different treatments. It ranged from 0.14 in T_7 to 0.23 in T_5. The highest value was recorded in T_5 (0.23).

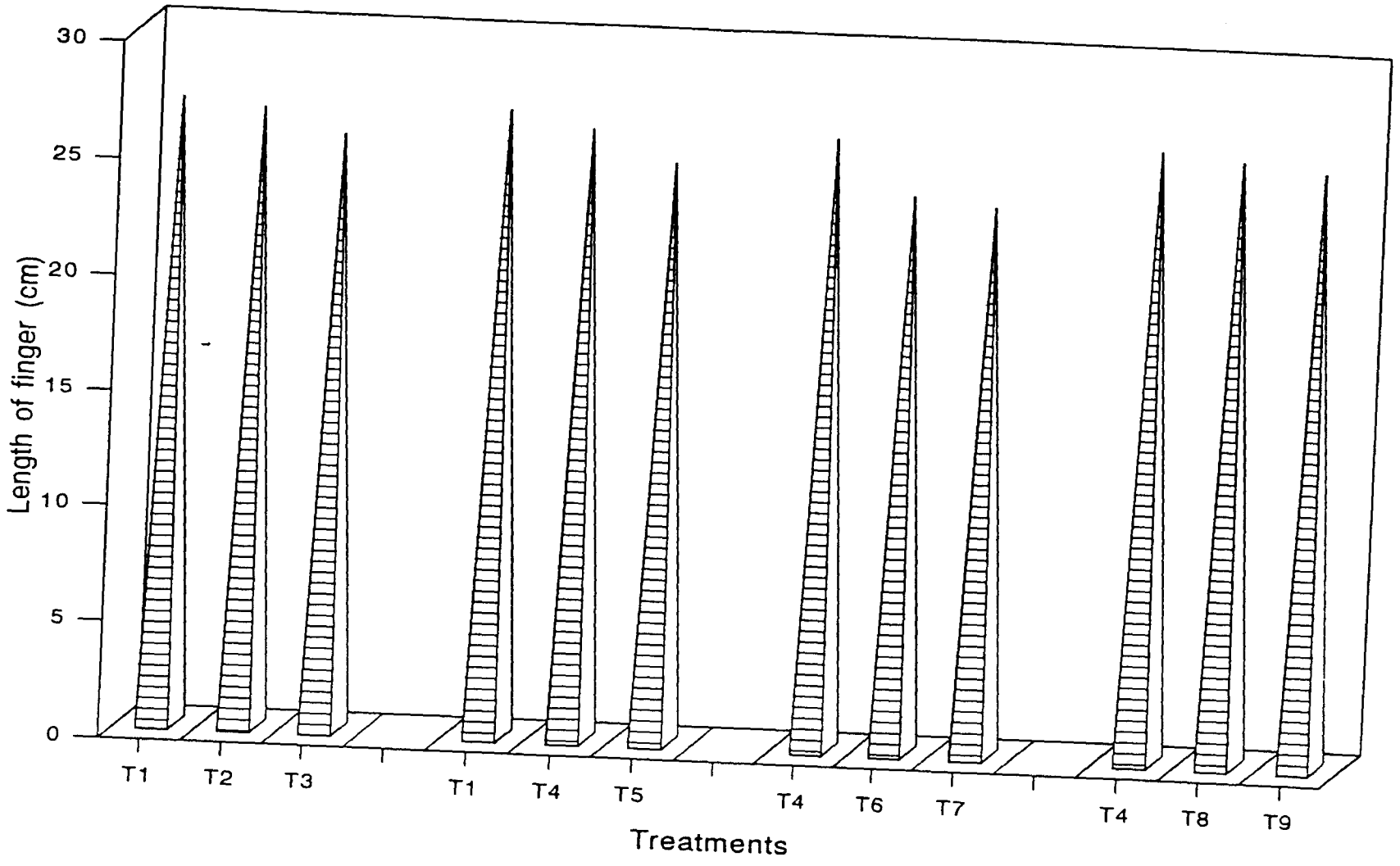


Fig. 14. Length of finger (cm)

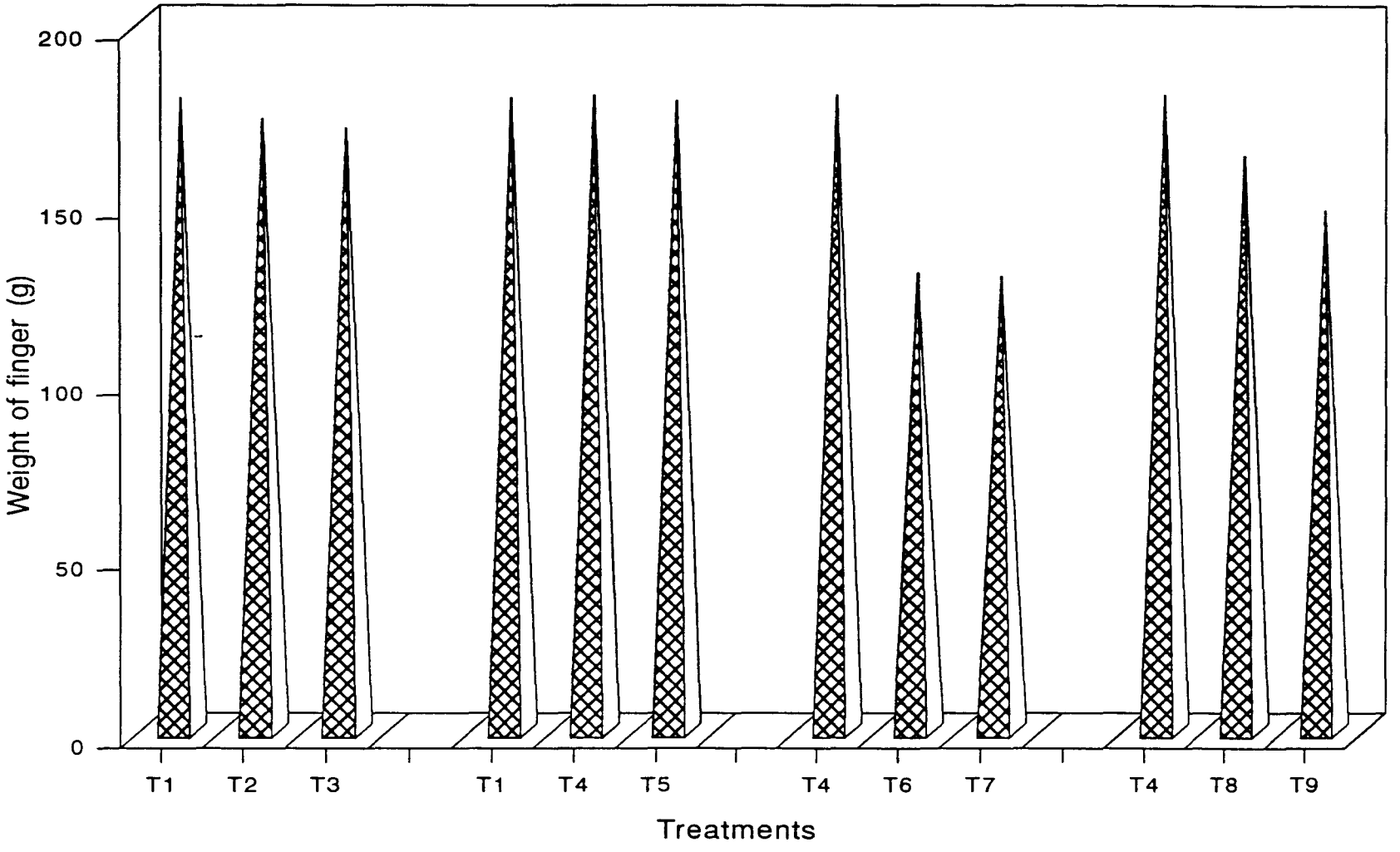


Fig. 15. Weight of finger (g)

Table 17. Harvest index and fullness index

Treaments	Harvest index	Fullness index
T_1	0.21	6.65
T_2	0.22	6.51
T_3	0.20	6.65
T_4	0.21	6.83
T_5	0.23	7.13
T_6	0.21	5.45
T_7	0.14	5.46
T_8	0.21	6.28
T_9	0.21	5.76
F	1.10^{ns}	13.98^{**}
SE	0.025	0.163
CD	—	0.490

ns not significant

** Significant at 1% level

Fullness index

The value for fullness index as given in table 17, ranged from 5.45 in T_6 to 7.13 in T_5. There was significant difference between treatments. The highest fullness index of 7.13 was recorded in T_5 which was on par with T_4 (6.83).

P content in various plant parts of banana

The P content of petiole, midrib, leaf blade, pseudostem and rhizome estimated at the three specified stages of growth of banana are presented in tables 18 to 23 and figures 16 to 18.

Petiole

As revealed from table 18, the average P content of the petiole of banana plants slightly increased from 0.342% at the vegetative to 0.362% at the shooting stage and decreased to 0.290% at the harvest stage. The difference in P content of the petiole in the various treatments was significant. It was highest in T_1 (0.430) at the shooting stage. T_4 recorded a uniformly higher value at the vegetative and harvest stages and was not significantly lower than T_1 at these stages. Treatments receiving PB along with MRP recorded an appreciably higher P content in the petiole compared to the corresponding treatments without PB.

Table 18. P content in petiole at different stages (%)

Treatments	Vegetative stage	Flowering stage	Harvest stage	Pooled data
T_1	0.403	0.430	0.313	0.382
T_2	0.360	0.357	0.233	0.382
T_3	0.290	0.323	0.200	0.271
T_4	0.407	0.400	0.407	0.404
T_5	0.317	0.380	0.370	0.356
T_6	0.340	0.357	0.250	0.316
T_7	0.273	0.320	0.203	0.266
T_8	0.360	0.383	0.330	0.358
T_9	0.320	0.310	0.307	0.314
Mean	0.341	0.362	0.290	
F	75.171**	22.853**	80.550**	
SE	0.053	0.008	0.008	
CD	0.016	0.025	0.024	

Pooled ANOVA

	F	CD
Treatment	0.012^{ns}	—
Stage	0.006^{ns}	—
Treatment x stage	0.0008^{ns}	—

ns not significant

** Significant at 1% level

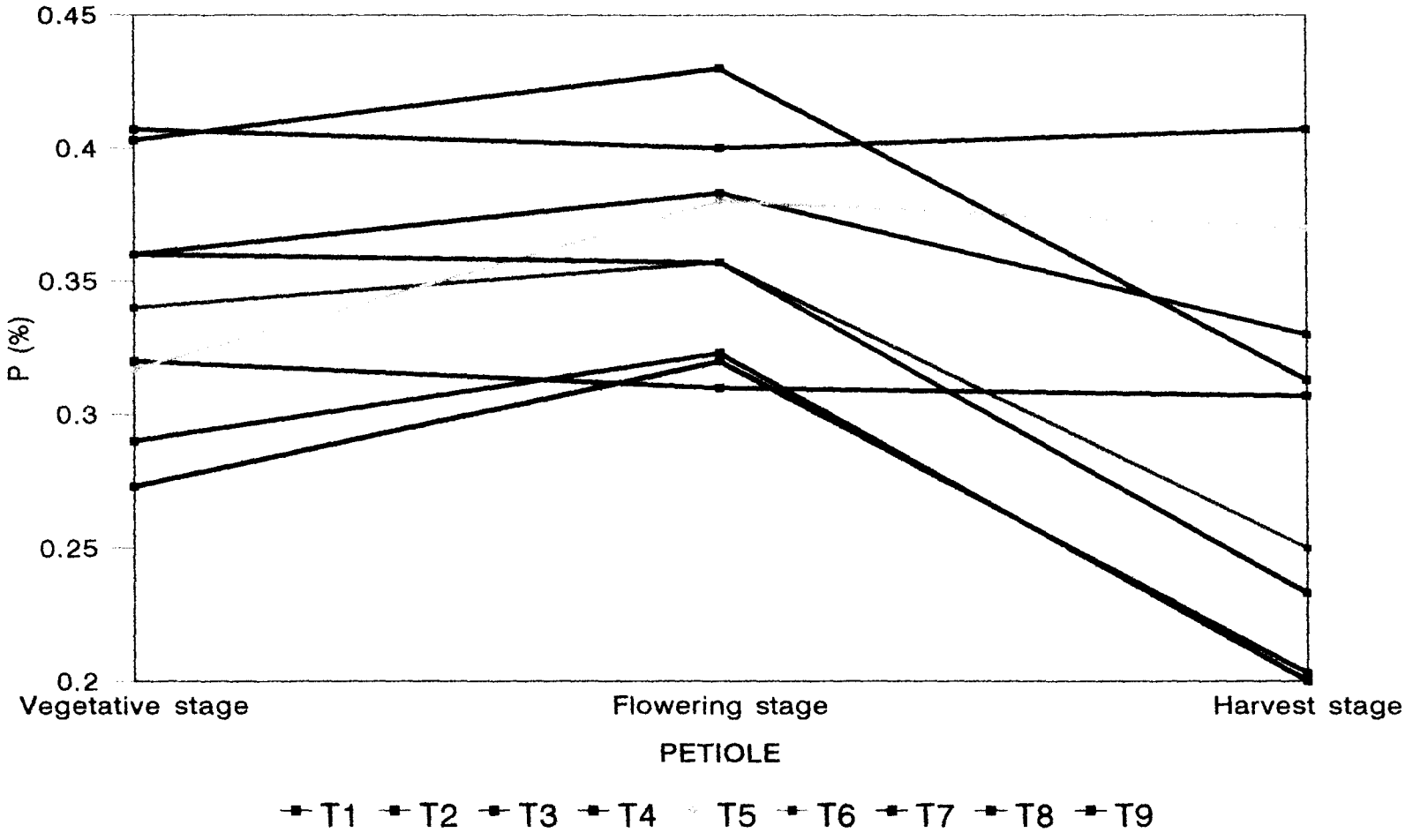


Fig. 16. P content (%) in petiole at vegetative, flowering and harvest stages of banana

Table 19. P content in midrib at differant stages (%)

Treatments	Vegetative stage	Flowering stage	Harvest stage	Pooled data
T_1	0.387	0.357	0.300	0.348
T_2	0.290	0.300	0.217	0.269
T_3	0.247	0.237	0.187	0.223
T_4	0.403	0.353	0.307	0.354
T_5	0.287	0.293	0.213	0.264
T_6	0.240	0.260	0.217	0.239
T_7	0.207	0.217	0.157	0.193
T_8	0.307	0.277	0.207	0.263
T_9	0.260	0.247	0.173	0.227
Mean	0.292	0.282	0.220	
F	224.58**	43.19**	41.18**	
SE	0.004	0.008	0.008	
CD	0.013	0.022	0.024	

Pooled ANOVA

	F	CD
Treatment	0.018ns	
Stage	0.011ns	
Treatment x stage	0.003ns	

ns not significant

** Significant at 1% level

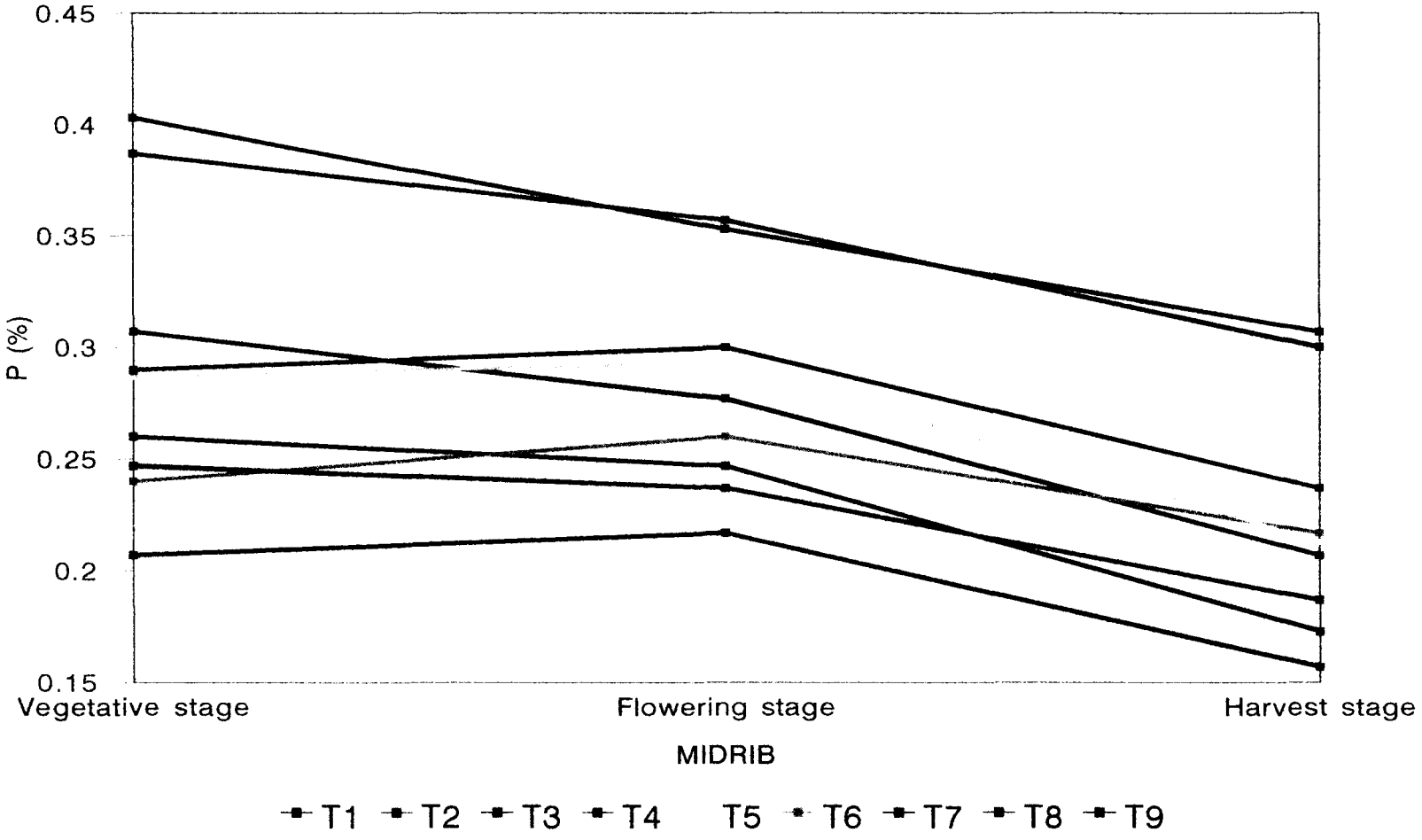


Fig. 17. P content (%) in midrib at vegetative, flowering and harvest stages of banana

Midrib

The P content in the midrib showed a slight decrease from vegetative stage and it ranged from a mean value of 0.292 at the vegetative to 0.220% at harvest stage. There was significant difference in P content of midrib due to the different treatments. Treatment T_4 recorded the maximum P concentration of 0.403% at the vegetative stage followed by T_1 (0.387%) and T_8 (0.307%). As in the above case, the midrib in T_1 at flowering stage showed the highest P content (0.357%) which was not significantly different from T_4 (0.353%). All the other treatments showed only much lower values.

At the shooting stage, the P content of midrib of plants in T_4 was on par with T_1, the values being 0.353% and 0.357% respectively. At harvest stage also T_4 continued to record the highest P content of 0.307%. Data on pooled analysis also showed the superior effect of T_4 over the other treatments in maintaining a higher P content.

Leaf blade

As seen from table 20 significant difference in P content of leaf blade was evident due to the different treatments. At all stages the highest P content was recorded in treatment T_4 which was closely followed by T_1.

Table 20. P content in leaf blade at different stages (%)

Treatments	Vegetative stage	Flowering stage	Harvest stage	Pooled data
T_1	0.413	0.397	0.347	0.386
T_2	0.333	0.347	0.227	0.386
T_3	0.237	0.233	0.110	0.193
T_4	0.417	0.420	0.377	0.404
T_5	0.333	0.360	0.330	0.341
T_6	0.300	0.277	0.200	0.259
T_7	0.277	0.250	0.153	0.227
T_8	0.323	0.300	0.210	0.278
T_9	0.243	0.250	0.173	0.222
Mean	0.320	0.315	0.236	
F	60.08**	0.204.07**	370.75**	
SE	0.008	0.005	0.005	
CD	0.025	0.014	0.015	

Pooled ANOVA

	F	CD
Treatment	0.02ns	—
Stage	0.01ns	—
Treatment x stage	0.004ns	—

ns not significant

** Significant at 1% level

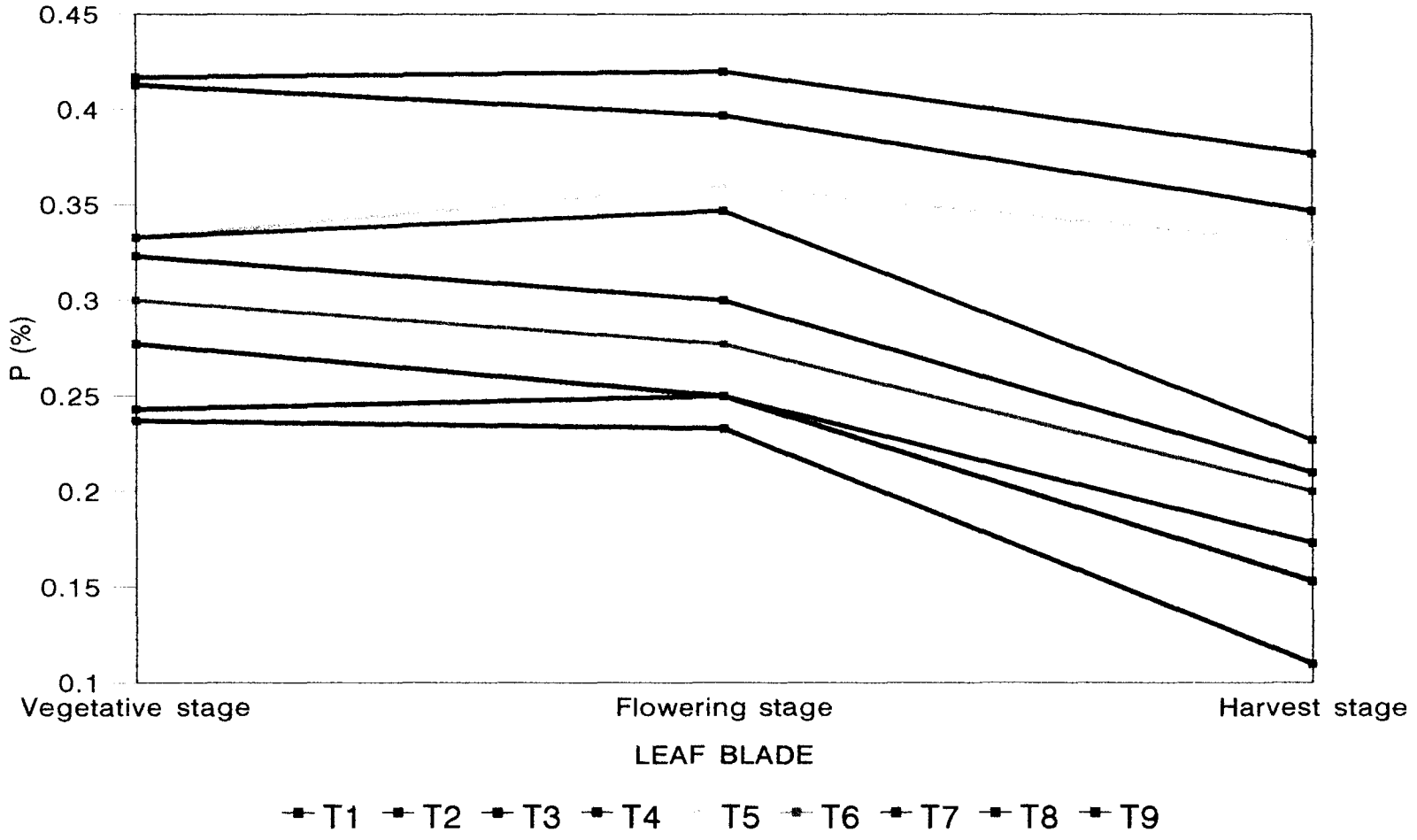


Fig. 18. P content (%) in leaf blade at vegetative, flowering and harvest stages of banana

The lowest P concentration at all stages was recorded in T_3, where only 1/2 level of recommended P was given without PB inoculation. There was significant difference in P content of lamina at different stages and it did not vary much between the vegetative and shooting stages (0.320 and 0.315%) and recorded a lower value of (0.236%) at harvest stage. The same pattern was revealed by the other treatments also with respect to the P content in the leaf blade.

Pooled analysis of the data has revealed the superiority of treatment T_4 over the other treatments in maintaining a higher level of P in the leaf blade.

Flower

Results presented in table 21 reveal that there was significant difference in the P content of flower between various treatments. The highest P content of 0.283 % was present in T_4. The treatments T_6 and T_7, where PB was applied without FYM recorded comparatively lower P content (0.193 and 0.173% respectively) when compared to the corresponding treatments with FYM.

Fruit

Table 21 shows the P content of mature banana fruits. There was significant difference between treatments and the highest P content of 0.453% was recorded in T_4 which was significantly superior to all the other treatments followed by T_8 (0.420%). T_1 and T_5 were on par and the values ranged from 0.283 in T_3 to 0.450% in T_4.

Table 21. P content in flower and fruit (%)

Treatment	Flower	Fruit
T_1	0.227	0.403
T_2	0.187	0.353
T_3	0.153	0.283
T_4	0.283	0.453
T_5	0.207	0.403
T_6	0.193	0.337
T_7	0.173	0.310
T_8	0.250	0.420
T_9	0.227	0.400
F	99.59**	200.10**
SE	0.040	0.004
CD	0.012	0.012

** Significant at 1% level

Pseudostem

As seen from table 22, there was significant difference in the P content of the pseudostem due to the different treatments at the three stages of growth of banana plant. Both at the shooting and harvest stages, the maximum P content of 0.470 and 0.413% was recorded in T_4. But at the vegetative stage, eventhough T_1 recorded the highest value 0.436, which was on par with T_4 having a P content of 0.423%. The average value for P content of pseudostem increased from 0.281% at the vegetative to 0.321% at the shooting stage and then decreased to a lower value of 0.280% at the harvest stage.

Data on pooled analysis also showed a significant influence of the inputs in T_4 on the P content in pseudostem compared to the other treatments.

Rhizome

Table 23 presents the data on P content in rhizome. There was significant difference in P content of banana due to the effect of different treatments. The rhizomes in treatment T_4 recorded the highest P content at all the three stages of growth. Significant difference in P content was evident at the three stages also. It decreased from 0.321% at the vegetative to 0.285% at the shooting stage and then increased to 0.390% at the harvest stage.

Table 22. P content in pseudostem at different stages (%)

Treatments	Vegetative stage	Flowering stage	Harvest stage	Pooled data
T_1	0.436	0.433	0.357	0.409
T_2	0.243	0.340	0.273	0.286
T_3	0.133	0.157	0.133	0.141
T_4	0.423	0.470	0.413	0.436
T_5	0.347	0.377	0.337	0.353
T_6	0.236	0.273	0.250	0.253
T_7	0.203	0.253	0.207	0.221
T_8	0.280	0.313	0.300	0.298
T_9	0.227	0.273	0.253	0.251
Mean	0.281	0.321	0.280	
F	466.85^{**}	159.53^{ns}	545.01^{ns}	
SE	0.005	0.008	0.004	
CD	0.014	0.023	0.011	

Pooled ANOVA

	F	CD
Treatment	0.01^{ns}	—
Stage	0.03^{ns}	—
Treatment x stage	0.0004^{ns}	—

ns not significant

** Significant at 1% level

Table 23. P content in rhizome at different stages (%)

Treatments	Vegetative stage	Flowering stage	Harvest stage	Pooled data
T_1	0.390	0.307	0.423	0.373
T_2	0.263	0.283	0.383	0.310
T_3	0.240	0.253	0.323	0.272
T_4	0.423	0.347	0.487	0.419
T_5	0.333	0.287	0.367	0.329
T_6	0.303	0.257	0.390	0.317
T_7	0.280	0.200	0.340	0.273
T_8	0.357	0.327	0.430	0.371
T_9	0.303	0.303	0.370	0.326
Mean	0.321	0.285	0.390	
F	88.845**	191.804**	63.72**	
SE	0.006	0.003	0.006	
CD	0.019	0.009	0.019	

Pooled ANOVA

	F	CD
Treatment	0.01^{ns}	
Stage	0.03^{ns}	—
Treatment x stage	0.0004^{ns}	—

ns not significant

** Significant at 1% level

The data on pooled analysis also revealed the superior effect of T_4 on increasing the P content of rhizome over the other treatments.

P uptake in various plant parts of banana

P uptake in the differently treated plants at the three stages computed by multiplying the per cent P content in each plant part with the corresponding dry matter produced are presented in tables 24 to 31.

Petiole

Significant difference was observed in the P uptake of petiole in banana due to the different treatments. P uptake was highest at the shooting and least at the harvest stage. The highest P uptake of 0.387 g was recorded in T_4 at the vegetative stage, where as the same treatment recorded an uptake of only 0.200 g at the harvest stage. At shooting, the highest uptake of 0.963 g was recorded in treatment T_1, which was on par with T_4 (0.960 g). The average P content increased from 0.243 g from vegetative to 0.790 g at shooting and then declined to 0.120 g at harvest stage. Pooled analysis also revealed the superiority of T_4 over other treatments in promoting a high uptake of P in the petiole.

Midrib

As evident from table 25, the treatment effects were significant in increasing the P uptake in midrib also. As in the case of petiole, the average values were highest (0.599g) at the shooting stage followed by vegetative (0.219g) and harvest stages (0.145g).

Table 24. P uptake in petiole (g plant^{-1}) at different stages

Treatments	Vegetative stage	Flowering stage	Harvest stage	Pooled data
T_1	0.290	0.963	0.147	0.467
T_2	0.250	0.703	0.083	0.346
T_3	0.193	0.687	0.063	0.314
T_4	0.387	0.960	0.200	0.516
T_5	0.237	0.857	0.157	0.417
T_6	0.190	0.783	0.100	0.358
T_7	0.147	0.617	0.063	0.276
T_8	0.270	0.820	0.163	0.418
T_9	0.227	0.717	0.107	0.350
Mean	0.243	0.790	0.120	
F	173.10**	13.21**	68.46**	
SE	0.005	0.033	0.006	
CD	0.016	0.100	0.018	

Pooled ANOVA

	F	CD
Treatment	1.08^{ns}	—
Stages	0.02^{ns}	—
Treatment x stage	0.002^{ns}	—

ns not significant

** Significant at 1% level

Table 25. P uptake in midrib (g plant^{-1}) at different stages

Treatments	Vegetative stage	Flowering stage	Harvest stage	Pooled data
T_1	0.323	0.790	0.213	0.442
T_2	0.243	0.587	0.153	0.328
T_3	0.200	0.520	0.093	0.271
T_4	0.337	0.840	0.223	0.467
T_5	0.227	0.643	0.153	0.341
T_6	0.127	0.510	0.143	0.260
T_7	0.087	0.370	0.077	0.178
T_8	0.250	0.630	0.153	0.341
T_9	0.177	0.507	0.097	0.260
Mean	0.219	0.599	0.145	
F	566.16**	95.64**	35.43**	
SE	0.004	0.015	0.009	
CD	0.010	0.045	0.026	

Pooled ANOVA

	F	CD
Treatment	0.510^{ns}	—
Stage	0.02^{ns}	—
Treatment x stage	0.002^{ns}	—

ns not significant

** Significant at 1% level

Midrib in the treatment T_4 recorded the maximum P uptake at all the three stages followed by T_1, which recorded only a significantly lower value. All the other treatments indicated much lower values.

The superior effect of T_4 was pronounced in the data on pooled analysis also.

Leaf blade

The effect of treatments was significant on the uptake of P in the leaf blade (Table 26). Here also the pattern of P uptake was similar to that in the other two plant parts. The highest P uptake of 0.833 g P was recorded in T_1 at the vegetative stage, which was on par with the P uptake in T_4 (0.777g). But at the shooting and harvest stages the highest P uptake was recorded in T_4 (2.901 and 0.743 g respectively) which was closely followed by T_1. Average P uptake increased from 0.537 g at the vegetative stage to 1.808 g at shooting which then declined to 0.390 g at harvest stage. Highest P uptake was noticed in the leaf blade compared to the petiole and lamina.

On pooled analysis, the effect of treatment was not found significant. But the relative superiority of T_4, a combination of MRP, PB and FYM was evident from the data.

Table 26. P uptake in leaf blade (g plant^{-1}) at different stages

Treatments	Vegetative stage	Flowering stage	Harvest stage	Pooled data
T_1	0.833	2.313	0.583	1.243
T_2	0.597	1.900	0.377	0.958
T_3	0.427	1.167	0.130	0.574
T_4	0.777	2.901	0.743	1.476
T_5	0.530	1.813	0.593	0.979
T_6	0.360	1.550	0.240	0.716
T_7	0.296	1.377	0.173	0.616
T_8	0.607	1.807	0.373	0.616
T_9	0.403	1.440	0.297	0.713
Mean	0.537	1.808	0.390	
F	54.98**	294.48**	502.37**	
SE	0.025	0.031	0.009	
CD	0.075	0.093	0.028	

Pooled ANOVA

	F	CD
Treatment	8.75**	0.373
Stage	0.43ns	
Treatment x stage	0.06ns	—

ns not significant

** Significant at 1% level

Flower

Significant difference between treatment in P uptake was noticed here also. The highest P uptake of 0.700 g was recorded in T_4 which was followed by T_8 (0.610g). All the other treatments resulted in only much lower accumulation of P in the flower (Table 27).

Pseudostem

From table 28, it may be seen that P uptake in pseudostem differed significantly due to the different treatments. The treatment T_4 recorded the highest uptake of 1.940 g at vegetative, 8.217 g at shooting and 7.176 g at harvest stage, which was followed by the treatment T_1 and T_5 at all the stages. There was an increase in P uptake from 1.081 g at vegetative to 5.381 g at shooting which then declined to a lower level of 4.687 g P per plant at the harvest stage. The data on pooled analysis also revealed the superiority of T_4 even though it was not significantly greater than the other treatments.

Rhizome

The treatment effect was significant and the highest P uptake at all the stages was recorded in T_4 (Table 29). The rhizome recorded an uptake of 2.183 g at vegetative stage, 5.043 g at shooting and 1.940 g at the time of harvest.

Table 27. P uptake in flower and fruit (g plant^{-1}) at different stages

Treatments	Flower	Fruit
T_1	0.378	13.18
T_2	0.373	11.20
T_3	0.307	8.40
T_4	0.700	14.99
T_5	0.453	13.28
T_6	0.427	9.89
T_7	0.257	7.83
T_8	0.610	12.78
T_9	0.523	10.51
F	342.44**	59.25**
SE	0.008	0.312
CD	0.023	0.937

** Significant at 1% level

Table 28. P uptake in pseudostem (g plant $^{-1}$) at different stages

Treatments	Vegetative stage	Flowering stage	Harvest stage	Pooled data
T_1	1.813	7.887	6.453	5.384
T_2	1.006	5.653	4.620	3.760
T_3	0.550	2.413	2.190	1.718
T_4	1.940	8.217	7.176	5.778
T_5	1.430	6.547	5.466	4.478
T_6	0.680	4.427	4.053	3.053
T_7	0.533	3.993	3.210	2.559
T_8	1.043	5.050	5.203	3.766
T_9	0.733	4.307	3.827	2.956
Mean	1.081	5.388	4.689	
F	309.95**	307.35**	63.26**	
SE	0.030	0.108	0.197	
CD	0.091	0.325	0.592	

Pooled ANOVA

	F	CD
Treatment	71.50**	0.386
Stage	7.81**	0.669
Treatment x stage	0.79ns	—

ns not significant

** Significant at 1% level

Table 29. P uptake in rhizome (g plant^{-1}) at different stages

Treatments	Vegetative stage	Flowering stage	Harvest stage	Pooled data
T_1	1.163	4.387	1.813	3.308
T_2	1.260	3.553	1.006	2.661
T_3	1.237	2.653	0.550	2.169
T_4	2.183	5.043	1.940	3.841
T_5	1.590	3.460	1.430	2.803
T_6	1.406	3.350	0.680	2.393
T_7	1.163	2.517	0.533	1.828
T_8	1.707	3.940	1.043	3.140
T_9	1.333	2.960	0.733	2.286
Mean	1.541	3.540	3.061	
F	114.77**	68.80**	309.95**	
SE	0.003	0.079	0.030	
CD	1.00	0.236	0.091	

Pooled ANOVA

	F	CD
Treatment	13.98**	0.395
Stage	1.70ns	—
Treatment x stage	0.11ns	—

ns not significant

** Significant at 1% level

The average effect of all treatments at the vegetative stage was 1.541 g which increased to 3.540 g at shooting and then decreased to 3.061 g at harvest. Though the interaction effect of treatments and stages was not significant, the superiority of T_4 over other treatments was evident on pooled analysis of the data.

Fruit

The P uptake of mature fruits (Table 27) in the different treatments varied between 7.83g in T_7 to 14.99g and was highest in T_4 (14.99g). This was followed by T_5 (13.28) which was on par with T_1 (13.18). The treatments are thus seen to affect significantly the uptake of P by banana fruit.

The results on the data on P uptake by different plant parts show that in general, the highest P uptake in almost all the plant parts was recorded in T_4 and was significantly superior to T_1. T_6 and T_7 which received no FYM along with MRP and PB recorded lower values when compared to the corresponding treatments receiving FYM (T_8 and T_9).

Total P uptake

The total P uptake of banana plants at the different stages of growth are presented in tables 30 and 31 and figures 19 to 21. There was significant difference in the total P uptake by the banana plant due to the different treatments. The treatment T_4 ranked first at the three stages of growth.

Table 30. Total P uptake (g plant^{-1}) at different stages

Treatments	Vegetative stage	Flowering stage	Harvest stage	Pooled data
T_1	5.253	16.720	24.116	15.365
T_2	3.357	12.770	19.600	11.909
T_3	2.606	7.746	13.497	7.950
T_4	5.750	18.666	27.626	17.348
T_5	4.016	13.773	23.000	13.596
T_6	2.753	11.046	16.850	10.216
T_7	2.226	9.070	13.156	8.151
T_8	3.876	12.923	22.683	13.161
T_9	2.873	10.453	17.400	10.242
Mean	3.635	12.57	19.770	
F	441.19**	559.65**	22.18**	
SE	0.057	0.148	0.329	
CD	0.173	0.444	0.989	

Pooled ANOVA

	F	CD
Treatment	149.35**	0.935
Stage	7.744**	11.620
Treatment x stage	4.48**	2.806

** Significant at 1% level

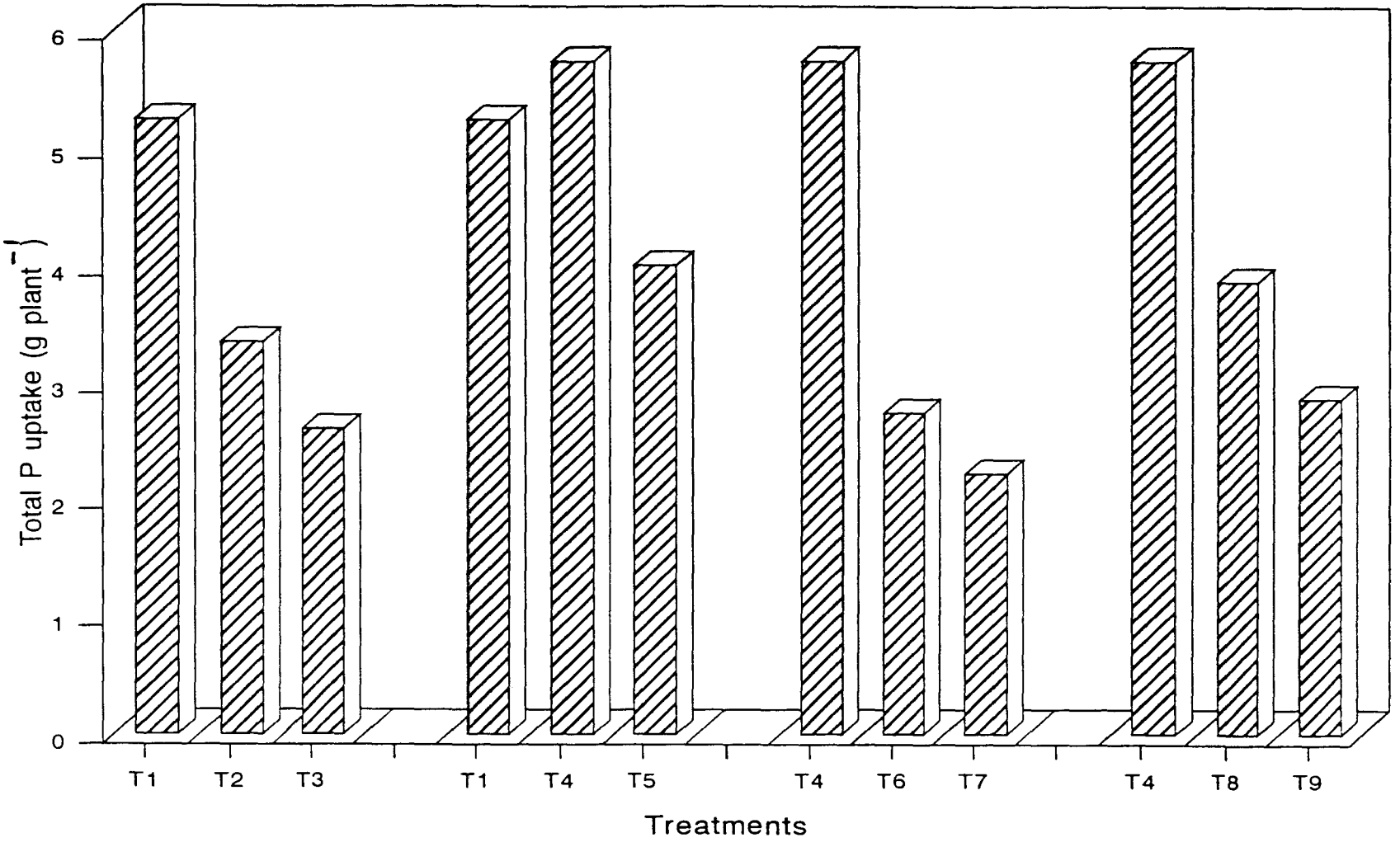


Fig. 19. Total P uptake (g plant^{-1}) at vegetative stage

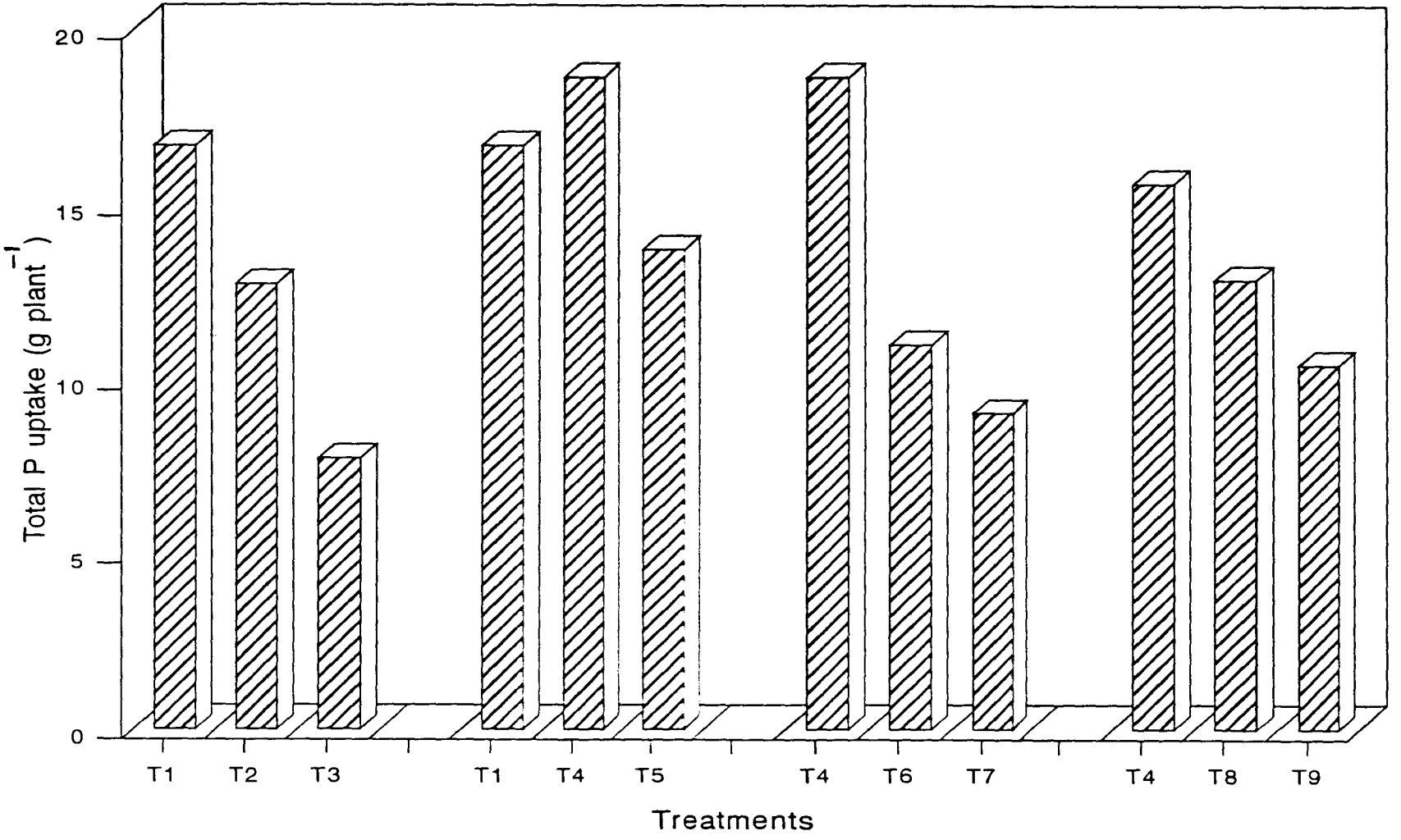


Fig. 20. Total P uptake (g plant^{-1}) at flowering stage

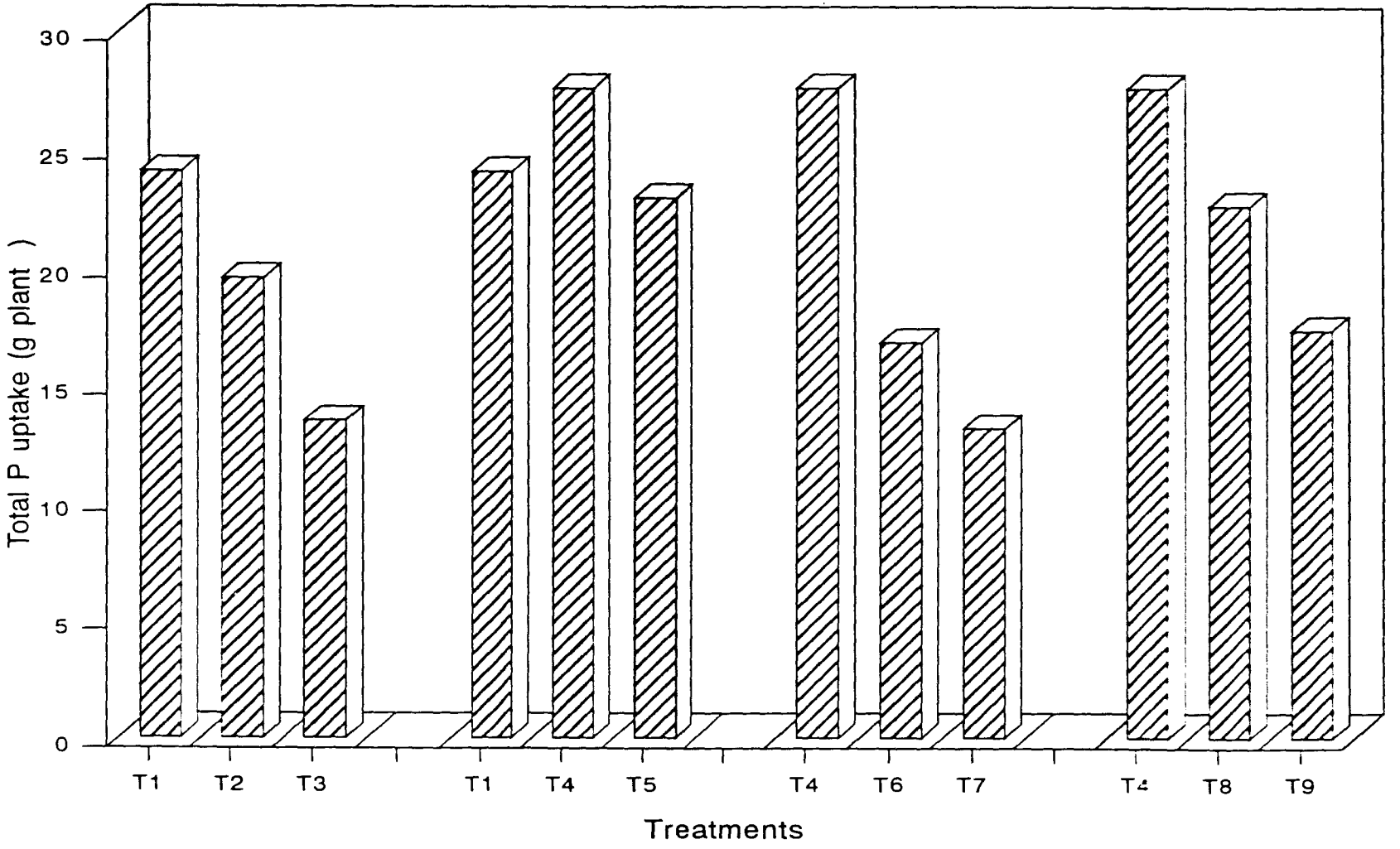


Fig. 21. Total P uptake (g plant^{-1}) at harvest stage

Table 31. Total P uptake (kg ha^{-1}) at different stages

Treatments	Vegetative stage	Flowering stage	Harvest stage	Pooled data
T_1	13.133	41.820	60.293	38.416
T_2	8.393	31.926	49.003	29.774
T_3	6.517	19.370	33.743	19.876
T_4	14.377	46.670	69.070	43.372
T_5	10.043	34.433	57.503	33.993
T_6	6.887	27.593	42.127	25.535
T_7	5.570	22.677	32.877	20.374
T_8	9.699	32.310	56.710	32.905
T_9	7.187	26.133	43.503	25.607
Mean	9.089	31.437	49.426	
F	440.65**	553.47**	226.33**	
SE	0.144	0.373	0.824	
CD	0.433	1.117	2.471	

Pooled ANOVA

	F	CD
Treatment	149.24**	2.339
Stage	7.74**	0.052
Treatment x stage	25.43**	7.018

** Significant at 1% level

In this treatment, the highest P uptake of 5.750 g per plant was recorded at the vegetative stage, 18.666 g at shooting and 27.626 g at harvest stage. The use of 3/4 and 1/2 level of recommended P when applied without PB (T_2 and T_3) recorded lower values when compared to the treatments with same level of P but applied along with PB, FYM and mulch (T_4 and T_5).

Application of 3/4 and 1/2 level of P along with PB but without the addition of FYM recorded significantly lower values when compared to the same treatments applied along with FYM. Pooled analysis showed the superiority of T_4 over other treatments but there was no significant difference between treatments as far as the total P uptake by the whole plant was considered.

Quality of Fruits

Table 32 furnishes different parameters related to the quality of banana fruits.

Total soluble solids

Fruits in the treatment T_4 recorded the highest content of total soluble solids (24.37%) which was on par with T_1 (24.00%). There was significant difference between the treatments with respect to this character. The values in the other treatments ranged from 18.20% in T_8 to 23.17% in T_2.

Table 32. Quality parameters of ripe banana fruits

Treatments	Total soluble solids (%)	Titratable acidity (%)	Reducing sugars (%)	Total sugars (%)	Non-reducing sugars (%)	Sugar-acid ratio	Protein (%)
T_1	24.00	0.204	10.19	16.73	6.53	49.95	8.44
T_2	23.17	0.309	10.83	16.16	5.33	35.10	8.24
T_3	19.33	0.414	10.48	14.25	3.77	25.31	8.90
T_4	24.37	0.215	11.24	17.51	6.30	52.40	8.43
T_5	23.03	0.234	11.96	17.24	5.30	51.27	8.80
T_6	21.20	0.218	10.08	15.38	5.30	40.28	8.09
T_7	20.13	0.217	9.85	14.41	4.40	45.27	8.08
T_8	18.20	0 215	10.42	15.12	4.70	37.57	8.11
T_9	20.63	0.204	10.26	15.39	5.13	47.38	8.18
F	265.80**	326.38**	15.25**	85.19**	188.48**	59.39**	7.53**
SE	0.133	0.004	0.169	0.128	0.063	1.162	0.112
CD	0.400	0.011	0.505	0.383	0.189	3.484	0.337

** Significant at 1% level

Titrable acidity

There was significant difference between treatments in the content of total acids in ripe banana. Maximum acidity (0.414%) was recorded in T_3 followed by T_2 (0.309%). T_4 and T_1 were on par. The values in the various treatments ranged from 0.204 to 0.414%

Reducing sugars

The value of reducing sugars varied from 9.85 to 11.96 % and the highest value was recorded in T_5. This was followed by T_4 (11.24%). T_6 and T_7 recorded the lowest value of 9.85%.

Total sugars

The total sugar content including reducing and non reducing sugars in ripe banana fruits varied from 14.25 in T_3 to 17.51% in T_4. The treatment T_4 recorded the highest sugar content follwed by T_5. Half level of P without PB (T_3) and with PB without FYM (T_7) recorded the lowest total sugar content.

Non reducing sugars

The non reducing sugar content in ripe banana fruits ranged from 3.77 to 6.53 %. The highest content was recorded for T_1 (6.53%) followed by T_4 (6.30%). Non reducing sugar content in T_5, T_6 and T_9 were on par.

The sugar acid ratio

The sugar acid ratio was highest (52.40) in T_4 followed by T_5 (51.27) The values ranged from 25.31 (T_3) to 52.40 (T_4).

Protein content

The protein content ranged from 8.08 in T_7 to 8.80% in T_5. The highest value of 8.80 was recorded in T_5.

SOIL ANALYSIS

Soil pH

The variation in soil pH in the banana pits at monthly intervals presented in table 33 revealed a significant reduction in pH after the first month. The mean pH decreased to 5.5 from the initial pH of 6.2 which was further lowered to 5.2 at the end of the sixth month. After the sixth month, though a significant increase in pH was noticed it was only 0.7 units less than the initial pH. The mean pH value of the different treatments for the ninth month period revealed a significant difference between treatments. The pH was highest in T_6 and T_7 (6.0) and lowest in T_4 and T_5 (5.5).

Over the entire period of growth, the lowest pH value of 4.6 was registered in T_9 followed by T_4 (4.9) at the end of six months. The highest value of 6.8 after first month of planting was noticed in the control plot (6.8). All the treatments followed a more or less similar trend, as far as lowering of pH value is concerned. The interaction effect between period and treatment was significant.

Table 33. Soil pH in banana pits at monthly intervals

Treatments	M0	M½	M1	M2	M3	M4	M5	M6	M7	Mean
T_1	5.7	6.3	6.8	6.3	5.3	5.4	5.3	5.5	6.1	5.8
T_2	5.7	6.2	6.5	6.1	5.7	5.6	5.3	5.2	5.3	5.8
T_3	6.3	6.3	6.6	6.3	5.4	5.7	5.3	5.2	5.3	5.8
T_4	6.4	6.1	6.0	5.5	5.2	5.3	5.1	4.9	5.1	5.5
T_5	6.3	6.3	6.1	5.3	5.1	5.0	4.9	5.1	5.2	5.5
T_6	6.3	6.4	6.4	6.2	6.2	6.0	5.4	5.6	5.8	6.0
T_7	6.1	6.5	6.4	6.6	5.3	5.8	5.5	5.8	6.0	6.0
T_8	6.3	6.2	6.0	6.4	5.4	5.6	5.2	5.1	4.6	5.0
T_9	6.5	6.5	6.3	6.3	5.6	5.2	5.1	4.6	5.0	5.7
Mean	6.2	6.3	6.3	6.1	5.5	5.5	5.2	5.2	5.5	

	T	P	TP
F	2.28^{ns}	7.66^{**}	1.19^{ns}
SE	0.064	0.067	0.176
CD	—	0.185	—

T - Treatment
P - Period
TP - Treatment x period
ns - Not significant
** - Significant at 1% level

M0 - Before planting
M½ - 15 DAP
M1 - 30 DAP
M2 - 60 DAP
M3 - 90 DAP
M4 - 120 DAP
M5 - 150 DAP
M6 - Flowering stage
M7 - Harvest stage

Available phosphorus

Data on available P extracted from the soil of banana growing pits before planting, after the application of fertilizers and after inoculation with PB are presented in tables 34 and 35.

The results indicate a significant effect of treatments on available P at monthly intervals and their interaction with different periods. The average effect of treatments at the different periods of sampling indicated a gradual rise in available P status from the time of planting up to the fourth month reaching a maximum of 11.40ppm which then declined to a lowest value of 7.44ppm at harvest time.

The mean values for available P in the various treatments were highest and on par for treatments T_1 and T_4 (9.25 and 9.21ppm) suggesting the influence of PB in maintaining a high level of available P in the soil inspite of the lower level of total P applied. This was followed by treatments T_8 and T_6 where PB inoculation was made along with a lower level of P only.

Highest content of available P, irrespective of the treatments was noticed at the end of the fourth month in all the treatments. The status of available P in treatments where full level of P was applied was more or less similar to the treatments where 3/4 level of P with PB was applied and did not reveal any significant difference. The interaction effect was also maximum during the fourth month after which the available P content declined in all the treatments. The level of available P in all treatments at the time of harvest was much higher than the initial level of P.

Table 34. Available P in banana pits (ppm) at monthly intervals

Treatments	M0	M½	M1	M2	M3	M4	M5	M6	M7	Mean
T_1	2.48	4.28	6.48	8.16	10.15	15.18	14.87	11.70	9.81	9.25
T_2	2.28	3.82	5.04	6.42	7.28	10.36	9.38	6.61	6.61	6.42
T_3	2.46	3.27	3.50	4.87	5.94	7.63	7.41	5.68	4.76	5.06
T_4	2.37	3.67	6.65	8.56	9.80	15.34	14.57	11.49	10.42	9.21
T_5	2.33	3.33	5.03	6.67	7.57	11.33	10.93	10.17	6.67	7.05
T_6	2.65	3.96	5.93	5.42	8.73	11.44	10.64	8.11	9.31	7.49
T_7	2.40	3.53	4.13	5.43	6.52	6.77	6.70	6.56	5.06	5.23
T_8	2.58	3.82	6.36	7.28	9.45	15.10	12.54	9.29	8.40	8.30
T_9	2.23	3.27	4.55	5.92	7.74	9.34	7.80	6.46	5.91	5.89
Mean	2.42	3.60	5.30	6.61	8.10	11.40	10.53	8.41	7.44	

	T	P	TP
F	138.48**	726.19**	13.47**
SE	0.090	0.074	0.221
CD	0.271	0.204	0.612

T - Treatment
P - Period
TP - Treatment x period
ns - Not significant
** - Significant at 1% level

M0 - Before planting
M½ - 15 DAP
M1 - 30 DAP
M2 - 60 DAP
M3 - 90 DAP
M4 - 120 DAP
M5 - 150 DAP
M6 - Flowering stage
M7 - Harvest stage

Table 35. Available P in banana pits (kg ha^{-1}) at monthly intervals

Treatments	M0	M½	M1	M2	M3	M4	M5	M6	M7	Mean
T_1	5.56	9.58	14.51	18.27	22.74	34.40	33.30	26.21	21.97	20.72
T_2	5.10	8.56	11.30	14.39	16.31	23.21	21.02	14.81	14.80	14.39
T_3	5.52	7.33	7.84	10.90	13.31	17.10	16.59	12.72	10.67	11.33
T_4	5.31	8.22	14.90	19.17	21.96	34.37	32.63	25.73	23.35	20.63
T_5	5.21	7.46	11.27	13.62	16.96	25.37	24.49	22.78	14.93	15.79
T_6	5.93	8.87	13.28	14.95	19.56	25.57	23.84	18.17	20.86	16.78
T_7	5.38	7.91	9.26	12.17	14.60	15.16	15.00	14.69	11.33	11.72
T_8	5.79	8.57	14.25	16.30	21.17	33.83	27.86	20.80	18.82	18.60
T_9	5.00	7.33	10.20	13.46	16.67	20.93	17.48	14.48	13.23	13.20
Mean	5.42	8.20	11.87	14.80	18.14	25.55	23.58	18.93	16.66	

	T	P	TP
F	310.20**	1626.65**	30.17**
SE	0.202	0.165	0.494
CD	0.607	0.457	1.370

** - Significant at 1% level

M0 - Before planting

M½ - 15 DAP

M1 - 30 DAP

M2 - 60 DAP

M3 - 90 DAP

M4 - 120 DAP

M5 - 150 DAP

M6 - Flowering stage

M7 - Harvest stage

T - Treatment

P - Period

TP - Treatment x period

Indexing of plant part in banana for P status

Results of analysis of the specified area of different plant parts such as lamina, petiole and midrib of the third leaf collected at monthly intervals from third month onwards to harvest are presented in table 36.

Invariably, petiole registered the highest content of P (average value) during all periods of observation followed by the lamina and midrib. All values increased up to the sixth month and then declined registering minimum values at the end of ninth month.

Third month

The P content of lamina, midrib and petiole were on par in T_1 which shows that P was uniformly distributed in the leaf. In the other treatments slight differences were noticed.

Fourth month

There was significant difference in the P content of lamina, midrib and petiole in treatments T_1, T_2, T_6 and T_7. Here also, petiole registered the highest P content in seven treatments whereas lamina recorded the highest P content in T_4 and T_5 only.

Fifth month

Significant difference in P content was noticed between the plant parts, in all treatments except T_8 and T_9. Petiole recorded the highest P content in eight treatments.

Table 36. P content in the different parts of the third leaf (%)

	Third month				Fourth month			
	Lamina	Midrib	Petiole	Mean	Lamina	Midrib	Petiole	Mean
T_1	0.413	0.387	0.403	0.401	0.440	0.417	0.443	0.433
T_2	0.333	0.290	0.360	0.328	0.337	0.320	0.380	0.346
T_3	0.237	0.247	0.290	0.258	0.243	0.253	0.303	0.267
T_4	0.417	0.403	0.407	0.409	0.460	0.430	0.437	0.442
T_5	0.333	0.287	0.317	0.312	0.350	0.310	0.333	0.331
T_6	0.300	0.240	0.340	0.293	0.313	0.277	0.360	0.317
T_7	0.277	0.207	0.273	0.252	0.290	0.243	0.303	0.279
T_8	0.323	0.307	0.360	0.330	0.343	0.340	0.390	0.358
T_9	0.243	0.260	0.327	0.277	0.280	0.283	0.357	0.307
Mean	0.320	0.292	0.342		0.340	0.319	0.367	
	T	P	TP		T	P	TP	
F	355.52**	114.40**	10.06**		322.17**	126.56**	9.01**	
SE	0.003	0.002	0.007		0.003	0.002	0.006	
CD	0.009	0.007	0.020		0.010	0.006	0.018	

T - Treatments TP - Treatment x parts

P - Parts ** - Significant at 1% level

Contd...

Table 36. (Contd....)

	Fifth month				Sixth month			
	Lamina	Midrib	Petiole	Mean	Lamina	Midrib	Petiole	Mean
T_1	0.463	0.427	0.467	0.452	0.483	0.437	0.490	0.470
T_2	0.360	0.337	0.400	0.366	0.400	0.347	0.413	0.387
T_3	0.273	0.300	0.343	0.306	0.290	0.310	0.357	0.319
T_4	0.460	0.433	0.463	0.452	0.467	0.447	0.480	0.464
T_5	0.383	0.350	0.373	0.369	0.403	0.350	0.387	0.380
T_6	0.333	0.310	0.387	0.343	0.357	0.333	0.400	0.363
T_7	0.303	0.277	0.327	0.302	0.310	0.290	0.347	0.316
T_8	0.383	0.373	0.413	0.390	0.403	0.390	0.433	0.409
T_9	0.297	0.283	0.373	0.318	0.317	0.310	0.393	0.340
Mean	0.362	0.343	0.394		0.381	0.357	0.411	
	T	P	TP		T	P	TP	
F	384.16**	20.18**	10.94**		299.73**	349.54	15.13**	
SE	0.003	0.002	0.002		0.003	0.001	0.004	
CD	0.009	0.005	0.015		0.010	0.004	0.012	

T - Treatments TP - Treatment x parts

P - Parts ** - Significant at 1% level

Contd...

Table 36. (Contd....)

	Seventh month				Nineth month			
	Lamina	Midrib	Petiole	Mean	Lamina	Midrib	Petiole	Mean
T_1	0.397	0.357	0.430	0.394	0.347	0.297	0.313	0.319
T_2	0.347	0.300	0.357	0.334	0.227	0.217	0.233	0.226
T_3	0.233	0.237	0.323	0.264	0.110	0.187	0.200	0.166
T_4	0.420	0.353	0.400	0.344	0.377	0.307	0.407	0.363
T_5	0.360	0.293	0.380	0.344	0.330	0.213	0.370	0.304
T_6	0.277	0.260	0.357	0.298	0.200	0.217	0.250	0.222
T_7	0.250	0.217	0.320	0.262	0.153	0.143	0.203	0.167
T_8	0.300	0.313	0.383	0.332	0.210	0.207	0.330	0.249
T_9	0.250	0.247	0.310	0.269	0.173	0.173	0.307	0.218
Mean	0.315	0.286	0.362		0.236	0.218	0.290	
	T	P	TP		T	P	TP	
FT	115.63**	282.28**	9.55**		217.19**	257.18**	30.31**	
SE	0.005	0.002	0.007		0.005	0.002	0.007	
CD	0.014	0.007	0.020		0.014	0.007	0.020	

T - Treatments TP - Treatment x parts

P - Parts ** - Significant at 1% level

Sixth month

The three plant parts such as lamina, midrib and petiole recorded the highest value of P in all cases except in T_5 where lamina recorded the highest P content of 0.403%.

Seventh month

The P content of midrib, lamina and petiole significantly differed in treatments T_1, T_2, T_4, T_5 and T_7. Petiole recorded the highest P content in eight treatments whereas lamina recorded the highest P content in T_4.

Nineth month

In treatments T_6, T_7, T_8 and T_9 the P content in lamina and midrib were on par. The P content of lamina, midrib and petiole in T_2 were on par. Petiole recorded the highest P content in eight out of the nine treatments.

Correlation studies

Correlation between the three parts of third leaf and yield in banana is as follows.

Lamina

The P content of lamina in the seventh month recorded the highest correlation coefficient ($r = 0.827$) and the lowest in the fourth month ($r = 0.724$) with yield (Table 37).

Table 37. Correlation between the three parts (lamina, midrib and petiole) of the third leaf and yield of banana

Plant part			Correlation coefficient
Lamina	3rd month	vs yield	0.730**
	4th month	"	0.724**
	5th month	"	0.766**
	6th month	"	0.791**
	7th month	"	0.827**
	9th month	"	0.772**
Midrib	3rd month	"	0.732**
	4th month	"	0.691**
	5th month	"	0.764**
	6th month	"	0.732**
	7th month	"	0.776**
	9th month	"	0.692**
Petiole	3rd month	"	0.692**
	4th month	"	0.624**
	5th month	"	0.682**
	6th month	"	0.656**
	7th month	"	0.792**
	9th month	"	0.593**

** Significant at 1% level

Mid rib

P content of mid rib in the seventh month recorded the highest correlation coefficient (r = 0.776) and the lowest in the fourth month (r = 0.691).

Table 38. Regression relationship of P content in the leaf parts of the third leaf on yield of banana

Regression co-effient of Y	Lamina	Midrib	Petiole
3rd month	-5.4659	4.9155	16.5687
4th month	-8.1674	-14.0831	- 4.9762
5th month	3.6841	13.3040	26.4134
6th month	6.9967	-10.9182	-37.0212
7th month	4.6892	13.3073	15.8396
9th month	-1.2383	8.6168	1.7003
Constant	4.3025	4.8186	2.8570
$F_{6,20}$	9.84**	9.07**	10.15**
Coefficient of determination R^2 %	75	73	75

Petiole

The same trend as in the leaf blade and midrib was noticed with petiole also. The correlation coefficient was highest in the seventh month (0.792) and lowest during the sixth month (r = 0.593) 75%.

It may be seen from the results that irrespective of the plant part, yield in general was influenced to the extent of 73 to 75% by the P content of the leaf. The data reveal that the P content in no particular plant part was found to be specifically influencing the yield of banana. The results presented in table 38 reveal that about 75% of the variation in yield of banana could be attributed to the P content in petiole and lamina and 73% of the same to the P content in the midrib.

Table 39 furnishes the coefficient of correlation between bunch yield and some important growth, yield and soil characters in banana.

Vegetative characters and yield

Most of the vegetative characters as given in table 39 showed positive and highly significant relationship with yield.

The plant height at the flowering stage showed the maximum relationship with yield (r = 0.792).

Girth of the plant at the base of the pseudostem measured at vegetative and flowering stages showed positive and significant association with yield, the highest being at the vegetative stage (r = 0.603).

Girth measured at 20 cm height also showed significant and positive correlation with yield at the three stages, the highest being (0.672) at the vegetative stage.

Table 39. Coefficients of correlation between some important crop characters and yield

Character		Correlation coefficient
Plant height at vegetative stage	vs yield	0.671**
Plant height at flowering stage	"	0.792**
Plant height at harvest stage	"	0.737**
Girth at base at vegetative stage	"	0.603**
Girth at base at flowering stage	"	0.468*
Girth at base at harvest stage	"	0.351
Girth 20 cm height at vegetative stage	"	0.672**
Girth 20 cm height at flowering stage	"	0.513**
Girth at 20 cm height at harvest stage	"	0.429*
Girth at 1 m height at vegetative stage	"	0.722**
Girth at 1m height at flowering stage	"	0.223**
Girth at 1m height at harvest stage	"	0.599**
Number of leaves at vegetative stage	"	0.347*
Number of leaves at flowering stage	"	-0.152
Number of leaves at harvest stage	"	-0.503*
LAI at flowering stage	"	-0.096
LAI at vegetative stage	"	0.142
LAI at harvest stage	"	0.293
Length of finger	"	0.280
Length of bunch	"	-0.098
Number of fingers	"	0.675**
Weight of finger	"	0.741**
Weight of hand	"	0.751**
Number of hands	"	0.209

* Significant at 5% level ** Significant at 1% level

Plant girth at 1 m height showed positive and significant correlation at vegetative and harvest stages only and the highest correlation was at vegetative stage (r = 0.722).

The number of leaves per plant at vegetative stage when the highest number of leaves were present had a positive correlation with yield where as both at flowering and harvest stages when the number of leaves declined due to the death of earlier leaves presented a negative correlation between leaf number and yield.

Yield and yield attributes

Among the six yield attributes studied only the number of fingers per bunch, (r = 0.675) weight of finger (r = 0.741) and weight of hand (r = 0.751) showed a significant and positive correlation with yield.

Total of P uptake and yield

Table 40 furnishes the coefficients of correlation between total P uptake, yield and yield attributes.

The total P uptake at vegetative, flowering and harvest stages also showed a positive correlation with yield (r=0.757, 0.754 and 0.809 respectively). The highest correlation of 0.809 was recorded at the harvest stage.

Table 40. Correlation of total P uptake with yield, weight of finger and total dry matter

Character			Correlation Coefficient
Total P uptake at vegetative stage	vs	yield	0.757**
Total P uptake at flowering stage	vs	yield	0.754**
Total P uptakeat harvest stage	vs	yield	0.809**
Total P uptake at vegetative stage	vs	weight of finger	0.728**
Total P uptake at flowering stage	vs	weight of finger	0.613**
Total P uptake at harvest stage	vs	weight of finger	0.679**
Total P uptake at vegetative stage	vs	Total dry matter at vegetative stage	0.835**
Total P uptake at flowering stage	vs	Total dry matter at flowering stage	0.934**
Total P uptake at harvest stage	vs	Total dry matter at harvest stage	0.835**

* Significant at 5% level ** Significant at 1% level

P uptake and weight of finger

Significant and positive correlation was also obtained between total P uptake at the three different growth stages and weight of finger also (r = 0.728, 0.613 and 0.679).

P uptake and total dry matter

There was significant and positive correlation between total P uptake and total dry matter production of banana plant at all stages of crop growth

namely vegetative, flowering and harvest stages. The highest correlation was obtained between the total P uptake and total dry matter production at the flowering stage (r = 0.934)

Available P content in soil and total dry matter

Available P content of the soil at the three growth stages also showed significant and positive correlation with the total dry matter produced at the respective stages (r = 0.454, 0.840 and 0.626) Table 41.

Available P content in soil and yield

Table 42 furnishes the co-efficient of correlation between bunch yield and available P status of soil during the period of crop growth. There was positive and significant correlation between yield and available P status of soil from the second month onwards.

Table 41. Correlation between soil available P and total dry matter at different stages

Soil available P at vegetative stage	vs	TDM at vegetative stage	0.454*
Soil available P at flowering stage	"	TDM at flowering stage	0.840**
Soil available P at harvest stage	"	TDM at harvest stage	0.626

* Significant at 5% level ** Significant at 1% level

Table 42. Correlation between available P status of soil at monthly intervals and yield

Available P	Coefficient of correlation
1st month	0.0961
2nd month	0.3856*
3rd month	0.5770**
4th month	0.6169**
5th month	0.5456**
6th month	0.7128**
7th month	0.7539**
8th month	0.7109**
9th month	0.6079**

* Significant at 5% level ** Significant at 1% level

The available P content of soil at the flowering stage had the highest correlation with yield (r = 0.7128).

The dependence of yield on available P in different months were worked out and is presented in table 42.

It may be seen from table 43, that 69 per cent of the variation in yield may be attributed to the variation in available P during the nine month duration of the crop.

Table 43. Regression relationship of available P content of soil at monthly intervals (m1, m2, m3, m4, m5, m6, m7, m8 and m9) with yield of banana

Character	MR of available P content with yield	$F_{9,25}$	Coefficient of determination
Available P content at m1	$y = 7.6583 - 0.127^{*} m1 + 0.1196^{*} m2 - 0.2365^{**} m3 - 0.0493 m4 - 0.1253 m5 + 0.82^{**} m6 + 0.1012^{**} m7 + 0.025^{*} m8 + 0.0605^{**} m9$	4.22^{**}	69 %

Influence of vegetative characters at different stages on yield of banana

The regression relationship of yield with vegetative characters such as girth and number of leaves at vegetative, flowering and harvest stages presented in table 43 show that all regressions were significant at the three growth stages and the variation in yield explained by these factors were 46, 52, 58 and 31% respectively.

Multiple regression of yield with P content in soil and yield attributes of banana

The regression relationship of yield with available P content in the soil and total P uptake by banana plants at vegetative, flowering and harvest stages (Table 44) was found to be significant and the variation in yield explained by these regression were 53 and 66% respectively.

Table 44. Multiple regresssion of various factors (X) with yield (Y) of banana

X	Multiple regression of Y on X1, X2, X3	$F_{3, 23}$	Co-efficient of determination R^2
Available P content in soil	Y = 6.438 - 0.0859 x1 + 0.1158 x2 + 0.0624 x3	8.48**	53 %
Total P uptake	Y = 5.407 + 0.0801 x1 0.0733 x2 + 0.1688* x3	14.83**	66 %

X1 = vegetative stage
X2 = flowering stage
X3 = harvest stage

Table 45. Multiple regression relationship of total P uptake at different stages (X1, X2, X3) with weight of finger in banana

Character	Multiple regression of total P uptake at X1, X2 and X3 with weight of finger	$F_{3, 23}$	Co-efficient of determination R^2
Total P uptake	Y = 125.758 + 30.158** x1 - 9.965**x2 + 2.590 x3	15.88	67 %

X1 = vegetative stage
X2 = flowering stage
X3 = harvest stage

The regression relationship of weight of finger witth total P uptake at vegetative, flowering and harvest stages was also found to be significant and the variation in finger weight due to P uptake was estimated to be 63%.

The multiple regression of yield attributes namely finger length (X_1), finger number (X_2), bunch length (X_3), finger weight (X_4), weight of hand (X_5) and number of hands (X_6) is given by the equation

$$Y = 0.448 - 0.2173\ X_1 + 0.1088\ X_2 + 0.0701\ X_3 + 0.0386\ X_4 - 0.6105\ X_5 + 0.2225\ X_6.$$

This regression was also found to be significant at 1% level ($F_{6,20} = 10.17$) explaining 75% of the variation in yield.

Path coefficient analysis of vegetative characters in banana

Growth characters such as plant height, girth of plant at base, 20 cm height, 1m height, number of leaves, leaf area index etc at three different growth stages were selected for studying their direct and indirect effects on yield (Tables 48 and 49).

The correlation of plant height with yield (Table 39) was found to be highly significant at all stages of crop growth. However, the path analysis of plant height at different stages with yield revealed that the height at flowering stage had both direct and indirect effects on yield, while the plant height at the other two stages had no influence. 94% of the variation in

yield may be attributed independently for plant height as is evident from the residue value of 6% in the table 48.

The correlation of girth at base with yield was found significant only at the vegetative stage and 26% of the variation in yield may be attributed to plant girth.

The number of leaves produced was positively correlated to yield during the vegetative stage whereas a negative correlation between these factors was obtained at the harvest stage. About 17% of the variation in yield may be attributed to the number of leaves produced.

Path coefficient analysis of yield parameters in banana cv. Nendran

The most important yield parameters such as length of finger, number of fingers bunch^{-1}, length of bunch, weight of finger, weight of hand and number of hands were selected to study their direct and indirect effect on yield (Table 49).

The direct effect of length of finger is negative while its correlation with yield was positive. This correlation may be attributed to the high positive indirect effect of length of finger *via* weight of finger. The direct effect of length of finger along with the indirect effect *via* weight of finger had contributed to a significant correlation of number of fingers with yield. Length of bunch, had neither a direct nor indirect influence on yield.

Table 46. Multiple regression of yield attributes with yield of banana

Character	Multiple regression of yield attributes X1, X2, X3, X4, X5, X6 on yield	$F_{6,20}$	Co-efficient of determination R^2
Yield attributes	Y = 0.4485 - 0.2173* X1 + 0.1088 X2 + 0.0701 X3 + 0.0386 X4 - 0.6105 X5 + 0.225 X6	10.17**	75 %

X1 = finger length X2 = finger number
X3 = bunch length X4 = finger weight
X5 = weight of hand X6 = number of hands

Table 47. Multiple regression of vegetative characters with yield of banana

Character	Multiple regression of vegetative characters on yield	$F_{3,23}$	Co-efficient of determination R^2
Plant height at three stages	Y = -8.2174 + 0.0096 X1 + 0.0458 X2 + 0.0055 X3	13.09**	63 %
Girth at base at three stages	Y = -5.718+0.282 X1 + 0.0840 X2 + 0.699 X3	6.42**	46 %
Girth at 20cm height at three stages	Y = -4.178 + 0.1650** X1 + 0.0580 X2 + 0.0558 X3	8.24**	52 %
Girth at 1m height at three stages	Y = -1.6516 + 0.2087** X1 -0.0233 X2 + 0.1148 X3	10.73	58 %
Number of leaves	Y = 9.0570 + 0.2136 X1 -0.1323 X2 - 0.5801 X3	3.45*	31 %
Leaf area index	Y = 5.5909 + 1.7350 X1 -0.2551 X2 + 2.9184 X3	2.01	21%

X1 - Vegetative stage X2 - Flowering stage X3 - Harvest stage

Table 48. Path analysis of vegetative characters with respect to different growth stages on yield

Vegetative Characters	Stages			Total correlation	Residue (%)
	X1	X2	X3		
Plant height	0.0786	0.5410	0.0517	0.671**	
	0.0636	0.6681	0.0604	0.792**	0.0608 (6%)
	0.0614	0.6098	0.0661	0.737**	
Girth at base	0.4701	0.0923	0.0407	0.603**	
	0.1975	0.2198	0.0507	0.468*	0.7360 (74%)
	0.0968	0.0564	0.1977	0.351	
Number of leaves	0.2473	-0.0188	0.1190	0.347*	
	0.0384	-0.1212	-0.0691	-0.152	0.8303 (83%)
	-0.0717	-0.0204	-0.4105	-0.503*	

X1 - Vegetative stage X2 - Flowering stage X3 - Harvest stage

The underlined figures are the direct effects

Table 49. Direct and indirect effect of yield parameters on yield in banana

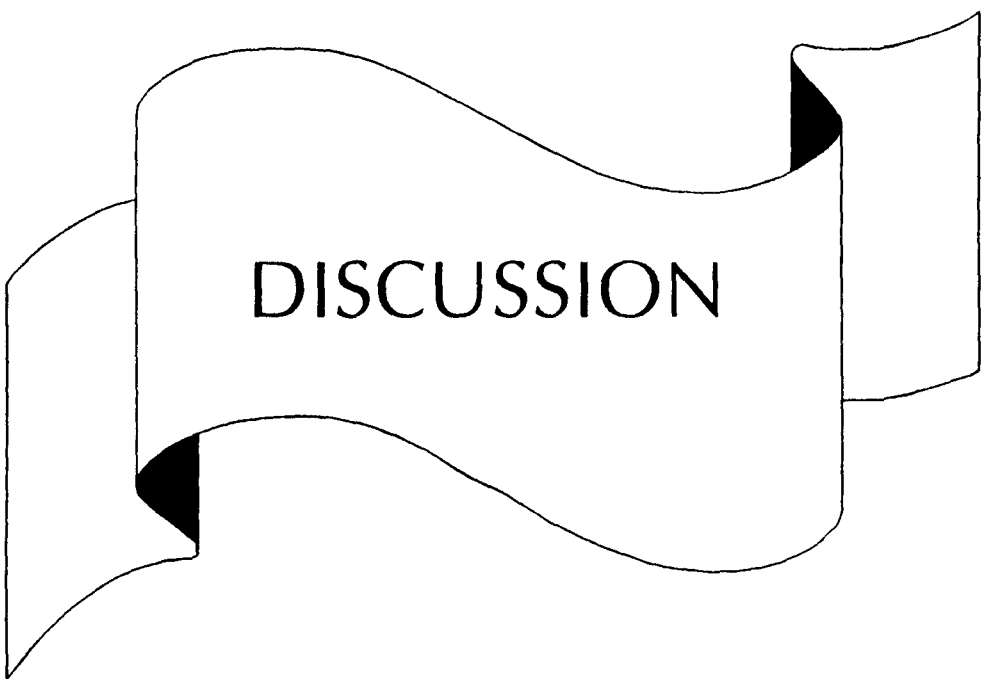
X1	X2	X3	X4	X5	X6	Total correlation with yield
-0.4136	0.2605	-0.0099	0.5589	-0.1262	0.0098	0.2795
-0.2194	0.4912	0.0349	0.5403	-0.1900	0.0176	0.6746**
0.0290	0.1211	0.1415	-0.3932	0.0023	0.0014	-0.0979**
-0.2457	0.2821	-0.0592	0.9408	-0.1883	0.0115	0.7412**
-0.2292	0.4097	-0.0014	0.7779	-0.2277	0.0215	0.7508
-0.0339	0.0727	0.0017	0.0905	-0.0412	0.1191	0.2089

Residue 0.4968 (50%)

The underlined figures are the direct effects

X1 = length of finger X2 = number of fingers X3 = length of bunch
X4 = weight of finger X5 = weight of hand X6 = number of hands

The high correlation of weight of finger with yield and also the high direct effect of weight of finger on yield is evident from the table. The correlation between weight of hand and yield was positive, but its direct effect was negative. The high indirect effect *via* weight of fingers had resulted in this correlation. Both direct and indirect effects of number of hands was small and the low correlation with yield indicates a lesser influence of number of hands on yield. About 50% of the variation in yield may be attributed to the six bunch characters mentioned. Of these, weight of finger is found to be the important character which determines the yield.


DISCUSSION

DISCUSSION

Banana is extensively cultivated in the laterite soils of Kerala where an efficient management of phosphate fertilizers is a serious problem. Increasing the efficiency of phosphate fertilizers in banana cultivation using phosphobacterin culture is a pioneer attempt in our state. The present study on "Increasing phosphorus use efficiency in banana" was conducted at the FSRS, Kottarakkara, where, as seen from table 1, the soil is a typical laterite, predominantly kaolinitic and possessing high P fixing capacity. The phosphorus source used was Mussoorie rock phosphate (MRP) with 20% P_2O_5 in an entirely acid soluble form. MRP is generally recommended for the long and short duration crops in the acidic laterite soils as a direct P fertilizer. The results of several experiments in several states including Kerala (Shanker and De, 1976, Sheeja, 1990 and Lin and Fox, 1992) have proved that at equivalent P levels, MRP is as effective as super phosphate for various crops. It may be noted that the amount of soluble P becoming available for plant uptake in either case, whether from MRP or SP is a net result of the balance between reactions that solubilise insoluble P from MRP and those which revert soluble P from super phosphate to insoluble reaction products.

It is well known that the principles underlying both these processes leading to the resultant status of available P in soils are controlled by the

physico-chemical and mineralogical properties of the soils. The phosphate concentration in soil solution as conceived by Mengel and Kirkby (1987) is also influenced by the P uptake of plants, release from inorganic/organic pool as well as by equilibration with P adsorption sites in the soil. It is under these widely varying conditions that phosphobacterin culture is considered as a valuable agent in promoting P utilisation of crops by maintaining an optimum concentration of soluble P in soil through biological action.

The first part of the study consisted of an experimental study in the laboratory, where field soil samples were incubated with MRP, phosphobacterin and FYM under optimum moisture level to monitor the pattern of P solubilisation as measured by the level of available P in soil. The second part was a field experiment with banana where the different treatments were designed to bring out the specific effect of phosphobacterin culture on the growth and yield and in maintaining a level of plant extractable P from MRP under the influence of FYM and an organic mulch. The effects were compared with the package of practice recommendations for banana of the KAU.

INCUBATION STUDY

The effect of incubation of soil with different inputs assessed by the periodical monitoring of changes in soil pH and available P for 90 days, presented in tables 2 and 3 under results are discussed.

Soil pH

Soil reaction, as measured by the pH value is considered as the best index to explain the cumulative effect of all factors contributing to the fraction of soil P accessible for plants. The primary $(H_2 PO_4)^-$ and secondary $(H PO_4)^{--}$ ortho phosphate ions, in which form plants take up P are predominant in the soil solution in a pH range 4.0 -8.0 (Bear, 1964). But, as the pH value of the soil decrease from 7.0, the solubility of Fe and Al in soil solution increase due to the dissolution of Gibbsite and Goethite like minerals. The phosphate reaction system will now be fundamentally influenced by their molar concentration. As the solubility product of Fe^{3+} and Al^{3+} increase logarithmically with decrease in pH, the chances for rendering P unavailable to crops is more in acid soils. Insoluble phosphate reaction products formed by double decomposition reaction with Fe^{3+} and Al^{3+} are numerous and though unstable in the beginning become more and more stable with ageing. At the same time, phosphorus retained on the clay surfaces by adsorption reactions are more prominent in the pH range of 5.0-7.0 as proposed by Tisdale *et al.* (1975).

As seen from table 2, the laterite soil of FSRS, Kotarakkara with an initial pH of 5.7, on incubation with MRP, FYM and PB, has maintained a pH range of 5.1 to 6.1 with a mean value of 5.5 to 5.9 indicating only a moderately low level of soil acidity . These pH values are suggestive of the likely absence of double decomposition reactions liable to occur in highly acid soils existing at very low pH values. On the other hand, the

predominance of sorption reactions in affecting P solubility under the pH range of 5.1-6.1 as indicated by moderately acidic soil conditions are likely to be more predominant.

Being of sedimentary origin (Tisdale *et al.*, 1975 and Goyal *et al.*, 1983), MRP is rich in carbonate and the phosphate is present as carbonatoapatite. The presence of free carbonates in MRP might have neutralised the resultant acidity arising out of the biochemical activities of the phosphate dissolving bacteria introduced through inoculation. Maintenance of a moderate level of acidity in the pH range of 5.1 to 6.1, can help in the greater dissolution of Ca from MRP rather than Fe and Al from the soil clay minerals. Chances for the formation of mono and dicalcium phosphates which are available in the pH range of 5.5 to 6.2 cannot be excluded under these conditions.

A drop in pH observed during the first 10 days of incubation in treatments T_5 and T_6 receiving PB inoculation agrees with similar findings reported earlier by Sahoo and Misra (1995) in soil incubation studies.

Available phosphorus

The status of available P in the incubated soil samples (table 3) is significantly different owing to the difference in the nature of treatments. The untreated control soil (T_1) registered a gradual rise in available P content from 2.4 to 3.9 ppm possibly due to the natural dissolution of insoluble P

compounds in the soil at a more favourable moisture content existed during incubation, The progressive increase in soluble P in treatments T_2 to T_7 indicate a greater solubilisation of P under the influence of different inputs.

A careful scrutiny of the results show that incubation of the soil with either PB (T_3) or FYM (T_4) alone has brought into solution about 4.7 and 3.9 times more P from the soil at the end of 90 days compared to the untreated control soil, at the start of the incubation experiment showing the positive effect of these two independent factors. At the same time, MRP applied to the soil (T_2) has also undergone solubilisation resulting in a much greater amount of soluble P during the period compared to T_3 and T_4. While soil incubation with MRP alone had released an additional quantity of 10.33 ppm available P, incorporation of FYM with MRP in T_7 has resulted in a numerical increase of only 0.33 ppm P. On the other hand, addition of PB along with MRP (T_5) has solubilised an additional amount of 2.55 ppm phosphorus. The greater effectiveness of PB than FYM in solublising P from MRP is thus evident from these results.

However, the phosphorus solublising effect was maximum when a combined application of PB, FYM and MRP was made. In this treatment (T_6), the available phosphorous content at the end of 90 days incubation was 19.31 ppm which is much higher than the amount of P solubilised in any of the other treatments. The results thus reveal the beneficial effect of FYM in activating PB culture consisting of a mixture of heterotrophic fungi and bacteria to digest MRP and release the highest amount of available P.

The pattern of P mobilisation in all the treatments was more or less uniform, indicating a slow pace in the earlier days and reaching a maximum by the end of 90 days. As the study was restricted to 90 days, the estimation of P becoming progressively soluble with continued incubation was not possible.

An important outcome from the incubation study is that out of the 100 ppm of total P applied as MRP, a maximum of only 15.41 ppm is solubilised as available P in the soil even in the best treatment. Apparently, this may be an equilibrium level remaining in solution after interaction with the soil constituents as proposed by Hooker *et al.* (1984) who have suggested that in acid soils rich in sesquioxides, P fertilizer application enrich Fe and Al phosphate fixation sites mainly by adsorption on the surfaces of oxide minerals like Gibbsite and Goethite and act as the strongest sink for phosphate. When the adsorption sites act as strong phosphate sink, the phosphorus concentration of the equilibrium solution decrease with an increase in the amount of adsorbed phosphate. As the laterite soil used for the study was rich in sesquioxides and the pH of the incubated soils was around 5.5-5.9, the possibility of the existence of active adsorption sites cannot be excluded. Further, as stated by Hauter (1983), the greater adsorption of P favoured at high pH will help to substantiate the role of P adsorption in retaining only a low level of soluble P in soil solution. Phosphate solubilising fungi like *Aspergillus* sp., *Penicillium* sp. and *Rhizopus* sp. have been reported (Narsian *et al.*, 1994) to solubilise 9.0 to

34.6% of total P in synthetic medium under ideal conditions of incubation. The difference in the rate of RP solubilisation may be attributed to the difference in the chemical nature of RP as well as to the efficiency of the organisms arising out of the variation in the nature and quantity of the organic acids secreted by them. Most of these species required a period of 8 to 15 days for maximum solubilisation of P from different types of rock phosphates (Venkateswarlu *et al.*, 1984).

From incubation studies on the dissolution of RP by PB under laboratory conditions, Misra and Sahoo, (1995) have shown that maximum P solubilisation could be achieved by 18 days of incubation beyond which the concentration of soluble P decreased. In the present study, however, P solubilisation continued eventhough at a low pace upto to 90 days incubation. Salih *et al.* (1989) have reported that PS fungi showed maximum efficiency in releasing P after 55 days in the soil treated with MRP and reported progressive increase in P solubilisation upto 70 days of incubation.

According to Mengel and Kirkby (1987), phosphate incubation in a moist soil is ideal to provide a more realistic picture with regard to P adsorption and P concentration in soil solution because incubation period for some weeks helps in maintaining an equilibrium between these two processes.

The incubation study has thus provided valuable information on the possible status of phosphorus that can be retained in an available form in soil solution for plant uptake by the use of MRP under different methods of fertilizer management in laterite soils.

FIELD EXPERIMENT

The role of phosphobacterin culture in increasing the efficiency of phosphorus utilisation from Mussorie rock phosphate in banana was evaluated by comparing the difference in vegetative characters, yield, P content and P uptake pattern as well as pH and available P in soils of the differently treated banana plants. The results on these observations presented in the preceeding chapter are discussed.

Vegetative characters

Banana is known to be a heavy feeder of nutrients and a steady supply of nutrients right from planting to bunch maturity is essential for a healthy plant to produce large and good quality bunches. Data on the vegetative characters such as height, girth, number of leaves, leaf area index and total dry matter production invariably point to the superiority of the combined effect of PB, FYM and mulching in providing a continuous supply of P from MRP resulting in a balanced crop nutrition.

Although the requirement for phosphorus by banana is much low when compared to N and K, any deficiency of phosphorus in soil is likely

to restrict plant growth even from the very early stages itself. (Freiberg, 1955, 1956). Significant difference in plant height was noticed in none of the treatments receiving either full, 3/4 or 1/2 the recommended level of P at the vegetative stage. However, at the shooting and harvest stages, the plants in T_4 and T_5 receiving the full complement of treatments recorded significantly higher values over the corresponding treatments T_2 and T_3 without PB inoculation, indicating the influence of PB in promoting plant height. It is clearly evident that these bioagents have become more active in soil towards the later stages of plant growth and were able to produce a significant effect.

Similarly, the treatments with different levels of P alone and with PB inoculation showed no significant difference in girth of pseudostem except at the vegetative stage. At this stage, plants getting 3/4 level of P as MRP along with PB (T_4) had the maximum girth. The higher girth of the plants in this treatment at this stage may be attributed to the larger size of the pseudostem resulting from the concentric arrangement of the leaf sheath which was maximum at the vegetative stage. It may be seen from the results in table 7 that the treatments without mulch (T_8) recorded the highest value for LAI indicating a sufficient supply of P inspite of the lower amount of P applied. The result is in conformity with the report (Sheeja, 1990) that provision of sufficient P can increase the LAI in banana.

Several workers have reported the positive influence of P nutrition on plant height and girth in banana. An increase in plant height with P_2O_5

upto 60g plant^{-1} has been reported by Ramaswamy (1974), Shankar (1980) and Chattopadhyay and Bose (1986). Sheeja (1990) has also reported an increase in the value of these parameters due to the application of P within limits in the red soils of Vellayani. These and several other reports confirm the necessity for a steady supply of adequate amount of P for the proper vegetative growth in banana.

The vegetative characters of plants receiving only 3/4 the recommended level of P were equal or slightly better than those receiving the full level of phosphorus. Even the plants in T_5, with only half the recommended level of MRP along with PB, FYM and mulch were in no way inferior to the banana plants receiving the full package of nutrients. It may also be noted from the results that the vegetative characters of banana receiving 3/4 and 1/2 level of recommended P, but without PB inoculation were inferior in many respects compared to the corresponding P levels supplemented with PB.

The results have pointed out that among the vegetative characters, leaf area index and total dry matter content were the only two features which showed a large and significant difference in T_4 compared to other treatments. The complementary effect of FYM and mulching on the phosphorus solubilising capacity of PB is evidently revealed from the significantly lower values for the LAI and total dry matter of plants in the absence of both FYM and mulch. Between FYM and mulching, mulching seems to be less significant in controlling vegetative growth.

Good vegetative growth, which is a pre requisite for good yield in banana, is thus ensured in plants where a combined application of PB, FYM and mulch was made even when only 3/4 or even 1/2 the recommended level of phosphorus was used.

Phosphorus, though a major nutrient has never been considered as directly responsible for a lushy vegetative growth. Nevertheless, for the proper growth and completion of life cycle of any plant, the requirement of phosphorus, though relatively smaller than N and K is most essential. In a plant like banana with high leaf area index and high dry matter content, regular supply of phosphorus is essential to sustain high photosynthetic activity. Optimum supply of N ensures enhanced root growth, which promotes maximum P absorption. As an efficient utilisation of P in plants is preceded by P uptake, maintaining soil P in a concentration sufficient for root interception is important. The results of the study definitely assure a regular supply of P to plants fertilised with only 3/4 or 1/2 level of recommended P, provided they are inoculated with PB and supplemented by the use of FYM and mulching under careful management.

It is interesting to note that, the plants which were given only a lower level of P but inoculated with PB were able to obtain adequate amount of P from the soil. Obviously, the PB have helped to solubilise P from MRP and maintain a situation wherein no P deficiency was experienced by the plant which otherwise would have reduced the vegetative growth and reflected in a lower plant height, girth and LAI.

The beneficial effects of PB on the vegetative characters and yield of banana need not entirely be attributed to the higher P uptake made possible through the maintenance of a high available P in the soil. As suggested by Brown (1974) and Tinker (1980), it may be due to certain plant growth substances produced by them in the rhizosphere These substances could cause plant growth stimulation which would result in a larger plant that naturally would contain larger amounts of P and other nutrients than a smaller plant. Such an action has been proposed by several Russian scientists as early as in 1962. Among these biologically active substances IAA, Giberellin and Cytokinin have been included (Barea *et al.*, 1975).

Among the vegetative characters, height and girth of the pseudostem at various stages of growth and leaf production at vegetative stage showed positive and highly significant relationship with yield ranging between 60.3 to 79.2%. Such a relationship has been recently reported in studies on the K nutrition of banana. (George, 1994). Absence of any significant difference in the vegetative characters of the banana plants provided with only 3/4 or 1/2 the level of recommended P compared to the plants receiving full level of P strongly upholds the beneficial influence of the bioagents in rendering sufficient P soluble and maintaining it in a plant available form in the banana pits. This is further confirmed when we compare the total dry matter yield and yield attributes of banana in the different treatments.

Dry matter content of plant parts and total dry matter production

A perusal of the data on the dry matter of plant parts and total dry matter production presented in tables 8 to 15 reveal that the application of 3/4 level of P along with PB, FYM and mulch has resulted in the production of the highest amount of total dry matter compared to all the other treatments. With regard to the content of dry matter in the plant parts, leaf petiole recorded the lowest value at all growth stages, whereas dry matter content was highest in the rhizome at vegetative stage, pseudostem at flowering and bunch at the harvest. The pattern of partitioning of dry matter in banana is clearly evident from these results. Gaur, (1990) reported maximum dry matter in lentil when FYM was applied along with RP, and observed that FYM alone augmented dry matter yield by 29.2% over control.

In almost all cases, application of MRP along with PB but without FYM has resulted in a lower dry matter compared to the other treatments where FYM was applied. This result is again suggestive of the positive influence of FYM in promoting the functions of PB.

Use of a lower level of P and inoculation of PSM along with FYM and mulch is thus shown to produce the same or a slightly better effect as compared to the addition of the full amount of fertiliser P recommended for banana. The findings from the study suggest that the adoption of these practices can effectively reduce the requirement of fertilizer P without appreciably affecting any of the vegetative characters or total dry matter

produced. The provision of a continuous and steady supply of available P in the soil is important and it is evidently ensured due to PB inoculation. Similar findings have been reported in literature for various crops under different agroclimatic conditions. (Goos *et al.*, 1994).

Yield and yield attributes

The highest bunch yield of 10.68 kg plant^{-1} which was significantly superior to the yield in all the other treatments was recorded in plants in T_4 supplied with 3/4 level of P (86g) as MRP, 10kg FYM and PB inoculation along with proper mulching.

The second highest bunch weight of 9.93 kg plant^{-1} was produced by plants in T_1 (POP recommendations) which received full level of P (115gm P plant^{-1}) as MRP and FYM, but without PB inoculation. This yield was not significantly different from the treatment where only half the recommended level of P was applied as MRP along with FYM, PB inoculation and mulch (T_5). The results show that even half the recommended level of P is sufficient to produce as much yield as that of full level of P provided it is applied along with PB, FYM and mulch.

Lack of supply of FYM had very conspicuously resulted in a lower bunch weight in the two treatments T_6 and T_7, even though P was applied as MRP at 3/4 and 1/2 level along with PB inoculation. Similarly, the same levels of P when applied along with PB, FYM and mulch gave better

yield response than the same treatments without mulch (T_8 and T_9). The necessity of mulching is clearly evident from the lower yield of banana in treatments without mulch.

Increase in yield due to PB inoculation

Among the various attributes that contribute to the bunch yield of banana, weight of hands, number and weight of finger have shown a significant difference between treatments. These characters have shown a positive and highly significant relationship with yield and were significantly higher in treatment T_4. The results indicate the superiority of the use of PB culture in promoting an efficient utilisation of phosphorus even from lower levels of P resulting in greater bunch yield. It may be seen that by the use of PB culture, with only 3/4 level of recommended P, a yield increase of 7.6% compared to POP recommendation and with only 1/2 level of P, a yield on par with POP recommendation can be achieved. The increase in yield in PB inoculated treatments compared to the uninoculated one is 24.6% with 3/4 level of P and 36.0% with 1/2 level of recommended P.

The independent effect of mulching, though lesser than that of PB or FYM should also be recognised as an important practice to promote the overall activity of PB leading to an increase in yield in banana. Use of FYM along with RP and PB has been reported (Gaur, 1990) to produce an increase in yield in grain and straw in pulses and cereals as compared to the yield in plots not receiving FYM. It is thus very clear from the results of the study

that use of PB culture along with FYM and mulch is an efficient method for increasing the P use efficiency of banana from indigenous RP.

The use of finely ground RP applied directly as P source to tropical soils is considered as an attractive option because they are cheaper than water soluble P fertilizers. Since the major objective of the study is to reduce the level of P application without affecting the productivity of the crop, the saving of fertilizer through the efficient utilisation of P in MRP using bio agents like phosphobacterin appears to be quite feasible. The study has thus proved the efficiency of PSM in providing enough soluble P from 3/4 level of recommended MRP to the crop resulting in an enhancement of yield not achieved through the application of the full level of recommended P for banana.

In banana, the number of hands bunch^{-1}, number of fingers bunch^{-1}, weight of hand, length, girth and weight of fingers are considered as the determinants of yield (Stover and Simmonds, 1987).The application of 3/4 level of recommended P along with PB inoculation, FYM and mulch has resulted in the maximum values for number of hands, girth of finger, weight of finger and weight of hand which was reflected in the yield also. This finding amply supports the assured supply of P to banana for the enhancement of yield attributing characters which has finally resulted in the attainment of highest yield.

This is further confirmed by correlation analysis where the positive relationship between number of fingers, weight of finger and weight of hand with yield of banana is established. The direct contribution of number of hands and fingers bunch^{-1} on yield as reported by Teaotia *et al.* (1970), Sreerangaswami *et al*, (1980), Krishnan and Shanmughavelu (1983), Kurien *et al.* (1985) and George (1994) is confirmed in the present study also.

Harvest index

Harvest index which denotes the ratio between the yield of banana and total dry matter produced did not show any significant difference between various treatments. It was minimum in the treatment which did not receive any FYM and maximum where 1/2 recommended level of P was used along with PB, FYM and mulching. The influence of PB inoculation under appropriate conditions even with 1/2 level of recommended P is revealed in the harvest index of 0.23 obtained for this treatment. It may be noted that this particular treatment produced a yield of banana which was on par with the yield in plants receiving fertililzers as per POP.

Fullness index

The fullness index which is an expression of the fullness of the fruit taking into account its weight and length of curvature is highest in the treatment T_5 followed by T_4 (7.1 and 6.8). This again points to the superiority of treatments T_4 and T_5 in producing fruits better in appearance compared

to fruits in other treatments. The beneficial effect of PB incoulation in producing good quality banana bunches is also evidenced from these results.

P content and P uptake in various plant parts of banana

The highest content of P in the various plant parts such as leaf blade, petiole, midrib, pseudostem and rhizome at all growth stages as well as flower and fruit was invariably observed in the plants in T_4 which received 3/4 level of recommended P as MRP along with PB inoculation, FYM and mulch.

The parts of plants which received different levels of P without PB on the otherhand, contained only a lower P content. The high content of P in the different plant parts in various treatments may be attributed to the higher status of available P present in the soil at the particular stages. The introduction of PB has increased the solubility of MRP, rendering more P in an available form which in turn has contributed to a higher absorption resulting in a higher P content in the various parts. Thus it may be seen that, the mere addition of a high quantity of MRP to the soil alone does not ensure a high status of available P ready for absorption by a crop like banana.

Increase in plant P concentration due to higher available P in soil as a result of PB inoculation has been reported in various crops by several scientists. Taha *et al.* (1969), Azcon *et al.* (1976), Kundu and Gaur, (1980,

1984), Banik and Dey (1981) and Khalafallah *et al.* (1982) have also confirmed that the inoculation of plants with PS organisms could increase the concentration of P within plants compared to the uninoculated control. The results of the present study also confirm this finding.

The use of 3/4 of the recommended level of P (86g P $plant^{-1}$) combined with PB, FYM and mulch has resulted in the maximum uptake of P in the various plant parts. The lower P uptake in plants receiving a higher amount of MRP without PB is illustrated from the results presented in tables 24 to 31 where a higher quantity of MRP (115g P $plant^{-1}$) has failed to produce high biomass and high P concentration in plants resulting in a lower total P uptake.

These findings are in confirmation with the reports of various scientist like Raltson and Mc Bride (1976), Kundu and Gaur, (1980, 1984) and Khalafallah et al (1982), who have shown that inoculation with PB can increase both P uptake and plant growth in various crops. Increased P uptake in pulses due to inoculation with PB is recently reported by Vaishya *et al.* (1996). It may be concluded from the results that the greater solubility of MRP through the activity of PB has resulted in a high content of available P in soil which consequently has promoted the vegetative growth of banana plants. As a result, the dry matter production was high and along with the high P content of the plants has finally resulted in a higher total P uptake and yield.

Available P in soil and its effect on banana

Phosphorus, as a major nutrient has never been considered directly responsible for a lushy vegetative growth. Neverthless, for the proper growth and completion of life cycle, the requirement of P, though relatively lesser than N and K is most essential. As phosphorus is an element highly immobile in soil and mobile in plant, the P nutrition of any plant is dependent on the amout of mobile P in a soil during cropping period. In a plant like banana with high leaf area index and high dry matter content, continued supply of P is important to sustain high photosynthetic activity and growth. Optimum supply of N ensures enhanced root growth which promotes maximum P absorption from soil. As an efficient utilisation of P is preceeded by proper P uptake, maintaining P in concentration sufficient for root interception is imperative.

The soil in treatment T_4, where only 3/4 level of recommended P was applied, has maintained available P (15.34ppm) at a level as that in the treatment receiving full recommended level of P (15.18ppm) due to the positive effect of PB inoculation. The same trend was revealed in treatments T_4 and T_5 which maintained a higher status of available P when compared to treatments T_2 and T_3 receiving the same level of P but without PB inoculation. This evidently points to the specific effect of PB in solubilising insoluble P from MRP to an available form.

The influence of FYM and mulching on the activity of PSM and P solubilisation can be further deduced from the lower status of available P in treatments which did not receive either FYM or mulch along with PB inoculation (T_6 and T_8). These results again confirm the essentiality of FYM and proper mulching for the efficient functioning of the bio agents in promoting P solubilisation from MRP. As compared to FYM, mulching was less effective in altering the solubilisation of P. The results presented in table 35 show that a lesser amount of MRP when inoculated with PB can produce an equal amount of available P in soil compared to that achieved by the application of a higher level of MRP. The increase in solubility observed due to the use of PB in combination with FYM and mulch along with 3/4 level of P was 43 and that with 1/2 level of P was 39% compared to the treatments which received the same levels of P but without PB.

The beneficial effect of a combined application of PB, FYM and mulch along with MRP reflected in the overall superiority of vegetative characters of banana receiving only 3/4 and 1/2 level of the recommended P, reveal that the P supply in soil is not affected by the amount of RP added alone. The deficit of applied P seems to be more than compensated by a greater solubilisation of RP or a lesser reversion of soluble P resulting in a equal or higher amount of available P in the soil due to the effect of PB. Improvement of vegetative growth and yield with increasing levels of P as reported by Ramaswamy (1976), evident in the present study also might be a consequence of the greater availability of P in the PB treated plants.

Role of PB in improving P availability

Aspergillus awamori, Bacillus sp. and *Pseudomonas* sp. used as the bio agents in phosphobacterin culture have been identified as specifically efficient for solubilising tricalcium phosphate from MRP, (Gaur, 1990). As stated by Narsian *et al.* (1994), the efficiency of a PB culture depends not only on the microbial strains used but also on the type of medium ie., whether synthetic, solid or soil where they are inoculated. It's efficiency in soil in turn is decided by the soil type, prevailing pH and other conditions favourable for microbial proliferation, in addition to the presence or absence of a growing crop. Besides all these, the differences in reactivity of rock phosphate arising out of the nature of apatite bond with which the P is held in the rock is also important. An interesting behaviour of these organisms in liquid culture (Ahmed and Jha, 1968) is the decrease in the rate of P solubilisation after reaching a peak. This behaviour is explained as due to the absorption of soluble phosphate by the fungal mycelia, which will be ultimately released by autolysis of the organism as stated by Agnihotri (1970).

The results of a large number of laboratory and field studies have proved beyond doubt the increase in available P status in soil, increase in plant dry matter production and yield in several cereal and pulse crops in India and abroad due to soil inoculation of PSM (Banik and Dey 1981, Kucey, 1987, Asea *et al.*, 1988 and Datta and Banik, 1994). The results of the present study are in agreement with the above reports and identifies banana as a field crop showing positive response to an integrated use of PB, MRP

and FYM. The increase in status of available P in the incubated as well as field soils receiving this package is evidence for enhanced P solubilisation. The superiority in vegetative growth and yield of banana obtained in the PB treated plots in the study amply supports this finding.

The greater concentration of available P in soil receiving PB treatment may possibly be attributed to the additive effect of a greater P solubilisation from MRP and a lower P fixation in soil achieved due to the chelation of the cationic counter parts like Fe and Al of the P ions by the organic acids excreted by PSM (Sperber, 1958 and Katznelson and Bose, 1959). A number of organic acids like lactic, glycolic, citric, maleic, oxalic and succinc acids, all of which have chelating properties are reported (Sperber, 1958, Louw and Webley, 1959, Taha *et al.*, 1969 and Banik and Dey, 1981, 1982) to be produced in the soil by PB in the presence of decomposing organic matter.

It is also possible that PSM can produce effective chelating materials in the immediate vicinity of rock phosphate or in the rhizosphere (Moghimi *et al.*, 1978). Under these conditions, P could be solubilised and be present in an available form in concentrations high enough to be available to plant roots, In the presence of chelating substances, it is not likely that all the P solubilised would be absorbed by the banana plant. Such a situation can be expected to be operating in the soils of the banana pits, where inspite of the comparatively higher P uptake by the plants, the available P status of the soil continued to be high.

Role of FYM in increasing the availability of P from MRP

A high rate of solubilisation of MRP was observed in treatments T_4 and T_5 supplied with FYM and PB (9.2 and 7.05 ppm P respectively) whereas a lower P release was visualised when FYM was skipped in T_6 and T_7 (7.49 and 5.23 ppm respectively). An increase of 23% of available P with 3/4 level and 39% with 1/2 level was thus observed due to the effect of FYM, compared to the application of similar levels of MRP and PB, but without FYM.

The mere introduction of PS organisms into the soil does not ensure a regular solubilisation of P. An ample supply of easily decomposable organic compounds to serve as a source of carbon and energy for the growth of these heterotrophic organisms is essential Gaur and Sachar (1980) and Gaur and Gaind (1983) have shown that by increasing the concentration of glucose from 1-3% in the medium, the rate and quantity of RP solubilised by *Aspergillus awamori* was appreciably increased. The provision of FYM in the present study has apparently provided a source of organic matter which has favoured the rapid multiplication of the organisms in PB resulting in a progressive increase in available P status as evidenced from the results presented in tables 34 and 35.

Partially decomposed organic matter in FYM stimulates and sustain the P solubilisers in an active state, making them more efficient in the soil. Banik and Dey (1981) have measured increased levels of available P in soils

to which FYM, RP and PB were added. FYM which is a mixture of the feed waste of animals and their dung and urine has a high load of heterotrophic microorganisms which continue to be active during storage also. Their continued action results in the decomposition of organic matter in FYM producing substantial amount of humus consisting of a mixture of humic and fulvic acids. The phosphate released as soluble P from MRP, which is not immediately absorbed by the plants is not subjected to fixation in the presence of this humified organic matter. Reaction of humus with P, forming phospho humic complexes which are more easily available to plants; replacement of the phosphate anion on the clay complex by humate anions and the coating of sesquioxide particles by humus, thereby reducing P fixing capacity are some of the ways by which the P availability to crops is improved by the use of FYM (Datta *et al.*, 1992 and Datta and Banik, 1994).

The specific effect of organic matter in stimulating P solubilising activity of microorganisms has been amply reported in literature (Venkateswarlu, 1984; Gaur, 1990 and Yadav and Singh, 1991).

The higher solubility of P observed in the present study may be attributed to the formation of phospho humic complexes also as proposed by Thomas (1981), Jorg and Herman (1982) and Fernando and Hugo (1983), in addition to the factors discussed above.

A positive response of PB has been reported (Chhonkar, 1994) in soils with high organic matter content and low P. Reports (Datta and Banik, 1994) also reveal that the application of poultry manure can serve as energy material for several PSM resulting in increased rice yields. The importance of FYM / organic matter is releasing a relatively high level of available P is evident from the higher P content in the treatments with PB and FYM in the present study.

A higher vegetative growth, yield as well as available P status in the soil, P content and P uptake in the plant in treatments with FYM, all point to the beneficial influence of FYM / organic matter in promoting an efficient solubilisation as well as utilisation of P from MRP. A steady supply of plant utilisable P needed for the banana crop right from planting to bunch maturity is thus attained by the combined use of FYM and PB along with MRP.

50% increase in the dry matter yield of maize in the treatments receiving FYM along with PB has been reported by Sahoo and Misra (1995). Datta and Banik (1994) have observed a tangible decrease in P fixing capacity of soils due to the combined application of MRP, poultry manure and PSM assuring a slow but steady supply of P which is not vulnerable for fixation. The same effect might have prevailed in the banana pits, where the maximum availability of P to the plant was assured under the favourable conditions created by the use of PB, FYM and MRP. The integraed use of MRP, FYM

and PB has thus helped to provide the essential nutrients in a balanced and efficient manner to the banana crop.

Effect of mulching on PSM activity

A positive effect of mulching was observed on the activity of PB. When mulching was provided, the extent of solubilisation of P increased from 7.49ppm observed in uninoculated soil to 8.30ppm in the inoculated soil for the 3/4 level of P (T_4). But for 1/2 level of P (T_5) under the influence of mulching the available P increased from 5.23 ppm in the uninoculated soil to only 5.89 ppm in inoculated soil.

The increase in the content of available P was 10.81% for 3/4 level and 12.62% for 1/2 level. The results reveal a lesser effect of mulching compared to FYM in promoting P solubilisation by PSM. Mulching the soil has been shown to raise the soil temperature in red and laterite soil (Jayasree, 1987) resulting in an increased transport of soluble P in the soil by diffusion (Tisdale *et al.*, 1975) leading to an enhancement in its uptake by plants.

Mulches are generally used for conserving soil moisture and for increasing soil temperature. Both these conditions are known to stimulate biological activity and result in greater nutrient availability. Othieno (1973) has reported a resultant increase in available P status, improved plant growth and dry matter production consequent to the use of organic mulches like paddy husk and rice straw in banana. A greater mobility of P by diffusion,

on account of the higher temperature maintained by mulching was also noticed by him. In the present study also, when MRP was solubilised under the combined influence of PB, FYM and mulch, a greater P mobilisation leading to higher P uptake and improved dry matter production and yield has been achieved.

Indexing of plant part in banana cv. Nendran for P status

Lundegardh (1935) defined index plant part as that part of a plant which gives the highest predictability on yield. Hewitt (1955), Boland (1980) and Prevel *et al.* (1986). considered the third leaf in banana as the index leaf. Lahav, (1972, 1977) had earlier identified petiole as the best plant part to estimate the P status which has been further confirmed from field studies in banana, var. Dwarf Cavendish. However, such a study has not so far been carried out with banana cv. Nendran which maintain only a comparatively lesser number of active leaves than the cavendish varieties.

The magnitude of correlation between P content in petiole, lamina and midrib of the third leaf at different stages with yield was highest in the fifth month at the shooting stage. Warner and Fox (1977) and Turner (1980) have reported the late vegetative stage before shooting to be physiologically the best time for sampling in banana cv. Williams and Giant Cavendish. In case of banana cv. Nendran, the highest R^2 value of 73-75% was noted with the P content of petiole and lamina and midrib with yield at all stages of sampling. Since P content in the three plant parts showed an equally

high degree of association with yield, it follows that any part of the third leaf at the flowering stage may be used as an index part for P. However, as the maximum association of 75% is shown by the petiole and lamina, these two parts may be considered equally suitable for predicting the P level which bears a relationship with yield.

P content at the late vegetative stage (before flowering) in petiole of banana cv. Nendran has been recently identified as the ideal index part (George, 1994) for estimating K level which bear maximum relationship with yield. Since petiole has been identified as the index part for P also, it follows that for both P and K, petiole at late vegetative / flowering stage may be indexed as the ideal plant part in banana cv. Nendran.

Fruit quality

Even though the vegetative and yield characters in the differently treated banana plants showed significantly variation, no appreciable difference in the quality of ripe fruits was revealed.

As seen from the foregoing discussion of results, the variation in vegetative and yield characters has been attributed mainly to the variation in P levels only, as N and K were applied uniformly at recommended levels in all treatments. At the same time, variations in the P status of soil have definitely affected these plant characters, revealing the efficiency of PB inoculation in altering the P status of soil and plant. The plants receiving

even half the recommended level of P along with PB did not appear to be affected by any serious deficit of P.

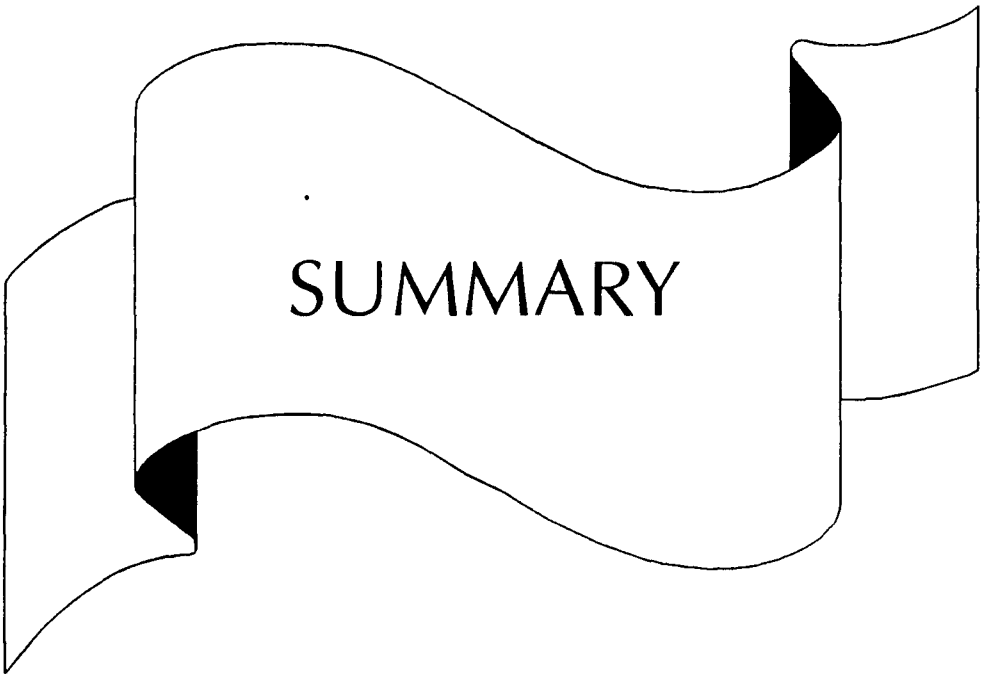
As the fruit quality in banana is known (Barnah and Mohan (1980), George (1994) and Sheela (1995) to be highly influenced by K, followed by N, a slight variation in P content might not have affected any of the characters such as protein, total sugars and tritrable acidity. The values for these parameters obtained in the present study are in agreement with those reported in banana cv. Nendran by George (1994) and Sheela (1995).

The content of total soluble solids, total sugars, reducing sugars, non reducing sugars and titrable acidity did not differ significantly between treatments indicating that the variation in P status of soil and plant has not seriously influenced any of these characters. There was not much variation in the protein content of the fruits since the same level of N was applied for all the plants.

Economic consideration

A comparison of the cost of inputs and yield of banana from plants receiving fertilizer as per POP recommendation with that receiving only 3/4 level of P along with PB shows that, with an additional input of Rs. 0.30 plant^{-1}, a yield increase of 7.5% leading to an additional income of Rs. 8.70 plant^{-1} (@ Rs. 12 kg^{-1}is obtained. This works out to a total amount of Rs. 21750 ha^{-1} (2500 plants ha^{-1}). At the same time, a comparison of POP

recommendation with 1/2 recommended level of P and PB shows no difference between the cost of inputs and the yield obtained. Therefore, it may be concluded that for a higher net return from banana cultivation, along with other inputs, use of 3/4 level of P with PB may be considered as a viable alternative to the present POP recommendation (Appendix 2).


SUMMARY

SUMMARY

With the main objective to study the efficiency of phosphobacterin culture in increasing the utilisation of P from MRP, a laboratory incubation study and a field experiment with banana cv. Nendran were conducted at the FSRS, Kottarakkara where the soil is a typical laterite classified in soil taxonomy as "Plinthic Kandiustult". The salient results of this study are summarised below.

Incubation study

Representative soil samples of FSRS, Kottarakkara was incubated at 60% WHC under laboratory conditions for a period of 90 days to study the pattern of P solubilisation under the influence of phosphobacterin along with different inputs. Periodical changes in pH and available P with progressive incubation was monitored.

There was only a slight variation in the pH of soil upto 20 days due to the effect of different inputs. After 20 days, the soil showed a tendency to become slightly acidic reaching a mean value of only 5.6 from the initial pH of 5.7.

The P solubilising effect was maximum with a combination of PB, FYM and MRP. At the end of 90 days incubation, out of the 100ppm P applied as MRP, a maximum of 19.31ppm P became available in this treatment. The P solubilised in the unamended soil was only 3.90 ppm and in the other treatments receiving FYM, lime and MRP either alone or in different other combinations, the values ranged from 9.21 to 16.73ppm.

Field experiment

The salient results from the field experiment conducted to evaluate the efficiency of P solubilisation from MRP inoculated with PB and its effect on growth and yield of banana are summarised.

The application of 3/4 level of the recommended P along with PB, FYM and mulch has produced a significant positive effect on growth and yield characters compared to all the other treatments including the treatment as per package of practices recommendations of the KAU.

Among the vegetative characters, plant height, girth of pseudostem and total dry matter production were highly influenced by this treatment and the values for these parameters were significantly higher compared to those in all the other treatments.

Most of the vegetative characters such as plant height at flowering, girth at the base of the pseudostem at vegetative and flowering stages, girth

at 20cm height at the three stages, girth at 1m height at vegetative and harvest stages and the number of leaves per plant at the vegetative stage, showed a significant and positive correlation with yield.

The highest bunch yield of 10.68 kg plant^{-1}, which was significantly superior to the yield in all the other treatments was recorded by plants supplied with 3/4 level of recommended P as MRP, 10 kg FYM and PB inoculation with proper mulching. The increase in yield in this treatment was 7.55% higher than the yield from plants given fertilizers as per the POP recommendations of the KAU.

The second highest bunch weight of 9.93 kg plant^{-1} was recorded by the plants which received the full recommended level of P along with N and K (POP recommendation). This yield was on par with the yield obtained in the treatment where only 1/2 the recommended level of P was used along with PB, FYM and mulch.

Use of 3/4 level of recommended P along with PB, FYM and mulch resulted in the highest values for number of hands, girth of finger and weight of hand in the banana bunch.

An increase in yield of 24.6 and 36.0% was obtained when 3/4 and 1/2 the recommended P level was applied along with PB inoculation when compared to the treatments receiving the same level of P but without inoculation.

Use of FYM was found to be an essential practice to obtain the maximum benefit from the use of PB. This was evident from the lower yield of banana as well as lower dry matter produced in treatments receiving PB without FYM. Application of FYM along with PB inoculation for the treatments where 3/4 and 1/2 levels of the recommended P were applied, resulted in a yield increase of 47.3 and 36.2% over the corresponding treatments without FYM.

The supply of a high level of plant available P in the banana pit was evident from the highest content of P in the various plant parts such as leaf blade, petiole, midrib, pseudostem, rhizome, flower and fruit in the plants which received 3/4 level of the recommended P as MRP along with PB inoculation, FYM and mulch. This observation again substantiates the complementary effect of PB, FYM and mulch in promoting greater P solubilisation and resultant availability of P to crop. This is further evidenced from the similar values for available P in the soil of the banana pit receiving 3/4 P (15.34ppm) and the treatment with full level of P (15.18ppm).

Available P content in soil, plant P content, P uptake, dry matter production and other yield attributing characters in banana were thus found to be favourably influenced by the use of PB along with a lesser level of P than what is recommended at present.

A positive and significant correlation between yield and available P status in soil was noticed from the second month onwards. The available P

content in soil at the three growth stages of banana plant showed significant and positive correlation with total dry matter produced at the respective stages.

Among the yield attributes in banana, the number of fingers per bunch ($r = 0.675$) weight of finger ($r = 0.741$) and weight of hand ($r = 0.751$) showed a significant and positive correlation with yield.

Petiole and lamina of the third leaf were identified as the best plant part or index for estimating P content as it was observed that about 75% of the variation in yield of banana could be attributed to the P content in these parts. It is suggested that both these parts may be considered as equally ideal for predicting the P level in banana which bears a relationship with yield.

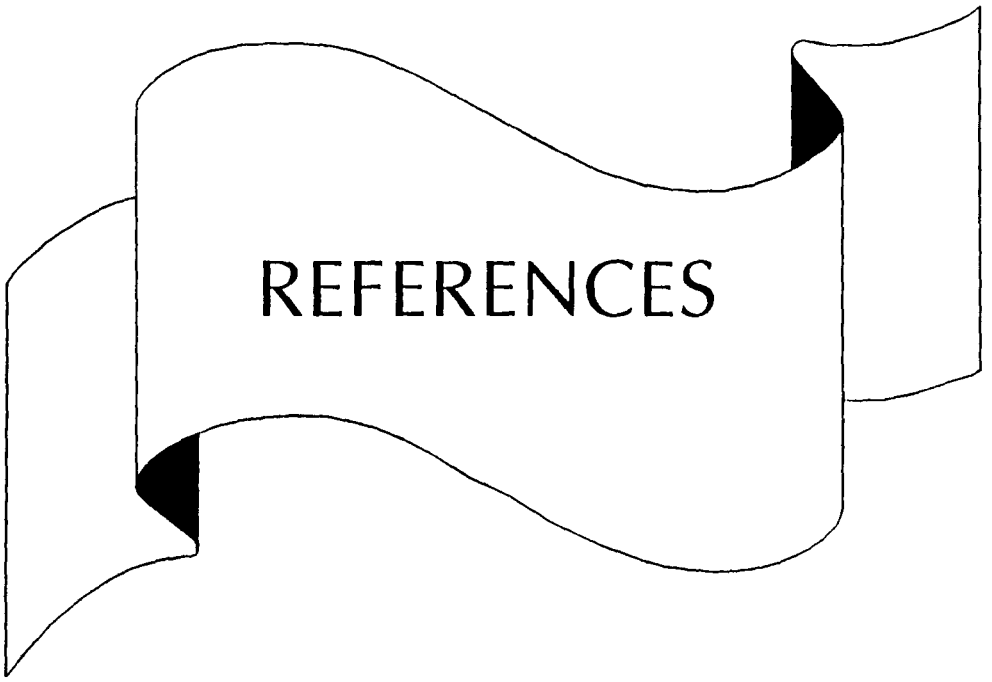
Path coefficient analysis of yield parameters revealed that the weight of finger is the most important character which determined the yield. The direct effect of number of fingers along with the indirect effect *via.* weight of finger with yield contributes to 50% of the variation in yield.

Among the parameters determining the quality of fruits, the highest content of total soluble solids, total sugar content and sugar-acid ratio were recorded by the fruits in T_4, which apparently received a higher amount of available P from the soil and favoured by the biological activity of PB. No appreciable difference in the quality of ripe fruits was revealed between

treatments possibly due to the uniform application of N and K, the nutrients which are most decisive in producing good quality banana fruits. Since the fruit quality is known to be highly influenced by K followed by N, a variation in P content might not have significantly affected any of the quality parameters.

It may be concluded from the results of the study that for increasing the efficiency of utilisation of applied P to banana in the acidic laterite soils, a combined application of MRP and PB along with FYM and mulch is essential. This package was found to be very effective in increasing the available P status of soil, promoting plant growth and increasing the yield of banana with a lower level of P than what is recommended at present.

For achieving a higher net return from banana cultivation along with other inputs like FYM and mulch, the use of 3/4 level of P and PB inoculation may be considered as a viable alternative to the present POP recommendation.


REFERENCES

REFERENCES

Agnihotri, V.P. 1970. Solubilisation of insoluble phosphates by some soil fungi isolated from nursery seed beds. *Can. J. Microbiol.* **16** : 877-880.

Ahmad, N. and Jha, K.K. 1968. Solubilisation of rock phosphate by micro organisms isolated from Bihar Soils. *J. Can. Appl. Microbiol.* **14** : 89-95.

*Antarikanonda, P., Sassanarakkit, S., Amaret, P. and Waiamai, P. 1990. Biological system for improving availability of RP to plants. In : *NCRT, NUS, DOST-JSPS.* Joint seminar on Biotechnology. 22-66.

Arora, D. and Gaur, A.C. 1978. Periodic microbial solubilization of P^{32} labelled hydroxyapatite. *Indian J. Microbiol.* **10** : 315.

Asea, P.E.A., Kucey, R.M.N. and Stewart, J.W.B. 1988. Inorganic phosphate solubilisation by two penicillium species in solution culture and soil. *Soil Biol. Biochem.* **20** : 459-464.

Ashokkumar, A.R. 1977. Studies on the growth and development of banana, Musa (AAB group, Cavendish sub group) Robusta in relation to foliar and soil application of nitrogen and Azotobacter. M.Sc. (Ag) Thesis, Tamil Nadu Agricultural University, Coimbatore.

Awasthi, P.K. 1990. Marketting of rock phosphate as direct phosphate fertilizer. *Fert. News.* **35**(4) : 91-94.

Azcon, R., Barea, J.M. and Hayman, D.S. 1976. Utilisation of rock phosphate in alkaline soils by plants inoculated with mycorrhizal fungi and phosphate solubilising bacteria. *Soil Biol. Biochem.* **8** : 135-138.

*Bajpai, P.D. 1965. The influence of selected microflora on the solubilisation of phosphorus and uptake of this element by wheat, cowpea and berseem crops. Ph.D. Thesis, P.G. School, IARI, New Delhi.

Bajpai, P.D. and Sundara Rao, W.V.B. 1971. Phosphate solubilising bacteria III. Soil inoculation with phosphorus solubilising bacteria. *Soil Sci. Plant. Nut.* **17** : 46-63.

Balakrishnan, R. 1980. Studies on growth, development, sucker production and nutrient uptake at different ploidy levels in banana cv. 'Nendran'. M.Sc. (Hort.) Thesis, Kerala Agricultural University, Vellanikkara.

*Banik, S. and Dey, B.K. 1981. Solubilization of inorganic phosphate and production of organic acids by micro organisms isolated in sucrose tricalcium phosphate agar plate. *Zentralblat. Bakterol. Parasilenkl. Infektionskr.* Hyg. II. **136** : 478-486.

*Banik, S. and Dey, B.K. 1982. In : *Microbially mediated increases in plant available phosphorus.* Kucey, R.M.N., Janzen, H.H. and Legget, M.E. 1989. *Adv. Agron.* **42** : 200-223

Banik, S., Bhattacharya, S.K. and Pandey, S.N. 1989. Rock phosphate as substitute for single super phosphate in tossa Jute (*Corchorus olitorius*) cultivation. *Indian J. Agr. Sci.* **59**(10) : 676-679.

*Bardiya, M.C. and Gaur, A.C. 1974. Isolation and screening of microorganisms dissolving low grade rock phosphate. *Folia Microbiol.* **19** : 386-389.

*Barea, J.M., Azcon, R. and Hayman, D.S. 1975. Possible zynergistic interaction between Endogone and phosphate solubilising bacteria in low phosphate soils. In : *Endomycorrhia*. (Eds) by Sanders, F.E., Mosse, B. and Tinker, P.B. Academic Press, London and New york. 409-418.

Barthakur, H.P. 1978. Solubilisation of relatively insoluble P by some fungi isolated from the rhizosphere of rice. *Indian. J. Agri. Sci.* **48** (12) 762-764.

Baruah, P.J. and Mohan, N.K. 1988. Effect of potassium on fruit sugar, acidity, TSS and sugar-acid ratio of 'Jahaji' Banana (Musa, AAB, Cavendish sub group) *Banana News Letter* **11** : 14.

Baya, Ana, M., Boethling, R.S. and Ramos cormenzana, A. 1981. Vitamin production in relation to phosphate solubilisation by soil bacteria. *Soil Biol. Biochem.* **13** : 527-531.

Bear, F.E., 1964. Chemistry of the soil. Monograph series No. 160. Oxford & IBH. Publishing Co.

Bhargava, B.S. and Reddi, B.M.C. 1992. Selection Index tissue in banana for nutritional diagnosis. *Indian. J. Hort.* **49**(2) 120-126.

*Boland, D.E. 1980. Some aspects of banana leaf analysis in *Jamaica. Fruits* **35** : 335-360.

Bopiah, B.M. 1985. Occurance of phosphate solubilizing micro-organisms in the root region of Arecanut Palm. *J. Plantation Crops.* **13** : 60-62.

*Bromfield, S.M. 1959. The microbial decomposition of sugar and it's effect on phosphate solubility. *J. Aust. Inst. Agric. Sci.* **25** : 67-69.

*Brown, M.E. 1974. Seed and root bacterization. *Ann. Rev. Phyto pathol.*, **12** : 181-198.

*Chambers, J.W. and Yeomans, J.C. 1990. The effect of PB-50 (*Penicillium bilaji* inoculant) on yeild and phosphorus uptake by wheat. In : Proc. *Manitoba Soc. Soil.* Winnipeg, Manitoba, 9-10 Jan., 1990, 203-293.

Chang and Young 1994. Selection and application of biofertilizers in Taiwan, *FFTC. Tech. Bull.* **12** : 4-10.

Chathopadhyay, P.K. and Bose, T.K. 1986. Effect of NPK nutrition on growth, yield and quality of Dwarf Cavendish banana. (*Musa cavendishii* Lamb) *Indian Agri.* **30**(3) : 213-222.

Chhonkar, P.K. 1994. Crop response to phosphate biofertilizers. *Fert. News.* **39**(4) : 39-41.

Chhonkar, P.K. and Subba Rao, N.S. 1967. Phosphate solubilization by fungi associated with legume root nodules. *Can. J. Microbiol.* **13** : 743-753

Chiu-Chung-Young. 1994. Selection and application of biofertilizers in Taiwan. *FFTC. Techn. Bull.* **12** : 4.

Chopra, S.L. and Kanwar, J.S. 1976. *Analytical agricultural chemistry.* Kalyani Publishers, New Delhi p. 356-360.

Datta, M. and Banik, S. 1994. Effect of poultry manure and phosphate dissolving bacteria on rice (*Oryza sativa*) in acid soil. *Indian J. Ag. Sci.* **64**(11) : 791-793.

Datta, M., Banik, S. and Gupta, R.K. 1982. Studies on the efficiency of a phytohormone producing phosphate solubilising *Bacillus firmus* in augmenting paddy yield in acid soils of Nagaland. *Plant and Soil.* **69** : 365-373.

Datta, M., Banik, S. and Laskar 1992. Effect of inoculation of P dissolving bacteria on rice (*Oryza sativa*) in acid soil. *Indian J. Agri. Sci.* **62**(7) : 482-485.

*Diab, A. and Al- Gounaim, M.Y. 1984. Distribution of Azotobacter, actinomycetes, cellulose degrading, acid producing and phosphate dissolving bacteria in desert and salt marsh soils of Kuwait. Zentrabl. Microbiol. **139**: 423-433.

*Dox, A.W. and Golden, R. 1911. Phytase in lower fungi. *J. Biol. Chem.* **10** : 183-186.

Dubey, S.K. 1996. Response of soybean to Rock Phosphate Applied with *Pseudomonas striata* in a Typic Chromustert. *J. Indian Soc. Soil Sci.* **44**(2) : 252-55.

Dubey, S.K. and Billore, S.D. 1992. Phosphate solubilizing microorganisms (PSM) as inoculant and their role in augmenting crop productivity in India-a review. *Crop Res.* **5** : 11-24.

Duff, R.B., Webley, D.M. and Scott, R.P. 1963. Solubilization of minerals and related materials by 2-Ketogluconic producing bacteria. *Soil Sci.* **95** : 105-114.

*EL-Sawah, M.M.A., Hauka, F.A. and El-Hamdi, H.H. 1995. Role of bacterial phytate fertilizers on increasing soil fertility and crop production. *Egy. J. Soil Sci.* **35**(3) : 311-323.

Fernando, B. and Hugo, Z. 1983. Organic matter - phosphorus associations as a sink in P fixation processes in allophanic soils of chile. *Soil. Biol. Biochem.* **15**(5) : 599-603.

*Freiberg, S.R. 1955. *Annual report*, United Fruit Co., Dept. of Res. Boston, Mass

*Freiberg, S.R. 1956. *Annual report*, United Fruit Co., Dept. of Res, Boston, Mass.

Gaur, A.C. 1972. Role of phosphate solubilising microorganisms and organic matter in soil productivity. *Symp. Soil Productivity*, National Academy of Sciences, 259-268.

Gaur, A.C. 1990. *Phosphate solubilising micro-organims as biofertilizer.* Omega scientific Publishers, New Delhi.

Gaur, A.C. and Sachar, S. 1980. Effect of rock phosphate and glucose concentration on phosphate solubilisation by *Aspergillus awamori.* Curr. Sci., **49** : 553-554.

Gaur, A.C., and Gaind, S. 1983. Microbial solubilization of phosphates with particular reference to iron and aluminium phosphate. *Sci. Cult.* **49** : 110-112.

Gaur, A.C., Madan, M. and Ostwal, K.P. 1973. Solubilization of phosphate compounds by native microflora of rock phosphates. *Indian J. Exptl. Biol.* **11** : 427-429.

Gaur, A.C., Mathur, R.S. and Sadasivan, K.V. 1980. Effect of organic materials and phosphate dissolving cultures on the yield of wheat and green gram. *Indian J. Agron.* **25**(3) : 501-503.

Geetha, V.N. 1988. Nutritional requirement of Nendran Banana under Rice Fields M.Sc. (Ag) Thesis, Kerala Agricultural University, Vellanikkara, Thirissur.

George, Sumam. 1994. Standardisation of Plant part as an index of potassium status in Banana, Musa (AAB of group) Nendran, Ph.D Thesis, Kerala Agricultural University, Vellanikkara, Thrissur.

*Gerretsen, F.C. 1948. The influence of micro-organisms on the phosphorus uptake by the plant. *Plant and Soil.* **1** : 51-81.

*Ghazvinizadeh, H., Ciafardinif, G., Atti, R. and Vittelle, A. 1980. Indagine soil batter fosfatolificidi un terreno coltivatoa Mais. *Agrochemica.* **24** : 195-200.

*Golebiowska, J., Jaknistak, B. and Sypnswska, U. 1964. Influence of the rhizosphere microflora of alfalfa on tranformation of soil phosphorus compounds. *Roczn. Globozn.* **14** : 121-130.

Goos, R.J., Johnson, B.E. and Stack, R.W. 1994. *Penicillium bilaji* and phosphorus fertilization effect on the growth, development, yield and root rot-severity of spring wheat. *Fert. Res.* **39** : 97-103.

Goswami, K.P. and Sen, A. 1962. Solubilization of calcium phosphate by three strains of phosphobacterin. *Indian J. Agric. Sci.* **32** : 96-101.

*Gottriech, M., Bradu, D. and Halevy, Y. 1964. A simple method for determining average banana fruit weight. *Ktavani,* **14** : 161-162.

Goyal, V.K.S., Phogat, M.M., Mishra and Yadav, K.S. 1983. *Indian. J. Microbiol.* **23**(2) : 136-138.

*Greaves, M.P., Anderson, G. and Webley, D.M. 1963. A rapid method of determining phytase activity of soil micro-organism. *Nature.* **200** : 1231-1232.

*Gupta, R., Aparna, Shanker, A.B., Saxena, R.K. and Kuhad, R.C. 1993. Solubilisation of low grade Indian RP and inorganic phosphates by *Bacillus licheniformis. Folia. Micro.* **38**(4) : 274-276.

*Hauter, R. 1983. Phosphatmobilisierung in Abhangigkeit vom pH des Bodens unter besonderer Berucksichtigung der Rhizosphare, Ph.D. Thesis FB 19, Justus Lebig - University Gussen In : *Advances in Soil Science* Vol. 2. (Eds.) Stewart, B.A. Springer Verlag, New York. p. 96-106.

Hazra, C.R. 1994. Response of biofertilizers in forage and fodder crops. *Fert. News.* **39**(4) : 43-53.

Hegde, D.M. and Dwivedi, B.S. 1994. Crop Response to Biofertilizers in Irrigated areas. *Fert. News.* **39**(4) : 19-26.

Heggo, A.M. and Barakah, F.N. 1993. Proto co-operation effect of VAM fungi and P dissolving bacteria on Phosphatase activity and nutrient uptake by maize (*Zea mays*) plant grown in calcareous soils. *Annals of Ag. Sci.* **38**(1) : 71-77.

*Hewitt, C.W. 1955. Leaf analysis as guide to the nutrition of banana. *Emp. J. Ag.* **23** : 11-16.

*Hnatowich, G.L., Gleddie, S.C. and Polonenko, D.R. 1990. Wheat response to PB-50 (*Penicillium bilaji*), a phosphate-solubilising inoculant. In : Havlin. JL and Jacobsen, J.S. (Eds) *Proc. Great Plains Soil Fert. Conf.* Denver, Co, 6-7 March, 1990. Kansas State Univ, Manhattan.

Hooker, M.L., Peterson, G.A. and Daigger, L.A. 1980. Phosphate fractions in calcareous soils as altered by time and amounts of added phosphate. *Soil Sci. Soc. Am. J.* **44** : 269-277.

Huggag, L.F., Azzazy, M.A. and Mak soud, M.A. 1994. Abstract in Tropical Agriculture. *Annals. Ag. Sci.* **39**(1) : 345-353.

Illmer, P. and Schinner, F. 1992. Solubilisation of inorganic phosphates by microorganisms isolated from forest soils. *Soil Biol. Biochem.* **24**(4) : 389-395.

Illmer, P. and Schinner, F. 1995. Solubilisation of inorganic calcium phosphates-solubilisation machanism. *Soil Biol. Biochem.* **27**(3) : 257-263.

Illmer, P., Barbato, A. and Schinner, F. 1995. Solubilisation of hardly soluble $AlPO_4$ with P solublising micro organisms. *Soil Biol. Biochem* **27**(3) : 265-270.

Jackson, M.L. 1973. Soil Chemical Analysis. Prentice - Hall of India Pvt. Ltd. New Delhi.

Jaggi, T.N. 1989. Evaluation of Indian phosphate rocks as resources for phosphatic fertilizers. *Fert. News.* **34** : 43-49.

*Janossy, G. 1963. Changes in phosphatase activity of micro organisms in relation to phosphorus supply. *Agrokem. Talajit.* **12** : 285-292.

Jayasree, P. 1987. Effect of different mulches on soil temperature and soil water retention in relation to seedling emergence and crop growth M.Sc. (Ag) Thesis, Kerala Agricultural University, Vallanikkara, Thrissur.

Jorg, G. and Herman, R. 1992. Adsorption of orthophosphate to Humic-Fe-Complexes and to amorphous Fe-oxide *Z. Pflanzenerndhr. Bodenk.* **155** : 233-236.

*Kabesh, M.O. 1957. Effect of P dissolving bacteria and P fertilization on the P uptake by pea plants cultivated in a calcareous soil. *Z. Pflanzenern. Bodenk.* **6** : 605-611.

Kathiresan, G., Manickam, G. and Parameswaran, P. 1995. Efficiency of phosphobacterin addition on cane yield and quality. *Co-op. Sugar.* **26**(8) : 629-631.

Katznelson, H., and Bose, B. 1959. Metabolic activity and phosphate dissolving capacity of bacterial isolates from wheat roots, rhizosphere and non-rhizosphere soil. *Can. J. Microbiol.* **5** : 79-85.

Kavimandan, S.K. and Gaur, A.C. 1971. Seed inoculation with *Pseudomonas* spp. on phosphate uptake and yeild of maize. *Curr. Sci.* **12** : 439.

Khalafallah, M.A., Saber, M.S.M. and Abd- El - Maksoud. 1982. *Z. Pflanzenernachr. Bodenkd*, **145** : 445-59.

Khan, J.A. 1977. Studies on solubilisation of insoluble phosphates by micro-organisms : I Solubilisation of Indian RP by *Aspergillus niger* and *Penicillium* sp. *Fert. Techno.*, (14) **4** : 329-333.

Khan, J.A. and Bhatnagar, R.M. 1977. Studies on solubilisation of insoluble phosphates by micro-organisms. Part I. Solubilisation of Indian phosphate rocks by *A. niger* and *Penicillium* sp. *Fert. Techno.*, **14** : 329-333.

Kotoky, U. and Bhattacharyya, R.K. 1992. Leaf nutrient concentration of some banana cultivars as influenced by organic mulches. *Acta Horticulture* 296 : 113-117.

Krishnan, B.M. and Shanmughavelu, K.G. 1980. Studies on water requirements of banana cv. Robusta III leaf nutrient concentration and total uptake of nutrients. *Mysore J. Agric. Sci.* **14**(2) : 215-223.

Kucey, R.M.N. 1983. Phosphate solubilizing bacteria and fungi in various cultivated and Virgin Alberta soils. *J. Soil Sci.* **63** : 671-678.

Kucey, R.M.N. 1987. Increased phosphate uptake by wheat and field beans inoculated with a phosphorus solubilising *Pencillium bilaji* strain and with vesicular - arbuscular mycorrhizal fungi. *Appl. Environ. Mcrobiol.* **53** : 2699-2703.

Kucey, R.M.N. 1988. Effect of *Penicillium bilaji* on the solubility and uptake of P and micro nutrients from soil by wheat. *Can. J. Soil Sci.* **68** : 261-70.

Kucey, R.M.N. and Leggett, M.E. 1989. Increased yields and phosphorus uptake by Westar Canola (*Brassica napus*. L.) inoculated with a phosphate - solubilising isolate of *Penicillium bilaji*. *Can. J. Soil Sci.* **69** : 425-432.

Kucey, R.M.N., Janzen, H.H. and Legget, M.E. 1989. Microbially mediated increases in plant available phosphorus. *Adv. Agron.* **42** : 200-223.

Kumar, B.S.D. and Dube, H.C. 1993. Siderophere production by a plant growth promoting fluorescent *pseudomonas*, RBT 13. *Indian J. Microbial* **33**(1) : 61-65.

Kumar, A., Sinha, M.N. and Rai, P.K. 1993. Comparative performance of chick pea, lentil and pea at various P levels and inoculation. *Anna. Ag. Res.* **14**(3) : 345-347.

Kumaraswamy, K. and Rajasekharan, 1990. Phosphobacteria biofertilizer more beneficial to sugar cane. *Kissan world.* May, 1990. p. 3.

Kundu, B.S. and Gaur, A.C. 1980. Effect of phosphobacteria on the yield and phosphate uptake of potato crop. *Curr. Sci.* **49** : 159-161.

Kundu, B.S. and Gaur, A.C. 1984. Rice response to inoculation with N_2 fixing and P solubilising micro organisms. *Plant and soil.* **79** : 227-234.

Kurien, T.M., Prabhakaran, P.V. and Varkey, P.A. 1985. Path coefficient analysis in Nendran variety of banana. *South Indian Hort.* **33**(1) : 386-390.

*Lahav, E. 1972. Le role de l'analyse des parties de la plante pour determinar le nivean potassique du bananier *Fruits.* **27** : 855-864.

*Lahav, E. 1977. The suitability of sampling the leaf petiole for determining the mineral content of the banana sucker, *Fruits.* **32** : 297-30.

*Lahav, E., Bareket, M. and Zamet, D. 1981. The suitability of the blade, vein and petiole for determination of nutrients in the banana sucker, *Fruits* **36** : 417-428.

*Lin, M.L. and Fox, R.L. 1992. The comparative agronomic effectiveness of rock phosphate and super phosphate for banana. *Fert. Res. Int. J. Fert. Use Technol.* Dordrecht : Kluwer Academic Publishers. **31**(2) : 131-135.

Louw, H.A. and Webley, D.M. 1959. A study of soil bacteria dissolving certain mineral phosphate fertilizers and related compounds. *J. Appl. Bact.* **22** : 227-233.

Lundegardh, H. 1935. The influence of the soil upon the growth of the plant. *Soil Sci.* **40** : 89-101.

*Mahmoud, S.A.Z, Abdel - Hafez, A.M., El-sawy, M. and Hanafy, E.A. 1973. Phytin - hydrolysing bacteria in soils of Egypt. *Zbl. Bakt. Abt,* II, **128** : 528-531.

Mathew, Valsamma. 1980. Nitrogen nutrition in rainfed banana cv. 'Palayankodan'. *M.Sc (Hort) Thesis,* Kerala Agricultural University, Vellanikkara, Thrissur.

Mengel, K. and Kirkby, E.A. 1987. *Principles of Plant Nutrition,* Intern. Potash, Inst., Berne,

*Menkina, R.A. 1950. Bacteria which mineralise organic phosphorus compounds. *Mikro biologiya*, **19** :308-316.

*Meyer, L. and Konig, E. 1960. Experimental results on the biological decomposition of difficultly soluble phosphates by soil fungi. *Landw. Forsch.* **13** : 7-24.

Misra, U.K. and Sahoo, R.N. 1995. Dissolution of Rock Phosphate as affected by Phosphate Solubilising Microorganisms. A laboratory incubation study. In : National Seminar on Development in soil Science, 60th Annual Convention Nov 2-5, 1995.

*Moghimi, A. and Tate, M.E. 1978. In : Microbially mediated increases in plant available phosphorus. Kucey, R.M.N., Janzen, H.H. and Legget, M.E. 1989. *Adv. Agron.* **42** : 200-223.

*Moghimi, A., Lewis, D.G. and Oades, J.M. 1978. In : Microbioally mediated increases in plant available phosphorus. Kucey, R.M.N., Janzen, H.H. and Legget, M.E. 1989. *Adv. Agron.* **42** : 200-223.

Mohan, N.K. and Madhava Rao, V.N. 1985. Determination of active root zone in banana using radio active P. *South Indian Hort.* **33**(4) : 217-220.

Mohod, S.P., Gupta, D.N. and Chavan, A.S. 1989. Enhancement of P availability and P uptake by P solubilising culture. *J. Maharashtra. Ag. Univ.* **14**(2) : 178-181.

Molla, M.A.Z., Choudhary, A.A., Islam, A. and Ibeque, S. 1984. Microbial mineralization of organic phosphate in soil. *Plant and Soil.* **78** : 393-399.

*Moreau, R. 1959. The biological liberation of soluble phosphates from insoluble phosphorus compounds in soil. *Compt. Rend. Akad. Sci. Paris.* **249** : 1804-1806.

*Muromtsev, G.S. 1958. The dissolving action of some root and soil microorganisms on calcium phosphate insoluble in water. *Agrobiologiya.* **5** : 9-14.

Murray, D.B. 1960. The effect of deficiencies of the major nutrients on growth and leaf analysis of the banana. *Trop. Ag.* **37** : 97-106.

Nair, S.K. and Rao, N.S.S. 1977. Distribution and activity of phosphate solubilising micro-organisms in the rhizosphere of coconut and cacao under mixed cropping *J. Plantation Crops.* **5** : 67-70.

Nair, M.K. 1978. Studies on increasing the efficiency of rock phosphate in Kerala soils. M.Sc. (Ag) Thesis, Kerala Agricultural University, Vellanikkara, Thrissur.

Nair, S.C. 1977. Investigations on the use of Mussorie rock phosphate in the acid soils of Kerala M.Sc. (Ag) Thesis, Kerala Agricultural University, Vellanikkara, Thrissur.

Narsian, V. Jugnu Thakkar, and Patel, H.H. 1993. Solubilisation of natural RP and pure insoluble inorganic phosphates by *Aspergillus awamori. I. J. Exp. Bio.* **31**(9) : 747-749.

Narsian, V., Jugnu Thakkar, and Patel, H.H. 1994. Isolation and screening of phosphate solubilising fungi. *Indian J. Microbiol.* **34**(2) : 113-118.

Natesh, B. 1987. Effect of split application of fertilizers in Banana cv. Nendran. M.Sc (Hort.) Thesis, Kerala Agricultural University, Vellanikkara, Thrissur.

*Osman, A.Z., Saber, M.S.M and EL-Sherif, A.E. 1975. Studies on microbial fertilizers. II Effect of P dissolving bacteria on the uptake of P from calcareous soils. *Isotopes and Radiation Research.* **7** : 49-53.

Ostwal, K.P. and V.P. Bhide 1972. Solubilization of tri calcium phosphate by soil *Pseudomonas*. *Ind. J. Exptl. Biol.* **10** : 153-154.

Othieno, C.O. 1973. The effect of organic mulches on yield and P utilisation by plants in acid soil. *Plant and Soil* **38** : 17-32.

Panse, V.G. and Sukhatme, P.V. 1967. *Statistical methods for Agricultural Workers.* Indian Council of Agricultural Research, New Delhi.

Patgiri, I. and Bezharuah, B. 1990. Strains contributing to P mobilization in acid soils. *Indian J. Agr. Sci.* **69** (3) : 197-200.

Patil, R.B., Rajasekharappa, B.J., Viswanath, D.P. and Santha Ram. M.V. 1979. Solubilization and immobilization of phosphate by some microorganisms and P availability to plants. *Bull. Indian. Soc. Soil Sci.* **12** : 550-556.

Paul, N.B. and Sundara Rao, W.V.B. 1971. Phosphate dissolving bacteria in rhizosphere of some cultivated legumes. *Pl. and Soil,* **25**(1) : 127-143.

Pillai, G.R., Balakrishnan, S., Veeraraghavan, P.G. and Gopalakrishnan, R. 1977. Response of Nendran Banana to different levels of N, P and K. *Agric. Res. J. Kerala,* **15**(1) : 37-40.

Piper, C.S. 1967. *Soil and Plant analysis.* Asia Publishing House, Bombay.

Podyapolskaya, V.P. 1960. Distribution in light chest nut soils of bacteria dissolving tri calcium phosphate, *Agrobiologiya,* **1** : 86-90.

Podile, A.R. 1995. Seed bacterization with *Bacillus subtilis*. AF enhances seedling emergence, growth and nodulation of pigeon pea. *Indian J. Microbiol.* **33**(3) : 199-204.

Prabhakar, M. and Saraf, C.S. 1990. Dry matter accumulation and distribution in chick pea (*Cicer arietinum*) as influenced by genotype, P source and irrigation level. *Indian J. Ag. Sci.* **60**(3) : 204-206.

Prema, D. 1992. Status, Availability and Transformation of Magnesium in Acid soils of Kerala. Ph.D. Thesis, Kerala Agricultural University, Vellanikkara, Thrissur.

Prevel, P.M. Gagnard, J. and Gauter, P. 1986. Banana, In : *Plant analysis as a guide to the nutrient requirements of temperate and tropical crops.* SBA publications, Calcutta. p. 637-670.

Rachewad, S. N., Rauti, R.S., Malewar, G.U. and Hasnabade, A.R. 1991. Effect of phosphate solubilising biofertilizer on P utilisation by maize. *Annals of plant physiology.* **5**(1) : 117-120.

Raltson, D.B. and Mc Bride, R.P. 1976. Interaction of mineral phosphate dissolving microbes with red pine seedlings. *Plant and Soil.* **45** : 493-507.

Ramaswamy, N. 1974. Studies on the effect of different levels of phosphorus on the yield and quality of robusta banana. Annamalai University. *Ag. Res. Annual.* **6** : 30-37.

*Ramirez, R., Haddad, O., Laboren, G. and Albarran, S.E. 1978. Accumulation of N, P and K in banana leaf tissue in Aragua state. *Agronomia Tropical.* **28**(5) : 421-433.

Ranganna, S. 1977. *Manual of analysis of fruit and vegetable products.* Tata Mc. graw Hill Publishing Company Ltd., New Delhi.

Rangasamy, A. 1972. Response of rainfed sorghum to phosphobacterin with and without N and P. M.Sc (Ag) Thesis, Tamil Nadu Agricultural University, Coimbatore.

Rangasamy, A. and Morachan, Y.B. 1974. Influence of phosphobacterin on the P uptake of sorghum under rainfed conditions. *Madras Agric. J.* **61** : 721-723.

Rao, W.V.B.S. and Sinha, N.K. 1963. Phosphate dissolving organisms in the soil and rhizosphere. *Indian. J. Agri. Sci.* **33** : 272-278.

Rao, W.V.B.S., Bajpai, P.D., Sharma, J.P. and Subbaiah, B.V. 1963. Solubilisation of phophates by phosphorus solubilizing organisms using P^{32} as tracer and the influence of seed bacterization on the uptake by the crop. *J. Indian Soc. Soil Sci.*, **11**: 209-219.

Rasal, P.H., Kalbhor, H.B. and Patil, P.L. 1988. Effect of cellulolytic and PS fungi on cowpea growth. *J. Indian. Soc. Soil. Sci.* **36** : 71-74.

Rathore, R.S., Khandwe, R., Khandwe, N. and Singh, P.P. 1992. Effect of irrigation schedules, P levels and PS organisms on lentil. *Lens. News letter* **19**(1) : 17-19.

Ray, D.P., Parida, Y.N., and Chatterjee, B.K. 1988. Nutrient concentration in leaf tissue with different nutritional levels in Robusta banana. *Indian Agri.* **32**(4) : 249-256.

Research Report (1987-1990). Kerala Agricultural University, Vellanikkara, Thrissur.

*Saber, M.S.M. 1975. Studies on microbial fertilizers. III Effect of P and Si dissolving bacteria on the uptake of P and K from calcareous soils by *Sorghum halepensis*. *Z. Pflanzenern. Bodenk.* **6** : 613-619.

*Saber, M.S.M. and Kabesh, M.O. 1990. Utilisation of biofertilizers in field crop production. 2. A comparison study on the effect of biofertilisation or S application on yield and nutrient uptake by lentil plants. *Egy. J. Soil Sci.* **30**(3) : 415-422.

*Sahoo, R.N. and Misra, U.K. 1995. Enhancing efficiency of rockphosphate for maize grown in acid soil through inoculation of phosphate solubilising micro organisms. In : *National Seminar on Development in Soil Science*, 60th Annual Convention, Nov 2-5.

Salih, H.M., Yahya., A.I., Abdul Rahem, A.M. and Manam, B.H. 1989. Availability of P in calcareous soil treated with RP or SP as affected by P-dissolving fungi. *Pl. and Soil.* **120** (2) : 181-185.

Sen, A. and Paul, N.B. 1957. Solubilisation of phosphates by some common bacteria. *Curr. Sci.* **26** : 222-223.

Sethi, R.P. and Subba Rao, N.S. 1968. Solubilisation of tri calcium phosphate and calcium phosphate by soil fungi. *J. Gen. Appl. Microbiol.* **14** : 329-331.

*Shanker, R. and De, B. 1976. Report on Mussorie phosphate investigation. *Geoglogy Survey of India*, Northern Region, Lucknow, India, 82-98.

Shankar, K.B. 1980. Nutritional investigation in Nendran Banana (French plantain AAB), M.Sc. (Ag) Thesis, Tamil Nadu Agricultural University, Coimbatore.

Sharma, J.P. and Singh, M. 1971. Response of rice to phosphate and nitrogenous fertilizers with and without phosphobacterin culture. *Indian J. Agron.* **16** : 15-18.

Sheeja, V.G. 1990. Comparative Efficiency of different phosphatic fertilizers in rainfed Nendran banana. M.Sc. (Ag) Thesis, Kerala Agricultural University, Vellanikkara, Thrissur.

Sheela, V.L. 1982. Potassium nutrition in rainfed banana Musa (AAB group) Palayankodan. M.Sc. (Hort) Thesis, Kerala Agricultural University, Vellanikkara, Thrissur.

*Singal, R., Gupta, R. and Saxena, R.K. 1994. Rock phosphate solubilisation under alkaline conditions by *Aspergillus* and *A. foetida*. *Folia Microbiologica.* **39**(1) : 33-36.

*Singh, D., Mannikkar, N.D. and Srivas, N.C. 1979. Comparative performance of indigenous rock phosphate and super phosphate in a forage legume cropping pattern. *J. Indian Soc. Soil Sci.* **27** : 170-173.

Singh, H.P., Pareek, R.P. and Singh, T.A. 1984. Solubilisation of rock phosphate by phosphate solubilizer in broth. *Curr. Sci.* **53** : 1212-1213.

Singh, R.K. and Choudhary, B.D. 1985. *Biometrical methods in quantitative genetic analysis.* Kalyani Publishers, New Delhi.

Singh, S. and Kapoor, K.K. 1992. Solubilisation of insoluble phosphate by bacteria and their effect on growth and P uptake by mung bean. *Int. J. Trop. Ag.* **10**(3) : 209-213.

Smith, J.H., Allison, F.E. and Soulides, D.A. 1961. Evaluation of phosphobacterin as a soil inoculant. *Soil Sci. Soc. Amer. Proc.* **25** : 109-111.

Snedecor, G.W. and Cochran, W.G. 1967. *Statistical methods.* Oxford and IBH publishing Co, Calcutta.

Sperber, J.I. 1958. The incidence of apatite dissolving organisms in the rhizosphere and soil. *Aust. J. Agric. Res.* **9** : 778-781.

Sreerangaswami, S.R., Sambandamurthy, S. and Murugesan, M. 1980. Genetic analysis in banana. In : *Proc. Nat. Seminar in banana production technology*, Tamil Nadu Agricultural University, Coimbatore. 50-56.

Srivastava, T.K. and Ahlawat, I.P.S. 1995. Response of pea (*Pisum sativum*) to P, Mo and biofertilizers. *Indian. J. Agric.* **40**(4) : 630-635.

Stover, R.H. and Simmonds, N.W. 1987. *Bananas*. Long man Scientific & Technical, England.

Subramanian, A. and Purushothaman, P. 1974. Effect of seed treatment of bengal gram with *Bacillus circulans* on P uptake. *Madras. Agric. J.* **61** : 793-794.

Surange, S. 1985. Comparative Phosphate solubilising capacity of some soil fungi. *Curr. Sci.* **54** : 1134-1135.

Sushama, P.K., Susheela Devi, and Channa Basave Gowda, 1993. Efficiency of P fertilizers for Rice-Pulse cropping system in the Laterite Soils of coastal Karnataka. *J. Indian Soc. Soil Sci.* **41**(3) : 508-510.

Szember, A. 1960. Influence of plant growth on breakdown of organic phosphorus compounds by micro-organisms. *Plant and Soil.* **13** : 147-158.

Taha, S.M., Mahmoud, S.A.Z., El-Damaty, A.A. and Abd-El-Hafez, A.M. 1969. Activity of phosphate dissolving bacteria in Egyptian soil. *Plant and Soil.* **3** : 149-160.

Teaotia, S.S., Bhati, D.R. and Phogat, K.P.S. 1970. Simple partial and multiple correlations of quantitative characters of banana, *Musa sapientum* var. *Harichal*. *Progressive Hort.* **1** : 17-24.

Thakkar J., Varsha Narsian and Patel, H.H. 1993. Inorganic P solubilisation by certain soil bacteria. *I. J. Exp. Bio.* **31**(9) : 743-746.

Thomas, G.V., Shantaram, M.V., and Saraswathy, N. 1985. Occurrence and activity of phosphate solubilising fungi from coconut plantation soils. *Plant and Soil.* **87** (3) : 357-364.

Tinker, P.B. 1980. In : *The Role of phosphorus in Agriculture"* (F.E. Kasawneh, E.C. sample and E.J. Kamprath, (Eds.), 617-654. *Amer. Soc. Agron.* Madison, Wisconsin.

Tisdale, S.L. and Nelson, W.L. 1975. *Soil Fertility and Fertilizers* 3rd Edn. Macmillan Publishing Co., Inc. p. 224.

Tiwari, V.N., Pathak, A.N. and Lehri, L.K. 1993. Rock phosphate-super phosphate in wheat in relation to inoculation with phosphate solubilising organisms and organic waste. *Indian J. Ag. Res.* **27**(3-4) : 137-145.

Turner, D.W. 1980. Some factors related to yield components of bananas in relation to sampling to assess nutrient status. *Fruits.* **35**(1) : 19-23.

Usha kumari, K. 1991. Acidulation of phosphate rocks by iron pyrites oxidation and their evaluation as phosphate fertilizers Ph.D. Thesis, IARI, New Delhi.

Vaishya, U.K., Bapat, P.N. and Dubey, A.V. 1996. Phosphate Solubilising Efficiency of Microorganisms on Gram Grown on Vertisol. *J. Indian Soc. Soil Sci.* **44**(3) : 524-526.

Venkateswarlu, B., Rao, A.V. and Raina, P. 1984. Evaluation of phosphorus solubilization by micro-organisms isolated from arid soils. *J. Indian Sco. Soil Sci.* **32** : 273-277.

Vinayak, A.K. and Patil, V.K. 1978. Bacterial fertilizers. *Kissan World* **5** : 13.

Viswambharan, K. 1995. Agronomic evaluation of chemical and bioagents on P dynamics in Redloam soils of Kerala. Ph.D Thesis, Kerala Agricultural University, Vellanikkara, Thrissur.

Vlassak, K., Van Holm, L., Duchateau, L., Vander leyden, J. and Demot, R. 1992. Isolation and characterization of fluorescent *Pseudomonas* associated with the roots of rice and banana grown in Sri Lanka. *Plant and Soil.* **145** (1) : 51-63.

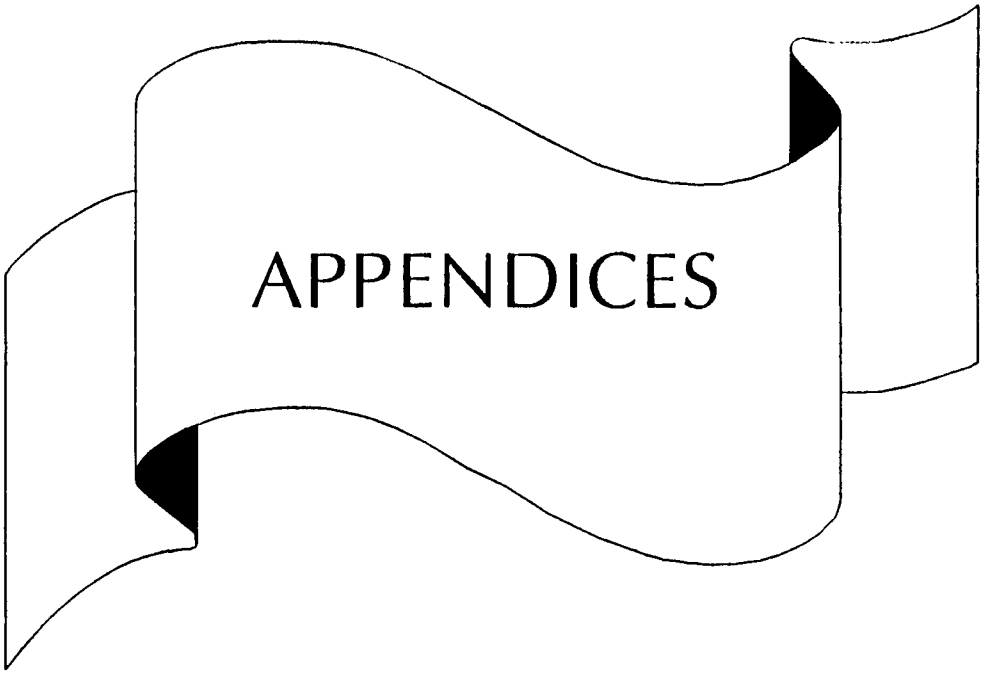
*Warner, R.M. and Fox, R.L. 1977. Nitrogen and K nutrition of Giant Cavendish banana in Hawaii. *J. Amer. Soc. Hort. Sci.* **102**(6) : 739-743.

White, R.E. and G.W. Thomas. 1981. Hydrolysis of aluminium on weakly acidic organic exchangers - implication for phosphate adsorption. *Fert. Res.* **2** : 159-167.

Yadav, K. and Singh, T. 1991. P solubilisation by microbial isolate from a calcifluent. *J. Indian Soc. Soil. Sci.* **39** : 89-93.

Yousry. M., 1978. Manganese availability in a calcareous soil as a result of P fertilization and inoculation with phosphobacteria. *Afr. J. Agric. Sci.* **5**(2) 75-80.

* Originals not seen.


APPENDICES

APPENDIX 1

Main meteorological parameters (monthly mean) during the cropping period (January 1994 to December 1994)

Month	Relative Humidity %	Temperature °C		Total Rainfall (mm)
		Maximum	Minimum	
1994				
January	78	32.4	16.5	—
February	80	34.0	16.5	107.0
March	80	33.8	16.8	42.8
April	53	31.9	17.4	144.9
May	66	31.4	17.7	146.6
June	72	27.9	16.4	431.9
July	83	27.8	15.6	180.5
August	77	27.9	15.8	229.5
September	90	30.3	16.1	220.6
October	85	29.3	15.4	343.6
November	75	29.4	15.6	43.0
December	80	30.6	15.7	59.2

APPENDIX - 2

Economic consideration

In the field experiment, the cost of labour, plant protection chemicals, FYM, nitrogenous and potassic fertilizers was uniform for all the treatments. A comparison of the cost of inputs and income from yield per plant between T_1 (POP recommendation) and the best treatment T_4 (¾P + PB) excluding the common expenditure is made as follows :

Treatment	Cost of MRP Rs Ps	Cost of PB @ Rs. 3.00 200 g^{-1} Rs Ps	Total expenditure Rs Ps	Yield of banana kg^{-1}	Income from sale @ Rs. 12kg^{-1}	Net return Rs Ps
T_1	1.25	—	1.25	9.93	119.16	117.91
T_4	0.94	0.60	1.54	10.68	128.16	126.62

It may be seen that an additional income of Rs. 8.71 per plant is achieved in treatment T_4 compared to T_1

INCREASING PHOSPHORUS USE EFFICIENCY IN BANANA cv. NENDRAN

By

SHEHANA, R. S.

ABSTRACT OF A THESIS
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AGRICULTURAL CHEMISTRY
COLLEGE OF AGRICULTURE
VELLAYANI
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ABSTRACT

The efficiency of phosphobacterin culture in increasing the availability of phosphorus from MRP and the resultant effect on the growth and yield of banana, cv. Nendran was evaluated by conducting laboratory incubation and field studies at FSRS, Kottarakkara during 1993-96.

Representative soil samples from the field at FSRS, Kottarakkara were mixed with MRP, PB, FYM and lime in different combinations and incubated at 60% WHC for 90 days. There was only a slight variation in the pH of soil upto 20 days due to the effect of different inputs. After 20 days, the soil showed a tendency to become slightly acidic reaching a mean value of only 5.6 from the initial pH of 5.7.

The P solubilising effect was maximum with a combination of PB, FYM and MRP. At the end of 90 days incubation, out of the 100 ppm P applied as MRP, a maximum of 19.31 ppm P became available in this treatment. P solubilised in the unamended soil was only 3.90 ppm and in the other treatments receiving FYM, lime and MRP either alone or in different other combinations, the values ranged from 9.21 to 16.73 ppm.

The application of 3/4 level of the recommended P along with PB, FYM and mulch has produced a significant positive effect on growth and yield characters compared to all the other treatments including the treatment as per package of practices recommendation of the KAU.

The highest bunch yield of 10.68 kg plant^{-1}, which was significantly superior to the yield in all the other treatments was recorded by plants supplied with 3/4 level of recommended P as MRP, 10 kg FYM and PB inoculated with proper mulching. The increase in yield in this treatment was 7.55% higher than the yield from plants given fertilizers as per the POP recommendations of the KAU.

The second highest bunch weight of 9.93 kg plant^{-1} was recorded by the plants which received the full recommended level of P along with N and K (POP recommendation). This yield was on par with the yield obtained in the treatment where only 1/2 the recommended level of P was used along with PB, FYM and mulch.

The use of FYM and mulching was found to be an essential practice to obtain the maximum benefit from the use of PB.

It may be concluded from the results of the study that for increasing the efficiency of utilization of applied P to banana in the acidic laterite soils, a combined application of MRP and PB along with FYM and mulch is

essential. This package was found to be very effective in increasing the available P status of soil, promoting plant growth and increasing the yield of banana with a lower level of P than what is recommended at present.

For achieving a higher net return from banana cultivation along with other inputs like FYM and mulch, the use of 3/4 level of P and PB inoculation may be considered as a viable alternative to the present POP recommendation.