

**EFFECT OF DIFFERENT LEVELS OF
PHOSPHORUS AND BIOFERTILIZERS ON SOIL
PROPERTIES, YIELD, QUALITY AND UPTAKE OF
NUTRIENTS BY GROUNDNUT (*Arachis hypogaea* L.)**

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AUGUST, 2019

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A thesis submitted to

**Dr. BALASAHEB SAWANT KONKAN KRISHI VIDAYPEETH,
DAPOLI
(Agricultural University)
Dist. Ratnagiri (Maharashtra State), India**

in partial fulfilment of the requirements for the degree of

Doctor of Philosophy (Agriculture)

in

SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

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CERTIFICATE

This is to certify that, the thesis entitled “**Effect of different levels of phosphorus and biofertilizers on soil properties, yield, quality and uptake of nutrients by groundnut (*Arachis hypogaea* L.)**” submitted to the Faculty of Agriculture, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri, Maharashtra State, in partial fulfillment of the requirements for the degree of **DOCTOR OF PHILOSOPHY (AGRICULTURE) in SOIL SCIENCE AND AGRICULTURAL CHEMISTRY**, embodies the results of a piece of *bonafide* research carried out by **Mr. MANOJ RAMDAS WAHANE** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma or published in other form. All the assistance and help received during the course of investigation and the sources of literature have been duly acknowledged by him.

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Chairman,

Advisory Committee and

Research Guide

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ACKNOWLEDGMENT

*I express my deepest sense of gratitude and fathomless respect to my esteemed teacher and chairman of my advisory committee, **Dr.V. G. Salvi**, Professor and Head, Department of Soil Science and Agril. Chemistry, Dr. B. S. Konkan Krishi Vidyapeeth, Dapoli, for his invaluable guidance, constant encouragement and constructive suggestion during the course of the present investigation and in the presentation of the findings in this thesis.*

*I deeply moved to acknowledge to member of my Advisory Committee **Dr. S.B. Dodake**, Khar Land Scientist, K. L. R. S., Panvel, Dist. Raigad, **Dr. B.R. Salvi**, Head and Associate Dean, College of Horticulture, Dapoli, **Dr. M. S. Joshi**, Professor, Department of Plant Pathology, College of Agriculture, Dapoli, and **Dr. J. S. Dhekale**, Professor (CAS), Department of Agril. Economics and Statistics, College of Agriculture, Dapoli, for their inspiration, kind and helpful discussion and suggestion, valuable advice and timely help during the course of study.*

*I am especially indebted to **Prof. N. H. Khobragade**, Assistant Professor, Department of Soil Science and Agriculture Chemistry, college of Agriculture, Dapoli for his painstaking efforts, all-round help and valuable suggestions.*

*I thankfully acknowledge **Dr. S. S. Prabhudesai and Dr. K. D. Patil**, Ex. Head, Department of Soil Science and Agril. Chemistry, for providing necessary facilities during my research work.*

*I am extremely thankful to **Dr. K.P. Vaidya**, Professor (CAS), **Dr. M. C. Kasture**, Associate Professor, **Dr. Smt. P. S. Sawant**, Associate professor (CAS), **Dr. S. S. More**, Assistant Professor, Department of Soil Science and Agril. Chemistry, College of Agriculture, Dapoli. **Dr. N. A. Meshram**, Scientist S-I, AICRP-Agroforestry, C.E.S. Wakavali, and Shri. **D.J. Dabke**, Ex-Associate Professor, for their noteworthy help, valuable suggestions, constant encouragement throughout the period of my doctoral studies.*

I thank to the members of Board of Study for their support at various phases of the programme.

*I am extremely grateful to visionary to **Dr. S. D. Sawant**, Hon. Vice Chancellor, Dr. B.S.K.K.V., Dapoli, also grateful to **Dr. Tapas Bhattacharyya**, Ex. Hon. Vice Chancellor, Dr. B.S.K.K.V., Dapoli for permitting me to peruse higher education. I also place on record my cordial thanks to **Dr. P.M. Haldankar**, Director of Research,*

Dr. S.G. Bhawe, Director of Extension, Dr. S.S. Narkhede, Dean, Faculty of Agriculture and Dr. U.V. Mahadkar, Associate Dean, college of Agriculture, Dapoli for provision of necessary facilities for conducting this study. Also, thankful to Dr. B. L. Thaware, Ex. Head, Department of Botany and Prof. M. G. Palshetkar for their constant help during my research work.

I would like to thank Shri. A. A. K. Dosani, Jr. Research Assistant and Shri. Sanjay Salvi, Agril. Assistant, who helped me by making all the material available at hand very promptly, whenever needed and provide labours to conduct my research work. I am also obliged to mention my sincere regards to Smt. Bhosale madam, Munna Shaikh, Mr. Mahadik, Mr. Pawar, Prakash, Satish, Mr. R. D. Pawar, Mr. R. V. Jadhav and Mr. Surendra Kadam and all non-teaching staff who helped me throughout this journey.

Completion of this project could not have been accomplished without the support of my Ph.D. colleagues Prof. M. J. Mane, Prof. S. G. Mahadik, Prof. N. V. Dalvi, Mr. U. K. Sawant and Prof. T. J. Bedse, Biochemist, RARS, Karjat who helped me a lot in all respect and love offered to me as a small brother throughout the degree course. I also share the credit of my work with my batch-mates Ms Praneti, Ms Ashwini, Ms Aparna and Ms. Sanika for their sincere co-operation and love.

No words are enough to express my wholehearted sense of reverence to beloved father Mr. Ramdas Wahane and beloved mother Mrs. Parbata Wahane, my beloved elder brother Dr. Saroj and Sister-in-law Mrs. Shrushti and younger brother Dhiraj who have their bondless love, constant encouragement, support and efforts to shape my career. I also extend my heartfelt gratitude to my wife Mrs. Varsha who has been an unending source of inspiration and affection for me. I cannot stop myself from placing cordial thanks to my daughter Pearl and my niece Shragvi and Shambhavi for their love. I take this opportunity to express my affection towards I also wish to convey my thanks to all my friends of who always supported me with their love and inspiration.

I would like to thank my juniors Subodh, Sagar, Ms. Pranali, and Ms. Meldy who helped whole heartedly. I am also obliged to thank my junior Nitin, Ajinkya, Akash, Sanket, Akhildas, Naveena, Priyanka, Asawari, Utkarsha, Sumit, Ranjit, Amit, Ms. Rahi, and Ms. Ashwini for their excellent company and healthy friendship.

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Title of Thesis : **Effect of Different Levels of Phosphorus and Biofertilizers on Soil Properties, Yield, Quality and Uptake of Nutrients by Groundnut (*Arachis Hypogaea* L.)**

ABSTRACT

The field experiment was conducted to study the effect of different levels of phosphorus (*viz.*, 15, 30, 45 and 60 kg ha⁻¹) and biofertilizers (*viz.*, VAM @ 10 kg ha⁻¹, PSB @ 10 kg ha⁻¹, VAM + PSB @ 5 kg ha⁻¹ each and VAM + PSB @ 10 kg ha⁻¹ each) on soil properties, yield, quality and uptake of nutrients by groundnut cv. *Konkan Trombay Tapora* / TKG-Bold (*Arachis hypogaea* L.) grown on Alfisol in *Konkan* region of Maharashtra. The experiment was undertaken during *Rabi*, 2017-18 and 2018-19 at Research Farm of Department of Agril. Botany, College of Agriculture, Dapoli with Factorial Randomized Block Design with twenty treatment combinations, which were replicated thrice. The soil and plant samples were collected at peg initiation stage, at pod formation stage and at harvest stage and the soil samples were analyzed for various physical, chemical and biological properties. The plant samples were analysed for major and micronutrients content as well as the quality parameters of groundnut were estimated.

The results of the experiment showed that the application of graded doses of phosphorus (*viz.*, 15, 30, 45 and 60 kg ha⁻¹) and biofertilizers (*viz.*, VAM @ 10 kg ha⁻¹, PSB @ 10 kg ha⁻¹, VAM + PSB @ 5 kg ha⁻¹ each and VAM + PSB @ 10 kg ha⁻¹ each) noted significant increase in pH however, the electrical conductivity and organic carbon content was decreased from peg initiation stage to harvest of the crop during 2017-18 and 2018-19. The bulk density, particle density, porosity and maximum water holding capacity showed non-significant effect due to application of various treatments. The cation exchange capacity was significantly highest with

application of phosphorus @ 60 kg ha⁻¹ and inoculation of VAM + PSB @ 10 kg ha⁻¹ each.

There was significant and graded increase in biological properties with the application of graded doses of phosphorus (*viz.*, 15, 30, 45 and 60 kg ha⁻¹), where the highest dose of phosphorus i.e. 60 kg ha⁻¹ (RDF) and inoculation of VAM + PSB @ 10 kg ha⁻¹ each and their interaction recorded the significantly highest value. The soil biological properties increased from peg initiation stage to pod formation stage and thereafter decreased at harvest.

The available nitrogen and potassium content was increased irrespective of treatments from peg initiation stage to pod formation stage and then decreased gradually up to harvest stage. Irrespective trend of available phosphorus content was observed. The DTPA extractable Zn and Fe content decreased from peg initiation to harvest stage. DTPA extractable Mn content decreased at pod formation stage over peg initiation stage and thereafter it increased at harvest while, DTPA extractable Cu increased at pod formation stage and decreased at harvest.

As far as the yield of groundnut was concerned, the application phosphorus @ 60 kg ha⁻¹ recorded significantly highest pod yield (35.67 q ha⁻¹ and 36.06 q ha⁻¹ during 2017-18 and 2018-19) and it was at par with application of phosphorus @ 45 kg ha⁻¹ i.e. P₄₅ (31.43 and 32.49 q ha⁻¹ during 2017-18 and 2018-19, respectively), which indicated that the application of phosphorus @ 60 kg ha⁻¹ can be substituted by the application of phosphorus @ 45 kg ha⁻¹. The application of biofertilizers (*viz.*, VAM @ 10 kg ha⁻¹, PSB @ 10 kg ha⁻¹, VAM + PSB @ 5 kg ha⁻¹ each and VAM + PSB @ 10 kg ha⁻¹ each) and interaction of phosphorus and biofertilizers was found to be non-significant. Application of phosphorus @ 60 kg P₂O₅ ha⁻¹ through SSP along with VAM + PSB @ 10 kg ha⁻¹ each resulted in marked improvement in growth and yield attributes, nutrient content, nutrient uptake by groundnut and oil, protein and methionine content in groundnut. The application of phosphorus @ 60 kg ha⁻¹ with combined inoculation of biofertilizers i.e. VAM + PSB @ 10 kg ha⁻¹ each fetched maximum net returns and mean net returns/rupee invested (₹ 1.34).

The results of present investigation have clearly indicated that, the application of phosphorus @ 60 kg ha⁻¹ + 100 per cent recommended dose of N and K along with VAM and PSB 10 kg ha⁻¹ each may be instrumental in harvesting a good groundnut crop alongwith quality and improving soil quality status of Alfisol under Konkan condition. However, keeping in view the optimum net return with higher B:C ratio, the application of phosphorus @ 60 kg ha⁻¹ with VAM and PSB 10 kg ha⁻¹ each can be used for enhancing groundnut production.

CHAPTER I

INTRODUCTION

Agriculture primarily depends on soil, which is a living body, because it consists of microflora such as bacteria, actinomycetes, fungi and algae. Normally there are more than ten crores of microorganisms in one gram soil. Though, the use of chemical inputs in agriculture is inevitable to meet the growing demand for food in the world, there are opportunities in selected crops and niche areas where organic production can be encouraged to tap the domestic export market. Biofertilizers play a very significant role in improving soil fertility by fixing atmospheric nitrogen. They help in fixation of nitrogen in association with plant roots and solubilize insoluble soil phosphates by producing plant growth substances in the soil (Mishra *et al.* 2013). The rapid industrialization, urbanization and increase in human population have caused agricultural land shrinkage by nearly 2.76 million hectares in last two decades, resulting in food crisis in India (Abbasdokht and Gholami 2010) and all over the world. By 2050, the world's population will reach 9.1 billion, 34 per cent higher than today. Hence, the food production must increase by 70 per cent to feed the growing human population. This production level will require about 30 million tonnes of nitrogen (N), phosphorus (P), and potassium (K), including 8.6 million tonnes of P₂O₅. In addition, another 14 to 15 million tonnes of NPK would be needed for vegetable, plantation, sugarcane, cotton, oilseed, potato, and other crops. Thus, about 40 to 45 million tonnes of NPK, containing 11 to 13 million tonnes of P₂O₅, will be required just to maintain a broad average N:P₂O₅:K₂O ratio of 4:2:1 (Krishnaraj and Dahale 2014) however, it is worsened to 8.2:3.2:1 in the year 2012-13 and 7:2.7:1 in the year 2018-19 (Chander 2019). As the production and manufacture cost of the chemical fertilizers are very high and its availability and uses are also becoming imperative. Hence, new options are needed to better exploit soil P resources through either the selection of efficient cultivars or using alternative strategies of management of soil and agro ecosystems to optimize P bioavailability. In this context, the reduced use of chemical fertilizers with the increased application of bio-fertilizers is considered a compulsory route to alleviate the pressure on the soil and environment derived from agricultural practices (Malus *et al.* 2012).

Groundnut (also called pea nut, earth nut, monkey nut, goober nut, manila nut, pinder and panda nut) is a native of South American leguminous oil seed (Hammons

1982). Groundnut (*Arachis hypogaea* L.) is an important oil seeds as well as food crop ranking 13th among the principal economic crops of the world. It was first found in Brazil or Peru as early as 950 B.C. (Higgins 1951). In India, the crop was introduced by the Portuguese in 16th century as an oil seed crop for commercial cultivation. Among the oilseed crop grown in India, groundnut occupies pre dominant position. Therefore, the groundnut is rightly called as “king of oilseeds” in India (Shree Ganesh *et al.* 2015) belongs to family *Fabaceae*.

In the world, groundnut is cultivated in more than 100 countries on 26.54 m hectare area with an annual production of 43.91 m tonnes and productivity of 1655 kg ha⁻¹. In India, groundnut is grown on 4.77 M hectare area with the production of 7.40 m tonnes. The productivity of groundnut in India is low (1552 kg ha⁻¹) compared to Israel (7389 kg ha⁻¹), USA (4397 kg ha⁻¹), China (3492 kg ha⁻¹) and Argentina (2848 kg ha⁻¹) (Anonymous 2015). Groundnut is the third major source of edible oil in India with a production of 8.94 M tones in 2017-18. The highest state average yield of 2380 kg ha⁻¹ was estimated for Rajasthan which was followed by 1879 for Gujarat, 1382 kg ha⁻¹ for Maharashtra, 1272 kg ha⁻¹ for Andhra Pradesh and the lowest of 874 kg ha⁻¹ for Karnataka (Anonymous 2018). At present, globally India ranks second after China with 4.56 M ha area with 6.771 m tones of production and 1485 kg ha⁻¹ productivity. In Maharashtra state it is cultivated on an area of 0.33 M ha having 0.42 M tones of production with a productivity of 1275 kg ha⁻¹ (Anonymous 2019). In *Konkan* region, groundnut is grown on an about 20,000 ha area with 1.8 t ha⁻¹ productivity (Waghmode *et al.* 2017). The groundnut is increasing fastly during *rabi* season in command areas of different dams and rivers in *Konkan* region. The soils are porous, rich in potash also the optimum temperature and humidity favors higher pod yields in groundnut which is considerably higher as compared to rest of Maharashtra.

Groundnut being a legume-oilseed crop, its P, S and Ca requirement is quite high (Behera *et al.* 2017). The seeds have high nutritive value for human consumption and for cake production as well as the green leaf is used as hay for livestock (Abdalla *et al.* 2009). Peanut seeds contain high oil content (50 %) which is utilized in different industries, in addition to 26-28 per cent protein, 20 percent carbohydrates and 5 per cent fibre (Fageria *et al.* 1997).

In crop production, Phosphorus (P) is second only to nitrogen as most essential macro-nutrient required by plants (Srinivasan *et al.* 2012). Various metabolic

processes *viz.*, energy transfer, signal transduction, macro-molecular biosynthesis, photosynthesis, respiration etc. require P as the key ingredient (Shenoy and Kalagudi, 2005). Plant roots usually absorb P as dihydrogen orthophosphate (H_2PO_4^-) in calcareous soils and monohydrogen orthophosphate (HPO_4^{2-}) ion (Panda, 2009) in acid soils. The proportion of different phosphorus fractions differs significantly because of soil type, soil use and management strategies (Li *et al.* 2007). These phosphorus forms differ in their behaviour and fate in soils. Inorganic phosphorus (Pi) usually accounts for 35 per cent to 70 per cent and organic P 15-80 per cent of the total phosphorus in soils. Organic P in soil is mainly exists in stabilizing forms as inositol phosphates (soil phytate), phosphonates and active forms as orthophosphate diesters, labile orthophosphate monoesters and organic polyphosphates (Condrón *et al.* 2005). One unique characteristic of phosphorus is its low availability due to slow diffusion and high fixation in soils. The phenomenon of fixation and precipitation is generally highly dependent on pH and soil type (Mahantesh and Patil 2011). Thus, in acid soils, P can be dominantly adsorbed by Fe/Al oxides by forming various complexes (Mohammadi 2012). While, in alkaline soils it is fixed by calcium (Oliveira *et al.* 2009). Therefore, efficiency of P solubilization rarely is exceeding 10–20 per cent (Kuhad *et al.* 2011). It has been reported that only 10 to 40 per cent of the applied phosphorus is available to the plants (Aulakh and Pasricha 1999) and the rest of applied P remains in soil reaction products of lower solubility such as calcium phosphate, iron phosphate and aluminium phosphate etc. It is present at levels of 400–1200 mg kg^{-1} of soil. However, 95-99 per cent soil phosphorus is present in insoluble phosphate form and hence cannot be utilized by the plants (Sridevi *et al.* 2013). Hence, a holistic understanding of P dynamics from soil to plant is necessary for optimizing P management and improving P-use efficiency, aiming at reducing consumption of chemical P fertilizer, maximizing exploitation of the biological potential of root/rhizosphere processes for efficient mobilization and acquisition of soil P by plants. Declined soil reaction (pH) increases the concentration of Fe and Al in soil solution thereby making complexes with aluminum and iron, free oxides and hydroxides (Richardson and Simpson 2001). Soil acidity thus triggers and increases rate of P fixation as well as immobilization (Fankem *et al.* 2006).

Microorganisms are integral to the soil phosphorus (P) cycle and play an important role in mediating the availability of P to plants (Kannapiran *et al.* 2011).

Particularly, phosphate-solubilizing microorganisms are able to solubilize unavailable soil P and enhance the yield of crops (Adesemoye and Kloepper 2009). Microorganisms, especially the use of such phosphate solubilizing bacteria (PSB) as inoculants simultaneously increases P uptake by the plant and therefore can be used as bio fertilizer (Nico *et al.* 2011). Moreover, the soil quality is being threatened by indiscriminate and uncontrolled use of P fertilizers. Hence, the use of PSB emerged as an economically sound innovative alternative option to traditional chemical P fertilizers.

A considerably higher concentration of phosphate solubilizing bacteria is commonly found in the rhizosphere in comparison with non-rhizosphere soil (Kundu *et al.* 2009). P-solubilizing ability of PSBs is affected by many physiological factors. Hence different bacterial species solubilize phosphorus at different extent. These bacteria can play an important role in plant nutrition through an increase in phosphorus uptake by plants (Rodriguez *et al.* 2006). The microorganisms have enormous potential in providing soil P for plant growth. Use of PSMs can increase crop yields up to 70 percent (Mohammadi, 2012). The phosphate-solubilizing bacteria as inoculants simultaneously increases P uptake by the plant and crop yield. The release of organic and inorganic compound by phosphate solubilizing microorganisms (PSM) has been reported as a primary mechanism of P-solubilization. The quantity and quality of organic acid produced is fully dependent on the type of P-solubilizing microorganisms. The PSB solubilize the fixed soil P and applied phosphates resulting in higher crop yields (Gull *et al.* 2004).

Mycorrhizal associations formed by *Glomeromycotan* fungi are known as arbuscular mycorrhizas or vesicular-arbuscular mycorrhizas and abbreviated as VAM (Brundrett *et al.* 1996). VAMs are considered as endo-mycorrhiza as they produce arbuscules, hyphae and vesicles within the root cortex cell (Quilambo 2000). VAM fungi form symbiotic associations with the roots of a wide variety of plant species, including many agricultural crop species (Kahiluoto *et al.* 2009). In this symbiosis, the host plant provides the fungus with soluble carbon sources, and the fungus facilitates the host plant with an increased access to water and nutrients from soil (Entry *et al.* 2002). This increased access of VAM fungi to nutrients is happened through their extra-radical hypae that extend outside the host root up to several centimeters in the soil, allowing the fungi to absorb soil nutrients (George *et al.*

1995). However, the relative abundance of VAM fungi within roots mostly depends on soil conditions that directly or indirectly affect the rapidity of fungal spore germination and plant root colonization such as growth and infectivity of both internal and external hyphae of the fungi (Smith and Read 2008). Although VAM fungi are present in soils of all textures from sandy to those with high clay content and at a wide range of soil pH (Brundrett, 2002), but many soil factors such as conventional tillage, soil compaction, high fertilizer and pesticides applications have a negative impact on VAM functions (Entry *et al.* 2002). However, in association with nitrogen fixers, arbuscular mycorrhizal fungi increase nitrogen and phosphatic nutrients of plants, especially in phosphorus-deficient soil (Cruz *et al.* 1988).

Combined inoculation of arbuscular mycorrhiza and PSBs give better uptake of both native P from the soil and P coming from the phosphatic rock and enhance plant growth by solubilizing P from different fractions of soil (Ahmed *et al.* 2008). Combined inoculation of rhizobium and *Glomus etunicatum* and application of rock phosphate or PSM and arbuscular mycorrhizal fungus gave the greatest yield and had variable effects on nodulation in clovers (Leopold and Hofner, 1991), mungbean (Zaidi *et al.* 2004), cowpea (Thiagarajan *et al.* 1992). Experiments have revealed that the establishment of arbuscular mycorrhizal fungus on the root system can alter the rhizospheric microbial populations (Ames *et al.* 1984), which in turn affects the competitive interaction between introduced and native rhizobia for nodulation sites.

Improving phosphorus nutrition is an urgent priority to meet the increasing global demand for food. So, the focus is placed on the use of soil microorganisms endowed with the phosphorus solubilizing ability, which could be used as inoculants to mobilize P from poorly available sources in soil. Therefore, the availability of soil P is extremely complex and needs to be systemically evaluated as it is highly associated with P dynamics and transformation among various P pools. Hence, keeping the above fact in view, the present investigation entitled "**Effect of different levels of phosphorus and biofertilizers on soil properties, yield, quality and uptake of nutrient by groundnut (*Arachis hypogaea* L.)**" was carried out during the *rabi* season of 2017-18 and 2018-19 with the following objectives.

1. To study the effect of different levels of phosphorus and biofertilizers on physical, chemical and biological properties of soil.

2. To study the effect of different levels of phosphorus and biofertilizers on available nutrient status of groundnut grown soil.
3. To study the effect of different levels of phosphorus and biofertilizers on yield, quality and uptake of nutrients by groundnut.
4. To study the relationship between different levels of phosphorus and biofertilizers with soil properties and yield of groundnut.

CHAPTER II

REVIEW OF LITERATURE

The United Nations Food and Agriculture Organization (FAO) estimates that the total demands for agricultural products will be 60 per cent higher in 2030 than present time and more than 85 per cent of this additional demand will come from developing countries, for over half a century the world has relied on increasing crop yields to supply an ever increasing demand for food. For optimal plant growth, nutrients must be available in sufficient and balanced quantities. Soils contain natural reserves of plant nutrients, but these reserves are largely in unavailable forms to plants and only a minor portion is released each year through biological activity or chemical processes. This release is too slow to compensate for the removal of nutrients by agricultural production and meet crop requirement. Therefore, fertilizers are designed to supplement the nutrients already present in soil. The use of chemical fertilizer, organic manures or biofertilizer has its advantages and disadvantages in the context of nutrient supply, crop growth and environmental quality. Nitrogen, phosphorus and potassium fertilizers are essential nutrients for crop growth and high yield with good quality. Further, the use of biofertilizers like Phosphate Solubilizing Micro-organism (PSM) and Vesicular Arbuscular Micorrhiza (VAM) is limited. Therefore, the present investigation was carried out with the objectives to study the, “Effect of phosphorus and biofertilizers levels on soil properties, yield, quality and nutrient uptake by groundnut.

The available literature on these aspects has been reviewed under suitable heads:

- 2.1 Effect of phosphorus and biofertilizers level on growth and yield attributing characters
- 2.2 Effect of phosphorus and biofertilizers on quality parameter of the crops
- 2.3 Effect of phosphorus and biofertilizers on content and uptake of nutrients by different crops
- 2.4 Effect of phosphorus and biofertilizers on biological properties of soil
- 2.5 Effect phosphorus and biofertilizers on physico-chemical properties and available nutrient status in soil
- 2.6 Effect of phosphorus and biofertilizers and their relationship with soil properties and yield

Brief history of biofertilizers

Inoculation of plants with beneficial bacteria can be traced back to centuries. Although bacteria were not proven to exist until Von Leeuwenhoek in 1683 discovered microscopic ‘animals’, their utilization to stimulate plant growth in agriculture has been exploited since ancient times. Theophrastus (372-287 BC) suggested the mixing of different soils as a means of remedying defects and adding heart to the soil (Vessey 2003). Historically, the bio-fertilizers were initially identified by a Dutch scientist in 1888 there after bio-fertilizer use started with the launch of ‘Nitragin’ by Nobe and Hiltner with a laboratory culture of ‘*Rhizobia*’ in 1895 (Ghosh 2004). Then subsequently *azotobacter*, *blue green algae* etc. were discovered. Among the recent discoveries, the most popular bio-fertilizers are *Azospirillum*, *Vesicular Arbuscular Micorrhiza* etc. Eventually the practice of legume inoculation with non-symbiotic, associative rhizosphere bacteria, like *azotobacter*, was used on a large scale in Russia in 1930s and 1940s. *Bacillus megaterium* for phosphate solubilization was used in the 1930s on large scale in Eastern Europe. In India, from 1920 onwards Joshi, Desai, Vyas, Biswas and Acharya worked on phosphate requirements of legumes for better recuperation of soil nitrogen and on anaerobic digestion of organic matter at Imperial Agricultural Research Institute. At the same time, Madhok introduced the practice of using bacterial cultures for berseem (*Trifolium alexandrium*) in Punjab. Raju and Rajagopalan worked on root nodulation of Bengal gram and groundnut at the Madras Agricultural College, Coimbatore (Subba Rao 1977). In India, the first commercial production of bio-fertilizer started in 1956 although its commercialization started in late 1960s when soybean was introduced for the first time in the country under the supervision of N.V Joshi. Accordingly, the Bureau of Indian Standards has sprung into action and specific standards for *Rhizobium*, *Azotobacter*, *Azospirillum* and *phosphate solubilizing bacterial* inoculants have been brought out. Some of the nitrogen fixers colonize the root zones and fix nitrogen in loose association with plants. In the late 1970s, *Azospirillum* was found to enhance non-legume plant growth. In recent years, various other rhizobacteria such as *Aeromonas veronii*, *Azotobacter sp.*, *Azoarus sp.*, *Cyanobacteria* (predominantly of the genera *Anabaena* and *Nostoc*) *Alcaligenas*, *Burkholderia*, *Comamonas acidovorans*, *Enterobacter*, *Erwinia*, *Flavobacterium*, *rhizobia* (including the *Allorhizobium*, *Azorhizobium*, *Bradyrhizobium*,

Mesorhizobium, *Rhizobium* and *Sinorhizobium*) *Gluconacetobacter diazotrophicus*, *Herbaspirillum seroepidicae*, *Serratia*, *Variovorax paradoxus* and *Xanthomonas maltophilia* have been identified for their use either as biofertilizers or biological control agents (Bio-inoculants).

Phosphate solubilizing bacteria

Phosphate solubilizing micro-organisms naturally occurring rhizospheric PSM dates back to 1903 (Khan *et al.* 2009). Various microorganisms play key role in solubilization of phosphorus which includes bacteria, fungi, and actinomycetes. Bacteria are proved more effective in phosphorus solubilization than fungi. In addition to *Pseudomonas* and *Bacillus*, other bacteria reported as P solubilizers these are *Arthrobacter*, *Rhodococcus*, *Serratia*, *Chryseobacterium*, etc. (Wani *et al.* 2005), *Azotobacter* (Kumar *et al.* 2001), *Xanthomonas* (De Freitas *et al.* 1997), *Enterobacter* and *Klebsiella* (Chung *et al.* 2005). PSB constitute 1 to 50% among all PSM in soil and fungi 0.1 to 0.5% (Chen *et al.*, 2006). The insoluble forms of P such as tricalcium phosphate, iron phosphate and aluminium phosphate etc. may be converted to soluble P by various P solubilizing microorganisms inhabiting soil ecosystems (Sharma *et al.* 2013). Soil microorganisms in this regard have generally been found more effective in making P available to plants from both organic and inorganic sources by solubilizing (Toro 2007) and mineralizing complex P compounds (Ponmurugan and Gopi 2006), respectively. In the natural environment or under in vitro conditions chelate mineral ions decrease the pH to bring P into solution (Pradhan and Shukla 2005). Consequently, the acidification of microbial cells and their surrounding leads to the release of P-ions from the P-mineral by H⁺ substitution for Ca²⁺ (Goldstein, 1994). The principle mechanism is the secretion of low molecular weight organic acids (oxalic acids, malic acid, gluconic acid) (Sperberg 1957; Buch *et al.* 2008). The production of these organic acids results in the acidification of microbial cells and its surrounds (Rodriguez and Fraga 1999; Chen *et al.* 2006). Subsequent ionization of acid takes place and either proton produced becoming responsible for phosphorus release from mineral phosphate by proton substitution for Ca, Al, and Fe or carboxylic anions chelate cations and release phosphate anions. The genes are directly or indirectly involved in secretion of organic acids (Buch *et al.* 2010). The carboxylic and hydroxyl groups of organic acids compete with cations (Ca, Al and Fe), make chelate complexes with metal ions and thus convert insoluble

phosphorus in to soluble form (Kpombrekou and Tabatabai 1994). Iron chelating agents (Siderophores) and exopolysaccharides synthesized by PSB bring out fixed or locked P in to soluble form (Sharma *et al.* 2013). Thus, the organic acids, chelating agents and enzymes produced by PSB are responsible for solubilization of inorganic phosphorus.

These bacteria play an important role in supplying phosphate to plants, in environment friendly and sustainable manner (Khan *et al.* 2007). Since agricultural soils have the inadequate supply of P; therefore application of phosphate fertilizers is must to complete the requirement of P in soil (Vikram and Hamzehzarghani 2008). PSB solubilize this P and make it available to the plants. Recently, PSB have also been used in soil for the mineralization of pollutants i.e. bioremediation of polluted soil (Middledrop *et al.* 1990; Burd *et al.* 2000).

Mycorrhizal Fungi

The symbiotic associations of plant roots and fungi have intrigued many generations of biologists and in the late 1880s these associations were given the name Mycorrhiza. Vesicular arbuscular Mycorrhiza (VAM) is a mutually beneficial symbiosis or partnership between beneficial soil fungi and plants. The arbuscular mycorrhizal fungi are all members of the Zygomycota and the current classification contains one order, the *Glomales*, encompassing six genera into which 149 species have been classified (Bentivenga and Morton 1994). The arbuscular mycorrhiza (AM) is the most common of all mycorrhizal types involved and can benefit plant growth and health. The main benefit of mycorrhizae is the uptake of nutrients especially phosphorus. Phosphorus nutrition brings with it drought resistance and other benefits, inhabit plant roots and affect plant growth promotion by mechanisms ranging from a direct influence such as increased solubilization and uptake of nutrients like P (Richardson *et al.* 2009), There is well documented evidence that VAM have important effects on plant phosphorous uptake and availability of other elements like zinc, copper, potassium, sulphur, aluminium, manganese, iron, etc. (Krishna and Bagyaraj 1991) in areas beyond the root's depletion zone. Mycorrhizal fungi play a significant role in the formation of soil aggregate. A well developed mycorrhizal symbiosis may enhance the survival of plants in polluted areas by better nutrient acquisition, water relations, pathogenic resistance, phytohormone production, contribution of soil aggregation, amelioration of soil structure and thus improved

success of all kinds of bioremediation (Jeffries *et al.* 2003). Soil microorganisms influence the establishment and activity of Arbuscular mycorrhizal (AM) fungi. They promote free living nitrogen fixing bacteria and enhance nitrogen fixation and supply of nutrients like phosphorus, sulphur, iron and copper (McMillan 2007). Indian soils are mostly deficient in Nitrogen and phosphorous. Among Mycorrhizae, Vesicular arbuscular mycorrhizae (VAM) fungi are ubiquitous and form obligate symbiotic associations with most families of crop plants. VAM have been shown to be beneficial to plants in better utilization of soil nitrogen (Marwaha 1995), phosphorous (Gerdeman 1968), they produce metal binding molecules siderophores (Pal *et al.* 2001), β -1,3 glucanase, fluorescent pigments, chitinases, antibiotics and cyanides to protect plants against pathogens (Cattelan *et al.* 1999). VAM biofertilizers is a natural product carrying living microorganisms derived from the plant root or cultivated soil and has no harmful effect on fertility or plant growth (Marwaha 1995). Mycorrhizal association in groundnut (*Arachia hypogaea* L.) was first reported by Butler in 1939. Later occurrence of the mycorrhizal fungi *Gigaspora gigantia* and *Glomus macrocarpus* in groundnut roots and *Glomus mossae* in groundnut pegs was reported (Graw and Rehme 1977). Arbuscular mycorrhizae enhances water uptake particularly in nutrient deficient and dry soils (Auge 2001).

Relationship of PSB and Vesicular -Arbuscular Fungi (VAM)

Vesicular arbuscular mycorrhiza (VAM) is mutualistic symbiont that is ubiquitous in roots of vascular plants in nature (Bajwa *et al.* 1999). There are various benefits of VAM in combination with phosphate solubilizing bacteria to plants since they impart nutrient absorption, stimulation of growth regulatory substances, osmotic adjustments under drought stress, enhancement of nitrogen fixation by symbiotic bacteria, increase resistance to soil pathogens and tolerance to environmental stresses (Bethlenfalvay and Linderman 1992). Symbiotic interaction was observed between PSB and VAM fungi, including the majority of those where plant growth promoting rhizobacteria and nitrogen fixing bacteria were involved (Meyer and Linderman 1986). These interactions were found to occur in the zone of soil surrounding the roots and fungal hyphae, which was commonly referred to as 'mycorrhizosphere' (Rambelli 1973). Uptake of phosphorous from the soil is mediated by mycorrhizal fungi in addition to plant roots. VAM in combination with PSB can improve the uptake of phosphorous and increase the crop production (Young 1990).

There are various soil fungi including VAM and bacteria which are helpful in solubilization of inorganic phosphorous (Singal *et al.* 1994). Some bacteria formed the synergetic interactions with VAM (Frey-Klett *et al.* 1997). PSB in combination with VAM exhibited a high efficiency to improve the plant growth and nutrition of alfalfa crop (Piccini and Azcon 1987). Combined inoculation with *Bacillus circulans* and *Cladosporium herbarum* and VAM fungus resulted in the improved wheat (*Triticum aestivum*) crop yields in nutrient deficient soils (Singh and Kapoor 1999). Single inoculation i.e. phosphorous alone, had no significant influence on yield of the crops, but the combined inoculation had shown the significant influence on growth, yield and uptake by wheat and chickpea (Mukherjee and Rai 2000). VAM fungi (*Glomus fasciculatum*) and PSB (*Bacillus megaterium* var. phosphaticum) had shown the improved nodulation, nutrient uptake and phosphorous balance, mineral uptake, seed yield and available phosphorous in soil by Soybean (*Glycine max*) plant under field conditions (Dadhich *et al.* 2006). AMF also have the ability to influence plant growth, water and nutrient content (Barea *et al.* 2002; Giovannetti *et al.* 2006). They have the high affinity phosphate mechanism which enhances phosphorous nutrition in plants. AMF together with some specific bacteria i.e. PSB were known to create a more synergism, which was helpful in improved plant growth, including nutrient uptake in the plants (Barea 2000). An experiment was carried out to evaluate the effects of nitrogen fixing bacteria (*Bradyrhizobium sp.*), PSB (*Bacillus subtilis*), phosphate solubilizing fungus (*Aspergillus awamori*) and AM fungus (*Glomus fasciculatum*) on the growth, chlorophyll content, seed yield and nodulation, N and P uptake of greengram plants which were grown in P deficient soils. The growth was promoted leading to improved yield of the greengram (Zaidi and Khan, 2006). These all microbes contributed as ‘mycorrhiza helper’ and enhanced the root colonization. There was increase in growth and nutrient uptake of the plants by the combined inoculation of *Glomus aggregatum* and *Bacillus polymyxa*.

Role of phosphorus in plants

Phosphorus is vital for plant growth and is found in every living plant cell. It is involved in several key plant functions including energy transfer, photosynthesis, transformation of sugars and starches, and nutrient movement within the plant. When P is limiting, the most striking effects are reduction in leaf expansion and leaf surface area, as well as the number of leaves. Shoot growth is affected to a greater extent even

the, root growth is also reduced by inadequate P, leading to less roots mass to reach water and nutrients. Inadequate P slows down the process of carbohydrate utilization, without affecting carbohydrate production through photosynthesis. The amounts of P taken up by different oilseeds to produce 1 tonne of seed were much higher than those for cereals as rice and sorghum, as well as pulses such as chickpea and pigeonpea (Tandon 1987).

Phosphorus is an essential nutrient both as a part of several key plant structure compounds and as a catalysis in the conversion of numerous key biochemical reactions in plants. Phosphorus is noted especially for its role in capturing and converting the sun's energy into useful plant compounds (Pierzinski 1994).

Phosphorus is a vital component of DNA, the genetic "memory unit" of all living things. It is also a component of RNA, the compound that reads the DNA genetic code to build proteins and other compounds essential for plant structure, seed yield and genetic transfer. The structures of both DNA and RNA are linked together by phosphorus bonds (Mallarino 2009).

Phosphorus is a vital component of ATP, the "energy unit" of plants. ATP forms during photosynthesis, has phosphorus in its structure, and processes from the beginning of seedling growth through to the formation of grain and maturity (Marschner 1995).

Phosphorus is critical to maximum yield expression of crops because of the role it plays physiologically within the plant. Phosphorus primarily acts as the plant's cellular energy supply. Plants require cellular energy to power chemical reactions that allow for the ultimate production of sugar. The sugar produced is then used to accumulate biomass (Majundhar and Govil 2010).

Phosphorus content in Indian soils

Dhamak *et al.* (2014) was of the opinion that the majority of soil samples were categorized as low P content in Ambejogai tahsil of Beed district in Maharashtra and the available P in Vertisols, Inceptisols and Entisols ranged from 1.14 to 21.62, 1.03 to 21.47 and 1.65 to 26.08 kg ha⁻¹ with a mean value of 7.44, 7.06 and 6.86 kg ha⁻¹.

Kumar *et al.* (2014) while evaluating soil fertility status of vertisols of Kabeerdhana of chatting observed that the available phosphorus ranged from 2.06 to 20.55 kg ha⁻¹ with a mean of 8.39 kg ha⁻¹. Eighty seven per cent of the samples had exhibited low, 13 per cent under medium range of phosphorus content.

Ninety four per cent of the soils are low in available phosphorus and the rest were under medium category. The available phosphorus content was low to medium in northern zone of Karnataka (Patil *et al.* 2012).

Organic phosphorus is abundant in soils and can contribute to the P nutrition of plants and microbes following hydrolysis and the release of free phosphate (Condrón *et al.* 2005).

Padmavathi *et al.* (2014) inferred that the available phosphorus status of the soils of Coimbatore district ranged from 5.30 to 75.1 kg ha⁻¹ with a mean of 24.1 kg ha⁻¹ and 50.5 per cent of the samples were under high category.

Rego *et al.* (2007) reported that wide spread deficiency of nutrients in semi-arid tropical soils observed that available P₂O₅ status ranged from 0.72 to 37.6, 0.7 to 61 and 0.4 to 36.4 kg ha⁻¹ with a mean of 8.5, 9.51 and 7.9 kg ha⁻¹ in the soils of Nalgonda, Mahaboob Nagar and Kurnool, respectively.

Sannappa and Manjunatha (2013) reported that the available phosphorus status in the western ghats of Karnataka showed great variation from 9.45 to 34.5 kg ha⁻¹. The available phosphorus content varied from 8.2 to 25 kg ha⁻¹ with a mean of 12.8 kg ha⁻¹ in the soils of chiraigon block of Varanasi in Uttar Pradesh (Singh and Mishra 2012).

Sharma *et al.* (2008) observed that the available phosphorus in the soils of Amrithsar district varied from 9.42 to 84.9 kg ha⁻¹. Forty eight and twenty nine per cent of the samples tested high and very high in available phosphorus, 20 per cent of the samples were in medium and only 3 per cent of the samples shown deficient in available phosphorus.

The available phosphorus content of Mantagani soils of Karnataka were low (24 %) to medium (76 %) and phosphorus status in the red soils are low and available phosphorus as noticed by Pulakashi *et al.* (2012).

The total P form in soil consists of inorganic-P and organic-P forms. It occurs as orthophosphates in the mineral form. The total P content of soils ranges between 200 to 2000 kg ha⁻¹ in the upper 15-cm soil layer, with an average of 1000 mg kg⁻¹ (Brady and Weil 2002).

The total P in Indian soils ranges from 120 to 2166 mg kg⁻¹. The soils derived from the parent material rich in P, contain higher amount of total P. The inorganic P constitutes a dominant part of total P, and is considered to be major contributor of P to

the growing plants. In Indian soils, the share of inorganic P in the total P-content varies from 54 per cent to 84 per cent. The proportion of organic P in mineral soils may vary between 20 per cent and 80 per cent of total depending on the age of soil, organic matter content, climate, vegetation, soil texture, land use, etc. the share of organic P to the total P on average, varies from 16 per cent to 46 per cent (Tomar *et al.* 2010).

2.1 Effect of phosphorus and biofertilizers levels on growth and yield attributing characters

Adak and Mehmet (2016) investigated the effect of different levels and the combined effect of nitrogen and phosphorus on the nodulation and yield components of faba bean (*Vicia faba* L.). A large seeded 584-066 accession numbered faba bean line, which was taken from a breeding programme of the Field Crops Department, was used in the experiment. Four different nitrogen (0, 30, 60, 90 kg ha⁻¹) and three phosphorus (0, 40, 80 kg ha⁻¹) levels were applied to the soil at the sowing time. The number of pods plant⁻¹, biological and grain yield per unit area, together with grain and plant N content, were increased by 60 kg ha⁻¹ nitrogen combined with 40 kg ha⁻¹ phosphorus applications. The highest nodule and nodule weight plant⁻¹ and 100 kernel weight were obtained from 80 kg ha⁻¹ phosphorus and 30 kg ha⁻¹ nitrogen combination.

Amruth *et al.* (2017) reported the results on the different growth parameters *viz.*, plant height, number of branches and nodules per plant, leaf area and root length, yield parameters *viz.*, test weight, shelling percentages, pod yield, haulm yield and quality parameters *viz.*, oil content revealed that the higher the height of the groundnut was recorded due to treatment T₆ was higher with application 75 per cent of 30 kg P₂O₅ ha⁻¹ through CF + 25 per cent through FYM along with PSB whereas, lowest plant height was recorded in treatment (T₁) application with 20 kg P₂O₅ ha⁻¹. The branches of groundnut at 30 DAS was found to be statistically non significant. Quality parameters *viz.*, oil content, oil yield (kg ha⁻¹) and protein content was recorded higher value in treatment T₆ with application 75 per cent of 30 kg P₂O₅ ha⁻¹ through CF + 25 per cent through FYM along with PSB whereas lowest value was recorded in lower dose application of phosphorus without PSB. The significantly highest yield was recorded in highest dose of phosphorus application (T₆) whereas; lowest yield was

recorded in treatment (T₁). The higher B: C ratio was recorded as 2.82 due to treatment (T₆).

A field experiments was conducted during *khariif* seasons of 2002 and 2003 at Indian Agricultural Research Institute, New Delhi to study the effect of different phosphatic fertilizers and biofertilizers on growth attributes and chlorophyll content of maize. Different doses of phosphatic sources (single super phosphate and rock phosphate with and without PSB and VAM) were applied either or in combination with nitrogen fertilizer or without nitrogen. The treatments N₁₂₀P₆₀ recorded the highest leaf area and dry matter plant⁻¹ during both the years and in second year; it was at par with treatment N₁₂₀SSP₃₀VAM. In case leaf area index (LAI), highest values were associated with treatment N₁₂₀P₆₀ at 40 DAS in 2002 and 2003. In second year, it was statistically at par with treatment N₁₂₀SSP₃₀VAM at 40 and 80 DAS. At knee high stage of maize, the highest chlorophyll content of 1.03 and 1.10 mg g⁻¹ fresh weight were recorded in treatment N₁₂₀SSP₃₀VAM and N₁₂₀RP₃₀VAM in 2002 and 2003 respectively. The treatments N₁₂₀SSP₃₀VAM and N₁₂₀RP₃₀PSB were statistically at par in both the years Banerjee *et al.* (2006).

Choudhary *et al.* (2011) revealed that the application of 25 kg N+ 50 kg P₂O₅ + 40 kg K₂O ha⁻¹ along with *Rhizobium*, VAM and PSB recorded significantly higher available nitrogen 164.1 kg ha⁻¹ and available phosphorus 26.6 kg ha⁻¹ whereas minimum were noted with the application of RDF-NPK alone. However, this treatment also provided significantly higher N, P and K uptake by the crop and crop yields (pod, kernel and haulm) over rest of the treatments. The minimum yields were noted with the application of RDF alone, poultry manure, vermicompost and their mixture.

A field experiment was carried out to study the influence of integrated nutrient management on greengram [*Vigna radiata* (L.) Wilczek]. Among different combinations, significant improvement in number of nodules plant⁻¹ (80.97), dry weight of nodules (32.89 mg plant⁻¹), yield attributes, seed yield (12.34 qt ha⁻¹), harvest index (28.32%), nutrient content, available NPK and organic carbon after harvest in soil were recorded with application of nutrients through 75 per cent RDF + 2.5 t ha⁻¹ vermicompost + rhizobium + Phosphate solubilizing bacteria (PSB) as compared to other combinations and control, but it was at par with 100 per cent RDF

+ 2.5 t ha⁻¹ vermicompost and 100 per cent RDF + rhizobium + PSB (Dhakal *et al.* 2016).

Gabhane *et al.* (2016) under field study during 2006-2007 on the effect of phosphorus management in greengram-safflower sequence in a Vertisol. They indicated that application of 100 per cent recommended P along with recommended N and K significantly enhanced the yield of greengram and safflower. However, these results were comparable with application of 50 per cent P (20 kg ha⁻¹ to greengram and 12.5 kg ha⁻¹ to safflower) + PSB along with recommended dose of N (20 kg ha⁻¹ to greengram and 25 kg ha⁻¹ to safflower) and K (20 kg ha⁻¹ to greengram and 25 kg ha⁻¹ to safflower) to greengram and safflower in crop productivity with higher nutrient uptake and apparent nutrient balance. The higher P use efficiency was observed with the application of 50 per cent recommended P to both the crops alongwith PSB.

Geetha *et al.* (2018) revealed that integration of 80 kg P₂O₅ ha⁻¹ curing with FYM + PSB + VAM (T₉) produced significant higher plant height, dry matter, number of nodules plant⁻¹, dry weight of nodule plant⁻¹, pods plant⁻¹ than the other treatments. Similarly, significant higher grain and stover yield were obtained from the treatment T₉. The protein content of seeds and available N, P, K and S and micronutrients of soil after the harvest of soybean were improved significantly due to the integration of inorganic fertilizers with organic manures. Thus, it shows the positive impact of biological and organic manure application on reduction of chemical fertilizer use.

A field experiment carried out during the winter season of two consecutive years to study the effect of six combinations of bio-fertilizers and two chemical fertilizers on onion cv. Sukhsagar. The treatments were *Azotobacter* + PSB, *Azotobacter* + VAM, *Azotobacter* + *Azospirillum*, *Azospirillum* + PSB, *Azospirillum* + VAM, PSB + VAM, NPK 100%, NPK 50% and Control. The height of the plant was maximum (43.46cm) with the application of *Azotobacter* + VAM. No. of leaves, no. of inflorescence / plot and bulb diameter were maximum of *Azotobacter* + *Azospirillum*. *Azotobacter* + *Azospirillum* and N, P and K 100 per cent gave maximum length of bulbs (6.03cm). The maximum number of scale per bulb (9.81) was counted from NPK 50 per cent. The plants raised under NPK 100 per cent produced the maximum bulb weight 67.45 g. TSS per cent was found maximum (12.29 %) from NPK 100 per cent but the highest reducing sugar (1.420 %) and starch

percentage (6.27 %) were noted from NPK 50 per cent. The total loss of weight (%) up to 60 days, was found minimum (11.5 %) from *Azotobacter* + PSB followed by *Azotobacter* + *Azospirillum* (14.32 %). It is therefore, concluded that *Azotobacter* + *Azospirillum* combination is the best for onion as compared to others so far as the sustainability in production and environmental consideration are concerned (Ghanti and Sharangi 2009).

At Raja Balwant Singh College Agricultural Research Farm, Bichpuri, Agra a field experiment was carried out during the *rabi* season of 2011-12 on sandy loam soil, to study the effect of phosphorus levels on growth and Yield of chickpea. The three varieties (Haryana-1, BG-7 and PBG-7) and four levels of phosphorus (P_0 , P_{30} , P_{60} , and P_{90}) were tested. Finding revealed that the highest growth parameters were recorded with the variety Haryana-1 and this was found significantly superior as compare to all other varieties. The maximum growth parameters were recorded with 90 kg P_2O_5 ha⁻¹ but this was found statistically at par with 60 kg P_2O_5 ha⁻¹. The total bio-mass, grain and straw yields were significantly higher with the variety Haryana-1 but harvest index did not differ significantly. Total bio-mass, grain, straw yields as well as harvest index were increased significantly with every increase in the level of phosphorus up to 60 kg ha⁻¹. Although the maximum total bio-mass, grain, straw yields as well as harvest index were recorded with 90 kg P_2O_5 ha⁻¹ but it was found statistically at par 60 kg P_2O_5 ha⁻¹ (Gulpadiya *et al.* 2014).

A field experiment was conducted on highly calcareous black soils (*Typic Haplustepts*) at Model Farm, Junagadh Agricultural University, Junagadh, during summer season. The results indicated that the pod and haulm yield of groundnut significantly increased with increasing levels of N, P and K. The application of NP increased the pod and haulm yield by 5.7, 14.0 and 26.4 and 34.9 per cent with the application of R_{100} (Recommended dose of N: P i.e., 25:50 kg ha⁻¹) and R_{150} ((Recommended dose of N: P i.e., 37.5:75 kg ha⁻¹), respectively over control (No fertilizer- R_0). Oil and protein yields of groundnut also increased significantly over control. The available N, P and K status in soil after harvest of crop were significantly increased with increasing levels of N, P and K (Hadwani and Gundalia 2005).

The role of Vesicular Arbuscular Mycorrhiza (VAM) and rock phosphate application on production and nutritional value of centro legumes was studied by Indriani *et al.* (2016). The treatments and rock phosphate levels was 0, 100, 200 and

300 kg ha⁻¹ of P₂O₅ with and without VAM. The results revealed that the VAM application increased the plant height and dry matter of centro legumes. The optimum dosage of Rock Phosphate was 200 kg P₂O₅ ha⁻¹.

A field experiment at farmer's field at village Nandupura (Vidisha) was conducted during 2012 and 2013 to study the effect of bio-fertilizers and fertilizers on yield and quality of soybean [*Glycine max* (L.) Merr.]. Results revealed that use of 75 per cent NPK with VAM, PSB and rhizobium recorded significantly higher nodules per plant (73.7) nodules weight (481 mg nodule⁻¹) plant height (76.2 cm) pods per plant (31.6), seeds per pod (3.45), seed yield (26.8 q ha⁻¹) leaf area index (14.2) and harvest index (49.4%). However, lowest yield of 12.6 q ha⁻¹ was obtained in control treatment. Dual inoculation of rhizobium and PSB improved the quality of soybean in presence of chemical fertilizers. The uptake of N P and K, protein and oil content was significantly higher with 75% NPK + PSB + VAM + *Rhizobium* compared to the other treatments and saves approximately 25% inorganic fertilizers. The use of PSB + VAM and *Rhizobium* + VAM gave at par results but statistically superior to control (Jaga and Sharma 2015).

Kausale *et al.* (2009) studied the effect of INM (Integrated Nutrient Management) on nodulation, dry matter accumulation and yield of summer groundnut crop during summer 2001-2002 at Navsari. The aim was to evaluate the change in nodulation, dry matter production responsible for difference in yield potential affected due to chemical fertilizer, organic manure and bio fertilizer. There was a linear increase in dry matter production from germination till harvest, whereas in case of nodulation linear increase in root nodule number up to 90 DAS and there after decrease root nodule number. It was observed that nodule number, dry matter plant⁻¹, pod and haulm yield of groundnut crop increased with application of 100 per cent RDF (25:50 N and P kg ha⁻¹, 10 t FYM ha⁻¹ and *rhizobium* or PSB seed inoculation).

A field experiment was carried out for three consecutive *kharif* seasons of research farm of Rajasthan Agricultural Research Institute, Durgapura, Jaipur to study the effect of organic practices on the yield and yield attributes of groundnut in semi arid region. They revealed that in treatment consisting, application of farmyard manure (FYM) (7.5 t ha⁻¹) inoculated with microbes (bio fertilizers + bio-pesticides) 15 days before sowing and seed treatment with bio fertilizers + bio-pesticides at the time of sowing gave significantly higher pod yield (2750 kg ha⁻¹) over absolute

control (2151 kg ha⁻¹) and FYM without inoculated with microbes but at par with other treatments. The same trend was also observed in B:C Ratio (3.66) with treatment T₅ comprising 7.5 t FYM +PSB+ PSM+ Bio-Pesticides + Seed treatment with PSB+ PSM+ Bio-pesticides (T₃)+ Foliar spray of NSKE @ 5 %. The study indicated that the groundnut showed greater response to the application of organic practices (i.e., organic farming) under semi arid region Kumar *et al.* (2013).

Laxminarayana (2005) carried out an experiment for three consecutive *kharif* seasons during 2000-2002 at Kolasib, Mizoram to study the effect of application of graded doses of rock phosphate along with P solubilizing microorganisms on yield of rice and nutrient availability in an acid Inceptisol. The results revealed that the grain yield was significantly increased with rock phosphate application up to 90 kg P₂O₅ ha⁻¹. Highest grain yield was recorded with the inoculation of P solubilizing bacteria in combination with rock phosphate @ 60 kg P₂O₅ ha⁻¹. A significant improvement in organic carbon and available NPK was also observed with the combined use of rock phosphate and P solubilizing microorganisms. The results indicated that bacterization of seedling in combination with optimum dose of rock phosphate produced highest and sustainable crop yields, maintained the soil health and minimized the expenditure on P fertilizer cost to an extent of 30-40 per cent.

Lingaraju *et al.* (2016) reported the higher seed yield (35.96 q ha⁻¹) of soybean with the treatment combination of dual inoculation of PSB+VAM with foliar spray of 0.1per cent humic acid at flower initiation and was higher to an extent 22.5 per cent as compared to control (27.90 q ha⁻¹). Similar trend was observed on microbial activity and nutrient uptake (N, P₂O₅ and K₂O) of the soybean crop.

Mohammad *et al.* (2017) was conducted field experiment during *kharif* 2015. The results of the study indicated the application of phosphorus up to 40 kg P₂O₅ ha⁻¹ recorded significantly higher number of pods per plant, number of seeds per pod and seed and straw yield of mungbean, nitrogen, phosphorus and potassium uptake in seed and straw, protein content in seed, microbial biomass carbon, nitrogen and phosphorus in soil as compared to absolute control and 20 kg P₂O₅ ha⁻¹ but was at par with 60 kg P₂O₅ ha⁻¹. Application of 40 kg P₂O₅ ha⁻¹ represented an increase of grain yield over control and 20 kg P₂O₅ ha⁻¹ by 32.15 and 7.48 per cent, respectively. Application of poultry manure @ 5 t ha⁻¹ + *Rhizobium* + PSB significantly increased the pods per plant, number of seeds per pod and seed and straw yield, nitrogen,

phosphorus and potassium content in seed and straw and their total uptake, protein content in seed, microbial biomass carbon, nitrogen and phosphorus in soil over control, poultry manure @ 2.5 t ha⁻¹, poultry manure @ 5 t ha⁻¹ and poultry manure @ 2.5 t ha⁻¹ + *Rhizobium* +PSB. The application of bio-organics on grain yield was found significant and all the treatments of bio-organics were differed significantly with each other. The application of poultry manure @ 5 t ha⁻¹ + *Rhizobium* +PSB recorded significantly higher grain yield over control, poultry manure @ 2.5 t ha⁻¹, poultry manure @ 5 t ha⁻¹ and poultry manure @ 2.5 t ha⁻¹ + *Rhizobium* +PSB. The application of poultry manure @ 5 t ha⁻¹ + *Rhizobium* + PSB significantly increased the grain yield by 52.63, 25.17, 7.15 and 15.20 per cent over B₀ (control), B₁ (PM @ 2.5 t ha⁻¹), B₂ (PM @ 5.0 ha⁻¹ t) and B₃ (PM @ 2.5 t ha⁻¹+ *Rhizobium* + PSB), respectively.

Munda *et al.* (2013) were conducted a field experiment in *kharif* 2008 and 2009 to assess the effect of phosphorus fertilization in conjunction with biofertilizers, *viz.* Phosphorus solubilizing bacteria (PSB) i.e. *Pseudomonas striata* and vesicular arbuscular mycorrhizae (VAM) on soybean (*Glycine max* (L.) Merrill). The yield attributes and yield were at par when full dose of P was applied in conjunction with biofertilizers irrespective of the source of P fertilization indicating increased efficiency of RP when supplied in conjunction with biofertilizers even in neutral soils. Soil application of biofertilizers showed the highest protein content in soybean seed (38.89 %), which signified the fact that qualitative improvement is possible with combined application of fertilizers and biofertilizers. Higher nutrient uptake by the crop was also recorded in biofertilizer applied plots. Maximum net returns (₹ 15,953/-) was obtained with full dose of DAP with biofertilizers.

An experiment was conducted to study the effect of integrated phosphorus management on growth, yield and quality of lentil (*Lens culinaris*) at Indira Gandhi Krishi Vishwavidalaya, Raipur (C.G.) reported that the crop was fertilized up to 80 kg ha⁻¹ of phosphorus application enhanced more growth, yield attributes, seed yield and protein yield than the 40 kg ha⁻¹ and control, however the initial plant population per running meter was remain non-significant during both the years. The PSB applied by seed inoculation and 20 kg ha⁻¹ sulphur application showed similar effects. The economic value also calculated to judge best combination and found that the 80 kg ha⁻¹ phosphorus application, seed inoculation with PSB and 20 kg ha⁻¹ sulphur

application received more net income (ha^{-1}) and benefit cost ratio also (Pandey *et al.* 2016).

Panwar *et al.* (2002) studied the effect of phosphorus, biofertilizers and organics on quality seed production of groundnut in mid altitude of Meghalaya during *kharif* 2000 to 2001. They observed that the application of $60 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$ significantly increased seed yield as well as quality parameters except shoot length. Seed inoculation with rhizobium, PSM or both improved seed yields and quality. Application of organic also increased quality seed production, but highest seed yield and seed quality parameters were recorded with application FYM @ 5 t ha^{-1} in the presence of rhizobium and phosphorus solubilizing microorganism followed by neem cake @ 1.5 t ha^{-1} with same biofertilizers.

An experiment was carried out during the summer season of 2011 at Research Farm, Department of Agronomy, College of Agriculture, Latur to evaluate the effect of inorganic and biofertilizers on growth and yield of summer groundnut. The experiment was laid out in Factorial Randomized Block Design with nine treatment combinations of three levels of fertilizers and three treatments of bio-inoculations were replicated thrice. The results of experiment revealed that the higher level of inorganic fertilizer ($37.5:75:0 \text{ kg NPK ha}^{-1}$) recorded significantly maximum growth and yield attributes consequently results in higher pod yield while it was found to be at par with the fertilizer level of $25:50:0 \text{ kg NPK ha}^{-1}$. The seed treatment of dual inoculation of bio-fertilizers (*Rhizobium* + PSB) recorded higher growth and yield attributes (Patil *et al.* 2014).

A field experiment was conducted to know the effect of site specific nutrient management (SSNM) on growth and yield of groundnut where the fertilizers were applied to the crop based on uptake pattern, target yield and soil fertility status (Patil *et al.* (2018).. The study indicated that application of fertilizers based on SSNM for target yield of $2.5 \text{ t ha}^{-1} + \text{S} (10 \text{ kg ha}^{-1}) + \text{B} (10 \text{ kg ha}^{-1}) + \text{Zn} (12.50 \text{ kg ha}^{-1})$ recorded significantly higher growth parameters viz., plant height (45.3 cm), number of branches (8.10), leaf area (814.95 cm^2), leaf area index (2.72) and total dry matter accumulation ($31.82 \text{ g plant}^{-1}$). The yield parameters viz., total number of pods per plant (19.57), pod weight per plant (12.05 g), 100 kernel weight (34.74 g) and shelling per cent (75.32) were significantly higher with the application of fertilizers based on SSNM for target yield of $2.5 \text{ t ha}^{-1} + \text{S} + \text{B} + \text{Zn}$ compared to recommended dose of

fertilizer. The Maximum gross returns were obtained in T₄ (application of SSNM for target yield of 2.5 t ha⁻¹ + S + B + Zn) (₹ 79219/-), whereas, higher net returns and B:C ratio were obtained with T₃ (SSNM for target yield of 2.5 t ha⁻¹) (₹ 46771/- and 2.47 respectively) and lower net returns and B:C ratio were with application of recommended dose of NPK + FYM (T₁) (₹ 33852/- and 2.13 respectively).

Poonia *et al.* (2014) were conducted experiments at Pulses Research Station, Junagadh Agricultural University, Junagadh during 2009-10 to 2012-13 in *kharif* season with the objective to find out the effect of various types of fertilizer (organic, inorganic and biofertilizers) on nutrient management in groundnut and pigeonpea relay intercropping system. The results of the study revealed that the application of recommended dose of fertilizers (100 % RDF) to both crops showed significant improvement in the final yield *viz.*, groundnut (1299 kg ha⁻¹) and pigeonpea (1501 kg ha⁻¹).

Pramanik and Bera (2012) conducted a field experiment during the *rabi* seasons of 2008-2009 and 2009-2010 to find out the response of biofertilizers and phytohormone on growth and yield of chickpea (*Cicer arietinum* L.). Results revealed that inoculation of biofertilizers significantly improved growth parameters like plant height yield parameters like number of pods plant⁻¹, weight of pods plant⁻¹, number of gains plant⁻¹, test weight, grain yield, stalk yield and harvest index. Among the biofertilizers, combined inoculation of *Rhizobium* + PSB + VAM produced higher grain yield amounting 60.17, 35.35, 17.60 and 13.32 per cent in first year and 58.64, 35.44, 18.24 and 15.15 per cent in second year higher kernel yield over no inoculation, *rhizobium*, phosphate solubilizing bacteria, vesicular arbuscular mycorrhizae respectively. With increase in levels of spraying of homo-brassinolide increased the growth and productivity of chickpea. Spraying of homo-brassinolide at pre-flowering + pod development stages increased higher grain yield by 30.50 and 12.71 per cent in first year and 29.59 and 12.21 per cent in second year in comparison with the higher grain yield than spraying of homo-brassinolide at no spray and pre-flowering stage.

A pot culture experiment was carried out to investigate the interactions between single, dual and triple inoculants of N-fixer *Azospirillum brasilense* NBF, phosphate solubilizer *Bacillus megaterium* var. *phosphaticum* (PSB) and the vesicular-arbuscular mycorrhizal fungus *Glomus microcarpus* (VAM) on the growth

and nutrition of cowpea plants in calcareous soil amended with rock phosphate, compost and fertilized with mineral N fertilizer. The results revealed that plant growth, nutrient accumulation, nodule formation and nitrogenase activity of cowpea plant were significantly improved by using biopreparations, especially mycorrhizal inoculation in the presence of 25 per cent dose of mineral nitrogen fertilizer. Mycorrhizal infection, mycorrhizal dependency as well as other plant growth parameters studied were significantly decreased in plants which received 50 per cent mineral nitrogen fertilizer. The use of bio-preparations of VAM, NFB and PSB as biofertilizer could reduce at least 50-75 per cent economic cost compared to mineral nitrogen fertilizers use (Rabiel and Al-Humiany 2004).

Ram Chatra *et al.* (2018) conducted an experiment at the Agronomy Farm, Bansilal Amrutlal College of Agriculture, Anand Agricultural University, Anand to study the effect of application of manures and bio-fertilizers on yield, soil fertility and economics of groundnut (*Arachis hypogaea* L.) under middle Gujarat conditions during *kharif* season of 2008. The results of experiment revealed that the groundnut crop fertilized with manures showed marked increase in pod yield (2.6 t ha⁻¹) and haulm yield (4.7 t ha) due to application of RDF (12.5 kg N ha⁻¹ + 25 kg P₂O₅ ha⁻¹) and was significantly superior over poultry manure @ 500 kg ha⁻¹ and vermicompost application @ 1000 kg ha⁻¹. The application of manures has also recorded the maximum net realization of ` 54,542/- ha⁻¹ with 4.16 benefit cost ratio emerged as optimum and the most economical for groundnut. The results indicated that the groundnut crop fertilized with bio-fertilizers significantly higher pod yield (2.7 t ha⁻¹) and haulm yield (5.0 t ha⁻¹) was registered under seed inoculation with *rhizobium* which was statistically at par with Phosphorus solubilizing bacteria (PSB) (Seed inoculation) treatment (B₄). The seed inoculation with *rhizobium* has also recorded the maximum net returns of ` 56,576/- ha⁻¹ with 4.17 benefit cost ratio.

A field experiment was carried out on sandy loam soil to study the effect of bio-fertilizers VAM and PSB along with their graded dose of fertilizers on growth, yield attributes and yield of French bean. The results revealed that the application of 75 per cent RDF (Recommended Dose of Fertilizer) + VAM (Vesicular Arbuscular Mycorrhizae) @ 2 kg ha⁻¹ + PSB (Phosphorus Solubilizing Bacteria) @ 2.5 kg ha⁻¹ significantly increased the plant height (cm), number of branches per plant, leaf area (cm²) and dry weight (g) of plant in the variety Arka suvidha (V₂) followed by

selection 9 and Arka komal. The number of clusters per plant, number of pods per plant, number of pods per cluster, number of seeds per pod, 100 seed weight (g), pod length, pod yield per plant (g) and pod yield per hectare ($t\ ha^{-1}$) was significantly increased by the application of 75 per cent RDF + VAM @ $2\ kg\ ha^{-1}$ + PSB @ $2.5\ kg\ ha^{-1}$ in Arka suvidha (V_2) variety (Ramana *et al.* 2010).

Rana *et al.* (2014) studied the effect of phosphorus solubilizing bacteria on the growth attributes and benefit cost ratio in soybean. Results revealed that growth attributes of soybean increased with the application of $60\ kg\ P_2O_5\ ha^{-1}$ along with *rhizobium* and phosphorus solubilizing bacteria but found to be at par with the treatment getting $45\ kg\ P_2O_5\ ha^{-1}$ along with *rhizobium* and phosphorus solubilizing bacteria. Application of $45\ kg\ P_2O_5\ ha^{-1}$, *rhizobium* and phosphorus solubilizing bacteria recorded the highest B: C ratio (1.39) followed by the crop sown with $60\ kg\ P_2O_5\ ha^{-1}$ along with *rhizobium* and phosphorus solubilizing bacteria (1.14). While highest gross and net returns ($\text{₹ } 67328/-$ and $\text{₹ } 35326/-\ ha^{-1}$, respectively) were recorded under the treatment applied with $60\ kg\ P_2O_5\ ha^{-1}$ along with *rhizobium* and phosphorus solubilizing bacteria followed by treatment getting $45\ kg\ P_2O_5\ ha^{-1}$ along with *rhizobium* and phosphorus solubilizing bacteria ($\text{₹ } 62219/-$ and $\text{₹ } 3380/-\ ha^{-1}$, respectively).

Rather *et al.* (2010) carried out experiment at Research Farm of Amar Singh. (P.G.) College, Lakhoati, Bulandshahr (U.P.) to find the out the effect of biofertilizers {*Rhizobium*, *Azotobacter* and phosphate solubilising bacteria (PSB)} application on growth, yield and economics of field pea (*Pisum sativum* L.). The results revealed that the treatment comprising *rhizobium* + *azotobacter* + PSB gave highest growth in terms of plant height (45.26 cm), number of leaves $plant^{-1}$ (13.33), number of branches $plant^{-1}$ (4.20), number of nodules $plant^{-1}$ (38.46), fresh weight and dry weight of nodules (562.34 and 122.62 mg, respectively). The yield attributes like pod length, number of pods $plant^{-1}$, number of seeds pod^{-1} and 1000 grain weight (g) and yield of grain and straw of pea increased by co-inoculation of bio-fertilizers and were highest for the treatment in which *rhizobium*, *azotobacter* and PSB were co-inoculated. More over the co-inoculation of *rhizobium* and PSB also gave beneficial results in respect to other treatments. However, single inoculation of *rhizobium*, *azotobacter* and PSB produced promising results compared to control. In economic consideration, it was found that co-inoculation of *rhizobium*, *azotobacter* and PSB

gave highest net income (₹ 17363.6/- ha⁻¹) and Benefit: cost ratio (1.90) as compared to other treatments.

Rathore *et al.* (2011) conducted field experiments to develop suitable integrated nutrient supply system for black gram-wheat cropping system. The study was aimed to find out the effect of integration of chemical source of phosphorus with bio-fertilizers on black gram and their residual effect on succeeding wheat crop at Udaipur. Incorporation of FYM @ 5 t ha⁻¹ considerably decreased the bulk density and increased the porosity, cation exchange capacity, organic carbon and available N, P and K status of the soil. Study showed the application of FYM @ 5 t ha⁻¹ or application of 40 kg P₂O₅ ha⁻¹ significantly increased the seed and stover yield of black gram as well as of succeeding wheat grown in sequence. Dual inoculation (PSB + VAM) to black gram also increased the yield of black gram and succeeding wheat crop grown in sequence.

Sharma *et al.* (2016) revealed that the organic sources comprising combined application of vermicompost @ 1 t ha⁻¹ and 0.35 t rock phosphate produced significantly higher number of pods per plant (18.33), number nodules per plant (13.11), pod weight per plant (13.43 g), test weight (36.39 g) and shelling percentage (54.06), pod yield (1377 kg ha⁻¹), halum yield (2944 kg ha⁻¹) of groundnut over no manure application and was superior over rest the treatments. The pod yield increased due to application of vermicompost @ 1 t ha⁻¹ + 0.35 t rock phosphate to the tune of 61.62 per cent over control. Application of vermicompost @ 1 t ha⁻¹ + 0.35 t rock phosphate gave highest net return (₹ 41137/- ha⁻¹) and B: C ratio (3.19).

An experiment was conducted during the summer season of 2013 in Junagadh Agricultural University, Junagadh, to evaluate the effect of micronutrients and biofertilizers on morpho-physiological parameters of summer groundnut (*Arachis hypogaea* L.) variety GJG-31. The yield and yield attributing characters i.e., pods plant⁻¹, shelling per cent (%), 100 kernel weight, pod yield (Kg ha⁻¹), haulm yield (Kg ha⁻¹), oil content (%) and harvest index were recorded maximum at harvest under the combined application of RDF + Mo + Zn + *rhizobium* + PSB. Significantly, the lowest values of these yield attributing characters were observed in control (Shree Ganesh *et al.* (2015).

Tensingh *et al.* (2016) aimed to study the nursery performance of different formulations of phosphate solubilizing bacteria (PSB) in cowpea (*Vigna unguiculata*

(L.) Walp.). The selected elite PSB strain was mass multiplied and prepared the bio-formulation with different carrier materials such as composted coir pith, lignite, organic manure, vermicompost and vermiculite. The result indicated the significant differences in the growth as well as biochemical parameters of cow pea. The response was varied with carrier material. Among the all carrier materials composted coir pith was the superior in both growth and biochemical response of cowpea.

A field experiment was carried out during summer season of 2016 on clay soil at College of Agriculture, Junagadh Agricultural University, Junagadh to study the integrated nutrient management in bold seeded summer groundnut (*Arachis hypogaea* L.). The study comprised of ten treatments consisting of three different organic sources of nutrients and the organic sources were combined with 50 and 75 per cent recommended dose of fertilizer. The results revealed that combined application of 75 per cent RDF (18.75:37.50:37.50:15 kg N:P₂O₅:K₂O:S ha⁻¹) + 25 per cent N through FYM (1.25 t ha⁻¹) + biofertilizer (*rhizobium* and PSM @ 10 ml kg⁻¹ seed) recorded significantly higher pod and haulm yield with gross (Rs. 102200 ha⁻¹), net realizations (Rs. 56582 ha⁻¹), benefit: cost ratio (2.24) N, P, K and S content (4.56, 0.51, 0.60, 0.32 % and 1.90, 0.31, 0.72, 0.26 %) and uptake (105.92, 11.80, 13.93, 7.36 kg ha⁻¹ and 58.64, 9.44, 36.12, 8.09 kg ha⁻¹) in pod and haulm, respectively and post-harvest N, P₂O₅ and S available status (255.00, 40.30 kg ha⁻¹ and 30.63 mg kg⁻¹, respectively) of soil which was closely followed by application of 75 per cent RDF + 25 per cent N through vermicompost + biofertilizer (Vala *et al.* 2018).

Yadav *et al.* (2017) conducted field experiment during *kharif* season of 2014 on loamy sand to study the effect of phosphorus levels and bio-fertilizers on growth and yield of urdbean. Result indicated that application of phosphorus up to 40 kg ha⁻¹ significantly increased the growth and yield determining characters *viz.*, plant height, number of branches plant⁻¹, dry matter accumulation m⁻¹ row length, number and weight of root nodules plant⁻¹, CGR, RGR, number of pods plant⁻¹, grains pod⁻¹, test weight, grain yield, straw yield, biological yield, harvest index and net returns and its remain at par with 60 kg ha⁻¹. Seed and soil inoculation with PSB + VAM significantly enhanced the growth and yield attributing characters over PSB, VAM and control.

Zalate and Padmani (2009) conducted an experiment during the *Kharif* season of 2006-07 at Junagadh in Gujarat to study the effect of organic manure with and

without biofertilizers on growth, nodulation and yield of groundnut (*Arachis hypogaea* L.). Seed inoculation with biofertilizers (*Rhizobium* + PSM) significantly increased the plant height, nodules per plant, yield attributing characters and yield of groundnut. Manuring the crop with FYM 6 t ha⁻¹ + *Rhizobium* + PSM gave significantly 40.19 and 35.96 per cent higher pod and haulm yields of groundnut, respectively over no manuring. Fertilizing the crop with vermicompost 2.0 t ha⁻¹ + *Rhizobium* + PSM and FYM 3.0 t ha⁻¹ + *Rhizobium* + PSM found equally effective and significantly superior to control in respect to growth parameters, yield attributes and yield of groundnut.

A greenhouse experiment was conducted and revealed that application of 22 mg P₂O₅ kg⁻¹ significantly increased the plant height, number of branches plant⁻¹, number of leaves plant⁻¹, pods size and number of grains pod⁻¹ and it was at par with 33 mg P₂O₅ kg⁻¹. However, 33 mg P₂O₅ kg⁻¹ showed significant increase over the lower phosphorus levels with respect to number of pods plant⁻¹, grain and stover yields. Dual inoculation with *rhizobium* + PSB significantly increased plant height, number of branches and leaves plant⁻¹, number of pods plant⁻¹ and pods size over control, while *rhizobium* alone was at par with control on those parameters. *rhizobium* significantly increased the grain and stover yields over control while *rhizobium* + PSB had significant effect over control as well as *rhizobium* alone. Interaction effects revealed that highest grain and stover yields were obtained with 33 mg P₂O₅ kg⁻¹ without inoculation and inoculation with *rhizobium*, but yield was at par with 22 mg P₂O₅ kg⁻¹ when crop inoculated with dual inoculants (*rhizobium* + PSB). Application of 33 mg P₂O₅ kg⁻¹ resulted in the highest content of nitrogen and phosphorus in grain and stover, whereas 22 mg P₂O₅ kg⁻¹ gave highest content of potassium. *Rhizobium* had significant effect only on nitrogen content whereas *rhizobium* + PSB increased both nitrogen and phosphorus contents. Uptake of nutrients by the crop increased significantly with application of P and bio-inoculants. Phosphorus and bio-inoculant application improved only phosphorus content significantly of post harvest soil (Zohmingliana *et al.* 2018).

2.2 Effect of phosphorus and biofertilizers on quality parameter of groundnut

Gajera *et al.* (2014) carried out the field experiment during summer 2010 at Instructional farm, Junagadh Agricultural University, Junagadh (Gujarat) on clay soil to study the effect of phosphorus and biofertilizers on growth, yield and economics of

green gram. The results of the experiment indicated that application of 60 kg P₂O₅ ha⁻¹ and seeds inoculated with *rhizobium* significantly increased the growth parameters viz., plant height, branches per plant, dry weight of nodules, leaf area index and dry matter accumulation as well as yield attributes like number of pods per plant, grain yield per plant, stover yield and test weight. The significantly highest seed (1140 kg ha⁻¹) and stover (5890 kg ha⁻¹) yields was recorded by application of 60 kg P₂O₅ ha⁻¹ which was at par with 40 kg P₂O₅ ha⁻¹ level. The highest seed yield (110 kg ha⁻¹) was recorded by application of *Rhizobium* inoculation over liquid PSB inoculation and control.

Heisnam *et al.* (2017) had undertaken an investigation to study the effects of *rhizobium*, PSB inoculation and phosphorus management on soil nutrient status and performance of cowpea at College of Horticulture and Forestry, Central Agricultural University, Pasighat during pre-*kharif* seasons of 2017. The results of the experiment revealed that dual inoculation with fertilizer (P₂O₅) significantly increase plant growth parameters viz. Plant height, number of green leaves, branching, plant biomass, etc., yield attributes, green pod yield, soil available N, P₂O₅, K₂O status and root nodulation. It was concluded that the dual inoculation along with P₂O₅ fertilizer (PSB + *rhizobium* + 40 kg P₂O₅) was 34 per cent better than dual inoculation without phosphatic fertilizer for improving pod yield of cowpea. Application of biofertilizer (PSB and *rhizobium*) along with 40 kg P₂O₅ also improved root nodulation and *rhizobium* population in soil. It was also observed that the nutrient availability to the crop without breaking the sustainability of the soil can be increased only by combined application biofertilizers (PSB and *rhizobium*) along with phosphatic fertilizers.

Jaga and Sharma (2015) revealed that use of 75 per cent NPK with VAM, PSB and *rhizobium* recorded significantly higher nodules per plant (73.7) nodules weight (481 mg nodule⁻¹) plant height (76.2 cm) pods per plant (31.6), seeds per pod (3.45), seed yield (26.8 q ha⁻¹) leaf area index (14.2) and harvest index (49.4%). However, lowest yield of 12.6 q ha⁻¹ was obtained in control. Dual inoculation of *rhizobium* and PSB improved the quality of soybean in presence of chemical fertilizers. The uptake of N P and K, protein and oil content was significantly higher with 75 per cent NPK + PSB+ VAM + *rhizobium* compared to the other treatments and saves approximately 25 per cent inorganic fertilizers. The use of PSB + VAM and *rhizobium* + VAM gave at par results but statistically superior to control treatment.

The co-inoculation of VAM, PSB and *rhizobium* with 75 per cent NPK gave maximum values of chlorophyll (2.81 mg g⁻¹ carbohydrates (5.46 mg g⁻¹) and reducing sugar (1.97 mg g⁻¹) Net returns (` 52739/-) and B: C ratio (2.91) were recorded highest with 75 per cent NPK +VAM + *rhizobium* + PSB.

An experiment was undertaken at Seed Technology Research Unit, Dr.PDKV, Akola (MS) during *kharif* season of 2010-2011 to study the effect of four soil treatments *viz.* FYM (20 t ha⁻¹) + *rhizobium* inoculation (5 kg ha⁻¹), vermicompost (3 t ha⁻¹) + *rhizobium* inoculation (5 kg ha⁻¹), green manuring (10 t ha⁻¹) + *rhizobium* inoculation (5 kg ha⁻¹) and Control (RDF) combination with seed treatments *viz.* No seed treatments, *Trichoderma viride* (2 g kg⁻¹ of seed) and PSB treatment (25 g kg⁻¹ of seed) on seed quality of groundnut variety TAG-24. Application of vermicompost + *rhizobium* in combination with *Trichoderma* seed treatment increased germination percentage (94.5%), seedling length (18.40 cm), seedling dry weight (0.39 g), vigour index (1738.43), shelling percentage (76.40 %), protein content (29 %) and oil content (43.20 %) in comparison to other treatments. Vermicompost (3 t ha⁻¹) + *rhizobium* (5 kg ha⁻¹) in combination with *Trichoderma viride* (2 g kg⁻¹ of seed) seed treatment was most beneficial for enhancing seed quality of groundnut (Kamdi *et al.* 2014).

Lekberg and Koide (2005) were examined arbuscular mycorrhizal fungal (AMF) colonization and nodulation of groundnut from nine soils collected from subsistence farmers fields in Zimbabwe. Nodule number, shoot dry weight, shoot N and P contents and AMF colonization were assessed after 6 weeks growth. Both nodule number and AMF colonization differed by an order of magnitude among the nine soils. Soil available P explained almost all the variability in nodule number ($r^2 = 0.98$), but had no significant effect on percent AMF colonization. By adding P to one soil, nodule numbers increased four fold resulting in a significantly higher N content in the shoots. Similar, but smaller, effects were obtained by increasing the abundance of AMF through an inoculation with *Glomus intraradices*, suggesting that nodulation in this soil was limited by AMF abundance and that the fungi could, to a limited extent substitute for P fertilizer.

Meena *et al.* (2015) conducted field experiment during *kharif* season of 2013 to know the effect of fertility levels and biofertilizers on growth and yield of cowpea on sandy loam soil of Rajasthan. Results indicated that, application of 100 per cent RDF+VC @ 2 t ha⁻¹ significantly increased the plant height, number of branches per

plant, chlorophyll content, total root and effective root nodules, fresh weight and dry weight of nodules, leghaemoglobin content, number of pods per plant, number of seeds per pod, seed, straw and biological yield and remained at par with the application of 75 per cent RDF+VC @ 2 t ha⁻¹ over control. However, application the test weight and harvest index unchanged under different fertility levels. Results further indicated that inoculation of *rhizobium* and PSB significantly increased the chlorophyll content, total root and effective root nodules, fresh weight and dry weight of nodules, leghaemoglobin content, number of pods per plant, number of seeds per pod, seed and biological yield. However, inoculation of *rhizobium* and PSB significantly increased the plant height, number of branches per plant and straw yield over the rest of treatments. However, the test weight and harvest index remained unchanged under different levels of biofertilizers.

Pingoliya *et al.* (2015) conducted a field experiment to see the effect of phosphorus (P) and iron (Fe) on protein content in grain and chlorophyll content in leaf of chickpea (*Cicer arietinum* L.). They reported that the increasing P levels increased protein content in grain up to 23.99 per cent in 40 kg P₂O₅ ha⁻¹ over control (19.09 %). But the chlorophyll content was higher in 40 (2.50 mg g⁻¹) and 60 kg P₂O₅ ha⁻¹ (2.52 mg g⁻¹) over control (2.30 mg g⁻¹) and 20 kg P₂O₅ ha⁻¹ (2.38 mg g⁻¹). Application of Fe also increased the protein content with increasing level from 0 to 7.5 kg Fe ha⁻¹. It was lower (23.45%) in control and higher in highest level, which was at par with 5 kg Fe ha⁻¹. In the chlorophyll content, maximum increased in 7.5 kg Fe ha⁻¹ over 0, 2.5 and 5 kg Fe ha⁻¹. From the study application of 40 kg P₂O₅ ha⁻¹ and 7.5 kg Fe ha⁻¹ were found better than the rest of the treatment.

Pramanik and Bera (2013) carried out an experiment to evaluate the effect of biofertilizers and phytohormone on growth, productivity and quality of sunflower. The results showed that inoculation of biofertilizers significantly increased aerial biomass production, crop growth rate (CGR), test weight, weight of thalamus, number of filled seeds capitulum⁻¹ and as well as seed yield, biological yield and oil content. The combined inoculation of PSB + VAM + *Azotobacter* recorded higher seed yield (3225 kg ha⁻¹) over *Azotobacter*, PSB + *Azotobacter* and VAM + *Azotobacter* inoculation. Application of brassinolide at budding + flowering stages significantly recorded higher value of biomass production, crop growth rate (CGR), yield parameters and yield as compared to brassinolide spraying at budding stage alone.

The maximum seed yield (2838 kg ha⁻¹) and oil yield was obtained from crop receiving the treatment of spraying of brassinolide over only one spraying at budding stage.

Tagore *et al.* (2013) carried out a field experiment during the *rabi* season of 2004-05 to find out the effect of *rhizobium* and phosphate solubilizing bacterial (PSB) inoculants on symbiotic traits, nodule *leghaemoglobin*, and yield of five elite genotypes of chickpea. Among the chickpea genotypes, IG-593 performed better in respect of symbiotic parameters including nodule number, nodule fresh weight, nodule dry weight, shoot dry weight, yield attributes and yield. *Leghaemoglobin* content (2.55 mg g⁻¹ of fresh nodule) was also higher under IG-593. Among microbial inoculants, the *rhizobium* + PSB was found most effective in terms of nodule number (27.66 nodules plant⁻¹), nodule fresh weight (144.90 mg plant⁻¹), nodule dry weight (74.30 mg plant⁻¹), shoot dry weight (11.76 g plant⁻¹), and *leghaemoglobin* content (2.29 mg g⁻¹ of fresh nodule) and also showed its positive effect in enhancing all the yield attributing parameters, grain and straw yields.

Ujjainiya *et al.* (2018) had undertaken a field experiments on Indian bean green pod yield to assess the effectiveness of inoculation with biofertilizers under various levels of phosphorus application. The data revealed that the inoculation significantly increased the Indian bean pod yield at all levels of phosphorus application including control. Application of 50 kg P ha⁻¹ along with PSB + VAM + *rhizobium* inoculation maximized Indian bean pod yield (43.67 q ha⁻¹) which was 42.67 per cent higher and significantly better than the yield obtained at same level of P application without biofertilizer inoculation. However, yield obtained with 50 kg P ha⁻¹ (43.67 q ha⁻¹) was statistically at par with that of 50 kg P ha⁻¹ with or without biofertilizers, 37.5 kg P ha⁻¹ with VAM, *rhizobium* and PSB + VAM + *rhizobium*. Higher values of yield, phosphorus use efficiency and apparent nutrient recovery were optimized under inoculation with PSB + VAM + *rhizobium* as compared to non-inoculation. The results depicted the beneficial effects of PSB + VAM + *rhizobium* inoculation on Indian bean pod yield resulting in saving of 6.50 to 14.70 kg ha⁻¹ phosphorus and enhanced pod yield ranging from 26 to 44 q ha⁻¹.

Yadav *et al.* (2017) conducted a field experiment during *kharif* season of 2014 on loamy sand soil to study the effect of phosphorus levels and bio-fertilizers on productivity, nutrient content and uptake of urban. Result indicated that application of

phosphorus up to 40 kg ha⁻¹ significantly increased grain and straw yield, net returns, protein content in grain, nitrogen, phosphorus and potassium concentration in grain and straw and total uptake of nitrogen, phosphorus and potassium over preceding levels and remained at par with 60 kg ha⁻¹. Whereas, raising the level of phosphorus from 0 to 20 kg ha⁻¹ registered the highest agronomic efficiency, apparent recovery and physiological efficiency of phosphorus after that, it showed significant decline up to 60 kg ha⁻¹. Combined inoculation of seed and soil with PSB + VAM significantly increased the grain and straw yield, net returns, nitrogen, phosphorus and potassium concentration in grain and straw, their total uptake as well as protein content in grain and available phosphorus in soil after crop harvest over PSB, VAM and control, whereas, the highest agronomic efficiency and apparent recovery of P was recorded under PSB + VAM inoculation and physiological efficiency under control treatment.

2.3 Effect of phosphorus and biofertilizers on content and uptake of nutrients by crops

Field experiments were conducted during *kharif* and *rabi* season from 2012-13 to 2014-15 at Agricultural Research Station, Kasabe, Digraj, Sangli, Maharashtra to study the effect of integrated use of different organic sources and fertilizers on nutrient availability, uptake, yield and economics of groundnut-wheat cropping sequence on an Inceptisol by Kamble *et al.* (2018). The results revealed that the application of GRD recorded significantly higher pooled groundnut dry pod yield, which was at par with 25 per cent RDN through vermicompost + 75 per cent RDN through chemical fertilizer + inoculation of *rhizobium* + PSB + AMF. However, higher pooled N use efficiency, net monetary returns and B:C ratio was reported under 25 per cent RDN through vermicompost + 75 per cent RDN through chemical fertilizer + inoculation of *rhizobium* + PSB + AMF. Application of GRD to *kharif* groundnut and wheat crop recorded higher pooled grain yield and straw yield of wheat. Application of 75 per cent GRD to wheat recorded higher pooled B:C ratio in wheat. The highest soil available N, P, K and total uptake of N, P and K by crops were recorded with application of GRD to groundnut and wheat. Application of 25 % RDN through vermicompost and 75 per cent through chemical fertilizer and 50 kg P₂O₅ ha⁻¹ along with seed inoculation of *rhizobium* + PSB and soil application of AMF to *kharif* groundnut and 75 per cent to succeeding wheat resulted in higher net

monetary returns and maintenance of soil fertility under groundnut-wheat cropping sequence.

Ahirwar *et al.* (2016) carried out a field experiment on effect of phosphorus and biofertilizers on nutrient contents and uptake by pigeon pea and residual soil constituent. The nutrient contents in grain and straw *viz.*, N, P and K deviated almost significantly due to phosphorus levels and biofertilizers but not due to their interaction. The highest phosphorus level (90 kg ha⁻¹) and dual biofertilizers (*Rhizobium* + PSB) resulted in almost significantly higher N, P and K contents and their uptake of pigeon pea. The highest uptake of nutrients by pigeon pea producing a total biomass up to 68.68 q ha⁻¹ with highest P₉₀ level was 81.15 kg N, 16.01 kg P and 48.84 kg K ha⁻¹ similarly under dual biofertilizers, the corresponding uptake values were 78.75 kg N, 15.18 kg P and 47.14 kg K ha⁻¹ significantly up to 90 kg P₂O₅ ha⁻¹ and dual biofertilizers.

Das *et al.* (2013) conducted a field experiment on chickpea during Rabi, 2009-10 at Agronomy farm, College of Agriculture, Bikaner. The results revealed that the application of 30 kg P₂O₅ ha⁻¹ significantly enhanced plant height, number of branches per plant, number of nodules per plant, pods per plant, seeds per pod, test weight, seed yield (1263 kg ha⁻¹) and straw yield (3336 kg ha⁻¹). Further, they also reported the significant increased in biological yield (4734 kg ha⁻¹), harvest index, N and P content in seed and straw and uptake and total uptake of N and protein content in seed over control and 15 kg P₂O₅ ha⁻¹ respectively. The combined inoculation of *rhizobium* and PSB significantly enhanced growth, yield attributes, yield, nutrient content and their uptake in seed and straw of chickpea.

Gajera *et al.* (2014) indicated that application of 60 kg P₂O₅ ha⁻¹ and seeds inoculated with *rhizobium* significantly increased the growth parameters *viz.*, plant height, branches per plant, dry weight of nodules, leaf area index and dry matter accumulation as well as yield attributes like number of pods per plant, grain yield per plant, stover yield and test weight.

Kant *et al.* (2017) conducted field experiment in *kharif* 2011 on blackgram genotype T-9. They revealed that there was significant improvement in yield, nutrient content, uptake and physico-chemical properties *viz.* pH, electrical conductivity, organic carbon, available N and available phosphorus in soil under black gram crop. Grain yield was increased by 47.06 per cent in treatment T₁₃ (75 kg P₂O₅ + PSB +

rhizobium) over control while, organic carbon showed significantly highly positive correlation with available nitrogen ($r=0.878$) in post harvest soil. However, combination of *rhizobium*, PSB and P levels had proved significant influence on yield, content, uptake of nutrient and physico-chemical properties of soil under blackgram. Furthermore, inoculation of rhizobia and PSB into the soil found beneficial to increase the availability of native fixed phosphate and to reduce the use of fertilizers and build up significant improvement in residual soil fertility.

Sajitha *et al.* (2016) carried out field experiment in the Department of Horticulture, Faculty of Agriculture, Annamalai University at vegetable unit. The study was to find out the effect of organic manures and biofertilizers on the productivity of garden bean cv. Konkan Bushan. Among the treatments tested, inoculation of *rhizobium* and vesicular arbuscular mycorrhizae along with vegetable waste, vermicompost and foliar supplementation of vermiwash proved superior and recorded significant increase on the growth characters of garden bean such as plant height, leaf area index and dry matter production during both years of crop growth. The same combination of treatments further recorded maximum pod yield in treatment T₇ consisting of *rhizobium*, VA mycorrhizae and vermiwash derived from vegetable waste. As a result of increased nutrient uptake, nodulation and biological nitrogen fixation of *rhizobium*, colonization of vesicular arbuscular mycorrhizae and supplement of nutrients through vermiwash and vermicompost (vegetable) and the highest 'N' content (3.02 %) of the vegetable derived vermicompost, the treatment *rhizobium*, VA mycorrhizae and vermiwash derived from vegetable waste was found to be superior.

Temegne *et al.* (2018) conducted experiment to evaluate the effect of mycorrhization on growth of *Vigna subterranea*. Seedlings of two landraces were inoculated with AMF composite (*Gigaspora margarita* and *Acaulospora tuberculata*). P was administered by Hoagland solution (0 and 1000 μMPi). Two months after sowing, plants were harvested. The results showed that, with or without phosphate, the number of nodules was three times ($p<0.001$) higher in mycorrhized plants compared to controls. Phosphate increased ($p<0.001$) the leaf P-content by 21 and 54 per cent for the control and mycorrhized plants, respectively. Soluble phosphate did not affect the frequency and intensity of mycorrhization. Soluble phosphate and mycorrhization significantly improve growth and leaf P-content.

Wahid *et al.* (2016) conducted a pot culture experiment under greenhouse condition to assess the synergistic effect of Arbuscular Mycorrhizal Fungi (AMF) and Phosphate Solubilizer Bacteria (PSB) strains (*Coccus* DIM7 *Streptococcus* PIM6 and *Bacillus* sp. PIS7) on P solubility from RP and their successive uptake by maize (*Zea-mays* L. Azam) crop at alkaline soil. The experimental design was completely randomized design with three replications having calcareous silty clay loam soil, low in organic matter, nitrogen and phosphorus contents. The rock phosphate was used as a crude phosphate alone and/or in combination with the native AMF and PSB inoculum. The results indicated that the rhizosphere interactions between AMF and PSB significantly promote rock phosphate mineralization in soil and improved all growth parameters including shoot (56%), root yield (52%), height (41%), N (80%) and P (91%) uptake by the maize plants as compared to control and single inoculation. A remarkable increased in soil spore density, PSB population and percent root colonization in maize plants were also recorded by the combined inoculation of AMF and PSB with RP.

2.4 Effect of phosphorus and biofertilizers on biological properties of soil

Andhare and Babu (2017) studied the compatibility among plant beneficial bacteria in the culture level by growing them near in the nutrient agar plates. Among all the bacteria tested, *rhizobium* was found to inhibit the growth of other bacteria. From the compatible group of PGPR, They selected one biofertilizer (*Azospirillum brasilense* strain TNAU) and one biocontrol agent (*Pseudomonas fluorescens* strain PF1) for further studies in the pot culture. They have also developed a bio-formulation which is talc powder based, for individual bacteria and mixed culture. The formulation was used as seed treatment, soil application, seedling root dip and foliar spray in groundnut crop in vitro germination conditions. *A. brasilense* was found to enhance the tap root growth and *P. fluorescens*, the lateral root growth. The other growth parameters like shoot growth, number of leaves were enhanced by the combination of both of the bacteria than their individual formulations. Among the method of application tested in the study, soil application was found to be the best in yielding better results of plant growth promotion.

Chand *et al.* (2010) conducted field study during *rabi* 2000-2001 exclusively on the PSB and *Azotobacter* count in the rhizosphere soil using mustard as test crop as influenced by organic and inorganic sources. The significant increase in PSB and

Azotobacter population was recorded with 10 t FYM ha⁻¹ (10.648 x 10⁴ and 10.662 x 10⁴ cfu g⁻¹ soil, respectively) compared to without FYM application. The results revealed that increasing doses of fertilizers significantly increased the phosphate solubilizing bacteria (PSB) and *Azotobacter* population. Positive significant correlation of inoculation of PSB with P content (r = 0.961, n = 8 p < 0.01), and *Azotobacter* inoculation with N content (r = 0.552, n = 16 p < 0.01) showed the significance of biofertilizers in improving the nutrient use efficiency.

The influence of VAM fungus and *rhizobium* inoculation on groundnut growth response in relation to growth, nodulation, phosphorus content and phosphatase activity studied in a pot culture. Concentration of VAM used as inoculum was 250 spores per pot, whereas *rhizobium* was 106 Cells. Data were counted at the 15, 25, and 45t h day after inoculation. Dual inoculation resulted in significant increase in growth, number of nodules, mycorrhizal colonization than inoculation with VAM fungus \ *Rhizobium* alone. The amount of phosphorus and activity of acid and alkaline phosphatases increased significantly with dual inoculation than with individual inoculations (Charitha Devi and Reddy 2001).

A greenhouse experiment was carried out to evaluate the effects of native arbuscular mycorrhizal fungi (*Glomus*, *Gigaspora* and *Acaulospora*) sourced from turmeric rhizosphere along with phosphate solubilizers (*Bacillus megaterium* and nitrogen fixers (*Azospirillum amazonense* and *Azotobacter* sp.) on soil enzyme activities and microbial characteristics of soil under turmeric cultivation. The single, dual and consortium inoculations showed higher enzyme activities over control. Results revealed an increase in phosphatase (18.3-21.3 μmol *p*-nitrophenol g⁻¹ h⁻¹), dehydrogenase (83.4 -100.5 nmol TPF g⁻¹ h⁻¹) and urease (83.2-99.5 μmol NH₃-N g⁻¹ h⁻¹) enzyme activities along with an increase of 1.30-1.82 μg g⁻¹ soil microbial biomass carbon content. Besides, mycorrhizal colonization rate showed a similar pattern in dual and consortium inoculation with single inoculation of arbuscular mycorrhizal fungi (95.2-97 %) suggesting the plant growth promoting microbes as mycorrhiza helper bacteria for a clear preference as bio-inoculants be used for a sustainable agricultural strategy (Dutta and Neog 2015).

Jangandi *et al.* (2017) reported an influence of phosphate solubilizing bacterium (*Bacillus polymyxa*) and arbuscular mycorrhizal fungi (*Rhizophagus fasciculatus*) on growth and phosphorus uptake in *Cajanus cajana* were studied, in

green house conditions. Experiments were carried out by using both sterilized and unsterilized garden soil (sandy loam). Mycorrhiza with P solubilizing bacteria inoculated with sterilized soil produced significantly higher growth, dry matter and increase in nodule number and P uptake in shoot. Moderate or lower growth response was observed among the plants grown in unsterilized soil either PSB or AMF inoculation. On the contrary non-inoculated plants in sterilized garden, soil did not showed meager growth and higher total P uptake. A synergistic effect was recorded with increased plant dry matter, nodule number and P uptake in the plants treated with both the inoculum and in sterilized soil.

The synergistic effect of two indigenous phosphate solubilizing bacteria (PSB) (*Pseudomonas fluorescens* BAM-4 and *Burkholderia cepacia* BAM-12) and arbuscular mycorrhizal (AM) fungus, *Glomus etunicatum* studied for growth, yield and nutrient uptake of wheat plants grown in nutrient deficient soils in pots amended with tri-calcium phosphate (TCP). A significant increase in growth, yield and nutrient uptake of wheat plants was noticed and both strains of PSB interacted positively with AM fungus towards all growth parameters studied. A remarkable enhancement of seed yield was recorded notably by 92.8 per cent and an increase in per cent root colonization of AM and PSB population in soil was also recorded with time (Minaxi *et al.* 2013).

Parewa *et al.* (2014) reported that the dehydrogenase, phosphatase enzyme activity and soil microbial biomass carbon (SMBC) and available N, P and K and microbial population of soil after the harvest of wheat were improved significantly due to the integration of inorganic fertilizers with FYM and bio-inoculants. Positive impact of biological and organic manure application have been recorded with an additional advantage of reduction of chemical fertilizer use.

Patel *et al.* (2018) investigated long term experiment effect on nutrient management on soil biochemical properties in a Vertisol under soybean–wheat cropping sequence, since 1972 at the Research farm of Department of Soil Science and Agricultural Chemistry, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh, India. They revealed that the significant increase in soil organic carbon was recorded with 100 % NPK + FYM @ 15 t ha⁻¹. The availability of N, P, K, S, soil microbial biomass carbon (SMBC) and soil microbial biomass nitrogen (SMBN) were increased significantly with the integrated application of fertilizers and

FYM over control and other fertilizer treatments. Further, conjoint use of fertilizers and FYM was also significantly superior to other treatments in terms of activities of soil enzymes like dehydrogenase, acid phosphatase, alkaline phosphatase and β -glucosidase. The correlation studies revealed significant positive relationship of available N, P, K and S, SMBC, SMBN, dehydrogenase, acid phosphatase, alkaline phosphatase and β -glucosidase activity with total productivity of soybean and wheat crops.

The pot culture experiment was conducted to investigate the potential effect of arbuscular mycorrhizal fungi (*Glomus mosseae* and *Acaulospora laevis*) and phosphate solubilizing bacteria (*Pseudomonas fluorescens*) with different level of super phosphate on *Chrysanthemum indicum* L. The results revealed that the inoculation of plants with biofertilizers and recommended dose of superphosphate significantly improved the growth parameters. Inoculation with *A. laevis* + *P. fluprescences* at medium concentration of superphosphate showed maximum height, fresh and dry root weight, Arbuscular Mycorrhiza (AM) root colonization, AM spore count, alkaline phosphatase activity, acidic phosphatase activity and the per cent phosphorus uptake in shoot and root whereas root length was maximum in *G. mosseae* + *A. laevis* + *P. fluorescen*. Leaf area and fresh and dry shoot weight were maximum in the treatment (*G. mosseae* + *A. laevis* + *P. fluorescen*) at low concentration of superphosphate. The use of AMF increased nutrient acquisition from an organic fertilizer source by enhancing acidic phosphatase (ACP) and alkaline phosphatase (ALP) activity, thus facilitating P acquisition and improving plant growth (Prasad *et al.* 2012).

A pot culture experiment and revealed that amongst the phosphate solubilizers, *Aspergillus awamori* showed significant effect in improving available P, which was followed by *Pseudomonas striata*. Combined application of phosphate solubilizers in presence of FYM improved the organic carbon status and proliferation of phosphate solubilizers. Seed treatment with *Aspergillus awamori* in mustard and wheat improved the soil P status over *Bacillus polymyxa*. The number of viable counts of phosphate solubilizers in the rhizosphere soil after the harvest of both the crops due to P sources and seed inoculation with phosphate solubilizers was improved over control (Qureshi *et al.* 2005).

Saini *et al.* (2005) was assessed the microbial biomass under integrated nutrient management in soybean-winter maize cropping sequence at Agricultural Research Station Banswara during 1999-2001. Microbial biomass C, N and P under soybean (*Glycine max* L.) and winter maize (*Zea maize* L.) was significantly higher ($r = 0.623-0.716$, $p < 0.01$) when a combination of *bradyrhizobium japonicum* or *azotobacter chroococcum*, *bacillus megaterium* and *glomus fasciculatum* were used, was maximum with 50 per cent recommended fertilizers (10 kg N ha⁻¹ and 20 kg P ha⁻¹ for soybean, 75 kg N ha⁻¹ and 30 kg P ha⁻¹ for winter maize) along with bio-inoculants. Microbial biomass C, N and P contents in the rhizosphere soil were maximum at 30 days and decreased subsequently (at 60 days or harvest) in the soybean-winter maize sequence. Population of *azotobacter* in the rhizosphere increased significantly from 73.5 cfu g⁻¹ under recommended fertilizer fertilizer to 146.5 cfu g⁻¹ under FYM and bio-inoculants. Acetylene reduction assay (ARA) and nodule dry weight were significantly higher in the treatments receiving *bradyrhizobium* inoculation. Vesicular arbuscular mycorrhizal (VAM) infectivity was also enhanced significantly with combined inoculants and FYM compared to sole application of FYM or fertilizers (N and P). Application of fertilizer nutrients along with FYM, use of nitrogen fixers, phosphate solubilizers and VAM increased the grain ($r = 0.614$, $p < 0.05$) and straw yields ($r = 0.604$, $p < 0.05$) and, in general, decreased C:N and C:P ratio. The results suggested that for maximum crop yield only 50 per cent of required fertilizer might be supplied along with bio-inoculants.

Sarma *et al.* (2017) was conducted to evaluate the effects of different organic amendments and inorganic fertilizers on C mineralization and soil enzyme activities along with the changes in soil pH, available nitrogen (N) and phosphorus (P). The higher activities of soil enzymes (urease, phosphatase and dehydrogenase) were recorded till 60 days of incubation with addition of organic amendments. Among the applied organic amendments, vermicompost showed greater availability of N and P. Both vermicompost and FYM application recorded enhanced activities of soil enzymes and C mineralization rate while biochar application noted higher C half-life and soil pH. Thus addition of biochar in acid soil would be a sustainable option to reduce the C mineralization which also maintains nutrient status of sandy loam soil of north-east India.

Selvi *et al.* (2004) revealed that the population of bacteria, fungi and actinomycetes was affected significantly with different treatments in all the three crops (finger millet, maize, cowpea fodder) of the cropping system. Bacteria, fungi and actinomycetes proliferated well under continuous applications of NPK and FYM treatments. Among the microbes, bacterial population was the highest compared to fungi and actinomycetes in the soil after all crops of cropping sequence. The application of 100 per cent N alone and control recorded lower values of microbial population. Higher grain and straw yields of finger millet, maize and cowpea were recorded by the application of 10 t FYM ha⁻¹ along with 100 % NPK continuously followed by 150 per cent NPK. There was a gradual increase in biomass C and N content of the soil for the graded levels of NPK from 50 to 150 per cent. Application of 100 per cent NPK + FYM recorded significantly the highest biomass C and N followed by 150 per cent NPK application, whereas 100 % N alone and control treatments recorded lower values in the soil.

Evaluate the role of *rhizobium* and VAM fungi for improvement in fertility and yield of green gram under temperate conditions studied under field condition by Singh *et al.* (2009) at the farm of SKUAT (K), Shalimar, Kashmir. The results indicate that a significant improvement in nodule dry weight, rhizobial counts, root colonization, spore density, availability of N, P K and yield of grain and straw of green gram over control. Application of 15 kg N ha⁻¹ alone enhanced nodule dry weight and rhizobial counts over 30 kg N ha⁻¹ whereas application of 30 kg N ha⁻¹ significantly improved root colonization, spore density, available N and yield of grain and straw over 15 kg N ha⁻¹. An increase in yield of grain and straw was 17.8 and 17.7 per cent due to application of 30 kg N ha⁻¹ over 15 kg N ha⁻¹. Interaction effect of *glomus fasciculatum* x *rhizobium* was most effective but at par with *glomus mosseae* x *rhizobium*. The highest grain and straw yield was recorded with *rhizobium* along with 30 kg N ha⁻¹ and increase was about 4.6 and 4.2 per cent over *rhizobium* x 15 kg N ha⁻¹. However, maximum nodule dry weight and rhizobial counts were observed with *rhizobium* x 15 kg N ha⁻¹ but further successive increase in nitrogen levels caused significant decrease at both the stages of plant growth. The available N, P and K status in the soil increased by 6.65, 7.18 and 3.30 per cent at flowering and 7.18, 14.82 and 6.20 at harvest over 30 kg N ha⁻¹ alone due to *rhizobium* x 15 kg N ha⁻¹, respectively.

Wang *et al.* (2018) studied the phosphorus (P)-release dynamics of phosphate solubilizing microorganisms. *Actinobacteria* with their sporulation, root colonization, bio-control, plant-growth-promotion and other activities could be potential field bio-inoculants. They reported one new type of rhizospheric phosphate solubilizing actinomycetes *Streptomyces griseoplanus* (namely PSA1) which was isolated from common maize crops planted in black soil of Northeast China. Phosphate solubilizing actinomycetes *Streptomyces griseoplanus* (PSA1) was capable of P-solubilization from tri-calcium phosphate in liquid medium. Day wise kinetics of maximum phosphate solubilization against tri-calcium phosphate suggested PSA1 as $284.80 \mu\text{g}\cdot\text{mL}^{-1}$. Release of different phosphates by PSA1 from aluminum phosphate, ferric phosphate and rock phosphate indicated its high efficient phosphate solubilizing ability. P-solubilization was inhibited by calcium salts and induced by EDTA, which indicated a dependence on the chelation of metal cations. Studies on the mechanism of P-solubilization by PSA1 provided a good foundation for its field application. In field conditions, PSA1 in combination with P fertilizer increased soil available P content, enhanced plant growth and enhanced grain yield of maize by 11 per cent. Thus, the actinobacterial isolate reported here were efficient phosphate-solubilizing and growth-promoting activities with the potential field applications.

2.5 Effect phosphorus and biofertilizers on physico-chemical properties and available nutrient status in soil

Kamble *et al.* (2018) were conducted field experiments during *kharif* and *rabi* season from 2012-13 to 2014-15 at Agricultural Research Station, Kasabe, Digraj, Sangli, Maharashtra to study the effect of integrated use of different organic sources and fertilizers on nutrient availability, uptake, yield and economics of groundnut-wheat cropping sequence on an Inceptisol. The results revealed that the application of GRD recorded significantly higher pooled groundnut dry pod yield, which was at par with 25 per cent RDN through vermicompost + 75 per cent RDN through chemical fertilizer + inoculation of *rhizobium* + PSB + AMF. However, higher pooled N use efficiency, net monetary returns and B:C ratio was reported under 25 per cent RDN through vermicompost + 75 per cent RDN through chemical fertilizer + inoculation of *rhizobium* + PSB + AMF. Application of GRD to *kharif* groundnut and wheat crop recorded higher pooled grain yield and straw yield of wheat. Application of 75 per cent GRD to wheat recorded higher pooled B:C ratio in wheat. The highest soil

available N, P, K and total uptake of N, P and K by crops were recorded with application of GRD to groundnut and wheat. Application of 25 % RDN through vermicompost and 75 per cent through chemical fertilizer and 50 kg P₂O₅ ha⁻¹ along with seed inoculation of *rhizobium* + PSB and soil application of AMF to *kharif* groundnut and 75 per cent to succeeding wheat resulted in higher net monetary returns and maintenance of soil fertility under groundnut-wheat cropping sequence.

A pot culture experiment was carried out in 2015 at Sir Karan Narendra College of Agriculture, Jobner during *kharif* season using cowpea as a test crop to investigate the effect of phosphorus management in cowpea (*Vigna unguiculata* L.) grown on saline soils. The results indicated that application of soil salinity having EC 1 dSm⁻¹ recorded the maximum yield, phosphorus and potassium content and uptake and nitrogen uptake of cowpea over rest of the treatments. But in case of nitrogen content lowest at EC 1 dSm⁻¹. Result further indicated that application of phosphorus source PROM recorded the maximum and significantly higher yield, nitrogen, phosphorus and potassium content and uptake of cowpea over rest of the treatments. However dual inoculation with PSB + VAM recorded the maximum and significantly higher significantly higher yield, nitrogen, phosphorus and potassium content and uptake of cowpea over rest of the treatments. Between treatments the application of EC 1 dSm⁻¹ + PROM + biofertilizer (PSB+VAM) proved superior in all these parameters over other treatments (Aechra *et al.* 2017).

Chesti and Tahir (2012) conducted field experiment for two consecutive *kharif* seasons of 2004 and 2005 at the Crop Research Farm, SKUAST, Shalimar campus, Srinagar to assess the rhizosperic microflora, nutrient availability and yield of green gram as influenced by organic manures, phosphate solubilizers and phosphorus levels in Alfisols. The results revealed that application of organic manures significantly increased the rhizospheric microbial population (bacteria, fungi and actinomycetes), available soil N, P, K, grain and straw yield of green gram. Among organic manures, application of FYM (10 t ha⁻¹) proved significantly superior to Dalweed (15 t ha⁻¹). Soil inoculation with P solubilizers recorded significant increase in grain and straw yield of green gram, soil available N and P and bacterial and actinomycetes population, whereas fungal population significantly decreased due to inoculation. Among P solubilizers, *Pseudomonas* proved significantly superior to *Bacillus* on yield of green gram, soil available P and bacterial population. Increasing levels of P up to

30 kg P₂O₅ ha⁻¹ significantly improved the grain and straw yield of green gram, microbial population (bacteria, fungi and actinomycetes) and soil available N, whereas available P of the post harvest soil increased significantly up to 60 kg P₂O₅ ha⁻¹ level. The application of 60 kg P₂O₅ ha⁻¹ decreased microbial population significantly over 30 kg P₂O₅ ha⁻¹. The application of 30 kg P₂O₅ ha⁻¹ could be designated as the safe limit for maximum microbial build up in the green gram rhizosphere.

Two separate field experiment was conducted at Post Graduate Institute, MPKV, Rahuri on wheat and chickpea crops to test the effect of rock phosphate (RP) along with organic manures on an Inceptisols (*Vertic Haplustepts*) and observed that the incubation of RP in organic manures and phosphate solubilizing bacteria (PSB) proved better for increasing the availability of major nutrients for both crops. Availability of P at 90 days after sowing and at harvest was significantly increased by incorporation of RP incubated with fresh cow dung and PSB. The nutrient uptake by both crops was also increased due to the application of RP with organic manures and PSB. This improvement in availability of nutrients ultimately resulted in significant increase in yield of both the crops over absolute control, P control and RP treatments. Among the organic manure treatments the availability of N and P yield of both crops was highest in RP + fresh cow dung + PSB treatment (Despande *et al.* 2015).

A field experiment was conducted on Mollisol at Pantnagar to examine the effects of varying rates and methods of application of carrier based liquid *Azotobacter* and PSB biofertilizers in combination with chemical fertilizers in wheat (*Triticum aestivum* L.). Application of 100 per cent NP showed maximum plant height, grain and straw yields, nutrient uptake and available NPK in soil after harvesting. Soil application of carrier biofertilizer at 10 kg ha⁻¹ and liquid biofertilizer at 0.625 and 1.25 L ha⁻¹ in combination with 75 per cent NP gave significantly more plant height over 75 per cent NP alone at different intervals. These treatments were at par with 100 per cent NP alone in plant height and grain and straw yields. The mean grain yield due to soil application of carrier biofertilizer at 10 kg ha⁻¹ and liquid biofertilizers at 0.625 and 1.25 L ha⁻¹ with 75 per cent NP was significantly more by 10.9, 10.5 and 10.8 per cent over 75 per cent NP alone, respectively. The respective increases in mean straw yield due to these treatments were 8.6, 8.2 and 9.1 per cent, respectively over 75 per cent NP alone. The trend that observed in grain and straw yield was also

observed in various yield attributes viz., total tillers, effective tillers, ear length and number of spikelet ear⁻¹, number of grains ear⁻¹ and 1000 grain weight. These treatments also significantly increased N, P and K uptake by grain and straw. All biofertilizer treatments with 75 per cent or 50 per cent NP gave significantly more available NPK in soil in comparison to 50 per cent NP alone. The carrier and liquid formulations of the biofertilizers respective rates were comparable in their performance. Irrespective of formulation and doses, application of biofertilizers in soil was found better than seed treatment for different recorded parameters. The increasing rates of the carrier and liquid biofertilizers applied in soil slightly improved the various recorded parameters. An application of 0.625 L ha⁻¹ liquid biofertilizers in soil with 75 per cent NP was found optimum for the growth, yield, nutrient uptake and available NPK in soil after harvesting (Khandare *et al.* 2015).

Nadeem *et al.* (2018) carried out field experiment on cowpea (*Vigna unguiculata* (L.) variety Kashi Kanchan during summer season at the experimental farm, department of Vegetable Science, College of Horticulture and Forestry, Central Agricultural University, Pasighat, Arunachal Pradesh. Result indicated that the application of P₂ (40 kg P ha⁻¹) significantly increased the plant height, leaf area index, stem girth, number of nodules per plant, number of branches per plant, total dry matter, pod yield, available soil nutrient status viz., pH, N, P, K, organic carbon and NPK content in plant after harvest of the crop. Similarly, seed inoculation with B₃ (*Rhizobium* + PSB) significantly enhanced the growth, yield, soil nutrient status and nutrient content in plant over single inoculation of *Rhizobium* and PSB. Combined inoculation of seed with *Rhizobium* + PSB (B₃) along with 40 kg P ha⁻¹ (P₂) significantly increased the stem girth (1.84 cm), total dry matter (13.91g plant⁻¹), green pod yield (196.37g plant⁻¹ and 120.90q ha⁻¹), soil nutrient status viz., pH (6.20), available N (370.89 kg ha⁻¹), available P₂O₅ (38.57 kg ha⁻¹), available K₂O (168.77 kg ha⁻¹), organic carbon (2.80%) and N, P and K (0.17%, 0.16% and 0.39%) content over rest of treatment combination.

Nath *et al.* (2015) evaluated the soil enzymes, microbial biomass carbon (MBC), microbial population and selected soil chemical properties in a field experiment involving integrated nutrient management (INM) for eight years of rice cultivation in an *Aeric Endoaquept*. Persistent application of biofertilizers for eight years illustrated the clear increase in fluorescein di-acetate (FDA) hydrolase (10.51 µg

fluorescein $\text{g}^{-1} \text{h}^{-1}$) and arylsulfatase (ARS) ($43.8 \mu\text{g } p\text{-nitrophenol } \text{g}^{-1} \text{h}^{-1}$) activities with 50:50 of NP fertilizers. Application of enriched compost (EC) (2 t ha^{-1}) demonstrated clear increase in dehydrogenase (DHA) ($220.0 \mu\text{g TPF } \text{g}^{-1} \text{24 hr}^{-1}$) and phosphomonoesterase (PME) ($388.8 \mu\text{g } p\text{-nitrophenol } \text{g}^{-1} \text{h}^{-1}$) activities with only 25 per cent of recommended nitrogenous (N) and phosphatic (P) fertilizer. The integration of biofertilizers of EC with reduction of 75 to 50 per cent NP fertilizers resulted the higher MBC in between 270.6 and 323.3 $\mu\text{g g}^{-1}$ compared to chemical fertilizer alone. Similarly, maximum accretion (11.2 g kg^{-1}) of organic carbon (OC) was observed with the application of EC (1 t ha^{-1}) and sizeable cut (50 % NP) of chemical fertilizers after eight crops. Abundance of *Azospirillum* (5.76 to 5.84×10^9 cfu g^{-1}) and PSB (5.52 to 5.90×10^9 cfu g^{-1}) were observed with application of either biofertilizers or EC (1 t ha^{-1}) and 50 per cent NP fertilizers. The MBC and OC displayed significant correlation with intracellular and extracellular soil enzymes and microbial populations in rice soil following INM. The overall multifaceted effects of different INM treatments facilitated beneficial soil conditions in the present study reflected the significant increase in the grain yield of rice (4.07 t ha^{-1}) which is equivalent to the 100 per cent NPK (3.86 t ha^{-1}). The application of biofertilizers with 50 per cent NP showed highest value (234.3 kg ha^{-1}) of available N, whereas highest available P (25.8 kg ha^{-1}) was obtained in the INM treatment that contained EC (2 t ha^{-1}).

Parewa *et al.* (2014) conducted field experiment during *rabi* seasons of 2009-10 and 2010-11 at the Agricultural Research Farm, Banaras Hindu University, Varanasi (U.P.) to study the effect of fertilizer levels, FYM and bio-inoculants and their interaction effect on soil properties. The treatments consisted four levels of recommended dose of fertilizer (0, 50, 75 and 100% NPK), two levels of farmyard manure (0, 10 t ha^{-1}) and four inoculation [no inoculation, PGPR (*Azotobacter chroococum* W5 + *Azospirillum brasilense* Cd+ *Pseudomonas fluorescens* BHU PSB06 + *Bacillus megaterium* BHU PSB14), VAM (vesicular arbuscular mycorrhiza) and PGPR+VAM]. The results revealed that application of different treatments did not affect the pH, EC and bulk density decreased, water holding capacity, organic carbon and CEC significantly improved after harvest of wheat.

Poonia *et al.* (2014) reported that organic matters are not showing any significant effect on the improvement of yield as compared to onward years in both

the crops. In case of equivalent seed yield, application of 100 per cent RDF recorded highest pigeonpea equivalent (PE) seed yield (2546 kg ha^{-1}) which statistically remained on the same bar with 50 per cent RDF + 5 ton FYM ha^{-1} + *Rhizobium* + PSB by producing 2350 kg ha^{-1} PE seed yield. However, three year study revealed that the reduction in chemical fertilizers upto 50 per cent of RDF gave 7.7 per cent less yield over 100 per cent RDF application. Similarly, higher net return was recorded in 100 per cent RDF to both the crops (Rs. $64.4 \times 10^3 \text{ ha}^{-1}$) than 50 % RDF + 5 ton FYM ha^{-1} + *Rhizobium* + PSB (Rs. $59.3 \times 10^3 \text{ ha}^{-1}$). From the view point of economics, application of 50 per cent RDF + 5 ton FYM ha^{-1} + *Rhizobium* + PSB to groundnut provided an alternate best option of nutrient management in groundnut-pigeonpea relay intercropping system.

Pot experiments was carried out to determine the effects of single and mixed inoculations with phosphorus-solubilizing bacteria and vesicular-arbuscular mycorrhizal (VAM) fungi on the growth of *Leucaena leucocephala*, *Acacia confusa*, *Acacia mangium*, and *Liquidarnber formosana* in three subtropical- tropical soils by Young (1990). The growth responses of *leucaena* to the inoculation with P-solubilizing bacteria alone increased in five out of six treatments with and without sterilized soils, with an average of 33.2 per cent. *Leucaena* growth significantly increased by 22-99 per cent in VAN fungal inoculation in the three soils. A synergistic effect of mixed inoculation with P-solubilizing bacteria and VAM fungi on the growth o occurred in unsterilized Wufun soil. Inoculation with these mixed inoculants also promoted the growth of *Acacia confusa* (14 to 63%), *Acacia mangium* (7 to 88 %), and *Liquidamber formosana* (24 to 280 %) in these three soils. The results showed that soil property is a significant factor in the modification of the response of these three tree species to the P- solubilizing bacteria and VAM fungi inoculations. The beneficial effect of P-solubilizing bacteria can be demonstrated in soils with a high content of available P (95 pg g^{-1} soil).

Qureshi *et al.* (2005) conducted pot culture experiment to know the direct and residual effect of rock phosphate when applied along with phosphate solubilizers and farmyard manure on available phosphorus, organic carbon and the viable counts of phosphate solubilizers in soil. The soil after harvest of soybean crop at 60 days stage was analyzed to know the direct effect while, soils after the harvest of mustard and followed by wheat were analyzed for studying the residual effect. After soybean the

0.5 M NaHCO₃ extractable P due to triple superphosphate was found to be the highest (19.0 mg P kg⁻¹ soil) followed by North Carolina, Udaipur and Mussoorie rock phosphates with 14.1, 12.0 and 11.7 mg P kg⁻¹ soil, respectively. Amongst the phosphate solubilizers, *Aspergillus awamori* showed significant effect in improving available P, which was followed by *Pseudomonas striata*. Combined application of phosphate solubilizers in presence of FYM improved the organic carbon status and proliferation of phosphate solubilizers. After mustard the available P in soil was highest in TSP treatment but decreased after wheat crop. Though, a difference was recorded amongst rock phosphates on soil available P after mustard, it was not noticed after wheat. Seed treatment with *Aspergillus awamori* in mustard and wheat improved the soil P status over *Bacillus polymyxa*. The number of viable counts of phosphate solubilizers in the rhizosphere soil after the harvest of both the crops due to P sources and seed inoculation with phosphate solubilizers were improved over control.

A field experiment was carried out to develop suitable integrated nutrient supply system for black gram-wheat cropping system. The study was aimed to find out the effect of integration of chemical source of phosphorus with bio-fertilizers on black gram and their residual effect on succeeding wheat crop at Udaipur. Incorporation of FYM @ 5 t ha⁻¹ considerably decreased the bulk density and increased the porosity, cation exchange capacity, organic carbon and available N, P and K status of the soil. Study showed the application of FYM @ 5 t ha⁻¹ or application of 40 kg P₂O₅ ha⁻¹ significantly increased the seed and stover yield of black gram as well as of succeeding wheat grown in sequence. Dual inoculation (PSB + VAM) to black gram also increased the yield of black gram and succeeding wheat crop grown in sequence (Rathore *et al.* 2011).

Sandhya *et al.* (2014) studied the co-inoculation effect of vesicular arbuscular mycorrhizal (VAM) fungi, and phosphate solubilizing bacteria (PSB) on nutrient uptake of *Marsdenia volubilis*. The plant seedlings harvested at various incubation days (30, 60, and 90) transplantation with two different treatments (individual VAM and PSB) resulted in uptake of shoot and root nutrients content, the dual inoculation (VAM and PSB) showed an excellent improvements in uptake of nutrients like N, P, K, Ca, Mg, Fe, Mn and Zn concentrations in *Marsdenia volubilis* than single applications.

Sharma (2014) studied the application of chemical and biofertilizers on growth and biomass production of *Madhuca latifolia* (Mahua) seedlings. The result indicates that biofertilizers were found much superior to chemical fertilizers in improving the soil fertility. *Azotobacter* was found the most efficient in improving the organic matter and nitrogen whereas PSB application is the best for improving phosphorus and potash. PSB has mobilized unavailable "P" to available form to the plants, which has resulted in increasing the growth of seedlings.

Sharma *et al.* (2012) carried out experiment to assess the influence of phosphorus levels and phosphorus solubilizing fungi on yield and nutrient uptake by wheat. The dry matter production by wheat at tillering, ear emergence, and harvest was significantly higher with 90 kg P₂O₅ ha⁻¹ and was at par with 60 kg P₂O₅ ha⁻¹. Application of *Aspergillus awamori* gave the highest dry matter accumulation at tillering, ear emergence, and harvest stage of crop growth. Increasing levels of phosphorus increased the grain and straw yield significantly up to 60 kg P₂O₅ ha⁻¹ of wheat crop. However, the maximum grain and straw yield were obtained at 90 kg P₂O₅ ha⁻¹, which was at par with 60 kg P₂O₅ ha⁻¹. The combined application of 60 kg P₂O₅ ha⁻¹ with *A. awamori* recorded significantly higher grain and straw yield. Increasing level of P application (0 to 90 kg P₂O₅ ha⁻¹) and inoculation with *A. awamori* and *A. niger* significantly increased uptake of N, P, and K in wheat at all stages of crop growth. The maximum nitrogen, phosphorus, and potassium uptake was recorded at harvest (grain and straw) followed by ear emergence and tillering when seeds were inoculated with *Aspergillus awamori*.

A field experiment was conducted during 1985 to 1996 on *Vertic ustochrepts* soils at Main Dry Farming Research Station, Targhadia (Gujarat) to study the effect of periodical application of phosphorus with and without FYM on content and uptake of nutrients by groundnut and soil fertility. The results revealed that the content of N, P and K in pod and haulm of groundnut and their total uptake as well as protein content were increased due to application of FYM and phosphorus. Significant positive effect of applied FYM was observed on status of organic carbon and available P, K and S in the soil. The organic carbon content and available status of potassium in the soil could not significantly alter due to periodical application of phosphorus. However, application of P was found beneficial in respect to available status of P and S in the soil (Sutaria *et al.* 2010).

Talwar *et al.* (2017) reported the highest soil organic carbon content (0.40 %) in the treatments T₁₂ (Farm Yard Manure (FYM) @ 20 t ha⁻¹) and T₁₁ (FYM @ 20 t ha⁻¹ + *Azotobacter* + Vesicular-Arbuscular Mycorrhizae (VAM)). Highest bacterial (24.5 X 10⁶) and actinomycetes count (29.9 X 10⁴) was recorded in T₁₁ (FYM @ 20 t ha⁻¹ + *Azotobacter* + VAM) treatment while highest fungal count (17.5 X 10³) was observed in T₃ (*Azospirillum* + Recommended dose of NPK) treatment. At the time of harvesting, available nitrogen (N), Available phosphorus (P) and Available potassium (K) were higher in treatment T₃ (*Azospirillum* + Recommended dose of NPK), T₉ (*Azotobacter* + VAM + Recommended dose of NPK) and T₁₃ (Poultry Manure @ 5 t ha⁻¹) treatments respectively than that in other treatments. *Azospirillum* and *Azotobacter* application along with recommended dose of N, P and K improved the fertility status of soil. The N uptake was significantly higher in T₃ treatment (162.6 Kg ha⁻¹) as compared to all other treatments except T₁ and T₉ treatments while P uptake (13.6 Kg ha⁻¹) was significantly higher in T₉ treatment than that in other treatments except T₁, T₃, T₅ and T₇ treatments. The K uptake was significantly higher in T₃ treatment (126.9 Kg ha⁻¹) as compare to all other treatments except T₁ and T₉ treatments. The present study highlights the need of use of biofertilizers alongwith organic and inorganic manures/fertilizer to enhance the nutrient availability and improve soil health.

2.6 Effect phosphorus and biofertilizers and their relationship with soil properties and yield of the crop

Chand *et al.* (2010) conducted field study during *rabi* 2000-2001 exclusively on the PSB and *Azotobacter* count in the rhizosphere soil using mustard as test crop as influenced by organic and inorganic sources. They revealed the positive significant correlation of inoculation of PSB with P content ($r = 0.961$, $n = 8$ $p < 0.01$), and *Azotobacter* inoculation with N content ($r = 0.552$, $n = 16$ $p < 0.01$) showed the significance of biofertilizers in improving the nutrient use efficiency.

Gharu and Tarafdar (2004) assessed the role of four organic acids (lactic, formic, citric, malic) on the mobilization of phosphorus in available form for the plant nutrition with three different soil types. The results indicated that malic acid was poor at mobilizing phosphorus from all the tested soils, while lactic, formic and citric acid were capable of mobilizing significant quantities of PA strong correlation ($R^2=0.68$ to

0.88) between release of P from inorganic (Pi) and organic (Po) sources irrespective of different organic acids was observed. The mobilization was 1.8 to 3.9 times higher from unavailable Pi sources than Po sources and depended on the type of organic acid present in the system. Per unit organic acid efficiency was maximum in Inceptisol followed by Aridisol and Alfisol. The efficiency to release P also depends on the pH of the soil ($r = -0.80$, $n = 84$, $p < 0.001$). The minimum soil solution concentration needed to start P mobilization due to different organic acids irrespective of the soil varies from 0.2 to 0.4 mM. The efficiency of different organic acids to mobilize P follows the order lactic acid > formic acid > citric acid > malic acid.

Kaur *et al.* (2017) laid down experiment to study the effect of biofertilizers, organic and inorganic fertilizers on physico-chemical properties of rhizospheric soil in pea crop during the *rabi* season of 2015-16. Soil electrical conductivity, available nitrogen and available potassium were found significantly higher in treatments having 50 per cent farm yard manure + 50 per cent recommended dose of nitrogen and phosphorus + consortium while soil organic carbon and available phosphorus were significantly higher in treatments having 100 per cent farm yard manure + consortium. The inoculation of biofertilizers in addition to organic and inorganic fertilizers resulted in higher residual soil nutrients.

Maheswar and Sathiyavani (2012) isolated phosphate solubilizing microorganisms from the groundnut rhizosphere soil. The isolated colonies were confirmed as *Bacillus subtilis* and *Bacillus cereus*. The effect of different pH, temperature, carbon sources, nitrogen sources, potash sources on the phosphate solubilization was optimized. Maximum solubilization was recorded at temperature range 40°C. Screening of phosphate solubilizing bacteria was done in *Bacillus subtilis*, *Bacillus cereus* in both solid and liquid medium. *Bacillus subtilis* was the most efficient for phosphate solubilizing activity, at pH 7, carbon sources (0.35±0.02), nitrogen sources (0.28±0.03) potash sources (0.12±0.09) strains on the basis of their phosphate solubilizing activity.

Nath *et al.* (2010) had undertaken study to harness prospective phosphate solubilizing bacteria (PSB) from rhizosphere of different crops of Assam. Twenty-nine PSB isolates representing rhizosphere samples were isolated, screened and evaluated on Pikovakaya's solid as well as in liquid media. Thirteen isolates were further screened out on the basis of maximum clear zone formation for elaborate

study to differentiate variation, if any, among cultures. Thus, the isolates were subjected to series of tests including quantification of P-solubilization followed by biochemical intrinsic antibiotic resistance characterization. The maximum (10.33×10^6 cfu g^{-1}) PSB were noted in wheat rhizosphere (PSB₂₈). The organic carbon (OC) of rhizospheres appeared strongest factor ($r = 0.880^*$) causing variation in PSB population across rhizospheres. The degree of tri-calcium phosphate (TCP) solubilization ranged from 7.33 to 59.66 per cent among individual cultures. The isolate PSB₆₃ from rice rhizosphere and PSB_{5W} from toria rhizosphere were regarded as excellent P-solubilizer that recorded as high as 59.66 per cent coupled with maximum drop of pH to 3.98 and 4.86, respectively from neutral. However, no significant correlation ($r = 0.124$) was observed between pH drop and extent of P-solubilization among isolates. Five isolates showing maximum P-solubilization were further evaluated for biochemical traits and intrinsic antibiotic resistance (IAR) potentials. However, the entire test isolates differed specifically in assimilating different carbohydrates and IAR profiles. However, the entire test isolates showed decarboxylase activity and could ferment citrate as sole carbon source and therefore established high activity in the rhizosphere.

A field experiments was carried out during 2003-04 and 2004-05 to develop suitable integrated nutrient supply system for black gram-wheat cropping system to find out the effect of integration of chemical source of phosphorus with bio-fertilizers on black gram and their residual effect on succeeding wheat crop was observed at Udaipur. Incorporation of FYM @ 5 t ha^{-1} considerably decreased the bulk density and increased the porosity, cation exchange capacity, organic carbon and available N, P and K status of the soil. Study showed further that the application of FYM @ 5 t ha^{-1} or application of 40 kg P_2O_5 ha^{-1} significantly increased the seed and stover yield of black gram as well as of succeeding wheat grown in sequence. Dual inoculation (PSB + VAM) to black gram also increased the yield of black gram and succeeding wheat crop grown in sequence (Rathore *et al.* 2011).

Sandhya *et al.* (2013) carried out experiment to determine the effects of microbial inoculants, (microbial fertilizers) on soil physico-chemical properties with supplementation of biofertilizers such as Vesicle Arbuscular Mycorrhizal (VAM), Fungi, and phosphate solubilizing bacteria (PSB). Supplementation of bio-inoculants to soil improved the physical properties such as colour, and chemical characteristics,

organic carbon, nitrogen, phosphorous, potassium, and lowered the electrical conductivity (EC). With increasing the soil incubation time also those parameters were improved in soil treated with microbial inoculants than control. Improved physical and chemical parameters in test soil in the study indicated the improvement of soil fertility due improved microbial and their biochemical and metabolic activities.

An experiment was conducted on a farmer's field on Alfisol to study the effect of different fertilizer recommendation practices on changes in organic carbon, available N, P and K status of the soil and yield of groundnut and finger millet. The highest yield of groundnut and finger millet was obtained when fertilizers were applied as per the package of practices of University of Agricultural Sciences, Bangalore where 100 per cent recommended NPK fertilizers along with 7.5 t FYM ha⁻¹ was applied. The organic carbon, available N, P and K content of soil were significantly improved with the use of 100 per cent recommended fertilizer + 7.5 t FYM ha⁻¹ in groundnut–finger millet cropping system (Varalakshmi *et al.* 2005).

CHAPTER III

MATERIAL AND METHODS

The present investigation pertaining to the “Effect of different levels of phosphorus and biofertilizers on soil properties, yield, quality and uptake of nutrients by groundnut (*Arachis hypogaea* L.)” was undertaken during *Rabi* season of 2017-18 and 2018-19 at Botany Farm, College of Agriculture, Dapoli. The analytical work was carried out in the research laboratory of the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Dapoli. The details regarding material used and methods followed during the course of investigation are presented in this chapter.

3.1 Material

3.1.1 Experimental site

The field trials were conducted at in plot No 14 (1) Botany Farm, College of Agriculture, Dapoli during *rabi* season of 2017-18 and 2018-19 where the facilities of irrigation water and protection from cattle were available.

3.1.2 Soil

3.1.2.1 Geography

The Konkan region of Maharashtra state is a long and narrow strip covering an area of 30,728 sq. km. The study area is situated in Dapoli of Ratnagiri district in south western part of Maharashtra State on the Arabian Sea coast. It is located at 17⁰ 45' 02" North latitude and 73⁰ 10' 55" East longitude. The area falls under 19.2 Agro-ecological sub-region (AESR) i.e., central and south sahyadris region represented by hot moist sub humid to humid transitional eco sub-region (ESR) with deep loamy to clayey red and lateritic soils, low to medium available water capacity (AWC) and length of growing period (LGP) being 210-270 days (Gajbhiye and Mandal 2000).

3.1.2.2 Geology

The study area is covered by volcanic rocks, principally basaltic lavas, known as the Deccan trap. It is the most important geological formation of Maharashtra. The term 'Trap' is applied to the step like aspect of the weathered hills of basalt which is the most common feature. In composition the basalts are singularly uniform, augite basalt is the most common. The study area indicate the presence of the Precambrians represented by the Archaean, granites and gneiss with mafics and the Proterozoic

sedimentaries, the basaltic lava flows, termed as the Deccan basalts, associated with the basic intrusives and acidic to basic and ultrabasic differentiates, laterites and consolidated and unconsolidated Quaternary sediments. The area is occupied by the Deccan volcanics. The Deccan Trap basalt is a thick pile of volcanic lava flows of Cretaceous-Miocene period (Krishnan 1968). These lava flows have been classified as 'aa', 'pahoehoe' and as simple and compound types (Adyalkar, 1984).

3.1.2.3 Climatic conditions

The climate of the area is hot humid to per humid with well-expressed three seasons *viz.*, rainy (June to October), winter (November to February) and summer (March to May). The mean annual rainfall is 3500 mm, of which about 90 per cent received during the months June to October with about 95 to 100 rainy days in most of the years. The hottest month is May with temperature above 33 °C, while months of December and January are coldest with temperature below 16 °C. The mean annual maximum and minimum temperature was 31.5 °C and 19.7 °C having 3633.5 mm average rainfall with 112 rainy days during the year 2017. The mean maximum and minimum temperature was 31.7 °C and 19.4 °C and 3071.8 mm annual rainfall with 99 rainy days in the year 2018. The mean maximum temperature during growing season was 32.7 °C and minimum temperature 18 °C and the relative humidity was 93.2 per cent in the year 2017-18. The mean temperature during growing period in the year 2018-19 was 32.7 °C and 16.4 °C and the relative humidity was 88.2 per cent. The weather parameters during the period of experimentation were recorded at the Meteorological Observatory, College of Agriculture, Dapoli in the year 2017-18 and 2018-19 are presented in Table 3.1 (a & b).

3.1.2.4 Topography

The typical topography associated with high rainfall and other climatic conditions has given rise to lateritic soil. It is mainly developed from basalt rock by the process of laterization which is poor in fertility and having low nutrient retention capacity. According to Alexander and Cady (1962) 'Laterite' is a highly weathered material, rich in secondary oxides of iron, aluminium or both. It is nearly devoid of bases and primary silicates but it may contain large amounts of quartz and kaolinite. It

Table 3.1 (a) Weekly meteorological data during the crop growth period (2017-18)

Period	MW	Tmax (°C)	Tmin (°C)	RH-I (%)	RH-II (%)	Wind speed (Kmph)	Rain (mm)	RD day	BSS (hrs.)	Epan (mm)
01.10 - 07.10	40	31.7	23.2	95	85	2.5	19.7	3	2.1	2.6
08.10 - 14.10	41	30.3	23.6	96	82	1.7	105.0	4	2.0	1.7
15.10 - 21.10	42	31.4	23.9	97	82	2.1	11.0	1	4.9	3.0
22.10 - 28.10	43	32.5	21.9	91	68	2.1	0.0	0	8.1	3.7
29.10 - 04.11	44	33.2	17.5	93	52	1.7	0.0	0	8.9	3.4
05.11 - 11.11	45	33.0	16.7	92	46	2.1	0.0	0	9.3	3.5
12.11 - 18.11	46	32.1	15.2	94	42	2.1	0.0	0	9.5	3.3
19.11 - 25.11	47	33.7	18.7	92	47	2.0	0.0	0	7.5	3.4
26.11 - 02.12	48	33.1	15.2	92.6	39.9	2.1	0.0	0	8.1	3.1
03.12 - 09.12	49	30.1	19.3	91	62	4.0	23.6	2	6.5	2.7
10.12 - 16.12	50	30.0	15.9	95	54	2.9	0.0	0	7.1	2.8
17.12 - 23.12	51	32.2	12.6	93	53	2.1	0.0	0	7.7	2.7
24.12 - 31.12	52	31.9	11.7	94	42	2.3	0.0	0	8.2	3.0
01.01 - 07.01	1	30.4	12.4	96	74	2.5	0.0	0	7.7	2.9
08.01 - 14.01	2	31.5	15.2	97	69	2.4	0.0	0	7.8	2.7
15.01 - 21.01	3	33.8	14.8	96	65	2.6	0.0	0	8.0	3.5
22.01 - 28.01	4	30.4	12.5	95	79	3.1	0.0	0	8.7	3.4
29.01 - 04.02	5	33.1	12.2	96	64	2.8	0.0	0	9.2	4.1
05.02 - 11.02	6	32.1	14.4	95	66	2.7	0.0	0	5.5	3.5
12.02 - 18.02	7	32.2	14.3	92	65	3.5	0.0	0	7.4	1.3
19.02 - 25.02	8	33.9	15.4	96	69	2.7	0.0	0	6.4	1.5
26.02 - 04.03	9	36.1	15.0	95	62	3.2	0.0	0	7.9	3.2
05.03 - 11.03	10	33.6	17.1	95	64	3.4	0.0	0	8.3	1.9
12.03 - 18.03	11	34.6	18.9	92	64	3.3	0.0	0	6.4	4.7
19.03 - 25.03	12	31.8	15.3	91	69	4.3	0.0	0	1.3	5.0
26.03 - 01.04	13	33.6	19.9	96	88	4.2	0.0	0	8.0	5.6
02.04 - 08.04	14	32.5	19.7	92	87	4.4	0.0	0	3.9	5.4
09.04 - 15.04	15	34.7	20.0	91	69	4.7	0.0	0	8.7	6.0
16.04 - 22.04	16	33.7	20.9	90	69	4.7	0.0	0	8.9	5.7
23.04 - 29.04	17	34.1	19.5	90	67	5.2	0.0	0	10.6	6.0
30.04 - 06.05	18	33.0	21.0	91	69	4.7	0.0	0	10.5	6.0
07.05 - 13.05	19	34.0	24.0	89	71	5.1	0.0	0	9.4	6.5
14.05 - 20.05	20	34.2	23.4	91	73	5.4	6.0	1	8.2	5.9
21.05 - 27.05	21	33.7	24.5	90	71	6.0	0.0	0	7.4	5.7
28.05 - 03.06	22	33.9	25.4	89	76	6.5	10.2	1	6.8	5.2

Table 3.1 (b) Weekly meteorological data during the crop growth period (2018-19)

Period	MW	Tmax (°C)	Tmin (°C)	RH-I (%)	RH-II (%)	Wind speed (Kmph)	Rain (mm)	RD day	BSS (hrs.)	Epan (mm)
01.10 - 07.10	40	34.1	21.7	91	64	1.4	28.2	3	5.1	4.2
08.10 - 14.10	41	33.2	22.5	90	73	0.9	0.0	0	5.8	4.5
15.10 - 21.10	42	33.4	21.0	90	69	0.5	8.8	1	6.3	4.4
22.10 - 28.10	43	33.9	19.5	89	60	0.5	0.0	0	7.9	4.7
29.10 - 04.11	44	33.6	17.0	86	60	0.9	0.0	0	8.9	4.5
05.11 - 11.11	45	34.6	19.6	85	68	0.6	0.0	0	8.7	4.7
12.11 - 18.11	46	34.6	15.2	90	65	0.6	0.0	0	8.9	4.6
19.11 - 25.11	47	33.5	18.4	88	65	0.8	0.0	0	7.2	4.5
26.11 - 02.12	48	33.2	14.0	89.9	66.1	0.9	0.0	0	8.4	4.8
03.12 - 09.12	49	33.1	15.7	91	66	1.0	0.0	0	6.1	4.0
10.12 - 16.12	50	31.4	13.2	84	63	1.8	0.0	0	6.7	3.8
17.12 - 23.12	51	26.6	12.0	88	65	1.2	0.0	0	7.0	3.9
24.12 - 31.12	52	31.8	11.9	88	66	0.8	0.0	0	8.5	4.5
01.01 - 07.01	1	32.6	10.1	90	61	0.2	0.0	0	8.8	4.3
08.01 - 14.01	2	32.0	10.6	86	60	0.2	0.0	0	8.5	4.1
15.01 - 21.01	3	33.8	13.4	89	58	0.2	0.0	0	8.0	4.0
22.01 - 28.01	4	29.2	11.5	89	59	3.0	0.0	0	8.4	3.8
29.01 - 04.02	5	31.4	13.3	90	61	3.8	0.0	0	8.2	4.3
05.02 - 11.02	6	30.5	10.8	88	62	4.5	0.0	0	8.8	4.8
12.02 - 18.02	7	32.1	12.8	88	62	3.8	0.0	0	9.1	5.4
19.02 - 25.02	8	32.6	14.9	89	60	3.8	0.0	0	8.5	5.9
26.02 - 04.03	9	31.2	12.7	90	65	4.6	0.0	0	8.8	6.1
05.03 - 11.03	10	31.0	14.0	90	64	4.7	0.0	0	7.0	5.8
12.03 - 18.03	11	32.4	14.5	85	56	4.8	0.0	0	7.6	5.7
19.03 - 25.03	12	33.0	14.6	89	52	4.4	0.0	0	7.6	6.4
26.03 - 01.04	13	34.6	20.5	88	64	4.7	0.0	0	7.3	6.3
02.04 - 08.04	14	33.2	20.1	89	53	5.0	0.0	0	7.2	6.6
09.04 - 15.04	15	33.7	21.7	90	52	5.7	0.0	0	7.2	6.9
16.04 - 22.04	16	33.6	19.6	90	56	5.7	0.0	0	8.4	6.8
23.04 - 29.04	17	34.9	23.4	85	65	6.0	0.0	0	7.9	6.4
30.04 - 06.05	18	33.0	21.1	85	60	5.2	0.0	0	8.0	6.7
07.05 - 13.05	19	33.5	22.5	82	60	6.2	0.0	0	8.8	6.7

is either hard or capable of hardening on exposure to wetting and drying. Schellmann (1981) observed that laterites are weathered products of intense subaerial rock weathering in which Fe and Al content is higher and Si content is lower than the kaolinised parent rock. Taking into consideration major oxide content, viz., SiO_2 , Al_2O_3 and Fe_2O_3 in laterites derived from different parent rocks and established the stages of lateritisation from the parent rock through kaolinisation to true laterite. In general, the soil is well drained, sandy clay loam in texture having high acidity and high content of organic matter. The soil showed the deficiency of phosphate, accentuated by high phosphate-fixing capacity as Fe and Al-phosphates, toxicity of aluminium and manganese and deficiency of potassium, calcium, magnesium. The micronutrients viz., Fe, Mn, and Cu are sufficient but the soil is deficient in Zn and B (Sehgal, 1999).

3.1.2.5 Soil

The experiment was conducted on terraced lateritic soil. About 1.5 kg representative surface soil sample (up to 22.5 cm) was collected in cloth bag prior to raising the crop on the experimental field by following the standard method of soil sample collection to know the initial fertility status of the soil. The bulk soil samples was allowed to air-dry. A wooden mortar and pestel was used to crush soil aggregates to pass through a 2 mm sieve. Soil material passing through the sieve was placed in labeled boxes. A small portion of less than 2 mm sample was ground to pass a 100 mesh sieve for organic carbon estimation. The soil after necessary laboratory processing was analyzed for different physico-chemical properties.

The analytical data of the collected initial soil samples are presented in Table 3.2. The soil of the study area is classified into a member of *fine, kaolinitic isohyperthermic family of Typic Hapludalf* (Sohan Lal 2000). It was revealed from the data that the soil was sandy clay loam, strongly acidic in reaction, low electrical conductivity, high in organic carbon, medium in available nitrogen and low in available phosphorus and very high in potassium content.

Table 3.2 Initial physico-chemical properties of the experimental soil

Sr. No.	Property	Content	
		2017-18	2018-19
1	Physico-chemical properties		
	I) Mechanical analysis		
	a) Sand (%)	45.80	45.47
	b) Silt (%)	17.60	17.78
	c) Clay (%)	36.60	36.75
	d) Textural class	Sandy clay loam	Sandy clay loam
	II) Particle density (Mg m^{-3})	2.64	2.63
	III) Bulk density (Mg m^{-3})	1.39	1.37
	IV) Porosity (%)	52.65	51.89
	V) Maximum water holding capacity (%)	42.90	43.07
2	Chemical Properties		
	I) pH (1:2.5)	4.96	5.01
	II) Electrical conductivity (dS m^{-1}) (1:2.5)	0.119	0.343
	III) Organic Carbon (g kg^{-1})	9.30	10.80
	IV) Available N (kg ha^{-1})	235.20	196.00
	V) Available P_2O_5 (kg ha^{-1})	7.43	9.87
	VI) Available K_2O (kg ha^{-1})	338.69	248.64
	VII) Cation Exchange Capacity [$\text{cmol}(\text{p}^+) \text{kg}^{-1}$]	9.25	10.35
	VIII) DTPA- extractable Fe (mg kg^{-1})	82.52	112.71
	IX) DTPA- extractable Mn (mg kg^{-1})	71.45	82.70
	X) DTPA- extractable Zn (mg kg^{-1})	1.85	1.71
	XI) DTPA- extractable Cu (mg kg^{-1})	2.78	4.17
3	Biological properties		
	I) CO_2 evolution ($\text{mg } 100\text{g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$)	28.56	29.84
	II) Microbial biomass carbon ($\mu\text{g g}^{-1} \text{ soil}$)	148.13	152.67
	III) Microbial biomass nitrogen ($\mu\text{g g}^{-1} \text{ soil}$)	28.41	28.83
	Microbial count		
	III) Bacteria ($\text{cfu} \times 10^5 \text{ g}^{-1} \text{ soil}$)	39.02	41.14
	IV) Actinomycetes ($\text{cfu} \times 10^5 \text{ g}^{-1} \text{ soil}$)	24.15	21.79
	V) Fungi ($\text{cfu} \times 10^3 \text{ g}^{-1} \text{ soil}$)	8.16	10.13
	VI) Urease activity ($\mu\text{g NH}_4\text{-N g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$)	35.20	34.44
	VII) Dehydrogenase activity ($\mu\text{g TPF g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$)	33.17	32.83
	Phosphatase activity		
	VIII) Alkaline phosphatase activity ($\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$)	49.48	52.65
	IX) Acid phosphatase activity ($\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$)	34.53	35.12

3.1.3 Experimental details

In the present investigation entitled, “Effect of different levels of phosphorus and biofertilizers on soil properties, yield, quality and uptake of nutrients by groundnut (*Arachis hypogaea* L.)” was laid out in the same field i.e. plot no 14 (1) (Fig.1 and plate. 1) during *rabi* 2017-18 and 2018-19. The details of the trials are given below.

3.1.3.1 Crop

Groundnut variety Konkan Trombay Tapora released by Dr.Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli was taken as a test crop. The variety is suitable for growing in *kharif* as well as *rabi* season. The variety is semi-spreading type having high shelling percentage and relatively high oil content with an average potential yield of 20-22 q ha⁻¹. The duration of variety is about 120-125 days. The germination was 88 per cent which resulted in good crop stand in the field. The crop was sown by dibbling method.

3.1.3.2 Biofertilizers

Phosphate Solubilizing Bacteria (PSB) as “M.P.K.V.’s Phospho Inoculant” (Phosphate solubilizers) having viable count in between 10⁷-10⁹ manufactured by Head, Department of Plant Pathology and Agril. Microbiology, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar, and the Phosphate Mobilizing Mycorrhiza i.e. Vesicular Arbuscular Mycorrhiza (VAM-Shubhodaya Mycorrhizal biofertilizers) manufactured by Cosmo Biotech Pvt. Ltd., Bicholim, Goa as “VAM Inoculant” with 1,00,000 number of infective propagules kg⁻¹ were brought and applied to the groundnut seeds.

3.1.3.3 Seed treatment with biofertilizers

The groundnut seeds were inoculated with *Rhizobium* @ 25 g kg⁻¹, PSB (Phosphate Solubilizing Bacteria) and VAM (Vesicular Arbuscular Mycorrhiza) @ 80 g kg⁻¹ seed each. The jaggery solution was prepared by dissolving 120 g gur in 1 litre water and was boiled for ½ hr and cooled to room temperature. Carrier based biofertilizers of PSB and VAM @ 80 g kg⁻¹ seed each were transferred to the cooled jaggery solution to make slurry. The seeds were thoroughly mixed with cultures slurry so as to obtain a uniform coating of the cultures on the seeds. The seeds thus

inoculated were spread on a clean gunny bag in shade for drying. These dried seeds were used for sowing and dibbled in pertinent treatment plots.

3.1.3.4 Application of Manures and Fertilizers

The plant nutrients were applied through fertilizer viz., urea, single super phosphate and muriate of potash for N, P and K, respectively. Along with this, FYM @ 10 t ha⁻¹ was also used as the organic source of nutrient. The composition of FYM as well as inorganic fertilizers used in the present study is given in Table 3.3.

Table 3.3 Nutrient composition of various inorganic fertilizers and FYM used in the study

Sr. No.	Name of fertilizer	Composition (%)		
		N	P ₂ O ₅	K ₂ O
1.	Urea	45.80	-	-
2.	Single super phosphate	-	16.0	-
3.	Muriate of potash	-	-	60.0
4.	FYM	0.52	0.16	0.51

After the preparation of plots, FYM was added @ 10 t ha⁻¹ and Rhizobium @ 25 gm kg⁻¹ seed common to all treatments including control. Nitrogen @ 30 kg ha⁻¹ and potassium @ 30 kg ha⁻¹ was applied at the time of sowing. Phosphorus @ 15, 30, 45 and 60 kg ha⁻¹ were applied in a single dose at the time of sowing in the pertinent treatments.

The information regarding various fertilizers and biofertilizers used and their rate of application on per hectare basis has been given in Table 3.4. On the basis of this information, the quantity of various fertilizers applied per plot was calculated.

3.1.3.5 Details of the experiment

- 1) Soil type : Alfisol
- 2) Year and season : Rabi, 2017-18 and 2018-19
- 3) Test Crop : Groundnut
- 4) Variety : Konkan Trombay Tapora/ TKG-Bold
- 5) Treatment Combinations : 20
- 6) Number of replications : Three
- 7) Design of experiment : Factorial Randomized Block Design
- 8) Spacing : 30 cm x 15 cm
- 9) Plot size : 4.50 m X 3.00 m
- 10) Recommended dose of fertilizer : 30:60:30 kg ha⁻¹ N:P₂O₅:K₂O
- 11) Seed rate : 120 kg ha⁻¹

* Absolute control plot was sown separately

Table 3.4 The information regarding different fertilizers used alongwith their rate of application

Sr. No.	Treatment combinations	Fertilizer used	Qty. of fertilizer applied (kg ha ⁻¹)	Nutreints supplied through fertilizer (kg ha ⁻¹)		
				N	P ₂ O ₅	K ₂ O
1.	B ₂ P ₁₅ + Biofertilizers @ 10 kg ha ⁻¹ (PSB)	1] Urea	65.21	30	-	-
		2] S.S.P.	93.75	-	15	-
		3] M.O.P.	50.00	-	-	30
2.	B ₄ P ₄₅ + Biofertilizers each @ 10 kg ha ⁻¹ (VAM + PSB)	1] Urea	65.21	30	-	-
		2] S.S.P.	281.25	-	45	-
		3] M.O.P.	50.00	-	-	30
3.	B ₁ P ₃₀ + Biofertilizers @ 10 kg ha ⁻¹ (VAM)	1] Urea	65.21	30	-	-
		2] S.S.P.	187.50	-	30	-
		3] M.O.P.	50.00	-	-	30
4.	B ₀ P ₆₀ No Biofertilizers	1] Urea	65.21	30	-	-
		2] S.S.P.	375.00	-	60	-
		3] M.O.P.	50.00	-	-	30
5.	B ₁ P ₁₅ + Biofertilizers @ 10 kg ha ⁻¹ (VAM)	1] Urea	65.21	30	-	-
		2] S.S.P.	93.75	-	15	-
		3] M.O.P.	50.00	-	-	30
6.	B ₃ P ₁₅ + Biofertilizers each @ 5 kg ha ⁻¹ (VAM + PSB)	1] Urea	65.21	30	-	-
		2] S.S.P.	93.75	-	15	-
		3] M.O.P.	50.00	-	-	30
7.	B ₃ P ₄₅ + Biofertilizers each @ 5 kg ha ⁻¹ (VAM + PSB)	1] Urea	65.21	30	-	-
		2] S.S.P.	281.25	-	45	-
		3] M.O.P.	50.00	-	-	30
8.	B ₄ P ₃₀ + Biofertilizers each @ 10 kg ha ⁻¹ (VAM + PSB)	1] Urea	65.21	30	-	-
		2] S.S.P.	187.50	-	30	-
		3] M.O.P.	50.00	-	-	30
9.	B ₂ P ₆₀ + Biofertilizers @ 10 kg ha ⁻¹ (PSB)	1] Urea	65.21	30	-	-
		2] S.S.P.	375.00	-	60	-
		3] M.O.P.	50.00	-	-	30
10.	B ₁ P ₆₀ + Biofertilizers @ 10 kg ha ⁻¹ (VAM)	1] Urea	65.21	30	-	-
		2] S.S.P.	375.00	-	60	-
		3] M.O.P.	50.00	-	-	30
11.	B ₄ P ₆₀ + Biofertilizers each @ 10 kg ha ⁻¹ (VAM + PSB)	1] Urea	65.21	30	-	-
		2] S.S.P.	375.00	-	60	-
		3] M.O.P.	50.00	-	-	30
12.	B ₀ P ₁₅ No Biofertilizers	1] Urea	65.21	30	-	-
		2] S.S.P.	93.75	-	15	-
		3] M.O.P.	50.00	-	-	30

13.	B ₄ P ₁₅ + Biofertilizers each @ 10 kg ha ⁻¹ (VAM + PSB)	1] Urea	65.21	30	-	-
		2] S.S.P.	93.75	-	15	-
		3] M.O.P.	50.00	-	-	30
14.	B ₂ P ₃₀ + Biofertilizers @ 10 kg ha ⁻¹ (PSB)	1] Urea	65.21	30	-	-
		2] S.S.P.	187.50	-	30	-
		3] M.O.P.	50.00	-	-	30
15.	B ₂ P ₄₅ + Biofertilizers @ 10 kg ha ⁻¹ (PSB)	1] Urea	65.21	30	-	-
		2] S.S.P.	281.25	-	45	-
		3] M.O.P.	50.00	-	-	30
16.	B ₁ P ₄₅ + Biofertilizers @ 10 kg ha ⁻¹ (VAM)	1] Urea	65.21	30	-	-
		2] S.S.P.	281.25	-	45	-
		3] M.O.P.	50.00	-	-	30
17.	B ₀ P ₄₅ No Biofertilizers	1] Urea	65.21	30	-	-
		2] S.S.P.	281.25	-	45	-
		3] M.O.P.	50.00	-	-	30
18.	B ₃ P ₃₀ + Biofertilizers each @ 5 kg ha ⁻¹ (VAM + PSB)	1] Urea	65.21	30	-	-
		2] S.S.P.	187.50	-	30	-
		3] M.O.P.	50.00	-	-	30
19.	B ₃ P ₆₀ + Biofertilizers each @ 5 kg ha ⁻¹ (VAM + PSB)	1] Urea	65.21	30	-	-
		2] S.S.P.	375.00	-	60	-
		3] M.O.P.	50.00	-	-	30
20.	B ₀ P ₃₀ No Biofertilizers	1] Urea	65.21	30	-	-
		2] S.S.P.	187.5	-	30	-
		3] M.O.P.	50.00	-	-	30

Note : S.S.P.=Single super phosphate, M.O.P.=Muriate of potash

3.1.3.6 Details of treatment combinations

There were twenty treatment combinations replicated thrice. The details are presented in Table 3.5.

Table 3.5 Details of the treatment combinations

Treat. Combinations	Description of Treatment
B ₂ P ₁₅ + Biofertilizers (PSB)	30:15:30 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹ Biofertilizers (i.e. PSB @ 10 kg ha ⁻¹)
B ₄ P ₄₅ + Biofertilizers (VAM + PSB)	30:45:30 kg N:P ₂ O ₅ :K ₂ O ha Biofertilizers (i.e. VAM + PSB each @ 10 kg ha ⁻¹)
B ₁ P ₃₀ + Biofertilizers (VAM)	30:30:30 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹ Biofertilizers (i.e. VAM @ 10 kg ha ⁻¹)
B ₀ P ₆₀ + No Biofertilizers	30:60:30 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹ No Biofertilizers
B ₁ P ₁₅ + Biofertilizers (VAM)	30:15:30 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹ Biofertilizers (i.e. VAM @ 10 kg ha ⁻¹)

B ₃ P ₁₅ + Biofertilizers (VAM + PSB)	30:15:30 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹ Biofertilizers (i.e. VAM + PSB each @ 5 kg ha ⁻¹)
B ₃ P ₄₅ + Biofertilizers (VAM + PSB)	30:45:30 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹ Biofertilizers (i.e. VAM + PSB each @ 5 kg ha)
B ₄ P ₃₀ + Biofertilizers (VAM + PSB)	30:30:30 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹ Biofertilizers (i.e. VAM + PSB each @ 10 kg ha ⁻¹)
B ₂ P ₆₀ + Biofertilizers (PSB)	30:60:30 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹ Biofertilizers (i.e. PSB @ 10 kg ha ⁻¹)
B ₁ P ₆₀ + Biofertilizers (VAM)	30:60:30 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹ Biofertilizers (i.e. VAM @ 10 kg ha ⁻¹)
B ₄ P ₆₀ + Biofertilizers (VAM + PSB)	30:60:30 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹ Biofertilizers (i.e. VAM + PSB each @ 10 kg ha ⁻¹)
B ₀ P ₁₅ + No Biofertilizers	30:15:30 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹ No Biofertilizers
B ₄ P ₁₅ + Biofertilizers (VAM + PSB)	30:15:30 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹ Biofertilizers (i.e. VAM + PSB each @ 10 kg ha ⁻¹)
B ₂ P ₃₀ + Biofertilizers (PSB)	30:30:30 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹ Biofertilizers (i.e. PSB @ 10 kg ha ⁻¹)
B ₂ P ₄₅ + Biofertilizers (PSB)	30:45:30 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹ Biofertilizers (i.e. PSB each @ 10 kg ha ⁻¹)
B ₁ P ₄₅ + Biofertilizers (VAM)	30:45:30 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹ Biofertilizers (i.e. PSB @ 10 kg ha ⁻¹)
B ₀ P ₄₅ + No Biofertilizers	30:45:30 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹ No Biofertilizers
B ₃ P ₃₀ + Biofertilizers (VAM + PSB)	30:30:30 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹ Biofertilizers (i.e. VAM + PSB each @ 5 kg ha ⁻¹)
B ₃ P ₆₀ + Biofertilizers (VAM + PSB)	30:60:30 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹ Biofertilizers (i.e. VAM + PSB each @ 5 kg ha ⁻¹)
B ₀ P ₃₀ + No Biofertilizers	30:15:30 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹ No Biofertilizers

* *Rhizobium* @ 25 g kg⁻¹ seed applied equally to all treatments

* Absolute control plot was sown separately

3.1.4.1 Other cultivation details

The various pre and post cultural operations were carried out as per the recommended package of practices for groundnut in Table 3.6.

i) Land preparation

The experimental plot was ploughed, the clods were crushed and raised beds were prepared as per experimental layout. Then bunds were made around each treatment plot so as to avoid mixing of fertilizers from one treatment to other.

ii) Seed treatment, seed rate and sowing

Healthy and well developed pods of groundnut (Konkan Trombay Tapora/TKG-Bold) were obtained and shelled manually for seed kernels. Seed inoculation

with PSB and VAM inoculants was done. Sowing was undertaken by dibbling the seeds at a spacing of 30 x 15 cm.

iii) Gap filling

Gap filling was done 10 days after sowing to maintain the plant population.

Table 3.6 The details of cultural operations followed during the course of investigation

Sr. No.	Operation	Date	Date
1	Ploughing	11/12/2017	14/11/2018
2	Clod crushing	13/12/2017	17/11/2018
3	Layout of experiment	14/12/2017	18/11/2018
4	Preparation of beds	14/12/2017	18/11/2018
5	Application of FYM	15/12/2017	25/11/2018
6	Application of fertilizers	16/12/2017	27/11/2018
7	Seed treatment with biofertilizers	21/12/2017	02/12/2018
8	Sowing (dibbling of seeds)	22/12/2017	02/12/2018
9	Gap filling	02/01/2018	12/12/2018
10	Weeding by manually	15/02/2017	14/01/2019
11	Earthing up	14/03/2017	18/02/2019
12	Plant protection		
	➤ Application of Phorate	03/01/2018	1/12/2018
	➤ Spraying of Monocrotophos	08/02/2018	14/01/2019
13	Harvesting	24/05/2018 to 27/05/2018	18/04/2019 to 23/04/2019
14	Sun drying	27/05/2018 to 30/05/2018	24/04/2019 to 30/04/2019
15	Recording of yield data	31/05/2018	02/05/2019

* Irrigation was given whenever required

iv) Earthing up

After hand weeding, earthing up was done for proper support to the plants.

v) Weed control

Hand weeding was done for 3 times to remove the weeds between the rows of plots.

vi) Harvesting

The experimental crop was harvested when the pods were matured fully. The plants from border rows of all the four sides were harvested separately to eliminate the border effect. For harvesting the plants were uprooted and the pods were separated manually. The produce was allowed to sundry for 4 days. Dry weight of the pods and haulm was recorded separately from each plot.

3.1.4.2 Biometric observations

Biometric observations to assess the effect of treatment on the growth and development of crop were recorded at an interval of 45 Days after sowing (45 DAS) i.e. peg initiation, pod formation stage and at harvest.

i) Sampling Technique

For recording biometric observations five plants from each net plot were randomly selected. The selected plants were labeled with proper notations.

ii) Growth studies

The details in respect of various biometric and other observations were recorded during the course of study which is presented in Table 3.7.

Table 3.7 Biometric and other observations

Sr. No.	Particular	Frequency	Growth stage or days after sowing (DAS)
A.	Growth and yield contributing characters		
i)	Plant height (cm)	3	Peg initiation, pod formation and at harvest
ii)	Number of rachis (cm)	3	Peg initiation, pod formation and at harvest
iii)	Number of pods per plant	1	After harvest
iv)	Weight of 100 pods (g)	1	After harvest
v)	Weight of 100 kernels (g)		After harvest
vi)	Pod yield ($q\ ha^{-1}$)	1	After harvest
vii)	Haulm yield ($q\ ha^{-1}$)	1	After harvest
B.	Nutrient content and uptake studies N, P, K, and micronutrients (Fe, Mn, Cu and Zn)	3	Peg initiation, pod formation and at harvest
C.	Soil reaction, E.C., organic carbon and changes in available nutrients in soil (N, P_2O_5 , K_2O , Cation exchange capacity and micronutrients (Fe, Mn, Cu and Zn)	3	Peg initiation, pod formation and at harvest
D.	Microbial count Bacteria, Fungi and Actinomycetes CO_2 evolution, Microbial biomass carbon, Urease, Dehydrogenase, Alkaline phosphatase, Acid phosphatase activity	3	Peg initiation, pod formation and at harvest At harvest

Note: 45 DAS correspondence to peg initiation stage

3.1.4.3 Pre harvest studies

1. Height of the plant

The height of the plant was measured in cm from ground level up to the base of last fully opened leaf of the plant.

2. Number of rachis

Number of rachis per plant was recorded by counting the main and the lateral rachis collectively of the five observational plants and the average number of rachis per plant were worked out.

3.1.4.4 Post harvest study

1. Number of pods

Treatment wise five observational plants were harvested separately and the number of pods plant⁻¹ was counted and the mean of these five plants was recorded.

2. Total dry pod yield

The pods obtained from each net plot were sun dried and pod yield per plot was recorded which was subsequently expressed on hectare basis.

3. Shelling percentage

A representative sample of 100 gram dry pods from each treatment was shelled to obtain the kernel weight. Then shelling percentage was worked out as follows.

$$\text{Shelling percentage} = (\text{Kernel weight (g)} \times 100) / (\text{Dry pod weight (q ha}^{-1}\text{)})$$

4. Weight of 100 kernels

Treatment wise random sample of 100 kernels was collected and its weight was recorded in gram.

5. Haulm yield

Yield of dry haulm per net plot was recorded separately after drying and was expressed on hectare basis.

6. Kernel yield

Kernel yield (q ha⁻¹) for each net plot was obtained based on shelling percentage and dry pod yield.

$$\text{Kernel yield (q ha}^{-1}\text{)} = \text{Shelling \%} \times \text{Dry pod yield (q ha}^{-1}\text{)} \times 1/100$$

3.2 Methods

3.2.1 Analysis of soil samples

A brief description of standard test procedures followed for various physical, chemical and physico-chemical characteristics of soil samples is given below:

The treatment wise representative surface soil samples (upto 22.5 cm) were collected at peg initiation, pod formation stage and at harvest of the crop with the help of screw auger. Then, the treatment wise composite samples were prepared by mixing the soil and following the principle of quartering. These samples were air-dry. A wooden mortar and pastel was used to crush soil aggregates to pass through a 2 mm sieve. Soil material passing through the sieve was placed in labeled boxes. A small portion of less than 2 mm sample was ground to pass a 100 mesh sieve for organic carbon estimation. The soil samples were stored in plastic bags in corrugated boxes for physical and chemical analysis. The following standard methods were used for soil analysis.

3.2.1.1 Soil physical properties

i) Particle size analysis

The soil separates such as sand, silt and clay in composite sample were estimated by Bouyoucos hydrometer method (Bouyoucos 1951) and the textural class was determined with the help of textural.

ii) Bulk density

Bulk density was determined by dry clod coating technique (Black 1965). Soil clods of about 20-25 gm in weight were tied with a fine thread and weighted in air. The clods were then coated with molten paraffin at 55-60 °C temperature and again the volume of soil clod was determined using Archimedes Principle and bulk density was determined by using following equation.

$$Db = Dw \text{ Wods} / [Wsa - Wspw + Wpa - (Wpa \text{ Dw} / Dp)]$$

Expressed in Mg m^{-3} or gm cm^{-3}

Where,

Dw = Density of water at temperature of determination

(approximately 1 g cm^{-3})

$Wods$ = Oven dry weight of soil sample (g)

$Wspw$ = Net weight of soil sample plus paraffin in water (g)

Wpa = Weight of paraffin coating in air (g)

Dp = Density of paraffin (approximately 0.9 gm cm^{-3})

Wsa = Weight of soil in air (g)

$Wods = Wsa / (1 + (P/100))$

$$W_{ods} = \frac{W_{sa}}{1 + \left(\frac{P}{100}\right)}$$

Where,

P = Per cent water on oven dry basis found in sub sample

W_{sa} = Net weight of soil sample in air (g)

iii) Particle density

Particle density was determined by using Pycnometer as described by Black (1965).

iv) Porosity

The porosity was calculated by using the following relationship as described by Black (1965).

$$\eta = (dp - db) \times 100 / dp$$

where,

η = Porosity (%)

dp = Particle density ($Mg\ m^{-3}$)

db = Bulk density ($Mg\ m^{-3}$)

v) Maximum water holding capacity

It was determined by using Keen-Raczkowski circular brass boxes as described by Piper (1966).

3.2.1.2 Soil chemical properties

i) Soil reaction

The hydrogen ion concentration, expressed as pH which was determined by using glass electrode pH meter after equilibrating soil with water for 30 minutes, measured in the suspension of 1:2.5 soil-water ratio by a pH meter. (Jackson 1967).

ii) Electrical conductivity

The soil to water extract (1:2.5) was used for electrical conductivity measurement using a conductivity bridge (Jackson 1973).

iii) Organic carbon

Modified Walkley and Black's rapid titration procedure was followed for estimating the organic carbon content (Jackson 1958). The organic carbon content in soil was oxidized by chromic acid by utilizing heat of dilution of sulphuric acid. The unreacted chromic acid was back titrated with standard ferrous ammonium sulphate.

iv) Available nitrogen

The soil available nitrogen was determined by using alkaline permanganate (0.32% KMnO_4) method (Subbiah and Asija 1956). The organic nitrogen present in soil was oxidized by potassium permanganate. The ammonia released during oxidation was absorbed by boric acid and it convert ammonia to ammonium borate. The ammonium borate was titrated with standard sulphuric acid.

v) Available phosphorus

Available phosphorus present in soil was determined by using Bray and Kurtz (1945) method with 0.03 NH_4F and 0.025N HCl by developing blue colour with ammonium molybdate and stannous chloride. Phosphorus in the extract was determined by colorimetric estimation of the reduced phosphomolybdate blue by using 660 m μ red filter as outlined by Black (1965).

vi) Available potassium

The available potassium was extracted from soil with 1N NH_4OAc having pH 7.0. The available potassium was determined by flame photometrically Jackson (1967).

viii) Cation Exchange Capacity

The cation exchange capacity of the soil after harvest of the crop was determined by using the procedure given by Chapman (1965). The exchangeable acid cations are extracted from soil with 1.0 N potassium chloride solution. The total exchangeable acidity determined by titration with standard alkali. The aluminium in the titrated solution was determined by adding potassium fluoride with standard sulphuric acid.

ix) DTPA extractable micronutrients (Zn, Fe, Mn and Cu)

DTPA extractable micronutrients (Fe, Mn, Cu and Zn) were determined by extracting the Fe, Mn, Cu and Zn in 0.005M DTPA (Diethylene triamine penta acetic acid) followed by procedure given by Lindsay and Norvell (1978) having pH 7.3 ± 0.05 using Atomic Absorption Spectrophotometer.

3.2.1.3 Biological properties**a) Microbial count of bacteria, fungi and actinomycetes**

For microbial count serial dilutions were prepared and dilutions were taken for inoculation of bacteria and actinomycetes (10^5) and fungi (10^3). For bacterial count nutrient agar medium, ken knight's medium for actinomycetes and potato dextrose

agar medium for fungi count was used (Pramer and Schmidt 1964 and Subba Rao 1988).

b) CO₂ evolution

To estimate CO₂ evolution during the course of decomposition of organic matter a test tube containing 10 ml 0.1N NaOH was suspended inside the air tight bottle with the help of string. This was taken out at 2 days interval up to 6th day of incubation. Thereafter, neutralized the excess alkali with addition of 5 ml saturated barium chloride precipitated as BaCO₃ (Debnath and Hajra 1972).

c) Microbial biomass carbon and nitrogen

The sample was analyzed following chloroform fumigation method. Duplicate sample was taken. One sample was fumigated for 24 hrs under vacuum desiccators by using ethanol free chloroform. After fumigation, fumes formed from chloroform were removed by evacuation. Non fumigated and fumigated samples were extracted using 200 ml of 0.5M K₂SO₄ and extracts were used for determination of carbon as described by Vance *et al.* (1987) and nitrogen described by Brookes *et al.* (1985).

d) Urease activity

Urease activity was determined using the method outlined by Tabatabai and Bremner (1972). The degradation of urea remaining in sample after hydrolysis was measured colorimetrically.

e) Dehydrogenase activity

To estimate dehydrogenase activity 2,3,5- Triphenyl Tetrazolium Chloride (TTC) was used as an electron acceptor and the results were expressed in micrograms using standards made by Triphenyl Formazan (TPF) produced g⁻¹ sample (Cassida 1964).

f) Phosphatase activity

The phosphatase activity was determined by hydrolysis of p-nitrophenyl phosphate to p-nitrophenol which was extracted by CaCl₂-NaOH solution and the colour intensity was measured at 420 nm wavelength (Tabatabai and Bremner 1969).

3.2.2 Plant analysis

The treatment-wise plant samples were collected at peg initiation, pod formation and at harvest of crop, which were dried at 60°C and used for analytical purpose. After recording the dry weight, the samples were grinded in Willey type grinding mill and stored in plastic bags for digestion.

Plant sample digestion

a) Total nitrogen

The plant samples collected at peg initiation, pod formation and at harvest of crop were digested with conc. H₂SO₄ using H₂O₂ and the total nitrogen content was determined by Kjeldahl apparatus (Jakson, 1973).

b) Total phosphorus, potassium and micronutrients (Fe, Mn, Cu and Zn)

For determination of P, K and micronutrients (Fe, Mn, Cu and Zn) 1.0 g plant sample was digested with di-acid mixture (HNO₃ + HClO₄) with the ratio 9:4 and acid extract was used for digestion of sample for P, K and micronutrients (Fe, Mn, Cu and Zn) (Singh *et al.* 1999).

Estimation

a) Nitrogen

A 10 ml aliquot of H₂SO₄ digested plant sample was taken for nitrogen distillation (AOAC 1990) during estimation by Kjeldahl Distillation apparatus.

b) Phosphorus

It was determined by using known quantity of di-acid extract as mentioned above and the yellow colour was developed with combined HNO₃ vanadomolybdate reagent. Phosphorus was determined colorimetrically by using spectrophotometer at 420 nm wave length (Jakson, 1973).

c) Potassium

It was estimated by flame photometrically by using diluted diacid digested solution duly diluted 10 times (Piper 1966).

d) Micronutrients (Zn, Fe, Mn and Cu)

It was estimated in di-acid digested solution with the help of Atomic Absorption Spectrophotometer (Jackson, 1973).

3.2.3 Analysis of quality parameters

The treatment wise kernel samples were collected after sun drying and stored in paper bags and used for analysis of quality parameters like oil, protein and methionine by the methods given below.

Protein content

Finely ground kernel (0.25 g) was digested in minimum volume of conc. H_2SO_4 using H_2O_2 . The volume of digested sample was made to 25 ml and 10 ml of aliquots from the digested sample were used for estimation of nitrogen by Micro-Kjeldahl method (Jackson 1973). Per cent protein was obtained by multiplying per cent nitrogen by 6.25

Oil content

1.0 g finely ground kernel sample was extracted with petroleum ether under constant extraction for estimation of oil content (AOAC 1965).

Methionine content

For Methionine content 1.0 g defatted finely ground kernel sample of groundnut were used and estimated by Papain hydrolysis method (Gehrke and Neuner 1974).

3.2.4 Nutrient uptake

The nutrient uptake was calculated considering the dry matter yield, kernel yield, shell yield and nutrient content in plants at the harvest stage of groundnut.

3.3 Economics of the treatments

The economics of groundnut as affected by different levels of phosphorus and biofertilizers was worked out considering the prevailing market rates for different inputs and produces. The gross return and cost of cultivation were worked out by considering the price rates.

3.3.1 Gross returns

The gross returns (₹ ha^{-1}) were worked out on the basis of dry pod yield and halum yield of groundnut for each treatment, considering the prices prevailing in the market during the 2017-18 and 2018-19.

3.3.2 Cost of cultivation

The cost of cultivation (₹ ha^{-1}) of each treatment was calculated considering the current charges of agricultural operations and market prices of inputs involved.

3.3.3 Net returns

The net returns (₹ ha^{-1}) for individual treatment was worked out by deducting the total cost of each treatment from gross returns of respective treatments.

3.3.4 Benefit: cost ratio

The benefit: cost ratio of each treatment was calculated by dividing the gross returns by the cost of cultivation of respective treatment

Benefit: cost ratio = $\text{Gross returns } (\text{₹ ha}^{-1}) / \text{Cost of cultivation } (\text{₹ ha}^{-1})$

3.4.1 Statistical analysis

The data obtained was subjected to statistical analysis by following procedure pertinent to “Factorial Randomized Block Design” as given by Panse and Sukhatme (1967). The correlation coefficient was worked out by using SAS Software 9.3 (TS 1 MO) Licenced to Indian Agricultural Statistics Research Institute (Site 11601386) executed on the XP_PRO platform.

CHAPTER IV

RESULTS AND DISCUSSION

In the present investigation, an attempt has been made to study the effect of phosphorus (*viz.*, 15, 30, 45 and 60 kg ha⁻¹) and biofertilizers (*viz.*, VAM @ 10 kg ha⁻¹, PSB @ 10 kg ha⁻¹, VAM + PSB @ 5 kg ha⁻¹ each and VAM + PSB @ 10 kg ha⁻¹ each) levels on soil properties, yield, quality and uptake of nutrients by groundnut (*cv. Konkan Trombay Tapora / TKG-Bold*) grown on Alfisol soil in Konkan region of Maharashtra during *Rabi*, 2017-18 and 2018-19. The effect of different treatments on changes in physico-chemical properties, biological properties and nutrient status of soil as well as yield, nutrients content and uptake by groundnut was studied from the samples collected at peg initiation, at pod formation and at harvest stage. The observations and analytical values obtained during course of investigation were analyzed statistically, described and contemplated to discuss the variations observed with an attempt to establish the 'effect and cause' relationship in the light of available evidences and literature. For brevity, the entire results and discussion has been divided into the following heads for better understanding.

- 4.1 Effect of different levels of phosphorus and biofertilizers on soil properties
- 4.2 Effect of different levels of phosphorus and biofertilizers on available nutrient status of soil
- 4.3 Effect of different levels of phosphorus and biofertilizers on yield attributing characters and yield of groundnut
- 4.4 Effect of different levels of phosphorus and biofertilizers on nutrients (N, P, K, Zn, Fe, Mn and Cu) content in plant
- 4.5 Effect of different levels of phosphorus and biofertilizers on uptake of nutrients (N, P, K, Zn, Fe, Mn and Cu) by plant
- 4.6 Relationship between soil properties and pod yield of groundnut

4.1 Effect of different levels of phosphorus and biofertilizers on soil properties

4.1.1 Physico-chemical properties of soil

The data pertaining to the application of different levels of phosphorus with seed treatment of biofertilizers i.e. Vesicular Arbuscular Mycorrhiza (VAM) and Phosphate Solubilizing Bacteria (PSB along with recommended doses of nitrogen (30 kg ha⁻¹), potassium (30 kg ha⁻¹) and FYM (10 t ha⁻¹) affected the physico-

chemical properties *viz.*, soil pH, electrical conductivity (EC), organic carbon (OC) content, bulk density (BD) and cation exchange capacity (CEC) of soil at peg initiation, at pod formation and at harvest stage of groundnut are presented in Table 4.1 to 4.8.

4.1.1.1 Soil pH

Effect of phosphorus

The perusal of the data presented in Table 4.1 revealed that, during peg initiation stage, the pH of the soil ranged from 4.58 to 4.66 and 4.61 to 4.71 in the year 2017-18 and 2018-19, respectively. The specific trend of increase or decrease in soil pH did not observed with the application of graded doses of phosphorus. However, the soil reaction was found to be significantly superior with application of phosphorus @ 15 kg ha⁻¹ (4.66 and 4.71 during 2017-18 and 2018-19, respectively) as well as @ 60 kg ha⁻¹ i.e. (RDF) (4.66 and 4.69 during 2017-18 and 2018-19, respectively). Both the treatments were at par with each other and were significantly superior over application of phosphorus @ 30 kg ha⁻¹ (4.60 and 4.63 during 2017-18 and 2018-19, respectively) and @ 45 kg ha⁻¹ (4.58 and 4.61 during 2017-18 and 2018-19, respectively).

At pod formation stage, the application of phosphorus found to be significant and it varied from 4.52 to 4.66 and 4.82 to 4.97 in the year 2017-18 and 2018-19, respectively. Alike, peg initiation stage, no specific trend of increase or decrease in soil pH with the application of graded doses of phosphorus was observed at pod formation stage. The application of phosphorus @ 15 kg ha⁻¹ (4.66 and 4.97 during 2017-18 and 2018-19, respectively) was found to be significantly superior over application of phosphorus @ 30 kg ha⁻¹ (4.58 and 4.88 during 2017-18 and 2018-19, respectively) and @ 45 kg ha⁻¹ (4.52 and 4.82 during 2017-18 and 2018-19, respectively) in both the years. The application of phosphorus @ 60 kg ha⁻¹ (4.64 and 4.94 during 2017-18 and 2018-19, respectively) were found to be at par with application of phosphorus @ 15 kg ha⁻¹.

At harvest of the groundnut, the application of different levels of phosphorus was found to be significant and it ranged from 4.82 to 5.19 and 5.09 to 5.41 in the year 2017-18 and 2018-19, respectively. Though the specific trend did not observed during 2017-18, there was specific trend of increase in soil pH with the application of graded doses of phosphorus during 2018-19. The application of phosphorus @ 60 kg ha⁻¹ (RDF) showed its superiority in increasing soil pH (5.19 and 5.41 during 2017-18 and

2018-19, respectively) as compared to all other treatments, consisting application of phosphorus @ 30 kg ha⁻¹ (5.00 and 5.13 during 2017-18 and 2018-19, respectively), @ 45 kg ha⁻¹ (4.98 and 5.10) and @ 15 kg ha⁻¹ (4.82 and 5.09 during 2017-18 and 2018-19, respectively).

Effect of biofertilizers

It is seen from the data presented in Table 4.1 that, at peg initiation stage the application of biofertilizers showed their significant effect on the soil pH. It varied from 4.59 to 4.69 and 4.62 to 4.74 in the year 2017-18 and 2018-19, respectively. The treatment without application of biofertilizers i.e. B₀ (4.69 and 4.74 during 2017-18 and 2018-19, respectively) was found to be significantly superior over inoculation of VAM @ 10 kg ha⁻¹, VAM + PSB @ 10 kg ha⁻¹ each, PSB 10 @ kg ha⁻¹ and VAM + PSB @ 5 kg ha⁻¹ each during both the years.

During the pod formation stage, the inoculation of biofertilizers was found to be significant and the soil pH varied from 4.46 to 4.70 and 4.76 to 5.02 in the year 2017-18 and 2018-19, respectively. The dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄) was found to be significantly superior in increasing soil pH (4.70 and 5.02 during 2017-18 and 2018-19, respectively) as compared all other treatments, consisting application of no biofertilizers (B₀), PSB @ 10 kg ha⁻¹ (B₂), VAM @ 10 kg ha⁻¹ (B₁) and application of VAM + PSB @ 5 kg ha⁻¹ each (B₃) in the year 2017-18 and 2018-19, respectively.

At harvest of the crop, the inoculation of biofertilizers was found to be non-significant in both the years and ranged from 4.90 to 5.10 and 5.03 to 5.27 in the year 2017-18 and 2018-19, respectively. However, the highest soil pH (5.10) was observed with dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each in the year 2017-18 and the lowest pH (4.90) was observed with application of PSB @ 10 kg ha⁻¹ in the year 2017-18. The highest soil pH (5.27) was recorded with no biofertilizers application i.e. B₀ and the lowest value of the soil pH (5.03) was observed with application of PSB @ 10 kg ha⁻¹ in the year 2018-19.

Interaction effect

The data pertaining to the interaction effect of phosphorus and biofertilizers (presented in Table 4.1) found to be significant on soil pH and it ranged from 4.46 to 4.88 and 4.48 to 4.91 at peg initiation stage during the year 2017-18 and 2018-19,

respectively. The application of phosphorus @ 30 kg ha⁻¹ with inoculation of VAM @ 10 kg ha⁻¹ was found to be significantly superior in increasing soil pH (4.88) over all other treatments in the year 2017-18. However, the application of phosphorus @ 30 kg ha⁻¹ with inoculation of VAM @ 10 kg ha⁻¹ was found to be significantly superior over all treatments, except treatment consisting application of phosphorus @ 60 kg ha⁻¹ (4.85) alongwith no biofertilizers application which was found to be at par with application of phosphorus @ 30 kg ha⁻¹ with application of VAM @ 10 kg ha⁻¹ during the year 2018-19.

During pod formation stage, the application of phosphorus and biofertilizers showed significant effect on the soil pH which varied from 4.25 to 4.88 and 4.91 to 5.25 in the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 15 kg ha⁻¹ alongwith dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₁₅) was found to be significantly superior over all other treatment combinations in increasing soil pH (4.88 and 5.25 during 2017-18 and 2018-19, respectively).

At harvest of the crop, the interaction of phosphorus and biofertilizers had significant effect on the soil pH and it ranged from 4.63 to 5.53 and 4.84 to 5.79 during the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 60 kg ha⁻¹ (RDF) with inoculation of VAM @ 10 kg ha⁻¹ i.e. B₁P₆₀ was found to be significantly superior in increasing soil pH (5.53 and 5.79 during 2017-18 and 2018-19, respectively) over all other treatment combinations, except treatment B₀P₆₀ consisting application of phosphorus @ 60 kg ha⁻¹ with no biofertilizers application (5.45 and 5.71 during 2017-18 and 2018-19, respectively). However, the treatment combination B₄P₆₀ i.e. application of phosphorus @ 60 kg ha⁻¹ (RDF) with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each was at par with treatment combinations of B₁P₆₀ as well as B₀P₆₀ during the year 2018-19.

The data indicated that the soils are acidic in nature. The acidic nature of soils might be attributed to leaching of soluble salts due to heavy precipitation. The pH of lateritic soils of Konkan region ranged from 4.75 to 6.50 (Anonymous 1990).

From the two years data, it was observed that the soil pH decreased during peg initiation stage (at 45 days after sowing) over initial soil pH (4.96 during 2017-18 and 5.01 during 2018-19) and further increased gradually from pod formation stage to harvesting stage and stabilized to the initial soil pH.

The decrease in the soil pH indicates production of organic acids in the medium that may help in the phosphate solubilization by the isolated microorganism. During active growing periods, the roots release CO₂ into the soil air many times of that in atmosphere. This CO₂ get dissolved in water, increase acidity or lower the pH further. It may also be due to decaying of organic matter produces an H⁺ ion, which is responsible for acidity. The CO₂ produced by decaying organic matter reacts with water in the soil to form a weak acid called carbonic acid. Several other organic acids are also produced during decomposition. Their accumulated effect over the years influences the soil reaction and creates acidity in soil.

During the year 2018-19, the soil pH increased gradually from peg initiation to harvest stage might be attributed to the consumption of protons during the reduction process. Also, it may be due to increased microbial growth and activity during the growth period of the crop as there was increase in organic matter due to accumulation of leaf litter fall during the growth period.

The data further revealed that, the soil pH in inoculated plots with biofertilizers recorded the lowest pH as compared to the uninoculated plots alongwith lower doses of phosphorus during peg initiation stage and pod formation stage. The reduction in the soil pH due to application of FYM alongwith sources of nutrients may be attributed to the formation of acids by the reaction between inorganic fertilizers. The release of organic acids on decomposition of added FYM and conversion of nutrient elements in the available forms due to the activity of microorganisms supplied through biofertilizers. In this context, Mondal *et al.* (2017) reported that the decrease in soil pH due to application of phosphate solubilizing bacteria as biofertilizers in maize field experiment. Basha *et al.* (2018) also recorded the lowest soil pH with application of phosphate solubilizing microorganisms (PSM) followed by partially acidulated Udaipur rock phosphate (PAURP) + FYM.

The soil pH increased gradually from pod formation stage to harvest of the crop with increasing level of phosphorus and inoculation of biofertilizers than uninoculated plots. Sandhya *et al.* (2013) reported slight increase in pH due to the supplementation of microbial cultures both individual and combination with Vesicular Arbuscular Mycorrhizal (VAM). Dhakal *et al.* (2016) recorded an increase in soil pH with application of nutrients through 75 per cent RDF + 2.5 t ha⁻¹ vermicompost + *rhizobium* + phosphate solubilizing bacteria (PSB) as compared to other combinations

in greengram. Nadeem *et al.* (2018) indicated that the application of different levels of phosphorus (0, 20 and 40 kg ha⁻¹) and recommended dose of nitrogen and potassium along with FYM in combination with seed treatment of *rhizobium* and phosphorus solubilizing bacteria increase the soil pH in cowpea crop.

4.1.1.2 Electrical conductivity (EC)

Effect of phosphorus

The electrical conductivity (EC) of soil was found to be significant during peg initiation stage (Table 4.2) and it varied from 0.11 to 0.18 and 0.27 to 0.42 dS m⁻¹ in the year 2017-18 and 2018-19, respectively. The EC (0.18 dS m⁻¹ during *rabi* 2017-18 and 0.42 dS m⁻¹ during *rabi* 2018-19) was found to be significantly superior due to application of phosphorus @ 45 kg ha⁻¹ over all other treatments of phosphorus application. However, the EC (0.14 dS m⁻¹) of soil with the application of phosphorus @ 30 kg ha⁻¹ and @ 15 kg ha⁻¹ was statistically superior over application of phosphorus @ 60 kg ha⁻¹ and both these treatments were found at par with each other in the year 2017-18.

During pod formation stage, the electrical conductivity of the soil with application of phosphorus was found to be non-significant in both the years. However, it varied from 0.20 to 0.30 dS m⁻¹ and 0.32 to 0.37 dS m⁻¹ during 2017-18 and 2018-19, respectively. Numerically the highest EC (0.30 dS m⁻¹ during 2017-18 and 0.37 dS m⁻¹ during 2018-19) was observed with application of phosphorus @ 30 kg ha⁻¹ as compared to all treatments of phosphorus application and the lowest EC (0.20 dS m⁻¹ during 2017-18 and 0.32 dS m⁻¹ during 2018-19) was recorded with application of phosphorus @ 45 kg ha⁻¹ in both the years.

At harvest of the groundnut, the EC of the soil showed significant effect with application of phosphorus and it ranged from 0.14 to 0.17 and 0.25 to 0.33 dS m⁻¹ in the year 2017-18 and 2018-19, respectively. The EC (0.17 dS m⁻¹ during 2017-18 and 0.33 dS m⁻¹ during 2018-19) of soil was found to be significantly superior with application of phosphorus @ 30 kg ha⁻¹ over all other treatments in both the years. However, the application of phosphorus @ 60 kg ha⁻¹ (0.15 dS m⁻¹) was found to be at par with application of phosphorus @ 30 kg ha⁻¹ (0.17 dS m⁻¹) in the year 2017-18.

Effect of biofertilizers

The inoculation of biofertilizers (*viz.*, VAM @ 10 kg ha⁻¹, PSB @ 10 kg ha⁻¹, VAM + PSB @ 5 kg ha⁻¹ each, and VAM + PSB @ 10 kg ha⁻¹ each) showed

significant effect on EC during peg initiation and it ranged from 0.13 to 0.17 dS m⁻¹ and 0.30 to 0.40 dS m⁻¹ in the year 2017-18 and 2018-19, respectively. The EC was found to be significantly superior with inoculation of VAM + PSB @ 10 kg ha⁻¹ each i.e. B₄ (0.17 dS m⁻¹ during 2017-18 and 0.40 dS m⁻¹ during 2018-19) over all the treatments. During 2017-18, application of VAM + PSB @ 5 kg ha⁻¹ each (B₃), PSB @ 10 kg ha⁻¹ (B₂) and VAM @ 10 kg ha⁻¹ (B₁) reported the similar values of EC (0.14 dS m⁻¹), whereas, application of VAM + PSB @ 5 kg ha⁻¹ each (B₃), PSB @ 10 kg ha⁻¹ (B₂) and VAM @ 10 kg ha⁻¹ (B₁) showed EC 0.33 dS m⁻¹, 0.32 dS m⁻¹ and 0.31 dS m⁻¹ during peg initiation and found to be at par with each other during 2018-19. The no application of biofertilizers (B₀) recorded the lowest EC i.e. 0.13 dS m⁻¹ and 0.30 dS m⁻¹ in the year 2017-18 and 2018-19, respectively.

During pod formation stage, the electrical conductivity of the soil varied from 0.15 to 0.44 dS m⁻¹ and 0.25 to 0.47 dS m⁻¹ in the year 2017-18 and 2018-19, respectively presented in Table 4.2. The EC of soil was found to be significantly superior with dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each i.e. B₃ (0.44 dS m⁻¹ during 2017-18 and 0.47 dS m⁻¹ during 2018-19) among all treatments. However, the inoculation of PSB @ 10 kg ha⁻¹ (0.38 dS m⁻¹) and VAM @ 10 kg ha⁻¹ (0.33 dS m⁻¹) were found at par with inoculation of VAM + PSB @ 5 kg ha⁻¹ each (0.47 dS m⁻¹) in the year 2018-19.

At harvest of the crop, the EC showed significant effect due to application of biofertilizers which ranged from 0.14 to 0.17 dS m⁻¹ and 0.25 to 0.33 dS m⁻¹ in the year 2017-18 and 2018-19, respectively. The EC was found to be significantly superior with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄) which indicated that the EC was 0.17 dS m⁻¹ during 2017-18 and 0.33 dS m⁻¹ during 2018-19 over all the treatments. During 2017-18, application of VAM + PSB @ 5 kg ha⁻¹ each (B₃), no biofertilizers (B₀), PSB @ 10 kg ha⁻¹ (B₂) and VAM @ 10 kg ha⁻¹ (B₁) reported the similar values of EC (0.14 dS m⁻¹). While, the application of VAM + PSB @ 5 kg ha⁻¹ each (B₃), no biofertilizers (B₀), PSB @ 10 kg ha⁻¹ (B₂) and VAM @ 10 kg ha⁻¹ (B₁) showed EC 0.27 dS m⁻¹, 0.27 dS m⁻¹, 0.26 dS m⁻¹ and 0.25 dS m⁻¹, respectively at harvest and found to be at par with each other during 2018-19.

Interaction effect

The interaction between phosphorus and biofertilizers application significantly influenced the EC during peg initiation stage (Table 4.2) and it varied

from 0.09 to 0.22 dS m⁻¹ and 0.19 to 0.51 dS m⁻¹. The highest EC values (0.22 dS m⁻¹ during 2017-18 and 0.51 dS m⁻¹ during 2018-19) were noted with the application of phosphorus @ 30 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₃₀) which was found to be at par with the application of phosphorus @ 45 kg ha⁻¹ with inoculation of PSB @ 10 kg ha⁻¹ each (B₂P₄₅). Both the treatments were significantly superior over all other treatment combinations in both the years. The lowest electrical conductivity was recorded due to the treatment combinations of B₀P₁₅.

During pod formation stage, the interaction between phosphorus and biofertilizers were found to be non-significant during both the years. However, the EC ranged from 0.08 to 0.70 and 0.10 to 0.56 dS m⁻¹ in the year 2017-18 and 2018-19, respectively. The highest EC of soil (0.70 dS m⁻¹ and 0.56 dS m⁻¹ during 2017-18 and 2018-19, respectively) was observed with application of phosphorus @ 30 kg ha⁻¹ with dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃P₃₀) and the lowest value of EC (0.08 dS m⁻¹ and 0.10 dS m⁻¹ during 2017-18 and 2018-19, respectively) was recorded with application of phosphorus @ 60 kg ha⁻¹ (i.e. RDF) with inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀).

The data pertaining to the EC as influenced by interaction effect of phosphorus and biofertilizers are presented in Table 9. The data indicated that the EC at harvest of the crop ranged from 0.11 to 0.21 dS m⁻¹ and 0.15 to 0.53 dS m⁻¹ during the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 45 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₄₅) recorded significantly superior EC (0.21 dS m⁻¹ and 0.53 dS m⁻¹ during 2017-18 and 2018-19, respectively) over all other treatment combinations, but found to be at par with the treatment combinations B₄P₃₀, B₁P₃₀ and B₃P₆₀ during 2017-18 and during 2018-19 B₂P₃₀, B₀P₆₀, B₁P₃₀, B₃P₃₀ and B₄P₃₀ were at par with each other.

No specific trend of increase or decrease in EC of soil was observed with the application of different levels of phosphorus. In general, lateritic soils are free from soluble salts due to high rainfall (Dongale 1989 and Anonymous 1990). By and large, the EC of soil tends to increased at pod formation stage over peg initiation stage, which was increased with the application of organic manures and their decomposition in soil. Further, the increase in EC may also be due to the direct uptake, translocation and transfer of ions by mycorrhizal hyphae to the host plant and VAM fungi, which

have a profound effect on the ionic balance (Yadav *et al.* 2007). In this connection, Yadav *et al.* (2009) stated that the different organic acids, such as malate, citrate and oxalate release by soil fungi also responsible for increasing the electrical conductivity of soil. The slight increase in electrical conductivity may be due to production of CO₂ during decomposition of organic matter, which lowers the soil pH and causes dissolution of minerals releasing ions such as Ca⁺⁺, Mg⁺⁺ and Na⁺ in soil solution. Sandhya *et al.* (2013) also reported that the supplementation of microbial cultures both individual and combination with Vesicular Arbuscular Mycorrhizal (VAM) improved the physicochemical properties of soil.

Further, it was observed that, the electrical conductivity was declined slightly at harvest and attained the initial value (0.119 dS m⁻¹ and 0.343 dS m⁻¹ during 2017-18 and 2018-19, respectively). Similar decline in EC in later periods of crop growth with the application of *rhizobium* and PSB in combinations along with phosphorus (*viz.*, 25 and 50 kg ha⁻¹) under groundnut were also observed by Gengaje (2013) in lateritic soils of Konkan. The similar trend of decrease in EC in lateritic soils of Konkan region due to application of *rhizobium* and PSB in combinations with phosphorus levels (*viz.*, 50, 60 and 70 kg ha⁻¹) in cowpea was also reported by Mhalshi (2013).

4.1.1.3 Organic carbon

Effect of phosphorus

The application of graded doses of phosphorus did not influence significantly on soil organic carbon during peg initiation stage (Table 4.3), which varied from 10.23 to 11.17 g kg⁻¹ and 12.23 to 13.24 g kg⁻¹ in the year 2017-18 and 2018-19, respectively. However, the application of lowest dose of phosphorus @ 15 kg ha⁻¹ recorded the highest values of organic carbon (11.17 g kg⁻¹ and 13.24 g kg⁻¹ during 2017-18 and 2018-19, respectively) content in soil, while the lowest organic carbon (10.23 g kg⁻¹ and 12.23 g kg⁻¹ during 2017-18 and 2018-19, respectively) was recorded with application of phosphorus @ 30 kg ha⁻¹.

Though, the treatments difference were not significant at pod formation stage, the soil organic carbon content varied from 10.80 to 11.56 and 11.89 to 12.49 g kg⁻¹ in the year 2017-18 and 2018-19, respectively and the highest carbon content (11.56 and 12.49 g kg⁻¹ in the year 2017-18 and 2018-19, respectively) was observed to be in the treatment consisting application of phosphorus @ 15 kg ha⁻¹. However, the lowest

organic carbon content (10.80 g kg^{-1} and 11.89 g kg^{-1} during 2017-18 and 2018-19, respectively) was observed with the application of phosphorus @ 30 kg ha^{-1} .

The soil organic carbon showed significant difference due to application of phosphorus at harvest of the crop and it varied from 10.72 to 12.08 g kg^{-1} and 10.18 to 11.51 g kg^{-1} in the year 2017-18 and 2018-19, respectively. Among, the graded levels of phosphorus, application of phosphorus @ 60 kg ha^{-1} showed significantly highest organic carbon content (12.08 g kg^{-1} and 11.51 g kg^{-1} during 2017-18 and 2018-19, respectively), which was at par with application of phosphorus @ 15 kg ha^{-1} (11.90 g kg^{-1} and 11.33 g kg^{-1} during 2017-18 and 2018-19, respectively), which was significantly superior over the application of phosphorus @ 30 and 45 kg ha^{-1} .

Effect of biofertilizers

The variations in soil organic carbon content at peg initiation stage ranged from 10.43 to 11.21 g kg^{-1} and 12.44 to 13.29 g kg^{-1} in the year 2017-18 and 2018-19, respectively, but the differences were statistically non-significant. No application of biofertilizers (B_0) noted the highest soil organic carbon content (11.21 g kg^{-1} and 13.29 g kg^{-1} during 2017-18 and 2018-19, respectively), whereas, the lowest value of soil organic carbon content (10.43 g kg^{-1} and 12.44 g kg^{-1} during 2017-18 and 2018-19, respectively) was observed with inoculation of VAM + PSB @ 5 kg ha^{-1} each in the year 2017-18 and with application of PSB @ 10 kg ha^{-1} in the year 2018-19.

At pod formation stage, significant differences were observed with the inoculation of biofertilizers alone or in combination presented in Table 4.3, which varied from 10.54 to 11.77 g kg^{-1} and 11.21 to 12.70 g kg^{-1} in the year 2017-18 and 2018-19, respectively. The soil organic carbon (11.77 g kg^{-1} and 12.70 g kg^{-1} during 2017-18 and 2018-19, respectively) was found to be significantly superior with no inoculation of biofertilizers (B_0) over all other treatments, except treatment B_2 and B_3 consisting inoculation of PSB @ 10 kg ha^{-1} and the treatment consisting VAM + PSB @ 5 kg ha^{-1} each (11.22 and 11.14 g kg^{-1} as well as 12.30 and 12.28 g kg^{-1} during both the years i.e. 2017-18 and 2018-19, respectively).

At harvest of the groundnut, the soil organic carbon content showed significant effect due to inoculation of biofertilizers and it varied from 10.61 to 12.32 and 10.11 to 11.70 g kg^{-1} in the year 2017-18 and 2018-19, respectively. Dual

inoculation of VAM + PSB @ 5 kg ha⁻¹ each showed significantly highest carbon content in soil (12.32 g kg⁻¹ and 11.70 g kg⁻¹ during 2017-18 and 2018-19, respectively), which was significantly superior over all the treatments of biofertilizers application. In the remaining treatments, no biofertilizer application (11.82 g kg⁻¹ and 11.26 g kg⁻¹ during 2017-18 and 2018-19, respectively) and VAM + PSB @ 10 kg ha⁻¹ each (11.53 g kg⁻¹ and 11.00 g kg⁻¹ during 2017-18 and 2018-19, respectively) were at par with each other, but were superior over VAM @ 10 kg ha⁻¹ (11.12 g kg⁻¹ and 10.60 g kg⁻¹ during 2017-18 and 2018-19, respectively) and inoculation of PSB @ 10 kg ha⁻¹ (10.11 g kg⁻¹ and 10.60 g kg⁻¹ during 2017-18 and 2018-19, respectively).

Interaction effect

The data regarding organic carbon content (Table 4.3) of the soil as influenced by various treatment combinations at peg initiation stage indicated that it varied from 9.41 to 12.63 g kg⁻¹ and 11.41 to 14.63 g kg⁻¹ in the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 45 kg ha⁻¹ with no biofertilizers application (B₀P₄₅) noted significantly highest soil organic carbon content (12.63 and 14.63 g kg⁻¹ during 2017-18 and 2018-19, respectively) over all treatment combinations, which was at par with B₁P₁₅, B₄P₁₅, B₀P₆₀, B₀P₁₅ and B₄P₄₅ in the year 2017-18 and with B₁P₁₅, B₄P₁₅, B₀P₆₀, B₀P₁₅, B₄P₄₅, B₄P₆₀ and B₂P₃₀ in the year 2018-19.

The soil organic carbon had significant effect during pod formation stage and it varied from 10.09 to 13.30 g kg⁻¹ and 11.02 to 14.23 g kg⁻¹ in the year 2017-18 and 2018-19, respectively. The soil organic carbon (13.30 g kg⁻¹ and 14.23 g kg⁻¹ during 2017-18 and 2018-19, respectively) was found to be significantly superior with application of phosphorus @ 15 kg ha⁻¹ with inoculation of PSB @ 10 kg ha⁻¹ each over all other treatment combinations, in both the years and found to be at par with application of phosphorus @ 60 kg ha⁻¹ with no biofertilizer application (B₀P₆₀) in the year 2017-18 and with B₀P₆₀ (13.62 g kg⁻¹) and B₃P₄₅ (13.27 g kg⁻¹) in the year 2018-19.

At harvest, the soil organic carbon showed the significant difference which varied from 8.66 to 14.03 g kg⁻¹ and 8.24 to 13.43 g kg⁻¹ in the year 2017-18 and 2018-19, respectively. The treatment combination consisting application of

phosphorus @ 45 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each was found significantly highest in soil organic carbon content (14.03 and 13.43 g kg⁻¹ during 2017-18 and 2018-19, respectively) over all treatment combinations but at par with B₃P₄₅ (13.81 g kg⁻¹ and 13.15 g kg⁻¹ during 2017-18 and 2018-19, respectively) and B₀P₆₀ (13.46 g kg⁻¹ and 12.82 g kg⁻¹ during 2017-18 and 2018-19, respectively). The lowest organic carbon content was observed due to B₂P₄₅ treatment during both the years (8.66 g kg⁻¹ and 8.24 g kg⁻¹).

In general, organic carbon content of lateritic soil of Konkan is 'very high' range as per the classification of organic carbon proposed by Bangar and Zende (1978). The similar ranges of soil organic carbon in lateritic soil were also reported in the Soils bulletin of Konkan Krishi Vidyapeeth (Anonymous 1990).

It was observed from the data that during the year 2017-18 there was increase in soil organic carbon content with different growth stages i.e. from peg initiation to harvest stage of crop due to application of different levels of phosphorus and biofertilizers and as well as the increase in organic carbon content over the initial values (9.30 g kg⁻¹ and 10.80 g kg⁻¹ during both the years, 2017-18 and 2018-19, respectively), which might be due to the addition of organic carbon through FYM, incorporation of biomass through root and leaf fall from the plants to varying degrees and creation of favorable conditions for the growth of soil microorganisms. Varalakshmi *et al.* (2005).

Similar findings were also reported by Majumdar *et al.* (2007) reported that among the different sources of phosphatic fertilizers, the application of single super phosphate alongwith FYM (60 kg P₂O₅ ha⁻¹ + 5 t ha⁻¹ FYM) significantly increased the organic carbon under soybean crop. Rathore *et al.* (2011) also recorded the highest organic carbon content with the application of FYM.

Extra radical hyphae, fungal spore and bacterial population in treated plants attributes to the increased organic carbon content in soil as reported by Sandhya *et al.* (2013). Similar increase in organic carbon content with the application of *rhizobium* and PSB in combinations with phosphorus (*viz.*, 25 and 50 kg ha⁻¹) under groundnut were also observed by Gengaje (2013) in lateritic soils of Konkan region. Mhalshi (2013) also reported similar trend of increase in organic carbon content in lateritic soils of Konkan region due to application of *rhizobium* and PSB in combinations with phosphorus levels (*viz.*, 50, 60 and 70 kg ha⁻¹) in cowpea. Ram Chatra *et al.* (2018)

also reported the increased in soil organic carbon over its initial content in groundnut.

However, during the second year (2018-19) the trend of organic carbon content due to application of phosphorus as well as biofertilizers showed decreasing trend which may be due to hydrolysis of organic matter with increase in soil pH. The results are in accordance with the findings of Bala and Sahu (1993).

4.1.2 Changes in physical properties

4.1.2.1 Bulk Density

Effect of phosphorus

The application of phosphorus showed non-significant results on bulk density (BD) of soil at harvest presented in Table 4.4, which ranged from 1.36 to 1.38 Mg m⁻³ and 1.35 to 1.36 Mg m⁻³ in the year 2017-18 and 2018-19, respectively. The lowest bulk density i.e. 1.36 Mg m⁻³ and 1.35 Mg m⁻³ during 2017-18 and 2018-19, respectively was recorded with application of phosphorus @ 30 kg ha⁻¹. However, the highest bulk density (1.38 Mg m⁻³ and 1.36 Mg m⁻³ during 2017-18 and 2018-19, respectively) was observed with application of phosphorus @ 15 kg ha⁻¹ (P₁₅).

Effect of biofertilizers

The inoculation of biofertilizers alone or inoculation showed non-significant effect on bulk density and it varied from 1.36 to 1.38 Mg m⁻³ and 1.35 to 1.37 Mg m⁻³ in the year 2017-18 and 2018-19, respectively. The lowest bulk density (1.36 Mg m⁻³ during 2017-18 and 1.34 Mg m⁻³ during 2018-19) was recorded with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each. However, similar lowest value of bulk density (1.36 Mg m⁻³) was recorded due to the treatments consisting B₁ (VAM @ 10 kg ha⁻¹) and B₂ (PSB @ 10 kg ha⁻¹) treatments. The highest soil bulk density (1.38 Mg m⁻³ and 1.37 Mg m⁻³) was observed with no biofertilizers (B₀) application.

Interaction effect

The interaction of phosphorus and biofertilizers could not reach the level of significance (Table 4.4) and it varied from 1.33 to 1.41 and 1.32 to 1.39 Mg m⁻³ during 2017-18 and 2018-19, respectively. The lowest bulk density i.e. 1.33 Mg m⁻³ and 1.32 Mg m⁻³ during 2017-18 and 2018-19, respectively was recorded with application of phosphorus @ 30 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₃₀) in both the years. The highest BD of the soil was found to be (1.41 Mg m⁻³ and 1.39 Mg m⁻³ during 2017-18 and 2018-19, respectively) with

application of phosphorus @ 30 kg ha⁻¹ with no biofertilizers (B₀P₃₀).

The data regarding bulk density of soil revealed that, there was slight reduction in BD at harvest stage over initial value (1.39 Mg m⁻³ and 1.37 Mg m⁻³ during 2017-18 and 2018-19, respectively). Soil organic matter imparts desirable physical environment to soils by favorably affecting soil structure expressed through soil porosity, aggregation, bulk density and water holding capacity. These findings corroborate the results of Prakash *et al.* (2002) and Selvi *et al.* (2005) who also reported a decrease in bulk density with increase in organic matter content in soil. Rathore *et al.* (2011) also reported that P application and bio-fertilizers did not significantly influence the bulk density and porosity.

4.1.2.2 Particle Density

Effect of phosphorus

The application of phosphorus showed non-significant results on particle density (PD) of soil at harvest presented in Table 4.5, which ranged from 2.61 to 2.69 Mg m⁻³ and 2.62 to 2.64 Mg m⁻³ in the year 2017-18 and 2018-19, respectively. The lowest particle density i.e. 2.61 and 2.62 Mg m⁻³ during 2017-18 and 2018-19, respectively was recorded with application of phosphorus @ 45 kg ha⁻¹. However, the highest particle density (2.69 Mg m⁻³ and 2.64 Mg m⁻³ during 2017-18 and 2018-19, respectively) was observed with application of phosphorus @ 30 kg ha⁻¹ (P₃₀).

Effect of biofertilizers

The inoculation of biofertilizers alone or inoculation showed non-significant effect on particle density and it varied from 2.64 to 2.66 and 2.61 to 2.65 Mg m⁻³ in the year 2017-18 and 2018-19, respectively. The lowest particle density of soil (2.64 Mg m⁻³) was recorded with dual inoculation of PSB @ 10 kg ha⁻¹. However, similar lowest value of particle density (2.64 Mg m⁻³) was recorded due to the treatments consisting B₁ (VAM @ 10 kg ha⁻¹). The highest value of particle density was recorded with no biofertilizers application i.e. B₀ 2.66 Mg m⁻³ and with application of VAM + PSB @ 5 kg ha⁻¹ each in the year 2017-18. The highest soil particle density (2.65 Mg m⁻³) was observed with no biofertilizers (B₀) application and the lowest particle density (2.61 Mg m⁻³) was recorded with application of VAM + PSB @ 10 kg ha⁻¹ each in the year 2018-19.

Interaction effect

The interaction of phosphorus and biofertilizers could not reach the level of significance (Table 4.5) and it varied from 2.62 to 2.69 and 2.60 to 2.69 Mg m^{-3} during 2017-18 and 2018-19, respectively. The lowest bulk density i.e. 2.62 Mg m^{-3} and 2.60 Mg m^{-3} during 2017-18 and 2018-19, respectively) was recorded with application of phosphorus @ 45 kg ha^{-1} with inoculation of PSB @ 10 kg ha^{-1} (B_2P_{45}) in both the years 2017-18 and 2018-19. However, the similar lowest particle density (2.60) was recorded with application of phosphorus @ 45 kg ha^{-1} with dual inoculation of VAM + PSB @ 10 kg ha^{-1} each (B_4P_{45}) in the year 2018-19. The highest particle density of the soil was found to be (2.69 Mg m^{-3}) with application of phosphorus @ 15 kg ha^{-1} with no biofertilizers (B_0P_{15}) in the year 2017-18 and with application of phosphorus @ 30 kg ha^{-1} with no biofertilizers (B_0P_{30}) in the year 2018-19, respectively.

The data regarding particle density of soil revealed that, no specific trend of decrease or increase in the particle density was observed in both the years. Rathore *et al.* (2011) also reported that P application and bio-fertilizers did not significantly influence the particle density. In lateritic soils of Konkan, Gengaje (2013) and Mhalshi (2013) reported the similar results with the dual inoculation of *rhizobium* and PSB with different levels of phosphorus under groundnut (*viz.*, 25 and 50 kg ha^{-1}) and cowpea (*viz.*, 50, 60 and 70 kg ha^{-1}), respectively.

4.1.2.3 Soil Porosity

Effect of phosphorus

The application of phosphorus could not reach the level of significance and the porosity of soil at harvest (Table 4.6), and it ranged from 48.17 to 48.58 per cent and 48.32 to 48.92 per cent in the year 2017-18 and 2018-19, respectively. The highest porosity of soil (48.58 per cent) was recorded with application of phosphorus @ 60 kg ha^{-1} in the year 2017-18 and 48.92 per cent with application of phosphorus @ 30 kg ha^{-1} in the year 2018-19. However, the lowest soil porosity (48.17 per cent and 48.32 per cent during 2017-18 and 2018-19, respectively) was observed with application of phosphorus @ 15 kg ha^{-1} (P_{15}) in both the years.

Effect of biofertilizers

The inoculation of biofertilizers alone or inoculation showed non-significant effect on soil porosity and it varied from 48.07 to 48.66 per cent and 48.35 to 48.67 per cent in the year 2017-18 and 2018-19, respectively. The lowest soil porosity (48.07 per cent and 48.35 per cent during the year 2017-18 and 2018-19) was recorded with no biofertilizers (B_0) application. However, the highest soil porosity (48.66 per cent and 48.67 per cent) was observed dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each in both the years.

Interaction effect

The interaction of phosphorus and biofertilizers could not reach the level of significance (Table 4.6) and it varied from 47.07 to 49.52 per cent and 47.83 to 49.50 per cent during 2017-18 and 2018-19, respectively. The lowest porosity of the soil i.e. 47.07 per cent and 47.83 per cent during 2017-18 and 2018-19, respectively was recorded with application of phosphorus @ 45 kg ha⁻¹ with no biofertilizers (B_0P_{45}). However, the highest soil porosity (49.52 per cent) with application of phosphorus @ 30 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B_4P_{30}) in the year 2017-18 and 49.50 per cent with application of phosphorus @ 30 kg ha⁻¹ with application of PSB @ 10 kg ha⁻¹ (B_2P_{30}) in the year 2018-19.

The data showed that, no specific trend of decrease or increase in the soil porosity was observed in both the years. Rathore *et al.* (2011) also reported that P application and bio-fertilizers did not significantly influence the porosity.

4.1.2.4 Maximum water holding capacity

Effect of phosphorus

The application of phosphorus showed non-significant effect on maximum water holding capacity of soil at harvest (Table 4.7), and it ranged from 42.59 to 43.00 per cent and 42.87 to 43.10 per cent in the year 2017-18 and 2018-19, respectively. The highest water holding capacity of soil (43 %) was recorded with application of phosphorus @ 15 kg ha⁻¹ in the year 2017-18 and 43.10 per cent with application of phosphorus @ 45 kg ha⁻¹ in the year 2018-19. However, the lowest water holding capacity (42.59 % and 42.87 % during 2017-18 and 2018-19, respectively) was observed with application of phosphorus @ 30 kg ha⁻¹ in both the years.

Effect of biofertilizers

The inoculation of biofertilizers alone or inoculation showed non-significant effect on soil porosity and it varied from 42.39 to 43.48 per cent and 42.83 to 43.09 per cent in the year 2017-18 and 2018-19, respectively. The lowest water holding capacity (42.39%) was observed with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each in the year 2017-18 and with inoculation of PSB @ 10 kg ha⁻¹ (42.83 %) in the year 2018-19. However, the highest water holding capacity (43.48%) was recorded with no biofertilizers application i.e. B₀ in the year 2017-18 and 43.09 per cent with inoculation of VAM @ 10 kg ha⁻¹ i.e. B₁ in the year 2018-19.

Interaction effect

The interaction of phosphorus and biofertilizers could not reach the level of significance (Table 4.7) and it varied from 41.59 to 43.88 per cent and 42.62 to 43.47 per cent during 2017-18 and 2018-19, respectively. The lowest water holding capacity of the soil i.e. 41.59 per cent was recorded with application of phosphorus @ 30 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each in the year 2017-18 and with application of phosphorus @ 30 kg ha⁻¹ with application of VAM @ 10 kg ha⁻¹ (42.62 %) in the year 2018-19. However, the highest water holding capacity was noted with application of phosphorus @ 30 kg ha⁻¹ (43.88 %) with no biofertilizers application i.e. B₀P₃₀ in the year 2017-18 and with application of phosphorus @ 45 kg ha⁻¹ with application of VAM @ 10 kg ha⁻¹ (B₁P₄₅) i.e. 43.47 per cent in the year 2018-19.

4.1.2.4 Cation exchange capacity

Effect of phosphorus

The data pertaining cation exchange capacity presented in the Table 4.8, which indicated that the cation exchange capacity (CEC) of the soil had significant effect and it ranged from 9.35 to 11.21 cmol (p⁺) kg⁻¹ and 9.59 to 11.73 cmol (p⁺) kg⁻¹ due to application of phosphorus in the year 2017-18 and 2018-19, respectively. The CEC of soil was 11.21 cmol (p⁺) kg⁻¹ and 11.73 cmol (p⁺) kg⁻¹ during 2017-18 and 2018-19, respectively and was found to be significantly superior with the application of phosphorus @ 30 kg ha⁻¹ over all other treatments consisting application of phosphorus @ 60 kg ha⁻¹, @ 45 kg ha⁻¹ and @ 15 kg ha⁻¹. However, the lowest CEC i.e. 9.35 cmol (p⁺) kg⁻¹ and 9.59 cmol (p⁺) kg⁻¹ during 2017-18 and 2018-19, respectively was recorded with application of phosphorus @ 15 kg ha⁻¹.

Effect of biofertilizers

The application of biofertilizers recorded significantly increased the cation exchange capacity of the soil after harvest of the groundnut (Table 4.8) and it varied from 9.26 to 11.77 $\text{cmol (p}^+) \text{ kg}^{-1}$ and 9.43 to 12.19 $\text{cmol (p}^+) \text{ kg}^{-1}$ in the year 2017-18 and 2018-19, respectively. The CEC of soil was 11.77 and 12.19 $\text{cmol (p}^+) \text{ kg}^{-1}$ during 2017-18 and 2018-19, respectively and was found to be significantly superior due to dual inoculation of VAM + PSB @ 10 kg ha^{-1} each (B_4) as compared to other treatments consisting inoculation of PSB @ 10 kg ha^{-1} (B_2), VAM @ 10 kg ha^{-1} (B_1), VAM + PSB @ 5 kg ha^{-1} each (B_3) and no biofertilizers application (B_0). No biofertilizers application (B_0) recorded the lowest CEC of soil, which was 9.26 and 9.43 $\text{cmol (p}^+) \text{ kg}^{-1}$ during 2017-18 and 2018-19, respectively.

Interaction effect

The cation exchange capacity of soil after harvest of groundnut crop due to application of phosphorus and biofertilizers showed the significant difference (Table 4.8) and it ranged from 7.71 to 13.24 and 8.18 to 13.43 $\text{cmol (p}^+) \text{ kg}^{-1}$ during the year 2017-18 and 2018-19, respectively. The treatment combination consisting application of phosphorus @ 60 kg ha^{-1} (RDF) with dual inoculation of VAM + PSB @ 10 kg ha^{-1} each (B_4P_{60}) recorded significantly highest CEC (13.24 $\text{cmol (p}^+) \text{ kg}^{-1}$ and 13.43 $\text{cmol (p}^+) \text{ kg}^{-1}$ during 2017-18 and 2018-19, respectively) and showed its superiority over all other treatment combinations.

The similar values of cation exchange capacity (10.86 $\text{cmol (p}^+) \text{ kg}^{-1}$ to 13.30 $\text{cmol (p}^+) \text{ kg}^{-1}$) was reported after harvest of rice in lateritic soils of Konkan region (Salvi, 2007). The variations in CEC may be attributed to the fact that the kaolinite dominantly with some quantity of illite (fine-grained micas) constitutes the clay mineralogy of soils (Anonymous 1990). The increase in cation exchange capacity may also be due to colloidal nature of humified organic matter added through FYM application.

The inoculated plots with biofertilizers alongwith higher dose of phosphorus significantly increases the CEC of soil over uninoculated plots with lower level of phosphorus. The increase in the cation exchange capacity of soil due to application of organic manure with inorganic fertilizers was also reported by Laxminarayana (2006).

4.1.3 Biological properties of soil

4.1.3.1 Bacterial population

Effect of phosphorus

The bacterial population in soil at peg initiation stage ranged from 45.49 to 57.07×10^5 cfu g⁻¹ soil and 49.13 to 61.78×10^5 cfu g⁻¹ soil in the year 2017-18 and 2018-19, respectively, presented in Table 4.9. There was graded increase in bacterial population with the graded doses of phosphorus. The highest dose of phosphorus i.e. 60 kg ha^{-1} (RDF) recorded the significantly highest bacterial population (57.07×10^5 cfu g⁻¹ soil and 61.78×10^5 cfu g⁻¹ soil during 2017-18 and 2018-19, respectively), which was found to be significantly superior over the lower doses of phosphorus.

At pod formation stage the application of graded doses of phosphorus increased bacterial population significantly and varied from 101.77 to 123.17×10^5 cfu g⁻¹ soil and 104.45 to 131.11×10^5 cfu g⁻¹ soil in the year 2017-18 and 2018-19, respectively. Among the different levels of phosphorus, the application of phosphorus @ 60 kg ha^{-1} noted significantly highest bacterial population (123.17×10^5 cfu g⁻¹ soil and 131.11×10^5 cfu g⁻¹ soil during 2017-18 and 2018-19, respectively), which showed its superiority over all other lower doses of phosphorus.

The graded doses of phosphorus significantly influenced the bacterial population at harvest and it ranged from 29.13 to 35.43×10^5 cfu g⁻¹ soil and 27.78 to 33.83×10^5 cfu g⁻¹ soil in the year 2017-18 and 2018-19, respectively. The bacterial population in soil increased with increasing doses of phosphorus and the highest bacterial population in soil (35.43×10^5 cfu g⁻¹ soil and 33.83×10^5 cfu g⁻¹ soil during 2017-18 and 2018-19, respectively) was found with the application of phosphorus @ 60 kg ha^{-1} (RDF), which was significantly superior over the remaining lower doses of phosphorus which indicated the different treatments consisting P₄₅, P₃₀ and P₁₅ during both years of observations.

Effect of biofertilizers

An alone or dual inoculation of biofertilizers had significant effect on the soil bacterial population at peg initiation stage (Table 4.9) and it ranged from 47.33 to 52.03×10^5 cfu g⁻¹ soil and 51.12 to 56.37×10^5 cfu g⁻¹ soil in the year 2017-18 and 2018-19, respectively. The bacterial population in soil (52.03×10^5 cfu g⁻¹ soil and 56.37×10^5 cfu g⁻¹ soil during 2017-18 and 2018-19, respectively) was found to be significantly superior with dual inoculation of VAM + PSB @ 10 kg ha^{-1} each (B₄)

thereby indicating its superiority over all other treatments consisting dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃), inoculation of PSB @ 10 kg ha⁻¹ (B₂), inoculation of VAM @ 10 kg ha⁻¹ (B₁) and with no biofertilizers application (B₀). But, the treatment consisting dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) and PSB @ 10 kg ha⁻¹ (B₂) were at par with each other during the year 2018-19.

The variation in soil bacterial population at pod formation due to application of biofertilizers in different treatments were observed to be from 103.14 to 112.11 and 108.65 to 119.63 x 10⁵ cfu g⁻¹ soil in the year 2017-18 and 2018-19, respectively. The bacterial population in soil (112.11 x 10⁵ cfu g⁻¹ soil and 119.63 x 10⁵ cfu g⁻¹ soil during 2017-18 and 2018-19, respectively) was found to be significantly superior with the application of VAM + PSB @ 10 kg ha⁻¹ each i.e. (B₄) over all other treatments of biofertilizers application. However, the dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) and application of PSB @ 10 kg ha⁻¹ (B₂) was found to be at par with each other, but significantly superior over B₁ treatment comprising inoculation of VAM @ 10 kg ha⁻¹ (108.95 x 10⁵ cfu g⁻¹ soil and 114.47 x 10⁵ cfu g⁻¹ soil) as well as no biofertilizers application i.e. (B₀) (103.14 and 108.65 x 10⁵ cfu g⁻¹ soil during the year 2017-18 and 2018-19, respectively).

At harvest, the bacterial count found to be in the range from 29.78 to 32.45 x 10⁵ cfu g⁻¹ soil and 28.18 to 30.89 x 10⁵ cfu g⁻¹ soil in the year 2017-18 and 2018-19, respectively. The bacterial population in soil (32.45 x 10⁵ cfu g⁻¹ soil and 30.89 x 10⁵ cfu g⁻¹ soil during 2017-18 and 2018-19, respectively) was found to be significantly superior with application of biofertilizers VAM + PSB @ 10 kg ha⁻¹ each (B₄) over all other treatments. However, the dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) and application of PSB @ 10 kg ha⁻¹ (B₂) were found to be at par with each other, but superior over the inoculation of VAM @ 10 kg ha⁻¹ (B₁) as well as no biofertilizers (B₀).

Interaction effect

The combined application of phosphorus and biofertilizers significantly increased the bacterial population at peg initiation stage and ranges from 43.17 to 62.30 x 10⁵ cfu g⁻¹ soil and 46.62 to 68.03 x 10⁵ cfu g⁻¹ soil during the year 2017-18 and 2018-19, respectively. The soil bacterial population (62.30 x 10⁵ cfu g⁻¹ soil and 68.03 x 10⁵ cfu g⁻¹ soil during the year 2017-18 and 2018-19, respectively) was found to be significantly superior with application of phosphorus @ 60 kg ha⁻¹ with dual

inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀) in all other treatment combinations in both the years, but was found to be at par with application of phosphorus @ 60 kg ha⁻¹ and inoculation of PSB @ 10 kg ha⁻¹ (62.00 x 10⁵ cfu g⁻¹ soil) i.e. B₂P₆₀ in the year 2017-18.

The application of graded doses of phosphorus either alone or in combination of biofertilizers increased bacterial population significantly at pod formation stage (Table 4.9) and ranged from 97.47 to 133.87 x 10⁵ cfu g⁻¹ soil and 99.06 to 143.70 x 10⁵ cfu g⁻¹ soil during the year 2017-18 and 2018-19, respectively. Significantly highest bacterial population (133.87 and 143.70 x 10⁵ cfu g⁻¹ soil during the year 2017-18 and 2018-19, respectively) were observed due to the treatment receiving phosphorus @ 60 kg ha⁻¹ with VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀) during both the years. However, the treatment consisting application of phosphorus @ 60 kg ha⁻¹ with inoculation of PSB @ 10 kg ha⁻¹ B₂P₆₀ treatment was at par with B₄P₆₀ in the year 2017-18.

The bacterial population increased significantly at harvest and it varied from 28.01 to 38.79 x 10⁵ cfu g⁻¹ soil and 26.61 to 37.68 x 10⁵ cfu g⁻¹ soil during the year 2017-18 and 2018-19, respectively. The significantly highest bacterial population (38.79 and 37.68 x 10⁵ cfu g⁻¹ soil during the year 2017-18 and 2018-19, respectively) was found due to the treatment combination application of phosphorus @ 60 kg ha⁻¹ alongwith dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀), indicating thereby its superiority of higher dose of phosphorus and biofertilizers combination. The same treatment (B₄P₆₀) was found to be at par with B₂P₆₀ in the year 2017-18 and was significantly superior over all other treatment during both the years.

The two years study revealed that, the bacterial population increased significantly during pod formation stage as compared to peg initiation as well as harvest stage over initial count of (39.02 x 10⁵ cfu g⁻¹ soil and 41.14 x 10⁵ cfu g⁻¹ soil during the year 2017-18 and 2018-19, respectively. This increase in bacterial population might be due to addition of FYM alongwith chemical fertilizers as well as inoculation of biofertilizers. Added FYM served as a source of nutrients and also as a substrate for decomposition and mineralization of nutrients, thereby creating favorable conditions for proliferation of microbes in the soil. Yadav *et al.* (2009) clearly indicated that addition of organic manure helped in the buildup of microbial population, which might be attributed to increase in mineralizable carbon.

There was gradual increase in bacterial population with the graded doses of phosphorus and the dual inoculation of biofertilizers increased the bacterial population, which may be attributed to increased availability of N, P and K through the applied fertilizers. It also might be due to the proliferation of root exudates and addition of crop residues including more root biomass than control, thus helped in providing the increased carbon substrate for microbial growth. Further, combination of inorganic fertilizers with organic manures further enhanced the rate of multiplication of bacteria. Patil and Varade (1998) also observed that NPK fertilizers helped in the buildup of microbial population.

Chand *et al.* (2010) observed that use of PSB and *Azotobacter* alone or in combination with 10 t FYM ha⁻¹ likely to trigger the soil microbial population, which results in, increased the population of PSB and *Azotobacter* in rhizosphere soil under mustard crop. They also reported that increasing doses of fertilizers significantly increased the phosphate solubilizing bacteria (PSB) and *Azotobacter* population.

Similar increase in bacterial count with the inoculation of *rhizobium* and PSB in combinations with phosphorus (*viz.*, 25 and 50 kg ha⁻¹) under groundnut was observed by Gengaje (2013) in lateritic soils of Konkan. Mhalshi (2013) also reported the similar trend of increase in bacterial population in lateritic soils of Konkan region due to application of *rhizobium* and PSB in combinations with phosphorus levels (*viz.*, 50, 60 and 70 kg ha⁻¹) in cowpea. The bacterial population of 69.23 x 10⁴ cfu g⁻¹ of soil to 140.41 x 10⁴ cfu g⁻¹ of soil was reported with the application of agro-forest tree leaf litter to mustard crop in lateritic soils of Konkan region (Anonymous 2019).

4.1.3.2 Actinomycetes population

Effect of phosphorus

Graded doses of phosphorus significantly influenced the actinomycetes population at peg initiation (Table 4.10) and ranged from 44.45 to 53.65 x 10⁵ cfu g⁻¹ soil and 45.78 to 55.80 x 10⁵ cfu g⁻¹ soil in the year 2017-18 and 2018-19, respectively. The actinomycetes population in soil increased with increasing doses of phosphorus and the highest actinomycetes population in soil i.e. 53.65 x 10⁵ cfu g⁻¹ soil and 55.80 x 10⁵ cfu g⁻¹ soil during 2017-18 and 2018-19, respectively was found with the application of phosphorus @ 60 kg ha⁻¹ (RDF), which was significantly superior over all the lower doses of phosphorus application.

The actinomycetes population in soil at pod formation stage ranged from

88.89 to 107.62×10^5 cfu g⁻¹ soil and 90.67 to 109.79×10^5 cfu g⁻¹ soil in the year 2017-18 and 2018-19, respectively. There was graded increase in actinomycetes population with the graded doses of phosphorus. The highest dose of phosphorus i.e. 60 kg ha⁻¹ (RDF) recorded the significantly highest actinomycetes population of 107.62×10^5 cfu g⁻¹ soil and 109.79×10^5 cfu g⁻¹ soil during 2017-18 and 2018-19, respectively, which was found to be significantly superior over all the lower doses of phosphorus.

At harvest stage the application of graded doses of phosphorus increased actinomycetes population significantly and varied from 28.21 to 34.67×10^5 cfu g⁻¹ soil and 29.07 to 35.21×10^5 cfu g⁻¹ soil in the year 2017-18 and 2018-19, respectively. Among the different levels of phosphorus, the application of phosphorus @ 60 kg ha⁻¹ noted the significantly highest actinomycetes population (34.67 and 35.21×10^5 cfu g⁻¹ soil during 2017-18 and 2018-19, respectively), which showed its superiority over the lower doses of phosphorus.

Effect of biofertilizers

The variation in soil actinomycetes population at peg initiation due to application of biofertilizers in different treatments was observed to be from 45.08 to 48.87×10^5 cfu g⁻¹ soil and 46.43 to 51.01×10^5 cfu g⁻¹ soil in the year 2017-18 and 2018-19, respectively. The actinomycetes population (48.87×10^5 cfu g⁻¹ soil and 51.01×10^5 cfu g⁻¹ soil during 2017-18 and 2018-19, respectively) was found to be significantly superior with the application of VAM + PSB @ 10 kg ha⁻¹ each i.e. (B₄) over all the treatments of biofertilizers application and which was at par with the treatments consisting dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) and application of PSB @ 10 kg ha⁻¹ (B₂) in the year 2017-18. However, dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) and application of PSB @ 10 kg ha⁻¹ (B₂) were found to be superior over application of VAM @ 10 kg ha⁻¹ (B₁) and no biofertilizers (B₀) and at par with each other in the year 2018-19.

At pod formation stage, the actinomycetes count found to be in the range from 90.15 to 98.13×10^5 cfu g⁻¹ soil and 91.95 to 100.11×10^5 cfu g⁻¹ soil in the year 2017-18 and 2018-19, respectively. The actinomycetes population in soil (98.13 and 100.11×10^5 cfu g⁻¹ soil during 2017-18 and 2018-19, respectively) was found to be significantly superior due to application of biofertilizers VAM + PSB @ 10 kg ha⁻¹ each (B₄) over all other treatments. However, the dual inoculation of VAM + PSB @

5 kg ha⁻¹ each (B₃) and application of PSB @ 10 kg ha⁻¹ (B₂) were found to be at par with each other, and were superior over application of VAM @ 10 kg ha⁻¹ (B₁) and no biofertilizers (B₀) application.

An alone or dual inoculation of biofertilizers had significant effect on the soil actinomycetes population at harvest of the crop (Table 4.10) and it ranged from 28.62 to 31.78 x 10⁵ cfu g⁻¹ soil and 29.48 to 32.11 x 10⁵ cfu g⁻¹ soil during the year 2017-18 and 2018-19, respectively. The actinomycetes population in the soil (31.78 and 32.11 x 10⁵ cfu g⁻¹ soil during 2017-18 and 2018-19, respectively) was found to be significantly superior with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄) indicating its superiority over all other treatments consisting dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃), PSB @ 10 kg ha⁻¹ (B₂), VAM @ 10 kg ha⁻¹ (B₁) and with no biofertilizers application (B₀). But, the treatment consisting dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) and PSB @ 10 kg ha⁻¹ (B₂) were at par with each other during both the years.

Interaction effect

The application of different levels of phosphorus and biofertilizers significantly increased the actinomycetes population at peg initiation stage and ranged from 42.56 to 58.42 x 10⁵ cfu g⁻¹ soil and 43.84 to 62.51 x 10⁵ cfu g⁻¹ soil during the year 2017-18 and 2018-19, respectively. The soil actinomycetes population (58.42 x 10⁵ cfu g⁻¹ soil and 62.51 x 10⁵ cfu g⁻¹ soil during the year 2017-18 and 2018-19, respectively) was found to be significantly superior with application of phosphorus @ 60 kg ha⁻¹ and inoculation of PSB @ 10 kg ha⁻¹ (58.07 x 10⁵ cfu g⁻¹ soil) i.e. B₂P₆₀ in all treatment combinations in both the years, but found to be at par with application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀) in the year 2017-18. The application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀) was found to be significantly superior in all treatment combinations in the year 2018-19.

The interaction between graded doses of phosphorus either alone or in combinations increased actinomycetes population significantly at pod formation stage (Table 4.10) and ranged from 85.13 to 117.73 and 86.83 to 120.16 x 10⁵ cfu g⁻¹ soil during the year 2017-18 and 2018-19, respectively. Significantly highest actinomycetes population of 117.73 x 10⁵ cfu g⁻¹ soil and 120.16 x 10⁵ cfu g⁻¹ soil during the year 2017-18 and 2018-19, respectively were observed to be in the treatment receiving phosphorus @ 60 kg ha⁻¹ with VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀), but at par with the treatment consisting phosphorus application @ 60 kg ha⁻¹

with inoculation of PSB @ 10 kg ha⁻¹ (B₂P₆₀) in the year 2018-19.

The actinomycetes population increased significantly at harvest and it varied from 27.02 to 39.89 x 10⁵ cfu g⁻¹ soil and 27.84 to 38.59 x 10⁵ cfu g⁻¹ soil during the year 2017-18 and 2018-19, respectively. The highest actinomycetes population (39.89 and 38.59 x 10⁵ cfu g⁻¹ soil during the year 2017-18 and 2018-19, respectively) found in the treatment combination application of phosphorus @ 60 kg ha⁻¹ alongwith dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀), indicating thereby the superiority of higher dose of phosphorus and biofertilizers combination, which found to be at par with B₂P₆₀ in the year 2018-19.

It is seen from the two years data that, the population of actinomycetes overall increased over initial population of actinomycetes (24.15 and 21.79 x 10⁵ cfu g⁻¹ soil during the year 2017-18 and 2018-19, respectively) irrespective of the treatments in both the years. Further, population of actinomycetes increased gradually from peg initiation to pod formation stage and thereafter decreased at harvest stage. The increased in population of actinomycetes may be due to the carbonaceous materials and substrates such as sugar, amino acids and organic acids to the soil from the decomposing organic materials decay of roots under the plant canopy are important for supplying energy for microbial population. The higher rate of actinomycetes population is mainly attributed to the higher return of organic matter to the soil as a result of their decomposition.

Similar findings were also reported by Sharma *et al.* (1986) who established a positive relationship between organic material and actinomycetes in soil. The number of actinomycetes increases in the presence of decomposing organic matter also reported by Subba Rao (1995).

The study further indicated the significant increase in the microbial population of actinomycetes with application of biofertilizers (i.e. *rhizobium*, VAM and PSB) along with different doses of inorganic fertilizers. This finding corroborate with the finding of Chesti and Ali (2012) who reported significant increase in actinomycetes with phosphate solubilizer's inoculation (*Pseudomonas* sp. and *Bacillus* sp.) and phosphorus application @ 30 kg ha⁻¹ over control under green gram crop. In this context, Sarawgi *et al.* (2012) also reported that rhizobial bacterial population was significantly increased with inoculation of *rhizobium* culture either alone or in combination with PSB and VAM and maximum was recorded with 30 kg P₂O₅ ha⁻¹

through rock phosphate + PSB + *rhizobium* inoculation + VAM, i.e. with higher dose of phosphorus (30 kg P₂O₅ ha⁻¹).

In lateritic soils of Konkan, Gengaje (2013) and Mhalshi (2013) also observed an increase in actinomycetes population with the dual inoculation of *rhizobium* and PSB with different levels of phosphorus under groundnut (*viz.*, 25 and 50 kg ha⁻¹) and cowpea (*viz.*, 50, 60 and 70 kg ha⁻¹), respectively. Actinomycetes population to the tune of 37.93 to 58.47 x 10⁴ cfu g⁻¹ soil were reported with the application of agro-forest tree leaf litter to mustard crop in lateritic soils of Konkan region (Anonymous 2019).

4.1.3.3 Fungal population

Effect of phosphorus

At peg initiation stage, the application of graded doses of phosphorus increased the fungal population significantly (Table 4.11) and it varied from 9.41 to 11.41 x 10³ cfu g⁻¹ soil and 10.44 to 12.81 x 10³ cfu g⁻¹ soil in the year 2017-18 and 2018-19, respectively. Among the different levels of phosphorus, the application of phosphorus @ 60 kg ha⁻¹ noted the significantly highest fungal population (11.41 and 12.81 x 10³ cfu g⁻¹ soil during 2017-18 and 2018-19, respectively), which showed its superiority over all the lower doses of phosphorus application.

The different doses of phosphorus significantly influenced the fungal population in soil at pod formation stage, which was ranged from 18.53 to 22.45 and 21.11 to 25.76 x 10³ cfu g⁻¹ soil in the year 2017-18 and 2018-19, respectively. The fungal population in soil increased with increasing doses of phosphorus and the highest fungal population in soil (22.45 x 10³ cfu g⁻¹ soil and 25.76 x 10³ cfu g⁻¹ soil during 2017-18 and 2018-19, respectively) was found with the application of phosphorus @ 60 kg ha⁻¹ (RDF), which was significantly superior over all the lower doses of phosphorus.

The fungal population in soil at harvest stage varied from 9.22 to 11.37 and 9.68 to 11.78 x 10³ cfu g⁻¹ soil in the year 2017-18 and 2018-19, respectively. There was graded increase in fungal population with the graded doses of phosphorus. The highest dose of phosphorus i.e. 60 kg ha⁻¹ (RDF) recorded the significantly highest fungal population (11.37 and 11.78 x 10³ cfu g⁻¹ soil during 2017-18 and 2018-19, respectively), which was found to be significantly superior over all the lower doses of phosphorus.

Effect of biofertilizers

The variation in soil fungal population at peg initiation with the application of biofertilizers in different treatments were observed to be from 9.54 to 10.42 and 10.59 to 11.74 x 10³ cfu g⁻¹ soil in the year 2017-18 and 2018-19, respectively. The fungal population in soil (10.42 x 10³ cfu g⁻¹ soil and 11.74 x 10³ cfu g⁻¹ soil during 2017-18 and 2018-19, respectively) was found to be significantly superior with the application of VAM + PSB @ 10 kg ha⁻¹ each i.e. (B₄) over all the treatments of biofertilizers application. However, the dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) and application of PSB @ 10 kg ha⁻¹ (B₂) was found at par with each other, but superior over application of VAM @ 10 kg ha⁻¹ (B₁) and no biofertilizers application (B₀).

At pod formation, the fungal count was found to be in the range from 18.79 to 20.48 x 10³ cfu g⁻¹ soil and 21.42 to 23.53 x 10³ cfu g⁻¹ soil in the year 2017-2018 and 2018-2019, respectively. The fungal population in soil (20.48 and 23.53 x 10³ cfu g⁻¹ soil during 2017-18 and 2018-19, respectively) was found to be significantly superior due to the application of biofertilizers i.e. VAM + PSB @ 10 kg ha⁻¹ each (B₄) over all other treatments. However, the dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) and application of PSB @ 10 kg ha⁻¹ (B₂) were found to be at par with each other, but superior over inoculation of VAM @ 10 kg ha⁻¹ (B₁) and no biofertilizers application (B₀).

An alone or dual inoculation of biofertilizers had significant effect on the soil fungal population at harvest stage (Table 4.11) and it ranged from 9.35 to 11.44 x 10³ cfu g⁻¹ soil and 9.82 to 10.76 x 10³ cfu g⁻¹ soil in the year 2017-18 and 2018-19, respectively. The fungal population in soil (11.44 and 10.76 x 10³ cfu g⁻¹ soil during 2017-18 and 2018-19, respectively) was found to be significantly superior with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄) indicating its superiority over all the treatments consisting dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃), PSB @ 10 kg ha⁻¹ (B₂), VAM @ 10 kg ha⁻¹ (B₁) and with no biofertilizers (B₀). But, the treatment consisting dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) and PSB @ 10 kg ha⁻¹ (B₂) were at par with each other during both the years.

Interaction effect

The application of graded doses of phosphorus both alone or in combination increased the fungal population significantly at peg initiation stage and ranged from 9.01 to 12.59 x 10³ cfu g⁻¹ soil and 10.00 to 14.69 x 10³ cfu g⁻¹ soil during the year

2017-18 and 2018-19, respectively. The highest fungal population (12.59×10^3 cfu g⁻¹ soil and 14.69×10^3 cfu g⁻¹ soil during the year 2017-18 and 2018-19, respectively) were observed to be in the treatment receiving phosphorus @ 60 kg ha⁻¹ with VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀), which was significantly superior over all other treatment combinations.

The fungal population increased significantly at pod formation stage (Table 4.11) and it varied from 17.75 to 24.65 and 20.23 to 28.89 $\times 10^3$ cfu g⁻¹ soil during the year 2017-18 and 2018-19, respectively. The highest fungal population (24.65×10^3 cfu g⁻¹ soil and 28.89×10^3 cfu g⁻¹ soil during the year 2017-18 and 2018-19, respectively) was found in the treatment combination application of phosphorus @ 60 kg ha⁻¹ alongwith dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀), indicating thereby the superiority of higher dose of phosphorus and biofertilizers combination during both the years.

At harvest stage, the combined application of phosphorus and biofertilizers significantly increased the fungal population, which ranged from 8.83 to 13.26 and 9.27 to 13.12 $\times 10^3$ cfu g⁻¹ soil during the year 2017-18 and 2018-19, respectively. The soil fungal population (13.26×10^3 cfu g⁻¹ soil and 13.12×10^3 cfu g⁻¹ soil during the year 2017-18 and 2018-19, respectively) was found to be significantly superior with application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀) in all treatment combinations in both the years.

The scrutiny of two years data indicated that, the fungal population increased over initial fungal population (8.16×10^3 cfu g⁻¹ soil and 10.13×10^3 cfu g⁻¹ soil during the year 2017-18 and 2018-19, respectively) irrespective of the treatments. Further, fungal the population increased gradually from peg imitation to pod formation stage and thereafter decreased at harvest stage. The inorganic NPK fertilizers proliferated the fungal growth, but when NPK fertilizers were combined with organic material especially FYM the fungal population was further stimulated, which might be attributed to the decayed food material available from FYM. The higher population of bacteria, actinomycetes and fungi under legumes might be due to the preferential stimulation exerted by the excretory products of their roots.

It was also observed that the recommended dose of N and K along with graded doses of P helped in the buildup of fungal population and the increase was graded with the graded doses of phosphorus. These results are in corroboration with

that of Martyniuk and Wagner (1978), who found that the microbial populations greater in fertilized than in unfertilized soil. Chesti and Ali (2012) also reported increase in fungi population with the application of phosphate levels over the control. The inhibition of fungal population may also be due to production of some specific siderophores, antibiotics, secondary metabolites or hydrolytic enzymes produced by P-solubilizers.

In lateritic soils of Konkan, Gengaje (2013) in groundnut and Mhalshi (2013) in cowpea observed increase in fungal population in soil with the dual inoculation of *rhizobium* and PSB with different levels of phosphorus. The fungal population in soil to the tune of 13.18 to 21.26 $10^4 \times \text{cfu g}^{-1}$ soil were reported with the application of agro-forest tree leaf litter to mustard crop in lateritic soils of Konkan region (Anonymous 2019).

4.1.3.4 CO₂ evolution

Effect of phosphorus

Graded doses of phosphorus significantly influenced the CO₂ evolution at peg initiation (Table 4.12) and it ranged from 35.49 to 44.57 mg 100 g⁻¹ soil 24 hr⁻¹ and 38.39 to 48.26 mg 100 g⁻¹ soil 24 hr⁻¹ in the year 2017-18 and 2018-19, respectively. The CO₂ evolution in soil increased with increasing doses of phosphorus where the increase was graded and the highest CO₂ evolution (44.57 mg 100 g⁻¹ soil 24 hr⁻¹ and 48.26 mg 100 g⁻¹ soil 24 hr⁻¹ during 2017-18 and 2018-19, respectively) was found in the soil with the application of phosphorus @ 60 kg ha⁻¹ (RDF) which was significantly superior over the lower doses of phosphorus. The increase in CO₂ evolution followed the order of P₁₅ < P₃₀ < P₄₅ < P₆₀.

The CO₂ evolution in soil at pod formation stage ranged from 54.65 to 68.99 mg 100 g⁻¹ soil 24 hr⁻¹ and 55.74 to 70.03 mg 100 g⁻¹ soil 24 hr⁻¹ in the year 2017-18 and 2018-19, respectively. There was graded increase in CO₂ evolution with the graded doses of phosphorus. The highest dose of phosphorus i.e. 60 kg ha⁻¹ (RDF) recorded the significantly highest CO₂ evolution (68.99 mg 100 g⁻¹ soil 24 hr⁻¹ and 70.03 mg 100 g⁻¹ soil 24 hr⁻¹ during 2017-18 and 2018-19, respectively), which was found to be significantly superior over the lower doses of phosphorus and it followed the order of P₁₅ < P₃₀ < P₄₅ < P₆₀.

At harvest stage the application of graded doses of phosphorus increased CO₂ evolution significantly and varied from 31.15 to 39.23 mg 100 g⁻¹ soil 24 hr⁻¹ and

32.39 to 40.73 mg 100 g⁻¹ soil 24 hr⁻¹ in the year 2017-18 and 2018-19, respectively. Among the different levels of phosphorus, the application of phosphorus @ 60 kg ha⁻¹ noted the significantly highest CO₂ evolution (39.23 mg 100 g⁻¹ soil 24 hr⁻¹ and 40.73 mg 100 g⁻¹ soil 24 hr⁻¹ during 2017-18 and 2018-19, respectively) and followed the order of P₁₅ < P₃₀ < P₄₅ < P₆₀, which showed its superiority over the lower doses of phosphorus application.

Effect of biofertilizers

At peg initiation stage, the CO₂ evolution found to be in the range of 36.85 to 40.77 mg 100 g⁻¹ soil 24 hr⁻¹ and 39.87 to 44.05 mg 100 g⁻¹ soil 24 hr⁻¹ in the year 2017-18 and 2018-19, respectively. The CO₂ evolution in soil (40.77 and 44.05 mg 100 g⁻¹ soil 24 hr⁻¹ during 2017-18 and 2018-19, respectively) was found to be significantly superior due to the application of biofertilizers VAM + PSB @ 10 kg ha⁻¹ each (B₄) over all other treatments. In the remaining treatments, the dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) and application of PSB @ 10 kg ha⁻¹ (B₂) were found to be at par with each other, but superior over application of VAM @ 10 kg ha⁻¹ (B₁) and no biofertilizers (B₀) during both the years.

An alone or dual inoculation of biofertilizers had significant effect on the soil CO₂ evolution at pod formation stage (Table 4.12) and it ranged from 56.94 to 62.96 mg 100 g⁻¹ soil 24 hr⁻¹ and 57.99 to 64.04 mg 100 g⁻¹ soil 24 hr⁻¹ in the year 2017-18 and 2018-19, respectively. The CO₂ evolution in soil (62.96 mg 100 g⁻¹ soil 24 hr⁻¹ and 64.04 mg 100 g⁻¹ soil 24 hr⁻¹ during 2017-18 and 2018-19, respectively) was found to be significantly superior with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄) indicating thereby its superiority over all other treatments. Further, the treatment consisting dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) and PSB @ 10 kg ha⁻¹ (B₂) were at par with each other.

The variation in soil CO₂ evolution at harvest due to application of biofertilizers in different treatments were observed to be from 32.41 to 35.82 and 33.70 to 37.14 mg 100 g⁻¹ soil 24 hr⁻¹ in the year 2017-18 and 2018-19, respectively. The CO₂ evolution in soil (35.82 and 37.14 mg 100 g⁻¹ soil 24 hr⁻¹ during 2017-18 and 2018-19, respectively) was found to be significantly superior with the application of VAM + PSB @ 10 kg ha⁻¹ each i.e. (B₄) over all the treatments of biofertilizers application. Among the other treatments dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) and application of PSB @ 10 kg ha⁻¹ (B₂) were at par with each other, but

superior over application of VAM @ 10 kg ha⁻¹ (B₁) and no biofertilizers (B₀) in both the years.

Interaction effect

The interaction effect between graded doses of phosphorus either or in combination increased CO₂ evolution significantly at peg initiation stage (Table 4.12) and ranged from 33.67 to 48.82 and 36.36 to 53.40 mg 100 g⁻¹ soil 24 hr⁻¹ during the year 2017-18 and 2018-19, respectively. Significantly highest CO₂ evolution (48.82 mg 100 g⁻¹ soil 24 hr⁻¹ and 53.40 mg 100 g⁻¹ soil 24 hr⁻¹ during the year 2017-18 and 2018-19, respectively) were observed to be in the treatment receiving phosphorus @ 60 kg ha⁻¹ with VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀), but at par with the treatment consisting application of phosphorus @ 60 kg ha⁻¹ with inoculation of PSB @ 10 kg ha⁻¹ (B₂P₆₀) in the year 2017-18.

The application of different levels of phosphorus and biofertilizers significantly increased the CO₂ evolution at pod formation stage and ranged from 51.85 to 76.73 mg 100 g⁻¹ soil 24 hr⁻¹ and 52.89 to 77.51 mg 100 g⁻¹ soil 24 hr⁻¹ during the year 2017-18 and 2018-19, respectively. The soil CO₂ evolution (76.73 and 77.51 mg 100 g⁻¹ soil 24 hr⁻¹ during the year 2017-18 and 2018-19, respectively) was found to be significantly superior with application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀) in all treatment combinations in both the year.

The CO₂ evolution increased significantly at harvest and it varied from 29.56 to 43.45 mg 100 g⁻¹ soil 24 hr⁻¹ and 30.74 to 44.73 mg 100 g⁻¹ soil 24 hr⁻¹ during the year 2017-18 and 2018-19, respectively. The highest CO₂ evolution (43.45 mg 100 g⁻¹ soil 24 hr⁻¹ and 44.73 mg 100 g⁻¹ soil 24 hr⁻¹ during the year 2017-18 and 2018-19, respectively) was found in the treatment combination application of phosphorus @ 60 kg ha⁻¹ alongwith dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀), indicating its superiority of higher dose of phosphorus and biofertilizers combinations.

The values of CO₂ evolution reported here are in conformity with Bedi *et al.* (2009) who obtained the similar values in slightly acidic soil (pH 6.2) of Sirmour, Himachal Pradesh. Somewhat higher values of CO₂ evolution (242.48 to 566.25 mg 100 g⁻¹ soil 24 hr⁻¹ and 87.14 to 242.23 mg 100 g⁻¹ soil 24 hr⁻¹) was mentioned under mustard crop in lateritic soils of Konkan region of Maharashtra (Anonymous, 2019).

When examine the data of CO₂ evolution was examine, it was revealed that the CO₂ evolution increased gradually from peg initiation to pod formation stage and thereafter decreased at harvest stage in both the years. Higher CO₂ evolution in the FYM / treated plots indicated that improvement in microbial population with application of FYM might have increased the metabolic activity by utilizing substrate in the form of root exudates whereas, FYM might have help in evolving more CO₂. Increase in the CO₂ evolution with the application of cow dung manure and green manure was reported by Tripathi *et al.* (2009) on silty clay loam soil (pH 6.34) of West Bengal.

The data on CO₂ evolution further indicated that, CO₂ evolution increased with increasing P levels, which were again increased with the application of biofertilizers indicating the positive role of biofertilizers application in increasing CO₂ evolution. This increase in CO₂ evolution with higher doses of inorganic fertilizers may be due to the maximum microbial population observed in the treatment. These results are corroborates findings of Lalande *et al.* (2000) who observed significantly higher evolution of CO₂ and MBC in soil receiving FYM alone or FYM alongwith inorganic over 100 per cent NPK fertilization alone. Increased CO₂ evolution with increasing P doses (*viz.*, 50, 60 and 70 kg ha⁻¹) and K doses (*viz.*, 30, 40 and 50 kg ha⁻¹) along with the *rhizobium* and PSB inoculation under cowpea in lateritic soils of Konkan region was also reported by Mhalshi (2013).

4.1.3.5 Dehydrogenase activity

Effect of phosphorus

Graded increase in the dehydrogenase activity in soil with graded doses of phosphorus was observed at peg initiation and it ranged from 44.85 to 56.22 µg TPF g⁻¹ soil 24 hr⁻¹ and 45.30 to 56.98 µg TPF g⁻¹ soil 24 hr⁻¹ in the year 2017-18 and 2018-19, respectively, presented in Table 4.13. The highest dehydrogenase activity in soil (56.22 µg TPF g⁻¹ soil 24 hr⁻¹ and 56.98 µg TPF g⁻¹ soil 24 hr⁻¹ during 2017-18 and 2018-19, respectively) was found with the application of phosphorus @ 60 kg ha⁻¹ (RDF), which was significantly superior over the lower doses of phosphorus application. The increase in dehydrogenase activity followed the order of P₁₅ < P₃₀ < P₄₅ < P₆₀.

Alike peg initiation stage, there was significantly graded increase in dehydrogenase activity with the graded doses of phosphorus at pod formation stage

(Table 4.13) which ranged from 60.55 to 76.08 $\mu\text{g TPF g}^{-1}$ soil 24 hr^{-1} and 65.46 to 82.18 $\mu\text{g TPF g}^{-1}$ soil 24 hr^{-1} in the year 2017-18 and 2018-19, respectively. The highest dose of phosphorus i.e. 60 kg ha^{-1} recorded the significantly highest dehydrogenase activity (76.08 and 82.18 $\mu\text{g TPF g}^{-1}$ soil 24 hr^{-1} during 2017-18 and 2018-19, respectively), which was found to be significantly superior over the lower doses of phosphorus and followed the order of $P_{15} < P_{30} < P_{45} < P_{60}$.

At harvest stage the application of graded doses of phosphorus increased dehydrogenase activity significantly and varied from 38.75 to 48.64 and 37.20 to 46.73 $\mu\text{g TPF g}^{-1}$ soil 24 hr^{-1} in the year 2017-18 and 2018-19, respectively. Among the different levels of phosphorus, the application of phosphorus @ 60 kg ha^{-1} noted the significantly highest dehydrogenase activity (48.64 $\mu\text{g TPF g}^{-1}$ soil 24 hr^{-1} and 46.73 $\mu\text{g TPF g}^{-1}$ soil 24 hr^{-1} during 2017-18 and 2018-19, respectively), and followed the order of $P_{15} < P_{30} < P_{45} < P_{60}$, thereby signifying its superiority over the lower doses of phosphorus application.

Effect of biofertilizers

At peg initiation stage, the dehydrogenase activity ranged from 46.67 to 51.23 $\mu\text{g TPF g}^{-1}$ soil 24 hr^{-1} and 47.14 to 51.99 $\mu\text{g TPF g}^{-1}$ soil 24 hr^{-1} in the year 2017-18 and 2018-19, respectively. The dehydrogenase activity in soil (51.23 $\mu\text{g TPF g}^{-1}$ soil 24 hr^{-1} and 51.99 $\mu\text{g TPF g}^{-1}$ soil 24 hr^{-1} during 2017-18 and 2018-19, respectively) was found to be significantly superior due to the application of biofertilizers i.e. VAM + PSB @ 10 kg ha^{-1} each (B_4) over all other treatments. However, the dual inoculation of VAM + PSB @ 5 kg ha^{-1} each (B_3) and application of PSB @ 10 kg ha^{-1} (B_2) were found to be at par with each other and were superior over application of VAM @ 10 kg ha^{-1} (B_1) and no biofertilizers (B_0) application.

The variation in soil dehydrogenase activity at pod formation presented in Table 4.13 due to application of biofertilizers in different treatments were observed to be from 63.00 to 69.39 and 68.04 to 75.04 $\mu\text{g TPF g}^{-1}$ soil 24 hr^{-1} in the year 2017-18 and 2018-19, respectively. The dehydrogenase activity in soil (69.39 and 75.04 $\mu\text{g TPF g}^{-1}$ soil 24 hr^{-1} during 2017-18 and 2018-19, respectively) was found to be significantly superior with the application of VAM + PSB @ 10 kg ha^{-1} each i.e. (B_4) over all other treatments of biofertilizers application. Dual inoculation of VAM + PSB @ 5 kg ha^{-1} each (B_3) and application of PSB @ 10 kg ha^{-1} (B_2) found to be at par with each other and were superior over application of VAM @ 10 kg ha^{-1} (B_1) and

no biofertilizers (B_0) in both the years.

Significant effect on the dehydrogenase activity of soil at harvest stage due to inoculation of biofertilizers either or in combination was observed and ranged from 40.32 to 44.35 $\mu\text{g TPF g}^{-1}$ soil 24 hr^{-1} and 38.71 to 42.62 $\mu\text{g TPF g}^{-1}$ soil 24 hr^{-1} in the year 2017-18 and 2018-19, respectively. The dehydrogenase activity in soil (44.35 and 42.62 $\mu\text{g TPF g}^{-1}$ soil 24 hr^{-1} during 2017-18 and 2018-19, respectively), was found to be significantly superior with dual inoculation of VAM + PSB @ 10 kg ha^{-1} each (B_4) indicating its superiority over all other treatments consisting dual inoculation of VAM + PSB @ 5 kg ha^{-1} each (B_3), PSB @ 10 kg ha^{-1} (B_2), VAM @ 10 kg ha^{-1} (B_1) and with no biofertilizers (B_0). But, the treatment consisting dual inoculation of VAM + PSB @ 5 kg ha^{-1} each (B_3) and PSB @ 10 kg ha^{-1} (B_2) were at par with each other.

Interaction effect

The dehydrogenase activity increased significantly at peg initiation stage (Table 4.13) and it varied from 42.56 to 61.16 $\mu\text{g TPF g}^{-1}$ soil 24 hr^{-1} and 42.99 to 62.75 $\mu\text{g TPF g}^{-1}$ soil 24 hr^{-1} in the year 2017-18 and 2018-19, respectively. The highest dehydrogenase activity (61.16 $\mu\text{g TPF g}^{-1}$ soil 24 hr^{-1} and 62.95 $\mu\text{g TPF g}^{-1}$ soil 24 hr^{-1} during the year 2017-18 and 2018-19, respectively) was found due to the treatment combination of application of phosphorus @ 60 kg ha^{-1} alongwith dual inoculation of VAM + PSB @ 10 kg ha^{-1} each (B_4P_{60}), indicating the superiority of higher dose of phosphorus and biofertilizers combination which was found to be at par with B_2P_{60} in the year 2017-18.

The application of different levels of phosphorus and biofertilizers significantly increased the dehydrogenase activity at pod formation stage and ranges from 57.46 to 83.52 $\mu\text{g TPF g}^{-1}$ soil 24 hr^{-1} and 62.05 to 90.26 $\mu\text{g TPF g}^{-1}$ soil 24 hr^{-1} during the year 2017-18 and 2018-19, respectively. The soil dehydrogenase activity (83.52 $\mu\text{g TPF g}^{-1}$ soil 24 hr^{-1} and 90.26 $\mu\text{g TPF g}^{-1}$ soil 24 hr^{-1} during the year 2017-18 and 2018-19, respectively) was found to be significantly superior with application of phosphorus @ 60 kg ha^{-1} with dual inoculation of VAM + PSB @ 10 kg ha^{-1} each (B_4P_{60}) in all treatment combinations in both the year.

The interaction between graded doses of phosphorus either alone or in combination increased dehydrogenase activity significantly at harvest stage and it ranged from 36.77 to 53.21 and 35.30 to 51.24 $\mu\text{g TPF g}^{-1}$ soil 24 hr^{-1} during the year

2017-18 and 2018-19, respectively. Significantly highest dehydrogenase activity ($53.21 \mu\text{g TPF g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$ and $51.24 \mu\text{g TPF g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$ during the year 2017-18 and 2018-19, respectively) was observed to be in the treatment receiving phosphorus @ 60 kg ha^{-1} with VAM + PSB @ 10 kg ha^{-1} each (B_4P_{60}), but at par with the treatment consisting application of phosphorus @ 60 kg ha^{-1} with inoculation of PSB @ 10 kg ha^{-1} (B_2P_{60}) in the year 2017-18.

A quick look at data of dehydrogenase activity of both the years highlighted that the dehydrogenase activity increased gradually from peg initiation to pod formation stage and thereafter decreased at harvest stage. The increase in at pod formation stage might be due to the application of organic amendment, which significantly enhanced dehydrogenase activity possibly due to utilization of energy in the form of carbon by microorganism from the organic material. The decrease in dehydrogenase activity from pod formation to harvest of the crop may be due to accumulation of nitrification product (NO_3^- and NO_2^-) as observed from findings or some other compounds that have inhibitory effect on dehydrogenase activity or likely be the consequence of decreased availability of easily degradable compounds in the organic amendments.

Further, it was observed that, the dehydrogenase activity increased with increasing phosphorus levels along with recommended dose of N and K, which were further increased with the application of biofertilizers thereby indicating the positive role of biofertilizers application in increasing dehydrogenase activity.

Ramesh *et al.* (2003) noted 9.2 to 83.1 and 11.0 to $88.2 \mu\text{g TPF g}^{-1} \text{ soil } \text{hr}^{-1}$ dehydrogenase activity in acidic soil under coffee growing soils in Kodagu (pH 4.43 to 5.42) and Chikmagalur (pH 4.72 to 6.34) district of Karnataka, respectively. Increase in dehydrogenase activity with the application of inorganic fertilizers may be attributed to the fact that inorganic source of nutrient stimulate the activity of microorganisms to utilize the native pool of organic carbon as a source of carbon, which acts as substrate of dehydrogenase.

Bedi *et al.* (2009) reported increase in dehydrogenase activity with the application of 100 per cent NPK in slightly acidic soil (pH 6.2) of Sirmour, Himachal Pradesh. Increased dehydrogenase activity with increasing P doses (*viz.*, 50, 60 and 70 kg ha^{-1}) and K doses (*viz.*, 30, 40 and 50 kg ha^{-1}) along with the *rhizobium* and PSB inoculation under cowpea in lateritic soils of Konkan region was also reported by

Mhalshi (2013). Higher values of dehydrogenase activity (319.44 to 422.00 $\mu\text{g TPF g}^{-1}$ soil 24 hr^{-1}) were reported in lateritic soils of Konkan region of Maharashtra (Anonymous, 2019).

4.1.3.6 Urease activity

Effect of phosphorus

Urease enzyme activity at peg initiation stage (Table 4.14) and ranged from 44.19 to 55.70 and 42.87 to 54.27 $\mu\text{g NH}_4\text{-N g}^{-1}$ soil 24 hr^{-1} in the year 2017-18 and 2018-19, respectively as significantly affected by the graded doses of phosphorus. The highest urease enzyme activity in soil (55.70 $\mu\text{g NH}_4\text{-N g}^{-1}$ soil 24 hr^{-1} and 54.27 $\mu\text{g NH}_4\text{-N g}^{-1}$ soil 24 hr^{-1} during 2017-18 and 2018-19, respectively) was found with the application of phosphorus @ 60 kg ha^{-1} (RDF), which was significantly superior over the lower doses of phosphorus application. The increase in urease activity followed the order of $P_{15} < P_{30} < P_{45} < P_{60}$.

The urease enzyme activity in soil at pod formation stage ranged from 69.38 to 87.38 $\mu\text{g NH}_4\text{-N g}^{-1}$ soil 24 hr^{-1} and 70.07 to 87.91 $\mu\text{g NH}_4\text{-N g}^{-1}$ soil 24 hr^{-1} in the year 2017-18 and 2018-19, respectively. There was graded increase in urease enzyme activity with the graded doses of phosphorus. The highest dose of phosphorus i.e. 60 kg ha^{-1} (RDF) recorded significantly highest urease enzyme activity (87.38 and 87.91 $\mu\text{g NH}_4\text{-N g}^{-1}$ soil 24 hr^{-1} during 2017-18 and 2018-19, respectively), which was found to be significantly superior over the lower doses of phosphorus and followed the order $P_{15} < P_{30} < P_{45} < P_{60}$.

The application of graded doses of phosphorus increased urease enzyme activity significantly at harvest stage and varied from 38.58 to 49.18 and 40.41 to 51.14 $\mu\text{g NH}_4\text{-N g}^{-1}$ soil 24 hr^{-1} in the year 2017-18 and 2018-19, respectively. Among the different levels of phosphorus, the application of phosphorus @ 60 kg ha^{-1} noted significantly highest urease activity (49.18 and 51.14 $\mu\text{g NH}_4\text{-N g}^{-1}$ soil 24 hr^{-1} during 2017-18 and 2018-19, respectively) and followed the order of $P_{15} < P_{30} < P_{45} < P_{60}$, thereby signifying its superiority over the lower doses of phosphorus application.

Effect of biofertilizers

The significant difference were observed due to inoculation of biofertilizers alone or in combination on urease enzyme activity which ranged from 45.98 to 50.86 and 44.60 to 49.64 $\mu\text{g NH}_4\text{-N g}^{-1}$ soil 24 hr^{-1} in the year 2017-18 and 2018-19,

respectively. The urease enzyme activity in soil ($50.86 \mu\text{g NH}_4\text{-N g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$ and $49.64 \mu\text{g NH}_4\text{-N g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$ during 2017-18 and 2018-19, respectively) was found to be significantly superior with dual inoculation of VAM + PSB @ 10 kg ha^{-1} each (B_4) indicating its superiority over all other treatments consisting dual inoculation of VAM + PSB @ 5 kg ha^{-1} each (B_3), PSB @ 10 kg ha^{-1} (B_2), VAM @ 10 kg ha^{-1} (B_1) and with no biofertilizers (B_0). But, the treatment consisting dual inoculation of VAM + PSB @ 5 kg ha^{-1} each (B_3) and PSB @ 10 kg ha^{-1} (B_2) were at par with each other.

Urease enzyme activity significantly influenced by the application of biofertilizers at pod formation stage (Table 4.14) and it varied from 72.19 to 79.78 and 72.91 to $80.14 \mu\text{g NH}_4\text{-N g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$ in the year 2017-18 and 2018-19, respectively. The urease enzyme activity in soil ($79.78 \mu\text{g NH}_4\text{-N g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$ and $80.14 \mu\text{g NH}_4\text{-N g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$ during 2017-18 and 2018-19, respectively) was found to be significantly superior due to the application of biofertilizers VAM + PSB @ 10 kg ha^{-1} each (B_4) over all other treatments. However, in the year 2017-18 the dual inoculation of VAM + PSB @ 5 kg ha^{-1} each (B_3) and application of PSB @ 10 kg ha^{-1} (B_2) were found to be at par with each other and were significantly superior over application of VAM @ 10 kg ha^{-1} (B_1) and no biofertilizers (B_0), while in 2018-19 the dual inoculation of VAM + PSB @ 5 kg ha^{-1} each (B_3), application of PSB @ 10 kg ha^{-1} (B_2) and VAM @ 10 kg ha^{-1} (B_1) were found to be at par with each other but, significantly superior over no biofertilizers (B_0) application.

At harvest, the variation in soil urease activity due to application of biofertilizers in different treatments were observed to be from 40.42 to 44.97 and 42.04 and $46.74 \mu\text{g NH}_4\text{-N g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$ in the year 2017-18 and 2018-19, respectively. The urease enzyme activity in soil ($44.97 \mu\text{g NH}_4\text{-N g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$ and $46.74 \mu\text{g NH}_4\text{-N g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$ during 2017-18 and 2018-19, respectively) was found to be significantly superior with the application of VAM + PSB @ 10 kg ha^{-1} each i.e. (B_4) over all other treatments of biofertilizers application and was at par with the treatment consisting dual inoculation of VAM + PSB @ 5 kg ha^{-1} each (B_3) and application of PSB @ 10 kg ha^{-1} (B_2) in both the years.

Interaction effect

The application of different levels of phosphorus and biofertilizers significantly increased the urease enzyme activity at peg initiation stage (Table 4.14) and ranges from 41.93 to 61.81 and 40.67 to $61.20 \mu\text{g NH}_4\text{-N g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$ during

the year 2017-18 and 2018-19, respectively. The soil urease enzyme activity ($61.81 \mu\text{g NH}_4\text{-N g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$ and $61.20 \mu\text{g NH}_4\text{-N g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$ during the year 2017-18 and 2018-19, respectively) was found to be significantly superior with application of phosphorus @ 60 kg ha^{-1} with dual inoculation of VAM + PSB @ 10 kg ha^{-1} each (B_4P_{60}) in all treatment combinations in both the year.

The urease enzyme activity increased significantly at pod formation stage and it varied from 65.83 to $96.75 \mu\text{g NH}_4\text{-N g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$ and 66.49 to $96.00 \mu\text{g NH}_4\text{-N g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$ during the year 2017-18 and 2018-19, respectively. The highest urease enzyme activity ($96.75 \mu\text{g NH}_4\text{-N g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$ and $96.00 \mu\text{g NH}_4\text{-N g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$ during the year 2017-18 and 2018-19, respectively) were found in the treatment combination of phosphorus application @ 60 kg ha^{-1} alongwith dual inoculation of VAM + PSB @ 10 kg ha^{-1} each (B_4P_{60}), indicating its superiority of higher dose of phosphorus and biofertilizers combination which was found to be at par with B_2P_{60} in the year 2017-18.

The interaction between graded doses of phosphorus either alone or in combination increased urease enzyme activity significantly at harvest stage and ranged from 36.87 to 55.37 and 38.34 to $57.45 \mu\text{g NH}_4\text{-N g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$ during the year 2017-18 and 2018-19, respectively. Significantly highest urease enzyme activity ($55.37 \mu\text{g NH}_4\text{-N g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$ and $57.45 \mu\text{g NH}_4\text{-N g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$ during the year 2017-18 and 2018-19, respectively) were observed to be in the treatment receiving phosphorus @ 60 kg ha^{-1} with VAM + PSB @ 10 kg ha^{-1} each (B_4P_{60}).

A close look at data of urease activity of both years indicated that the urease activity increased gradually from peg initiation to pod formation stage and thereafter decreased at harvest stage. Data further indicated that, urease activity increased with increasing phosphorus level, which were further increased with the application of biofertilizers indicating the positive role of biofertilizers application in increasing urease activity, which may be due to the contribution of organisms present in *rhizobium* in the secretion of urease enzymes.

Ramesh *et al.* (2003) noted 9.1 to 52.3 and 3.4 to $59.2 \mu\text{g NH}_4\text{-N g}^{-1} \text{ soil } \text{hr}^{-1}$ urease activity in acidic soil under coffee growing soils in Kodagu (pH 4.43 to 5.42) and Chikmagalur (pH 4.72 to 6.34) district of Karnataka. Increase in urease activity with the application of cow dung manure and green manure was reported by Tripathi *et al.* (2009) on silty clay loam soil (pH 6.34) of West Bengal.

The long-term experiments conducted by Rout *et al.* (2003) indicated higher urease activity in soils that received both FYM and NPK fertilizer. Increased urease activity with increasing P doses (*viz.*, 50, 60 and 70 kg ha⁻¹) and K doses (*viz.*, 30, 40 and 50 kg ha⁻¹) along with the *rhizobium* and PSB inoculation over control under cowpea in lateritic soils of Konkan region was also reported by Mhalshi (2013).

4.1.3.7 Phosphatase activity

Alkaline phosphatase

At peg initiation stage the application of graded doses of phosphorus increased alkaline phosphatase activity significantly and it varied from 92.62 to 116.66 µg p-NP g⁻¹ soil hr⁻¹ and 88.92 to 111.71 µg p-NP g⁻¹ soil hr⁻¹ in the year 2017-18 and 2018-19, respectively. Among the different levels of phosphorus, the application of phosphorus @ 60 kg ha⁻¹ noted the significantly highest alkaline phosphatase activity (116.66 µg p-NP g⁻¹ soil hr⁻¹ and 111.71 µg p-NP g⁻¹ soil hr⁻¹ during 2017-18 and 2018-19, respectively), which showed its superiority over the lower doses of phosphorus application.

The alkaline phosphatase activity in soil at pod formation stage presented in the Table 4.15 and it ranged from 119.48 to 151.68 µg p-NP g⁻¹ soil hr⁻¹ and 120.68 to 151.31 µg p-NP g⁻¹ soil hr⁻¹ in the year 2017-18 and 2018-19, respectively. There was graded increase in alkaline phosphatase activity with the graded doses of phosphorus. The highest dose of phosphorus i.e. 60 kg ha⁻¹ (RDF) recorded the significantly highest alkaline phosphatase activity (151.68 and 151.31 µg p-NP g⁻¹ soil hr⁻¹ during 2017-18 and 2018-19, respectively), which were found to be significantly superior over the lower doses of phosphorus application.

Graded doses of phosphorus significantly influenced the alkaline phosphatase activity at harvest and ranged from 81.25 to 103.21 µg p-NP g⁻¹ soil hr⁻¹ and 80.43 to 101.03 µg p-NP g⁻¹ soil hr⁻¹ in the year 2017-18 and 2018-19, respectively. The alkaline phosphatase activity in soil increased with increasing doses of phosphorus and the highest alkaline phosphatase activity in soil (103.21 µg p-NP g⁻¹ soil hr⁻¹ and 101.03 µg p-NP g⁻¹ soil hr⁻¹ during 2017-18 and 2018-19, respectively) were found with the application of phosphorus @ 60 kg ha⁻¹ (RDF), which was significantly superior over the lower doses of phosphorus application.

Effect of biofertilizers

Alkaline phosphatase activity observed to be increased significantly with application of biofertilizers at peg initiation stage (Table 4.15) and it ranged from 96.37 to 106.50 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ and 92.51 to 101.89 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ in the year 2017-18 and 2018-19, respectively. The alkaline phosphatase activity in soil (106.50 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ and 101.89 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ during 2017-18 and 2018-19, respectively) was found to be significantly superior with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄) indicating thereby its superiority over all other treatments consisting dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃), PSB @ 10 kg ha⁻¹ (B₂), VAM @ 10 kg ha⁻¹ (B₁) and with no biofertilizers (B₀). But, the treatment consisting dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) and PSB @ 10 kg ha⁻¹ (B₂) were at par with each other.

At pod formation stage, the alkaline phosphatase activity was found to be in the range from 124.31 to 138.71 and 125.56 to 137.73 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ in the year 2017-18 and 2018-19, respectively. The alkaline phosphatase activity in soil (138.71 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ and 137.73 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ during 2017-18 and 2018-19, respectively) was found to be significantly superior due to the application of biofertilizers VAM + PSB @ 10 kg ha⁻¹ each (B₄) over all other treatments. However, the dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) and application of PSB @ 10 kg ha⁻¹ (B₂) were found to be at par with each other and was significantly but superior over application of VAM @ 10 kg ha⁻¹ (B₁) and no biofertilizers (B₀).

The variation in soil alkaline phosphatase activity at harvest due to application of biofertilizers in different treatments were observed to be from 84.53 to 94.51 and 83.69 to 92.05 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ in the year 2017-18 and 2018-19, respectively. The alkaline phosphatase activity in soil (94.51 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ and 92.05 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ during 2017-18 and 2018-19, respectively) were found to be significantly superior with the application of VAM + PSB @ 10 kg ha⁻¹ each i.e. (B₄) over all the treatments of biofertilizers application and which was at par with the treatment consisting dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) and application of PSB @ 10 kg ha⁻¹ (B₂) in both the years.

Interaction effect

The interaction effect of different levels of phosphorus and biofertilizers significantly increased the alkaline phosphatase activity at peg initiation stage

presented in Table 4.15 and it ranges from 87.88 to 129.18 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ and 84.37 to 122.58 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ during the year 2017-18 and 2018-19, respectively. The soil alkaline phosphatase activity (129.18 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ and 122.58 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ during the year 2017-18 and 2018-19, respectively) were found to be significantly superior with application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀) in all treatment combinations during both the years.

The alkaline phosphatase activity increased significantly at pod formation and it varied from 113.37 to 171.92 and 114.50 to 164.46 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ during the year 2017-18 and 2018-19, respectively. The highest alkaline phosphatase activity (171.92 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ and 164.46 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ during the year 2017-18 and 2018-19, respectively) were found to be in the treatment combination of phosphorus application @ 60 kg ha⁻¹ alongwith dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀), indicating its superiority of higher dose of phosphorus and biofertilizers combination, which found to be at par with B₂P₆₀ in the year 2018-19.

The interaction effect between graded doses of phosphorus either alone or in combination increased alkaline phosphatase activity significantly at harvest stage or it ranged from 77.09 to 117.68 and 76.32 to 110.44 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ during the year 2017-18 and 2018-19, respectively. Significantly highest alkaline phosphatase activity (117.68 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ and 110.44 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ during the year 2017-18 and 2018-19, respectively) were observed to be in the treatment receiving phosphorus @ 60 kg ha⁻¹ with VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀) during 2017-18 and 2018-19.

The overall results of the alkaline phosphatase activity demonstrated that, the alkaline phosphatase activity increased from peg initiation to pod formation stage and thereafter decreased at harvest stage, which indicated that, the accumulation of P in soil solution and thereby decreasing the production of phosphatase activity. The significantly greater activity of alkaline phosphatase activity in the FYM treated plots may be due to enhanced microbial activity and perhaps diversity of phosphate solubilizing bacteria consequent to manure input. High alkaline phosphatase activity and significantly higher fungal population under legumes than under cereals have been reported for arid soils (Tarafdar *et al.* 1989). Praveen Kumar *et al.* (2007) stated that the increase in alkaline phosphatase activity may be due to a large fungal

population in the rhizosphere. Soil fungi are effective producers of alkaline phosphatase (Tarafdar and Chhonkar 1976).

Bedi *et al.* (2009) reported the increase in alkaline phosphatase activity with the application of fertilizer doses in slightly acidic soil (pH 6.2) of Sirmour, Himachal Pradesh. Increase in alkaline phosphatase activity with the application of urea fertilizer, cow dung manure and green manure over control was reported by Tripathi *et al.* (2009) on silty clay loam soil (pH 6.34) of West Bengal. Mali *et al.* (2015) observed the phosphatase activity to the tune of 96 $\mu\text{g p-NP g}^{-1}$ soil day^{-1} in control plot and from 118 to 194 $\mu\text{g p-NP g}^{-1}$ soil day^{-1} with 50 recommended dose of fertilizer alongwith FYM and recorded significantly highest with 50 per cent RDF and 50 per cent N through FYM in swell-shrink soils of central India. In lateritic soils of Konkan region of Maharashtra, 895.02 to 923.68 $\mu\text{g PNP g}^{-1}$ dry wt hr^{-1} values of alkaline phosphatase activity with the application of P doses (*viz.*, 50, 60 and 70 kg ha^{-1}) and K doses (*viz.*, 30, 40 and 50 kg ha^{-1}) along with the *rhizobium* and PSB inoculation under cowpea at harvest was reported by Mhalshi (2013).

4.1.3.8 Acid phosphatase

Effect of phosphorus

Increasing phosphorus levels from 15 to 60 kg ha^{-1} was associated with significant increase in acid phosphatase activity at peg initiation stage and presented in Table 4.16. The value of it ranged from 52.81 to 66.35 $\mu\text{g p-NP g}^{-1}$ soil hr^{-1} and 50.17 to 63.06 $\mu\text{g p-NP g}^{-1}$ soil hr^{-1} in the year 2017-18 and 2018-19, respectively. The higher dose of phosphorus @ 60 kg ha^{-1} (RDF) registered the highest acid phosphatase activity in soil (66.35 $\mu\text{g p-NP g}^{-1}$ soil hr^{-1} and 63.06 $\mu\text{g p-NP g}^{-1}$ soil hr^{-1} during 2017-18 and 2018-19, respectively), which was significantly superior over the lower doses of phosphorus. The increase in acid phosphatase activity followed the order of $P_{15} < P_{30} < P_{45} < P_{60}$.

The acid phosphatase activity significantly increased with successive dose of added phosphorus at pod formation stage and varied from 78.79 to 99.71 and 80.26 to 100.66 $\mu\text{g p-NP g}^{-1}$ soil hr^{-1} in the year 2017-18 and 2018-19, respectively. Among the different levels of phosphorus, the application of phosphorus @ 60 kg ha^{-1} noted the significantly highest acid phosphatase activity (99.71 $\mu\text{g p-NP g}^{-1}$ soil hr^{-1} and 100.66 $\mu\text{g p-NP g}^{-1}$ soil hr^{-1} during 2017-18 and 2018-19, respectively), which followed the order of $P_{15} < P_{30} < P_{45} < P_{60}$ and showed its superiority over the lower

doses of phosphorus application.

The acid phosphatase activity after crop harvest was in the order of $P_{15} < P_{30} < P_{45} < P_{60}$ and ranged from 40.92 to 51.33 and 38.87 to 49.14 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ in the year 2017-18 and 2018-19, respectively. The highest dose of phosphorus i.e. 60 kg ha^{-1} (RDF) recorded the significantly highest acid phosphatase activity (51.33 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ and 49.14 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ during 2017-18 and 2018-19, respectively), which was found to be significantly superior over the lower doses of phosphorus.

Effect of biofertilizers

Results of acid phosphatase activity at peg initiation stage presented in Table 4.16, revealed that it increased significantly and ranged from 54.95 to 60.44 and 52.20 to 57.53 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ in the year 2017-18 and 2018-19, respectively. The acid phosphatase activity in soil (60.44 and 57.53 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ during 2017-18 and 2018-19, respectively) was found to be significantly superior with dual inoculation of VAM + PSB @ 10 kg ha^{-1} each (B_4) indicating its superiority over all the treatments consisting dual inoculation of VAM + PSB @ 5 kg ha^{-1} each (B_3), PSB @ 10 kg ha^{-1} (B_2), VAM @ 10 kg ha^{-1} (B_1) and with no biofertilizers (B_0). But, the treatment consisting dual inoculation of VAM + PSB @ 5 kg ha^{-1} each (B_3) and PSB @ 10 kg ha^{-1} (B_2) were at par with each other during both the years.

At pod formation stage, the acid phosphatase activity was found to be in the range of 81.87 to 91.22 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ and 83.51 to 91.75 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ in the year 2017-18 and 2018-19, respectively. The acid phosphatase activity in soil (91.22 and 91.75 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ during 2017-18 and 2018-19, respectively) was found to be significantly superior due to application of biofertilizers VAM + PSB @ 10 kg ha^{-1} each (B_4) over all other treatments. However, the dual inoculation of VAM + PSB @ 5 kg ha^{-1} each (B_3) and application of PSB @ 10 kg ha^{-1} (B_2) were found at par with each other and were significantly superior over application of VAM @ 10 kg ha^{-1} (B_1) and no biofertilizers (B_0) application.

The variation in soil acid phosphatase activity at harvest due to application of biofertilizers in different treatments were observed to be from 42.58 to 46.78 and 40.44 and 44.92 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ in the year 2017-18 and 2018-19, respectively. The acid phosphatase activity in soil (46.78 and 44.92 $\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$ during 2017-18 and 2018-19, respectively) was found to be significantly superior with the

application of VAM + PSB @ 10 kg ha⁻¹ each i.e. (B₄) over all other treatments of biofertilizers application and which was at par with the treatment consisting dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) and application of PSB @ 10 kg ha⁻¹ (B₂) in the year 2017-18.

Interaction effect

The interaction effect regarding the application of graded levels of phosphorus in combination with biofertilizers along with recommended dose of N, K and FYM significantly influenced the acid phosphatase activity at peg initiation and it varied from 50.11 to 72.49 and 47.60 to 69.34 µg p-NP g⁻¹ soil hr⁻¹ during the year 2017-18 and 2018-19, respectively. The highest acid phosphatase activity in the soil (72.49 µg p-NP g⁻¹ soil hr⁻¹ and 69.34 µg p-NP g⁻¹ soil hr⁻¹ during the year 2017-18 and 2018-19, respectively) was found in the treatment combination application of phosphorus @ 60 kg ha⁻¹ alongwith dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀), indicating thereby the superiority of higher dose of phosphorus and biofertilizers combination, which found to be at par with B₂P₆₀ in the year 2017-18.

The integration of phosphorus doses and biofertilizers showed significant variation in acid phosphatase activity at pod formation stage (Table 4.16) and ranged from 74.66 to 112.72 µg p-NP g⁻¹ soil hr⁻¹ and 76.16 to 109.77 µg p-NP g⁻¹ soil hr⁻¹ during the year 2017-18 and 2018-19, respectively. Significantly highest acid phosphatase activity (112.72 µg p-NP g⁻¹ soil hr⁻¹ and 109.77 µg p-NP g⁻¹ soil hr⁻¹ during the year 2017-18 and 2018-19, respectively) were observed to be in the treatment receiving phosphorus @ 60 kg ha⁻¹ with VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀), but it was at par with the treatment consisting application of phosphorus @ 60 kg ha⁻¹ with inoculation of PSB @ 10 kg ha⁻¹ (B₂P₆₀) in the year 2018-19.

The application of different levels of phosphorus and biofertilizers increased significantly the acid phosphatase activity at harvest stage and ranged from 38.83 to 55.99 µg p-NP g⁻¹ soil hr⁻¹ and 36.38 to 55.11 µg p-NP g⁻¹ soil hr⁻¹ during the year 2017-18 and 2018-19, respectively. The soil acid phosphatase activity (55.99 and 55.11 µg p-NP g⁻¹ soil hr⁻¹ during the year 2017-18 and 2018-19, respectively), which was found to be significantly superior with application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀) in all treatment combinations in both the year, but found to be at par with application of phosphorus @ 60 kg ha⁻¹ and inoculation of PSB @ 10 kg ha⁻¹ (55.76 µg p-NP g⁻¹ soil hr⁻¹) i.e.

B₂P₆₀ in the year 2017-18.

Analysis of the two years data indicated that, the acid phosphatase activity increased from peg initiation to pod formation stage and thereafter decreased at harvest stage as well as its activity increased with increasing phosphorus levels alongwith inoculation of biofertilizers indicating the positive role of biofertilizers application in increasing acid phosphatase activity. The phosphatase activity strongly influenced by soil pH. Further, added manure amendment like FYM may affect enzyme activities differently depending upon soil characteristics including pH, texture.

Tarafdar *et al.* (1992) concluded that the activities of both acid and alkaline phosphatase was significantly improved over phosphorus application at the lower doses without biofertilizers over initial population in *Camborthid* great group (pH 8.1). 560 µg PNP g⁻¹ dry wt hr⁻¹ acid phosphatase in slightly acidic soil (pH 6.42) of West Bengal was reported by Tripathi *et al.* (2009). In lateritic soils of Konkan region of Maharashtra, 710.52 to 750.12 µg PNP g⁻¹ dry wt hr⁻¹ values of acid phosphatase activity with the application of P doses (*viz.*, 50, 60 and 70 kg ha⁻¹) and K doses (*viz.*, 30, 40 and 50 kg ha⁻¹) along with the *rhizobium* and PSB inoculation under cowpea at harvest was reported by Mhalshi (2013).

4.1.3.9 Soil Microbial biomass carbon

Effect of phosphorus

Graded doses of phosphorus significantly influenced the soil microbial biomass carbon (SMBC) at peg initiation (Table 4.17) and it ranged from 180.07 to 198.46 ug g⁻¹ soil and 178.28 to 196.50 ug g⁻¹ soil in the year 2017-18 and 2018-19, respectively. The SMBC in soil increased with increasing doses of phosphorus and the highest SMBC (198.46 ug g⁻¹ soil and 196.50 ug g⁻¹ soil during 2017-18 and 2018-19, respectively) was found with the application of phosphorus @ 60 kg ha⁻¹ (RDF), which was significantly superior over the lower doses of phosphorus application. The increase in SMBC followed the order of P₁₅ < P₃₀ < P₄₅ < P₆₀.

The soil microbial biomass carbon at pod formation stage ranged from 219.61 to 243.21 ug g⁻¹ soil and 221.81 to 244.32 ug g⁻¹ soil in the year 2017-18 and 2018-19, respectively. There was graded increase in SMBC with the graded doses of phosphorus and followed the order of P₁₅ < P₃₀ < P₄₅ < P₆₀. The highest dose of

phosphorus i.e. 60 kg ha⁻¹ (RDF) recorded the significantly highest SMBC (243.21 and 244.32 ug g⁻¹ soil during 2017-18 and 2018-19, respectively), which was found to be significantly superior over the lower doses of phosphorus.

At harvest of groundnut, the application of graded doses of phosphorus increased SMBC significantly and varied from 162.51 to 179.11 ug g⁻¹ soil and 167.38 to 184.46 ug g⁻¹ soil in the year 2017-18 and 2018-19, respectively. Among the different levels of phosphorus, the application of phosphorus @ 60 kg ha⁻¹ noted the significantly highest SMBC content (179.11 ug g⁻¹ soil and 184.46 ug g⁻¹ soil during 2017-18 and 2018-19, respectively) which followed the order of P₁₅ < P₃₀ < P₄₅ < P₆₀ and showed its superiority over the lower doses of phosphorus application.

Effect of biofertilizers

The variation in soil SMBC at peg initiation stage presented in Table 4.17 due to application of biofertilizers in different treatments were observed to be from 179.48 to 190.56 ug g⁻¹ soil and 177.55 to 188.94 ug g⁻¹ soil in the year 2017-18 and 2018-19, respectively. The SMBC in soil (190.56 ug g⁻¹ soil and 188.94 ug g⁻¹ soil during 2017-18 and 2018-19, respectively) was found to be significantly superior with the application of VAM + PSB @ 10 kg ha⁻¹ each i.e. (B₄) over all the treatments of biofertilizers application. The treatment consisting dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) and application of PSB @ 10 kg ha⁻¹ (B₂) in the year 2017-18 were at par with each other. However, dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) and application of PSB @ 10 kg ha⁻¹ (B₂) found to be superior over application of VAM @ 10 kg ha⁻¹ (B₁) and no biofertilizers (B₀) and at par with each other in the both the years.

At pod formation stage, the soil microbial biomass carbon found to range from 218.68 to 234.42 ug g⁻¹ soil and 220.87 to 235.38 ug g⁻¹ soil in the year 2017-18 and 2018-19, respectively. The SMBC in soil (234.42 ug g⁻¹ soil and 235.38 ug g⁻¹ soil during 2017-18 and 2018-19, respectively) was found to be significantly superior due to the application of biofertilizers VAM + PSB @ 10 kg ha⁻¹ each (B₄) over all other treatments. However, the dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) and application of PSB @ 10 kg ha⁻¹ (B₂) were found to be at par with each other and both the treatments were significantly superior over application of VAM @ 10 kg ha⁻¹ (B₁) and no biofertilizers (B₀) application during both the years.

An alone or dual inoculation of biofertilizers had significant effect on the soil

SMBC at harvest stage and it ranged from 163.48 to 171.52 ug g^{-1} soil and 166.68 to 177.74 ug g^{-1} soil in the year 2017-18 and 2018-19, respectively. The SMBC in soil (171.52 ug g^{-1} soil and 177.74 ug g^{-1} soil during 2017-18 and 2018-19, respectively) was found to be significantly superior with dual inoculation of VAM + PSB @ 10 kg ha^{-1} each (B_4) indicating its superiority over all the treatments consisting dual inoculation of VAM + PSB @ 5 kg ha^{-1} each (B_3), PSB @ 10 kg ha^{-1} (B_2), VAM @ 10 kg ha^{-1} (B_1) and with no biofertilizers (B_0). But, the treatment consisting dual inoculation of VAM + PSB @ 5 kg ha^{-1} each (B_3) and PSB @ 10 kg ha^{-1} (B_2) were at par with each other during both the years.

Interaction effect

The interaction effect between graded doses of phosphorus alone or in combination increased SMBC significantly at peg initiation stage and it ranged from 173.06 to 213.64 ug g^{-1} soil and 171.33 to 211.61 ug g^{-1} soil during the year 2017-18 and 2018-19, respectively. Significantly highest SMBC (213.64 and 211.61 ug g^{-1} soil during the year 2017-18 and 2018-19, respectively) were observed to be in the treatment receiving phosphorus @ 60 kg ha^{-1} with VAM + PSB @ 10 kg ha^{-1} each (B_4P_{60}), but it was at par with the treatment consisting application of phosphorus @ 60 kg ha^{-1} with inoculation of PSB @ 10 kg ha^{-1} (B_2P_{60}) during both the years.

The SMBC increased significantly at pod formation stage (Table 4.17) and it varied from 211.05 to 266.73 ug g^{-1} soil and 213.16 to 262.76 ug g^{-1} soil during the year 2017-18 and 2018-19, respectively. The highest SMBC (266.73 ug g^{-1} soil and 262.76 ug g^{-1} soil during the year 2017-18 and 2018-19, respectively) was found in the treatment combination of phosphorus application @ 60 kg ha^{-1} alongwith dual inoculation of VAM + PSB @ 10 kg ha^{-1} each (B_4P_{60}), indicating thereby its superiority of higher dose of phosphorus and biofertilizers combination, which found to be at par with B_2P_{60} in the year 2018-19.

The application of different levels of phosphorus and biofertilizers significantly increased the SMBC at harvest stage and ranges from 156.17 to 192.96 and 160.86 to 198.64 ug g^{-1} soil during the year 2017-18 and 2018-19, respectively. The soil SMBC (192.96 ug g^{-1} soil and 198.64 ug g^{-1} soil during the year 2017-18 and 2018-19, respectively) was found to be significantly superior with application of phosphorus @ 60 kg ha^{-1} with dual inoculation of VAM + PSB @ 10 kg ha^{-1} each (B_4P_{60}) over all other treatment combinations, but found to be at par with application

of phosphorus @ 60 kg ha⁻¹ and inoculation of PSB @ 10 kg ha⁻¹ (B₂P₆₀) during the year 2017-18 and 2018-19.

Examination of the two years data indicated that, the SMBC increased from peg initiation to pod formation stage and thereafter decreased at harvest stage. SMBC-Build up is mainly due to the microbial biomass content in the organic residues and the addition of substrate carbon, which stimulate the indigenous soil micro-biota. The data on microbial biomass carbon presented in Table 21 further indicated that microbial biomass carbon increased with increasing phosphorus levels, which were again increased with the application of biofertilizers indicating the positive role of biofertilizers application in increasing microbial biomass carbon. Further, Neha *et al.* (2019) reported that, the soil microbial biomass carbon ranges from 107.9 ug g⁻¹ soil to 312.3 ug g⁻¹ soil with different *rhizobium* isolates and 87.9 ug g⁻¹ soil in uninoculated or control plot under urdbean on sandy loam soils of Dehradun (Uttarakhand) having pH 6.9.

Nath *et al.* (2012) reported increase in microbial biomass carbon with the application of biofertilizers in the soils of Assam. In lateritic soils of Konkan region of Maharashtra, 72 mg kg⁻¹ to 160 mg kg⁻¹ with a mean value of 115.60 mg kg⁻¹ values of SMBC with the application of P doses (*viz.*, 50, 60 and 70 kg ha⁻¹) and K doses (*viz.*, 30, 40 and 50 kg ha⁻¹) along with the *rhizobium* and PSB inoculation under cowpea at harvest was reported by Mhalshi (2013). The values of soil microbial biomass carbon from 181.93 to 209.42 ug g⁻¹ soil were reported under mustard crop in lateritic soils of Konkan region of Maharashtra (Anonymous, 2019).

Lalande *et al.* (2000) also noted that manure input resulted in higher MBC than inorganic fertilization over control. A gradual increase in soil microbial biomass carbon with the application of NPK from 50 to 150 per cent of NPK was observed by Selvi *et al.* (2004).

4.1.3.10 Soil Microbial biomass Nitrogen

Effect of phosphorus

The soil microbial biomass nitrogen (SMBN) significantly increased with successive doses of phosphorus at peg initiation stage (Table 4.18) and varied from 32.50 to 36.02 ug g⁻¹ soil and 32.18 to 35.43 ug g⁻¹ soil in the year 2017-18 and 2018-19, respectively. Within the different levels of phosphorus, the application of phosphorus @ 60 kg ha⁻¹ noted the significantly highest SMBN (36.02 ug g⁻¹ soil and

35.43 ug g⁻¹ soil during 2017-18 and 2018-19, respectively), which showed its superiority over the lower doses of phosphorus and followed the order of P₁₅ < P₃₀ < P₄₅ < P₆₀.

The SMBN was found to be graded and in the order of P₁₅ < P₃₀ < P₄₅ < P₆₀ at pod formation stage, varied from 39.14 to 43.35 and 41.69 to 46.06 ug g⁻¹ soil in the year 2017-18 and 2018-19, respectively. The highest dose of phosphorus i.e. 60 kg ha⁻¹ (RDF) recorded the significantly highest SMBN (43.35 and 46.06 ug g⁻¹ soil during 2017-18 and 2018-19, respectively), which was found to be significantly superior over the lower doses of phosphorus.

The SMBN increased progressively and significantly with each successive doses of phosphorus at harvest and ranged from 32.33 to 36.19 ug g⁻¹ soil and 33.29 to 36.78 ug g⁻¹ soil in the year 2017-18 and 2018-19, respectively. The highest SMBN in soil (36.19 ug g⁻¹ soil and 36.78 ug g⁻¹ soil during 2017-18 and 2018-19, respectively) was found with the application of phosphorus @ 60 kg ha⁻¹ (RDF), which was significantly superior over the lower doses of phosphorus and followed the order of P₁₅ < P₃₀ < P₄₅ < P₆₀

Effect of biofertilizers

The SMBN tended to increase significantly with application of biofertilizers at peg initiation stage, which ranged from 32.36 to 34.65 ug g⁻¹ soil and 32.04 to 34.17 ug g⁻¹ soil in the year 2017-18 and 2018-19, respectively. The SMBN in soil (34.65 ug g⁻¹ soil and 34.17 ug g⁻¹ soil during 2017-18 and 2018-19, respectively) was found to be significantly superior due to the application of biofertilizers VAM + PSB @ 10 kg ha⁻¹ each (B₄) over all other treatments. However, the dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) and application of PSB @ 10 kg ha⁻¹ (B₂) were found to be at par with each other and were significantly superior over application of VAM @ 10 kg ha⁻¹ (B₁) and no biofertilizers (B₀) application.

Application of biofertilizers significantly influenced SMBN due to inoculation of biofertilizers either or in combination at pod formation stage and found in between 38.93 to 41.72 ug g⁻¹ soil and 41.51 to 44.76 ug g⁻¹ soil during the year 2017-18 and 2018-19, respectively. The SMBN in soil (41.72 and 44.76 ug g⁻¹ soil during 2017-18 and 2018-19, respectively) was found to be significantly superior with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄) indicating its superiority over all other treatments. The treatments consisting dual inoculation of VAM + PSB

@ 5 kg ha⁻¹ each (B₃), PSB @ 10 kg ha⁻¹ (B₂), VAM @ 10 kg ha⁻¹ (B₁) and with no biofertilizers (B₀) application. However, the treatment consisting dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) and PSB @ 10 kg ha⁻¹ (B₂) were at par with each other in both the years.

The variation in soil SMBN at harvest (Table 4.18) due to application of biofertilizers in different treatments were observed to be from 32.31 to 34.56 and 33.15 to 35.48 ug g⁻¹ soil in the year 2017-18 and 2018-19, respectively. Application of VAM + PSB @ 10 kg ha⁻¹ each i.e. (B₄) registered the highest SMBN in soil (34.56 ug g⁻¹ soil and 35.48 ug g⁻¹ soil during 2017-18 and 2018-19, respectively) which was found to be significantly superior over all other treatments of biofertilizers application. However, dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) and application of PSB @ 10 kg ha⁻¹ (B₂) were found to be at par with each other and were superior over application of VAM @ 10 kg ha⁻¹ (B₁) and no biofertilizers (B₀) in both the years.

Interaction effect

The integration of graded doses of phosphorus and biofertilizers showed significant variation in SMBN at peg initiation stage and it ranged from 31.23 to 39.62 ug g⁻¹ soil and 30.92 to 38.08 ug g⁻¹ soil during the year 2017-18 and 2018-19, respectively. Significantly highest SMBN i.e. 39.62 ug g⁻¹ soil and 38.08 ug g⁻¹ soil during the year 2017-18 and 2018-19, respectively was recorded in the treatment receiving phosphorus @ 60 kg ha⁻¹ with VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀), which was found to be at par with the treatment consisting application of phosphorus @ 60 kg ha⁻¹ with inoculation of PSB @ 10 kg ha⁻¹ (B₂P₆₀) in the year 2018-19.

The SMBN increased significantly at pod formation and presented in Table 4.18, which varied from 36.23 to 46.76 ug g⁻¹ soil and 40.06 to 50.07 ug g⁻¹ soil during the year 2017-18 and 2018-19, respectively. The highest SMBN (46.76 ug g⁻¹ soil and 50.07 ug g⁻¹ soil during the year 2017-18 and 2018-19, respectively) was found due to the treatment combination of phosphorus application @ 60 kg ha⁻¹ alongwith dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀), indicating its superiority of higher dose of phosphorus and dual inoculation of biofertilizers and were found to be at par with B₂P₆₀ in the year 2017-18.

Integrated use of graded doses of phosphorus and biofertilizers had significant effect on SMBN at harvest stage and it ranged from 30.61 to 39.86 ug g⁻¹ soil and

32.00 to 39.97 $\mu\text{g g}^{-1}$ soil during 2017-18 and 2018-19, respectively. The higher values of SMBN (39.86 $\mu\text{g g}^{-1}$ soil and 39.97 $\mu\text{g g}^{-1}$ soil during 2017-18 and 2018-19, respectively) in the treatment receiving application of phosphorus @ 60 kg ha^{-1} with dual inoculation of VAM + PSB @ 10 kg ha^{-1} each (B_4P_{60}) was found significantly superior over all other treatment combinations in both the years.

26.11 to 40.81 $\mu\text{g g}^{-1}$ soil microbial biomass nitrogen were reported in lateritic soils of Konkan region of Maharashtra under mustard crop (Anonymous, 2019). The results are in confirmation with Meshram *et al.* (2016) under soybean-safflower cropping system in Vertisol soil order.

Analysis of the two years data indicated that, the SMBN increased from peg initiation to pod formation stage and thereafter decreased at harvest stage. The MBN was significantly influenced with application of FYM over treatment receiving inorganic fertilization, as FYM is not only rich in C, but also in N and other macro and micronutrients. But, the availability of nutrients to crop from FYM is generally lower than N from inorganic fertilizers because of the slow release or organically bound N.

Manure addition causing high MBN than inorganic alone was reported by Lalande *et al.* (2000). Selvi *et al.* (2004) reported that the application of FYM @ 10 t ha^{-1} to finger millet annually alongwith 100 per cent NPK recorded the highest bacterial count at the end of rotation followed by 150 per cent NPK. There was a gradual increase in biomass C and N content of the soil at the graded levels of NPK from 50 to 150 per cent. The integration of FYM with optimal NPK increased the biomass C and N by 16 and 28 per cent, respectively over optimal NPK.

The values of soil microbial biomass nitrogen reported here are in conformity with Bedi *et al.* (2009) in slightly acidic soil (pH 6.2) of Himachal Pradesh. Rana *et al.* (2015) reported that the soil microbial biomass carbon, dehydrogenase activity, alkaline phosphatase and acid phosphatase activity increased significantly from 45 DAS to harvest due to inoculation of endophytic bacteria with *mesorhizobium* sp. in chickpea crop.

4.2 Effect of different levels of phosphorus and biofertilizers on available nutrient status

4.2.1 Available Macronutrients

4.2.1.1 Soil Available Nitrogen

Effect of phosphorus

The application of phosphorus during peg initiation stage (Table 4.19) was found to be non-significant on soil available nitrogen content and it ranged from 293.75 to 318.99 kg ha⁻¹ and 335.51 to 365.38 kg ha⁻¹ in the year 2017-18 and 2018-19, respectively. The highest soil available nitrogen (318.99 and 365.38 kg ha⁻¹ during 2017-18 and 2018-19, respectively) content was recorded due to application of phosphorus @ 30 kg ha⁻¹ and was observed lowest (293.75 and 333.51 kg ha⁻¹ during the year 2017-18 and 2018-19, respectively) with the application of phosphorus @ 15 kg ha⁻¹.

The non-significant effect on soil available nitrogen content at pod formation stage, was noticed with the application of phosphorus and it varied from 355.72 to 366.39 kg ha⁻¹ and 369.42 to 380.40 kg ha⁻¹ in the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 15 kg ha⁻¹ (366.39 and 380.40 kg ha⁻¹ during 2017-18 and 2018-19, respectively) was recorded the highest soil available nitrogen content, while application of phosphorus @ 30 kg ha⁻¹ (355.72 kg ha⁻¹ and 369.42 kg ha⁻¹ during 2017-18 and 2018-19, respectively) i.e. P₃₀ showed the lowest available nitrogen content in the soil.

At harvest of the crop, the soil available nitrogen content ranged from 329.32 to 357.53 kg ha⁻¹ and 266.26 to 289.70 kg ha⁻¹ in the year 2017-18 and 2018-19, respectively, but could not reach the level of significance due to application of phosphorus. The highest value (357.53 kg ha⁻¹ and 289.70 kg ha⁻¹ during 2017-18 and 2018-19, respectively) was observed due to application of phosphorus @ 45 kg ha⁻¹ and the lowest (329.32 kg ha⁻¹ and 266.26 kg ha⁻¹ during 2017-18 and 2018-19, respectively) were observed by application of phosphorus @ 15 kg ha⁻¹.

Effect of biofertilizers

The inoculation of biofertilizers did not influenced significantly on soil available nitrogen content at peg initiation stage, which varied from 290.28 to 319.85 and 331.58 to 366.52 kg ha⁻¹ in the year 2017-18 and 2018-19, respectively. The numerically highest value (319.85 kg ha⁻¹ and 366.52 kg ha⁻¹ during 2017-18 and

2018-19, respectively) of the soil available nitrogen was recorded by the inoculation of VAM + PSB @ 10 kg ha⁻¹ each and the lowest (290.28 kg ha⁻¹ and 331.58 kg ha⁻¹ during 2017-18 and 2018-19, respectively) was recorded due to no biofertilizers application (B₀) application.

The alone or dual inoculation of biofertilizers was not affected significantly on soil available nitrogen presented in Table 4.19 and it ranged from 357.27 to 371.47 and 370.83 to 386.12 kg ha⁻¹ in the pod formation stage in the year 2017-18 and 2018-19, respectively. The inoculation of VAM + PSB @ 5 kg ha⁻¹ each (371.47 and 386.12 kg ha⁻¹ during 2017-18 and 2018-19, respectively) showed the highest value of soil available nitrogen and lowest was observed in the treatment consisting no biofertilizers application i.e. B₀ (357.27 kg ha⁻¹ and 370.83 kg ha⁻¹ during 2017-18 and 2018-19, respectively).

At harvest of the crop, the inoculation of biofertilizers alone or in combination showed the significant effect on soil available nitrogen content and it varied from 315.56 to 365.82 kg ha⁻¹ and 255.55 to 295.78 kg ha⁻¹ in the year 2017-18 and 2018-19, respectively. The treatment with no biofertilizers application i.e. (B₀) (365.82 and 295.78 kg ha⁻¹ during 2017-18 and 2018-19, respectively) was found to be significantly superior over B₂ treatment consisting application of PSB @ 10 kg ha⁻¹ (339.86 kg ha⁻¹) and B₃ consisting dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (315.56 kg ha⁻¹) and it was found to be at par with B₁ (348.49 kg ha⁻¹) and B₄ (348.49 kg ha⁻¹) treatments in the year 2017-18. In the year 2018-19, the treatment consisting no biofertilizers application i.e. B₀ (295.78 kg ha⁻¹) was found to be significantly superior in respect of available nitrogen content of soil which was at par with B₁ (282.20 kg ha⁻¹), B₄ (282.18 kg ha⁻¹) and B₂ (275.44 kg ha⁻¹) treatments and were significantly superior over B₃ treatment (255.55 kg ha⁻¹).

Interaction effect

The application of phosphorus and the inoculation of biofertilizers indicated the significant effect on soil available nitrogen in the peg initiation stage (Table 4.19) and it ranged from 242.32 to 376.82 kg ha⁻¹ and 277.54 to 432.77 kg ha⁻¹ in the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 45 kg ha⁻¹ alongwith VAM @ 10 kg ha⁻¹ i.e. B₁P₄₅ (376.82 kg ha⁻¹ and 432.77 kg ha⁻¹ during 2017-18 and 2018-19, respectively) was found to be significantly superior over all other except the treatments comprising B₄P₃₀, B₀P₆₀, B₁P₆₀ in the year 2017-18 and treatment B₄P₃₀ in the year 2018-19 which were at par with each other.

In pod formation stage, the interaction effect was found to be significant in respect of soil available nitrogen content and it varied from 334.60 to 410.54 kg ha⁻¹ and 348.10 to 426.50 kg ha⁻¹ in the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 45 kg ha⁻¹ alongwith dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (i.e. B₃P₄₅) (410.54 kg ha⁻¹ and 426.50 kg ha⁻¹ during 2017-18 and 2018-19, respectively) was found to be significantly superior over all other treatments during the year 2017-18. However, it (B₃P₄₅) was at par with treatment combinations B₄P₁₅, B₀P₁₅, B₂P₁₅, B₁P₃₀, B₄P₆₀ and B₃P₆₀ in the year 2018-19.

At harvest of the crop, the application of phosphorus and inoculation of biofertilizers showed the significant effect on soil available nitrogen and it ranged from 283.81 to 401.41 kg ha⁻¹ and 229.64 to 325.14 kg ha⁻¹ in the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 30 kg ha⁻¹ and inoculation of VAM @ 10 kg ha⁻¹ (i.e. B₁P₃₀) (401.41 kg ha⁻¹ and 325.14 kg ha⁻¹) was found to be significantly superior over other remaining treatments except treatments B₂P₄₅, B₀P₄₅, B₀P₃₀, B₀P₁₅, B₄P₁₅ and B₄P₆₀ in the year 2017-18 and B₂P₄₅, B₀P₄₅, B₀P₃₀, B₄P₁₅, B₀P₁₅, B₄P₆₀, B₁P₆₀ and B₁P₄₅ in the year 2018-19.

It was surprising to note that the application of phosphorus @ 45 kg ha⁻¹ and application of phosphorus @ 30 kg ha⁻¹ alongwith inoculation of VAM maintained the available nitrogen in soil sufficiently at higher level even after harvest of the crop, which indicates the slow and steady release of nitrogen, which is essential for sustaining soil fertility and productivity.

The ranges of soil available nitrogen reported here indicated that available nitrogen in the soil was in “medium” to “moderately high” as per the ranges proposed by Bangar and Zende (1978). In general, the content of available nitrogen in lateritic

soil ranges from low to moderately high and the values vary between 149 to 674 kg ha⁻¹ (Anonymous 1990).

Close scrutiny of the data indicated that, the soil available nitrogen increased at peg initiation stage over its initial values 235.20 and 196.00 kg ha⁻¹ during 2017-18 and 2018-19, respectively irrespective of treatments. Further, available nitrogen tended to increase at pod formation stage over peg initiation stage, which later decreased at harvest. The increase in available nitrogen might be attributed to enzymatic hydrolysis of organic phosphate and also remobilization of fixed phosphate that had been added initially in a soluble form, consequently increased P availability might help in better nodulation and nitrogen fixation, thus increasing the availability of N in soil. Such findings were also reported by (Nirmalnath and Badnur 2001). The major losses of N from the soil are due to crop removal and leaching; however, under certain conditions inorganic N ions can be converted to gases and lost to the atmosphere (Tisdale 1995).

In this connection, Bodkhe *et al.* (2014) clearly indicated that the legume cropping helped to increase the available nitrogen content of the soil. This might be attributed to nitrogen fixation by the groundnut crop. Besides this, the increase in available nitrogen might also be attributed to the greater multiplication of soil microbes, which converts organically bound N to inorganic form.

There was initial enhancement in available nitrogen in soil up to pod formation stage with the application of biofertilizers alone or in different combination with the exception of few. This increase in available N in soil may be attributed to improvement in nodulation and N₂ fixation following inoculation as reported by Bhatta and Chandra (2014). Dual inoculation of biofertilizers further depleted available nitrogen in soil at harvest of the crop due to enhanced exploration of soil reserve nutrients, which may be ascribed to synergistic interactions between VAM and PSB leading to better nutrient dynamism in soil-plant continuum (Suri and Choudhary 2013).

Further, Sandhya *et al.* (2013) reported that the mycorrhizal fungi may contribute to an increased nitrogen status in the mycorrhizosphere by decomposing organic nitrogen compounds. This activity might be accelerated in presence of phosphate solubilizing bacteria, which could be the reason for more soil N content in dual inoculated plants. Elevated availability of soil available nitrogen with different

doses of phosphorus could be attributed to greater biological nitrogen fixation with adequate P supply (Geetha *et al.* 2018). Solanki *et al.* (2018) significantly recorded the highest available nitrogen content with application of higher dose of phosphorus (50 kg ha^{-1}), sulphur (50 kg ha^{-1}) alongwith inoculation of PSB after harvest of Indian mustard crop.

In lateritic soils of Konkan, Gengaje (2013) and Mhalshi (2013) observed increase in available nitrogen with the dual inoculation of *rhizobium* and PSB with different levels of phosphorus under groundnut (*viz.*, 25 and 50 kg ha^{-1}) and cowpea (*viz.*, 50, 60 and 70 kg ha^{-1}), respectively. Choudhary *et al.* (2011) recorded significantly higher available nitrogen 164.1 kg ha^{-1} with the application of $25 \text{ kg N} + 50 \text{ kg P}_2\text{O}_5 + 40 \text{ kg K}_2\text{O ha}^{-1}$ along with *Rhizobium*, VAM and PSB on loamy sand soil of Ghatolia (Kalakh), Jobner in Jaipur district of Rajasthan having pH 8.15 under groundnut crop.

4.2.1.2 Soil available phosphorus

Effect of phosphorus

Soil available phosphorus varied from 10.64 to 14.46 kg ha^{-1} and 14.80 to 19.37 kg ha^{-1} in the year 2017-18 and 2018-19, respectively as influenced by the application of graded doses of phosphorus during peg initiation stage, presented in Table 4.20. There were no specific trends was observed in available phosphorus to the graded doses of it and as a result of it the significantly superior and highest available phosphorus content was found with application of phosphorus @ 30 kg ha^{-1} during 2017-18 (i.e. 14.46 kg ha^{-1}) and with application @ 45 kg ha^{-1} during 2018-19 (i.e. 19.37 kg ha^{-1}). The increase in available phosphorus followed the order of $P_{60} < P_{15} < P_{45} < P_{30}$ during 2017-18 and of $P_{60} < P_{15} < P_{30} < P_{45}$ during 2018-19.

Application of graded doses of phosphorus as influenced available phosphorus at pod formation ranged from 15.33 to 16.67 kg ha^{-1} and 15.60 to 16.96 kg ha^{-1} in the year 2017-18 and 2018-19, respectively, but the variations was not statistically significant and showed the order of $P_{30} < P_{45} < P_{60} < P_{15}$. The highest soil available phosphorus content (16.67 kg ha^{-1} and 16.96 kg ha^{-1} during 2017-18 and 2018-19, respectively) was found in the treatment receiving phosphorus @ 15 kg ha^{-1} , while the lowest available phosphorus (15.33 kg ha^{-1} and 15.60 kg ha^{-1} during the year 2017-18 and 2018-19, respectively) was recorded with application of phosphorus @ 30 kg ha^{-1} .

Increasing phosphorus level from 15 to 60 kg ha⁻¹ was associated with significant increase in available phosphorus content at harvest stage, which varied from 16.24 to 19.97 kg ha⁻¹ and 13.51 to 16.63 kg ha⁻¹ in the year 2017-18 and 2018-19, respectively. Application of phosphorus @ 60 kg ha⁻¹ registered significantly highest available phosphorus (16.63 kg ha⁻¹ and 19.97 kg ha⁻¹ during 2017-18 and 2018-19, respectively) which was at par with the dose of phosphorus @ 30 kg ha⁻¹ and these two treatments were found to be significantly superior over application of phosphorus @ 45 kg ha⁻¹ and @ 15 kg ha⁻¹. The increase in available phosphorus followed the order of P₁₅ < P₄₅ < P₃₀ < P₆₀.

Effect of biofertilizers

The inoculation of biofertilizers alone or in combination had significant effect on soil available phosphorus at peg initiation stage and it ranged from 10.88 to 15.42 and 14.12 to 20.84 kg ha⁻¹ during 2017-18 and 2018-19, respectively. Among the biofertilizers inoculation of PSB @ 10 kg ha⁻¹ (B₂) exhibited higher soil available phosphorus content (15.42 kg ha⁻¹ and 20.84 kg ha⁻¹ during 2017-18 and 2018-19, respectively), which was significantly superior over all other treatments of biofertilizers application and followed the increasing order of B₃ < B₄ < B₀ < B₁ < B₂.

The data presented in Table 4.20, of soil available phosphorus as influenced by inoculation of biofertilizers at pod formation stage increased significantly and varied from 14.87 to 17.57 kg ha⁻¹ and 15.13 to 17.86 kg ha⁻¹ during the year 2017-18 and 2018-19, respectively. The application of VAM + PSB @ 10 kg ha⁻¹ each registered significantly higher soil available phosphorus content (17.57 kg ha⁻¹ and 17.86 kg ha⁻¹ during 2017-18 and 2018-19, respectively) as compared to the other treatments and found to be significantly superior and it followed increasing order of B₂ < B₁ < B₃ < B₀ < B₄.

The application of biofertilizers alone or in combination showed non-significant effect on soil available phosphorus during harvest stage and it ranged from 16.77 to 19.15 kg ha⁻¹ and 13.96 to 16.25 kg ha⁻¹ in the year 2017-18 and 2018-19, respectively. The higher magnitude (19.15 kg ha⁻¹ and 16.25 kg ha⁻¹) of soil available phosphorus was observed with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each and the lowest soil available phosphorus (16.77 kg ha⁻¹ and 13.96 kg ha⁻¹) were recorded with inoculation of VAM @ 10 kg ha⁻¹ in all other treatments.

Interaction effect

The data regarding the effects of different levels of phosphorus and biofertilizers are presented in Table 25, which showed that the soil available phosphorus at peg initiation stage varied from 7.63 to 18.40 kg ha⁻¹ and 10.61 to 25.52 kg ha⁻¹ during 2017-18 and 2018-19, respectively. The soil available phosphorus (18.40 kg ha⁻¹ and 25.52 kg ha⁻¹ during 2017-18 and 2018-19, respectively) was found to be significantly superior with application of phosphorus @ 30 kg ha⁻¹ alongwith individual inoculation of PSB @ 10 kg ha⁻¹ (B₂P₃₀) over all other treatment combinations and which was found to be at par with application of phosphorus @ 30 kg ha⁻¹ with inoculation of VAM @ 10 kg ha⁻¹ (B₁P₃₀) in the year 2017-18.

Integration of phosphorus and biofertilizers significantly increased soil available phosphorus content at pod formation stage and it varied from 11.72 to 18.13 and 11.90 to 18.43 kg ha⁻¹ in the year 2017-18 and 2018-19, respectively. Application of phosphorus @ 30 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₃₀) recorded significantly highest soil available phosphorus (18.13 kg ha⁻¹ and 18.43 kg ha⁻¹ during 2017-18 and 2018-19, respectively), which was found to statistically at par with B₄P₁₅, B₂P₁₅, B₀P₃₀, B₄P₆₀, B₄P₄₅, B₃P₆₀, B₃P₄₅, B₁P₁₅ and B₀P₁₅ treatment combinations and was statistically superior over rest of the treatment combinations in the year 2017-18 and 2018-19.

The data on soil available phosphorus (Table 4.20) as influenced by different levels of phosphorus and biofertilizers at harvest ranged from 13.73 to 24.58 kg ha⁻¹ and 11.47 to 20.39 kg ha⁻¹ during the year 2017-18 and 2018-19, respectively. The significantly highest soil available phosphorus (24.58 and 20.39 kg ha⁻¹ during 2017-18 and 2018-19, respectively) was found with application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃P₆₀) and was found to be at par with B₄P₆₀ and B₂P₃₀ in the year 2017-18 and B₄P₆₀, B₂P₃₀ and B₄P₁₅ in the year 2018-19.

The value of soil available phosphorus ranged from (0.35 to 74.14 kg ha⁻¹) in lateritic soils of Konkan region (Anonymous 1990). The preponderance of less active (reductant phosphorus and occluded phosphorus) and inactive (residual phosphorus) phosphorus fractions over active phosphorus fractions, dominance of iron phosphorus over aluminum phosphorus, low concentration of solid phosphorus and high

phosphorus fixing capacity of soils are some of the important reasons for low phosphorus availability in lateritic soils of Konkan (Dongale, 1989 and Anonymous, 1990).

It was indicated that, the soil available phosphorus increased at peg initiation stage over its initial values 7.428 and 9.874 kg ha⁻¹ during 2017-18 and 2018-19, respectively irrespective of treatments. Further, available phosphorus tended to increase at pod formation stage over peg initiation stage, which later decreased at harvest. Incorporation of FYM along with inorganic P increases the availability of P is attributed to reduction in fixation of water soluble P, increased mineralization of organic P due to microbial action and enhanced mobility of P. The efficiency of FYM in increasing the P availability is attributed to its power to chelate phosphate-fixing cations (Fe³⁺ and Al³⁺) and reduced phosphate sorption with low bonding energy and exchange of adsorbed PO₄³⁻ by organic anions (Sharma and Tripathi 1999). The increase in phosphorus availability might be also due to synergistic effect of N with phosphorus and potassium, which increased the availability of P in the soil as reported by Shrivastava (2002).

The decrease of available phosphorus at harvest stage over the pod formation stage may be due to enhanced exploration of soil reserve nutrients which may be ascribed to synergistic interactions between VAM and PSB leading to better nutrient dynamisms in soil-plant continuum (Suri *et al.* 2013). The decreases of available phosphorus may also be due to the uptake of P₂O₅ by plants, which usually takes place intensively after flowering.

Kadam *et al.* (2008) in their experiment on effect of water soluble phosphatic fertilizers with and without biofertilizers on chemical properties of soil observed that application of water soluble phosphatic fertilizers along with FYM and biofertilizers resulted in higher recovery than their alone application. Sutaria *et al.* (2010) revealed that the application of FYM @ 10 t ha⁻¹ and phosphorus @ 20 kg P₂O₅ ha⁻¹ every year to groundnut crop improved NPK and maintained soil fertility.

In lateritic soils of Konkan, Gengaje (2013) and Mhalshi (2013) observed increase in available phosphorus with the dual inoculation of *rhizobium* and PSB with different levels of phosphorus under groundnut (*viz.*, 25 and 50 kg ha⁻¹) and cowpea (*viz.*, 50, 60 and 70 kg ha⁻¹), respectively. Similar results were reported by Nadeem *et al.* (2018) with 40 kg ha⁻¹ phosphorus in combination with *Rhizobium*;

Solanki *et al.* (2018) with phosphorus @ 50 kg ha⁻¹ alongwith PSB and Choudhary *et al.* (2011) with 50 kg P₂O₅ + *Rhizobium*, VAM and PSB in combination.

4.2.1.3 Soil available potassium

Effect of phosphorus

The data in respect of the available potassium content in soil are presented in Table 4.21. It was observed that the soil available potassium tended to increase significantly with application of different doses of phosphorus at peg initiation stage and it ranged from 391.55 to 453.02 kg ha⁻¹ and 250.99 to 294.61 kg ha⁻¹ in the year 2017-18 and 2018-19, respectively. The available potassium content in soil was to the tune of 453.02 kg ha⁻¹ and 294.61 kg ha⁻¹ during 2017-18 and 2018-19, respectively which was found to be significantly superior with the application of phosphorus @ 60 kg ha⁻¹ over all other treatments. Further, the application of phosphorus @ 30 kg ha⁻¹ and @ 15 kg ha⁻¹ was found to be at par with each other in both the years. Phosphorus @ 45 kg ha⁻¹ (391.55 kg ha⁻¹ and 250.99 kg ha⁻¹ during 2017-18 and 2018-19, respectively) recorded the lowest value of available potassium content in soil. No specific trend of increase or decrease in available potassium was observed with the graded doses of phosphorus application.

At pod formation stage, the graded doses of phosphorus could not reach the level of significance. Soil available potassium content varied from 295.89 to 358.49 and 247.49 to 276.31 kg ha⁻¹ in the year 2017-18 and 2018-19, respectively. The highest soil available potassium (358.49 kg ha⁻¹ and 276.31 kg ha⁻¹ during 2017-18 and 2018-19, respectively) was recorded with application of phosphorus @ 30 kg ha⁻¹ during 2017-18 and with application of phosphorus @ 15 kg ha⁻¹ during 2018-19. The lowest soil available potassium (295.89 kg ha⁻¹ and 247.89 kg ha⁻¹ during 2017-18 and 2018-19, respectively) content was recorded with application of phosphorus @ 60 kg ha⁻¹ in both the years. The increase in available potassium followed the order of P₆₀ < P₄₅ < P₁₅ < P₃₀ during 2017-18 and P₆₀ < P₄₅ < P₃₀ < P₁₅ during 2018-19.

Similar to pod formation stage, the soil available potassium content with the application of phosphorus could not reach the level of significance at harvest and varied from 271.96 to 295.62 kg ha⁻¹ and 214.79 to 233.07 kg ha⁻¹ in the year 2017-18 and 2018-19, respectively. Among the graded doses of phosphorus @ 30 kg ha⁻¹ recorded the highest content of potassium (295.62 kg ha⁻¹ and 233.07 kg ha⁻¹

during 2017-18 and 2018-19, respectively) and the lowest was observed with the application of phosphorus @ 45 kg ha⁻¹ in both the years.

Effect of biofertilizers

Application of biofertilizers alone or in combination at peg initiation stage tended to increase significantly the soil available potassium content (Table 4.21) and it ranged from 400.98 to 449.00 kg ha⁻¹ and 257.04 to 293.16 kg ha⁻¹ in the year 2017-18 and 2018-19, respectively. 449.00 kg K₂O ha⁻¹ and 293.16 kg K₂O ha⁻¹ during 2017-18 and 2018-19, respectively were found significantly highest with dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) over all other treatments and it was at par with VAM @ 10 kg ha⁻¹ (B₁) application.

At pod formation stage, the soil available potassium showed significant variations which varied from 253.60 to 404.60 kg ha⁻¹ and 238.92 to 304.86 kg ha⁻¹ in the year 2017-18 and 2018-19, respectively. Dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) during 2017-18 and no application of biofertilizers (B₀) during 2018-19 registered significantly highest soil available potassium (404.60 kg ha⁻¹ and 304.86 kg ha⁻¹, respectively) over all other treatments, whereas, VAM + PSB @ 5 kg ha⁻¹ each (B₃) was found to be at par with no application of biofertilizers (B₀) during 2017-18.

At harvest of the crop, the soil available potassium could not reach the level of significance with inoculation of biofertilizers alone or in combination and it varied from 273.45 to 295.26 kg ha⁻¹ and 215.99 to 233.10 kg ha⁻¹ in the year 2017-18 and 2018-19, respectively. The highest value of soil available potassium (295.26 kg ha⁻¹ and 233.10 kg ha⁻¹ during 2017-18 and 2018-19, respectively) was recorded with application of VAM + PSB @ 5 kg ha⁻¹ each (B₃) in all treatments and followed the increasing order of B₀ < B₄ < B₂ < B₁ < B₃.

Interaction effect

Different levels of phosphorus and biofertilizers significantly increased soil available potassium (Table 25) at peg initiation stage and varied from 337.21 to 576.44 kg ha⁻¹ and 216.16 to 390.88 kg ha⁻¹ due to application of phosphorus and inoculation of biofertilizers in the year 2017-18 and 2018-19, respectively. The soil available potassium with the value of 576.44 kg ha⁻¹ and 390.88 kg ha⁻¹ during 2017-18 and 2018-19, respectively was found to be significantly superior with application of phosphorus @ 60 kg ha⁻¹ along with VAM + PSB @ 5 kg ha⁻¹ each

(B₃P₆₀) over all other treatment combinations.

The soil available potassium does not showed significant effect due to application of phosphorus and inoculation of biofertilizers at pod formation stage (Table 4.21), which ranged from 196.27 kg ha⁻¹ to 473.52 kg ha⁻¹ in the year 2017-18 and 197.93 to 360.08 kg ha⁻¹ in the year 2018-19. The highest soil available potassium content was recorded with application of phosphorus @ 45 kg ha⁻¹ with dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃P₄₅) (473.52 kg ha⁻¹) during the year 2017-18 and application of phosphorus @ 15 kg ha⁻¹ with no biofertilizers application i.e. B₀P₁₅ (360.08 kg ha⁻¹) during the year 2018-19.

Regarding the effects of different levels of phosphorus and biofertilizers, the results showed that the soil available potassium at harvest varied from 248.17 to 349.06 kg ha⁻¹ and 196.00 to 275.52 kg ha⁻¹ during 2017-18 and 2018-19, respectively. The soil available potassium (349.06 kg ha⁻¹ and 275.52 kg ha⁻¹) was found to be significantly highest with application of phosphorus @ 30 kg ha⁻¹ along with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₃₀) and found to be at par with B₃P₃₀, B₂P₁₅, B₁P₆₀ and B₁P₁₅ over rest of the treatment combinations in both the years.

The values of soil available potassium content indicated that, the available potassium ranges from 'medium' to 'very high' as per the rating given by Bangar and Zende (1978). The soil available potassium ranged from 45 to 1152 kg ha⁻¹ in lateritic soils of this region (Anonymous 1990).

Close scrutiny of the data indicated that, the soil available potassium increased at peg initiation stage over its initial values 338.68 and 248.64 kg ha⁻¹ during 2017-18 and 2018-19, respectively irrespective of treatments and subsequently decreased at harvest. The reason for more availability of K might be due to disintegration of K minerals due to reduction of K fixation and its release in K available pool of the soil. According to Tisdale *et al.* (1995), organic matter improves CEC, which reduces potential leaching losses of element such as K⁺, Ca²⁺ and Mg²⁺ and increase its availability. The increase in potassium availability might be also due to synergistic effect of N with phosphorus and potassium, which increased the availability of K in the soil.

The data showed that, the soil available potassium increased with phosphorus along with dual inoculation of biofertilizers that indicates the increased availability of

soil K by direct supply of its K and by solubilizing K from K-bearing minerals by the organic acids released. Similar results of increase in available potassium were also reported by Nadeem *et al.* (2018) with 40 kg ha⁻¹ phosphorus in combination with *rhizobium*; Solanki *et al.* (2018) with phosphorus @ 50 kg ha⁻¹ alongwith PSB.

Dual inoculation of biofertilizers further depleted available potassium in soil at harvest of the crop due to enhanced exploration of soil reserve nutrients, which may be ascribed to synergistic interactions between VAM and PSB leading to better nutrient dynamism in soil-plant continuum (Suri and Choudhary 2013). Further, Tisdale *et al.* (1995) explained that in some soils, non-exchangeable K becomes available as the exchangeable and solution K⁺ are removed by cropping or lost by leaching.

4.2.2 Available micronutrients

4.2.2.1 DTPA-extractable Fe

Effect of phosphorus

The DTPA-extractable Fe as influenced by the application of phosphorus at peg initiation stage varied (Table 4.22) from 71.86 to 79.31 mg kg⁻¹ and 90.95 to 100.39 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The DTPA-extractable (79.31 mg kg⁻¹ and 100.39 mg kg⁻¹ during 2017-18 and 2018-19, respectively) was found to be highest with application of phosphorus @ 15 kg ha⁻¹ in all treatments while, lowest (71.85 mg kg⁻¹ and 90.95 mg kg⁻¹ during 2017-18 and 2018-19, respectively) were recorded with application of phosphorus @ 30 kg ha⁻¹ and did not showed any significant difference.

The DTPA-extractable Fe content was found to be non-significant due to application of phosphorus and ranged from 72.07 to 76.19 and 93.65 to 99.01 mg kg⁻¹ during pod formation stage in the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 15 kg ha⁻¹ (76.19 mg kg⁻¹ and 99.01 mg kg⁻¹ during 2017-18 and 2018-19, respectively) was recorded highest magnitude of DTPA-extractable Fe and the lowest (72.07 mg kg⁻¹ and 93.65 mg kg⁻¹ during 2017-18 and 2018-19, respectively) was recorded with application of phosphorus @ 30 kg ha⁻¹.

The DTPA-extractable Fe could not reach the level of significance at harvest due to application of phosphorus and it varied from 55.86 to 59.92 mg kg⁻¹ and 62.77 to 67.33 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The DTPA-

extractable Fe (59.92 mg kg^{-1} and 67.33 mg kg^{-1} during 2017-18 and 2018-19, respectively) was found highest with application of phosphorus @ 45 kg ha^{-1} and was recorded lowest content of DTPA-extractable Fe with application of phosphorus @ 30 kg ha^{-1} (55.86 mg kg^{-1} and 62.77 mg kg^{-1} during 2017-18 and 2018-19, respectively). However, the treatments difference found to be non-significant.

Effect of biofertilizers

The individual or dual inoculation of biofertilizers did not influence significantly on DTPA-extractable Fe at peg initiation stage and ranged from 70.34 to 81.85 mg kg^{-1} and 88.93 to $103.60 \text{ mg kg}^{-1}$ in the year 2017-18 and 2018-19, respectively. The individual application of PSB @ 10 kg ha^{-1} (81.85 mg kg^{-1} and $103.60 \text{ mg kg}^{-1}$ during 2017-18 and 2018-19, respectively) was noted the highest DTPA-extractable Fe while, lowest was observed with dual inoculation of VAM + PSB @ 5 kg ha^{-1} each (70.34 mg kg^{-1} and 88.93 mg kg^{-1} during 2017-18 and 2018-19, respectively).

At pod formation stage, the DTPA-extractable Fe tended to increase significantly with application of biofertilizers (Table 4.22) and it varied from 69.48 to 76.97 mg kg^{-1} and 90.35 to 99.98 mg kg^{-1} during the year 2017-18 and 2018-19, respectively. Significantly, highest DTPA-extractable Fe (76.97 and 99.98 mg kg^{-1} during 2017-18 and 2018-19, respectively) was found with inoculation of PSB @ 10 kg ha^{-1} over all other treatments of biofertilizers and found to be at par with treatments consisting B_1 , B_0 and B_4 and followed the increasing order of $B_3 < B_4 < B_0 < B_1$ and $< B_2$.

The inoculation of biofertilizers influenced the DTPA-extractable Fe content in the soil significantly at harvest stage and it varied from 54.79 to 61.62 and 61.56 to 69.24 mg kg^{-1} in the year 2017-18 and 2018-19, respectively. The dual inoculation of VAM + PSB @ 10 kg ha^{-1} each (61.62 mg kg^{-1} and 69.24 mg kg^{-1} during 2017-18 and 2018-19, respectively) was found to be significantly highest DTPA-extractable Fe over all other treatments of biofertilizers application and found at par with no biofertilizers application (59.01 mg kg^{-1} and 66.30 mg kg^{-1} during 2017-18 and 2018-19, respectively) and inoculation of VAM @ 10 kg ha^{-1} (57.52 mg kg^{-1} and 64.63 mg kg^{-1} during 2017-18 and 2018-19, respectively).

Interaction effect

The application of phosphorus and inoculation of biofertilizers alone or in

combination showed significant differences on DTPA-extractable Fe (Table 4.22) and it ranged from 42.34 to 104.41 mg kg⁻¹ and 53.59 to 132.17 mg kg⁻¹ at peg initiation stage in the year 2017-18 and 2018-19, respectively. Significantly highest DTPA-extractable Fe was recorded due to application of phosphorus @ 15 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each i.e. B₃P₁₅ (104.41 and 132.17 mg kg⁻¹ during 2017-18 and 2018-19, respectively) over all other treatment combinations except those which were found to be at par with B₂P₄₅, B₀P₃₀, and B₁P₆₀ in both the years of observation.

The data on DTPA-extractable Fe content was not influenced by the application of different doses of phosphorus and biofertilizers at pod formation stage which varied from 66.15 to 82.14 mg kg⁻¹ and 86.07 to 106.61 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 15 kg ha⁻¹ alongwith PSB @ 10 kg ha⁻¹ i.e. B₂P₁₅ (82.14 mg kg⁻¹ and 106.61 mg kg⁻¹ during 2017-18 and 2018-19, respectively) were recorded the highest DTPA extractable Fe content, while the application of phosphorus @ 45 kg ha⁻¹ with dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each i.e. B₃P₄₅ (66.15 mg kg⁻¹ and 86.07 mg kg⁻¹ during 2017-18 and 2018-19, respectively) noted the lowest DTPA extractable Fe content.

Application of phosphorus either or in combination with biofertilizers at harvest stage showed significant effect on DTPA-extractable Fe content and it varied from 49.39 to 64.15 mg kg⁻¹ and 55.49 to 72.08 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The DTPA-extractable Fe content was found to be highest (64.15 mg kg⁻¹ and 72.08 mg kg⁻¹ during 2017-18 and 2018-19, respectively) with application of phosphorus @ 45 kg ha⁻¹ alongwith dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₄₅) and the lowest (49.39 mg kg⁻¹ and 55.49 mg kg⁻¹ during 2017-18 and 2018-19, respectively) with application of phosphorus @ 15 kg ha⁻¹ alongwith dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃P₁₅).

Similar ranges of DTPA extractable Fe in lateritic soils of Konkan were reported by Pawar (2012) and Joshi (2012). The mean value of available Fe content (25 mg kg⁻¹) reported in lateritic soils of Konkan region indicated its adequate status (Anonymous 1990).

By observing of two years data it is revealed that, the DTPA extractable Fe content increased during peg initiation, pod formation and at harvest over initial

content of Fe in both the years. Further, it was observed, that the DTPA extractable Zn decreased from peg initiation to harvest stage in both the years. It was also noticed that, the DTPA extractable Fe increased significantly with lower levels of phosphorus application and the inoculation of PSB during peg initiation and pod formation and decreased at harvest stage in both the years. At harvest of the crop DTPA extractable Fe was increased with higher dose of phosphorus and dual inoculation of biofertilizers in both the years. This may be due to chemical components like phenolics of root exudates that solubilize Fe. These phenolics make Fe available by forming relatively stable chelates with Fe and Al present in insoluble Fe and Al phosphates thereby increasing the solubility of Fe. Similar findings were also reported by Dakora and Phillips, (2002).

Regarding high availability of Fe in acid lateritic soils, Katyal *et al.* (1982) cleared that the high content of available Fe may be due to accumulation of sesquioxides and also higher organic matter content, which keeps iron in complexes and available form.

Babulkar *et al.* (2000) found significant increase in available Fe of soil after harvest of crop due to application of NPK (15:30:00 kg N:P₂O₅:K₂O ha⁻¹) + biofertilizers. The increase in available Fe was 30.95 to 35.22 mg kg⁻¹ over control.

In lateritic soils of Konkan, Gengaje (2013) and Mhalshi (2013) observed increase in DTPA extractable Fe with the dual inoculation of *rhizobium* and PSB with different levels of phosphorus under groundnut (*viz.*, 25 and 50 kg ha⁻¹) and cowpea (*viz.*, 50, 60 and 70 kg ha⁻¹), respectively. Sandhya *et al.* (2014) reported that the plants, which treated with VAM and PSB, exhibited more levels of iron.

4.2.2.2 DTPA-extractable Mn

Effect of phosphorus

At peg initiation, the DTPA-extractable Mn was influenced by the application of phosphorus (Table 4.23), which varied from 52.02 to 65.39 mg kg⁻¹ and 75.40 to 94.77 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. Significantly higher DTPA-extractable Mn (65.39 mg kg⁻¹ and 94.77 mg kg⁻¹ during 2017-18 and 2018-19, respectively) was recorded with application of phosphorus @ 60 kg ha⁻¹ over all other treatments of phosphorus, which showed its superiority over all the treatments and followed the increasing order of P₁₅ > P₃₀ > P₄₅ in both the years.

Applications of graded doses of phosphorus significantly influenced the

DTPA-extractable Mn content at pod formation, which varied from 43.69 to 65.40 and 69.61 to 93.80 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The DTPA-extractable Mn (65.40 mg kg⁻¹) was found to be significantly superior with application of phosphorus @ 60 kg ha⁻¹ over all other treatments in the year 2017-18. However, the application of phosphorus @ 60 kg ha⁻¹ (93.80 mg kg⁻¹) was found to be significantly highest DTPA-extractable Mn and found at par with application of phosphorus @ 15 kg ha⁻¹ (90.22 mg kg⁻¹) in the year 2018-19.

At harvest, the DTPA-extractable Mn content could not reach the level of significance due to application of phosphorus and it varied from 88.84 to 91.91 and 118.45 to 122.48 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The highest content of DTPA-extractable Mn was observed with application of phosphorus @ 45 kg ha⁻¹ (91.91 mg kg⁻¹ and 122.48 mg kg⁻¹ during 2017-18 and 2018-19, respectively) and the lowest (88.84 mg kg⁻¹ and 122.48 mg kg⁻¹ during 2017-18 and 2018-19, respectively) was noted with the application of phosphorus @ 30 kg ha⁻¹ in both the years.

Effect of biofertilizers

On DTPA-extractable Mn content (Table 4.23), the treatment difference of biofertilizers were non-significant at peg initiation stage and it ranged from 52.65 to 61.99 mg kg⁻¹ and 76.31 to 89.84 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The highest DTPA-extractable Mn (61.99 mg kg⁻¹ and 89.84 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) was noted with inoculation of VAM @ 10 kg ha⁻¹ (B₁), while the lowest (52.65 mg kg⁻¹ and 76.31 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) was observed with no biofertilizers (B₀) application.

The inoculation of biofertilizers on DTPA-extractable Mn could not reach the levels of significance at pod formation stage and it varied from 50.72 to 56.91 and 75.59 to 85.72 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The application of VAM + PSB @ 5 kg ha⁻¹ recorded the highest DTPA-extractable Mn (56.91 mg kg⁻¹ and 85.72 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) and the lowest Mn content was observed with no biofertilizers application (B₀) in the year 2017-18 and application of PSB @ 10 kg ha⁻¹ (B₂) in the year 2018-19.

At harvest, the inoculation of biofertilizers showed significant effect on

DTPA-extractable Mn and it ranged from 87.07 to 93.96 mg kg⁻¹ and 116.10 to 126.00 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. Significantly highest DTPA-extractable Mn (93.96 mg kg⁻¹ and 126.00 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) was recorded with no biofertilizers application (B₀) over all other treatments and was found to be at par with application of VAM + PSB @ 5 kg ha⁻¹ each in the year 2017-18.

Interaction effect

The integration effect of different levels of phosphorus and biofertilizers significantly increased DTPA-extractable Mn at peg initiation stage and it varied from 34.03 to 78.37 mg kg⁻¹ and 49.32 to 113.58 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. Significantly highest DTPA-extractable Mn (78.37 mg kg⁻¹ and 113.58 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) was observed with application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀) over all other treatment combinations, which found to be at par B₃P₆₀, B₀P₁₅, B₃P₃₀, B₁P₄₅, and B₁P₆₀ with each other.

At pod formation stage, the data on DTPA-extractable Mn (Table 4.23) was significantly influenced by different levels of phosphorus and biofertilizers and it ranged from 39.23 to 98.39 mg kg⁻¹ and 54.67 to 135.11 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃P₆₀) (98.39 and 135.11 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) noted significantly superior DTPA-extractable Mn over all other treatment combinations in both the years.

Interaction effect of phosphorus and biofertilizers application significantly increased the DTPA-extractable Mn content at harvest stage and varied from 81.17 to 96.25 mg kg⁻¹ and 108.23 to 128.34 mg kg⁻¹ during 2017-18 and 2018-19, respectively. The DTPA-extractable Mn content i.e. 96.25 and 128.34 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively was found to be significantly highest with application of phosphorus @ 30 kg ha⁻¹ with no biofertilizers application (B₀P₃₀) over all other treatment combinations in both the years. However, the treatment combination B₀P₃₀ was found to be at par with B₄P₆₀, B₃P₃₀, B₂P₄₅, B₀P₄₅, B₃P₁₅ and B₁P₁₅ in the year 2017-18 and B₄P₆₀, B₃P₃₀, B₂P₄₅, B₀P₄₅, B₀P₁₅, B₀P₆₀, B₃P₁₅ and B₁P₁₅ in the year 2018-19.

Several research workers reported the similar values of DTPA extractable Mn in lateritic soils of Konkan (Pawar 2012 and Joshi 2012). The mean available manganese content (103 mg kg^{-1}) was reported in lateritic soils of Konkan region (Anonymous 1990).

The two years data revealed that, the DTPA extractable Mn content was significantly increased during peg initiation, pod formation and at harvest stage of the crop over initial values in both the years. However, the inoculation of biofertilizer showed slightly decreased pattern and it again showed increasing Mn content at harvest. The increase in micronutrient might be due to addition of FYM, which releases micronutrient to soil through its chelating effect. Further, FYM also prevents loss of micronutrients from precipitation, oxidation and leaching. The extent of build up of residual micronutrients status of soil at harvest might be attributed to the higher uptake of micronutrients by the crop during reproductive phase.

The high availability of Mn in acid lateritic soils, Mehta and Patel (1967) stated that the high concentration of available Mn might be due to decomposition and mineralization of organic matter due to warm and humid climate of the region.

Das (1950) explained that the micro-organisms increase the pH and oxidation of Mn^{2+} and precipitation as oxides follows standard chemical pathway. A number of bacteria (*Arthobacter*, *Bacillus*, *Corynebacterium*, *Metallogenium* etc.) and fungal (*Cladosporium*, *Fusarium* etc.) genera are recognized as being capable of performing this transformation and hence affect the transformation of manganese. Therefore, microorganisms are an integral part of both oxidation and reduction of manganese.

Further, Rengel (2015) reported that the ratio between Mn-oxidizing and Mn-reducing bacteria may determine availability of soil Mn to plants. Production of root exudates that are toxic to Mn-oxidizing microorganism in the rhizosphere also increases Mn availability.

In lateritic soils of Konkan, Gengaje (2013) and Mhalshi (2013) observed increase in DTPA extractable Mn with the dual inoculation of *rhizobium* and PSB with different levels of phosphorus under groundnut (*viz.*, 25 and 50 kg ha^{-1}) and cowpea (*viz.*, 50, 60 and 70 kg ha^{-1}), respectively. Sandhya *et al.* (2014) reported that the plants which were treated with VAM and PSB exhibited more levels of manganese and may perform better growth, survival and more biomass production in nutrient impoverished soil.

4.2.2.3 DTPA-extractable Zn

Effect of phosphorus

At peg initiation stage the DTPA-extractable Zn content observed due application of phosphorus was statistically non-significant (Table 4.24) and varied from 1.22 to 1.35 mg kg⁻¹ and 1.39 to 1.55 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. Amongst all treatment of phosphorus applications, the DTPA-extractable Zn was recorded highest with application of phosphorus @ 15 kg ha⁻¹ (1.35 mg kg⁻¹ and 1.55 mg kg⁻¹ during 2017-18 and 2018-19, respectively) and the lowest (1.22 mg kg⁻¹) was observed with application of phosphorus @ 30 kg ha⁻¹ in the year 2017-18 and with application of phosphorus @ 45 kg ha⁻¹ (1.39 mg kg⁻¹) in the year 2018-19.

Applications of different doses of phosphorus significantly affected the DTPA-extractable Zn at pod formation and it ranged from 1.05 to 1.17 mg kg⁻¹ and 1.09 to 1.21 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively. The DTPA-extractable Zn (1.17 mg kg⁻¹) was found to be significantly highest with application of phosphorus @ 45 kg ha⁻¹ over all other treatments of phosphorus application and found to be at par with application of phosphorus @ 30 kg ha⁻¹ (1.11 mg kg⁻¹) in the year 2017-18. However, the DTPA-extractable Zn recorded was significantly highest with application of phosphorus @ 15 kg ha⁻¹ (1.21 mg kg⁻¹) over all other treatments of phosphorus and found to be at par with application of phosphorus @ 60 kg ha⁻¹ (1.14 mg kg⁻¹) in the year 2018-19.

At harvest, the DTPA-extractable Zn, which was influenced by the application of phosphorus and varied from 0.93 to 1.04 mg kg⁻¹ and 0.78 to 0.89 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. Significantly highest DTPA-extractable Zn (1.04 mg kg⁻¹ and 0.89 mg kg⁻¹ during 2017-18 and 2018-19, respectively) were observed with application of phosphorus @ 15 kg ha⁻¹ over all other treatments of phosphorus application in both the years. The same treatment was found to be at par with application of phosphorus @ 30 kg ha⁻¹ (P₃₀) and @ 60 kg ha⁻¹ (P₆₀) in the year 2017-18 and phosphorus @ 45 kg ha⁻¹ (P₄₅) and @ 30 kg ha⁻¹ (P₃₀) during 2018-19.

Effect of biofertilizers

The alone or dual combination of biofertilizers showed the significant effect on DTPA-extractable Zn at peg initiation stage and it varied from 1.12 to 1.40 and 1.41 to 1.58 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The inoculation of PSB @ 10 kg ha⁻¹ recorded significantly highest DTPA-extractable Zn in soil (1.40 mg kg⁻¹) over all other treatments of biofertilizers application and found to be at par with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (1.36 mg kg⁻¹) in the year 2017-18. However, in 2018-19 the inoculation of VAM + PSB @ 10 kg ha⁻¹ each (1.58 mg kg⁻¹) noted significantly highest DTPA-extractable Zn, which was, be at par with dual inoculation of VAM @ 10 kg ha⁻¹ each (1.56 mg kg⁻¹).

The DTPA-extractable Zn influenced by the inoculation of biofertilizers at pod formation stage (Table 4.24) ranged from 1.06 to 1.14 and 1.00 to 1.25 mg kg⁻¹ due to inoculation of biofertilizers alone or in combination in the year 2017-18 and 2018-19, respectively. During the year 2017-18, the DTPA-extractable Zn (1.14 mg kg⁻¹) was found to be significantly highest with inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄) in all other treatments of biofertilizers application and found at par with VAM + PSB @ 5 kg ha⁻¹ each (B₃) (1.14 mg kg⁻¹), with no biofertilizers application (B₀) (1.12 mg kg⁻¹). Whereas, in the year 2018-19 application of PSB @ 10 kg ha⁻¹ i.e. B₂ (1.25 mg kg⁻¹) recorded significantly highest DTPA-extractable Zn which was found at par with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each i.e. B₄ (1.22 mg kg⁻¹).

During harvest, DTPA-extractable Zn tended to increase significantly due to application of biofertilizers and varied from 0.94 to 1.05 and 0.82 to 0.88 mg kg⁻¹ with application of biofertilizers in the year 2017-18 and 2018-19, respectively. Significantly highest (1.05 mg kg⁻¹) DTPA-extractable Zn was observed with individual application of VAM @ 10 kg ha⁻¹ (B₁) over all treatments and found at par with VAM + PSB @ 10 kg ha⁻¹ each i.e. B₄ (1.04 mg kg⁻¹) and application of PSB @ 10 kg ha⁻¹ i.e. B₂ (0.98 mg kg⁻¹) in the year 2017-18. However, the DTPA-extractable Zn (0.88 mg kg⁻¹) was found to be significantly higher (0.88 mg kg⁻¹) with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄) in all treatments and was found at par with application of VAM @ 10 kg ha⁻¹ i.e. B₁ (0.86 mg kg⁻¹), VAM + PSB @ 5 kg ha⁻¹ each i.e. B₃ (0.85 mg kg⁻¹) and with no biofertilizers application i.e. B₀

(0.84 mg kg⁻¹) in the year 2018-19.

Interaction effect

The different levels of phosphorus alongwith biofertilizers showed significant difference on DTPA-extractable Zn content at peg initiation stage and it varied from 0.85 to 1.73 mg kg⁻¹ and 1.20 to 1.97 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The DTPA-extractable Zn (1.73 mg kg⁻¹) during the year 2017-18 was found significantly highest with application of phosphorus @ 45 kg ha⁻¹ with application of PSB @ 10 kg ha⁻¹ over all other treatment combinations and found at par with B₂P₁₅, B₁P₆₀, B₄P₁₅, and B₄P₄₅ treatment combinations. While, application of phosphorus @ 15 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each recorded significantly highest DTPA-extractable Zn (1.97 mg kg⁻¹) over all other treatment combinations and application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each found to be at par with each other in the year 2018-19.

During pod formation stage, the interaction of phosphorus and biofertilizers showed significant effect on DTPA-extractable Zn (Table 4.24) and it ranged from 0.94 to 1.29 mg kg⁻¹ and 0.76 to 1.55 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. Significantly highest DTPA-extractable Zn (1.29 mg kg⁻¹) was recorded with application of phosphorus @ 15 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₁₅) over all treatment combinations and this treatment combination found at par with B₃P₃₀, B₀P₄₅, B₁P₄₅, and B₂P₄₅ in the year 2017-18. During the year 2018-19, the application of phosphorus @ 45 kg ha⁻¹ with individual inoculation of PSB @ 10 kg ha⁻¹ found significantly highest in respect of DTPA-extractable Zn (1.55 mg kg⁻¹) over all other treatment combinations and B₂P₁₅, B₁P₆₀, B₄P₁₅ and B₄P₄₅ treatment combinations were found to be at par with each other.

The integration of phosphorus and biofertilizers showed significant variations in DTPA-extractable Zn at harvest and it varied from 0.80 to 1.32 mg kg⁻¹ and 0.76 to 1.08 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 15 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₁₅) recorded significantly highest DTPA-extractable Zn in soil (1.32 mg kg⁻¹) over all other treatment combinations in both the years, which showed its superiority in the year 2018-19 and found at par with B₂P₃₀ and B₄P₆₀ in the year 2017-18.

Pawar (2012) and Joshi (2012) reported similar ranges of DTPA extractable Zn in lateritic soils of Konkan. The mean value of DTPA extractable Zn (0.98 mg kg^{-1}) was reported in soils of Konkan region (Anonymous 1990).

From the two years data, it was observed that the DTPA extractable Zn declined irrespective of treatment from peg initiation to harvest stage which was found to highest over initial value in both the years. The increased in Zn content in soil may be due the effective use of FYM, biofertilizers along with chemical fertilizer improved Zn content in soil. The above results are in conformity with the results reported by Bodkhe *et al.* (2014).

Babulkar *et al.* (2000) found significant increase in available Zn content of soil after harvest of crop due to application of NPK ($15:30:00 \text{ kg N:P}_2\text{O}_5:\text{K}_2\text{O ha}^{-1}$) + biofertilizers. The increase in available Zn was 0.95 to 1.16 mg kg^{-1} over control. Sandhya *et al.* (2014) reported that the plants, which treated with VAM and PSB, exhibited more levels of zinc.

Further, it can be seen from the Table 4.24, that the application of biofertilizers increased the available Zn over sole use of chemical fertilizers. In this context, Tisdale *et al.* (1995) cleared that increasing soil temperature increases the availability of Zn to crops by increasing solubility and diffusion of Zn^{2+} . In lateritic soils of Konkan, Gengaje (2013) and Mhalshi (2013) observed increase in DTPA extractable Zn with the dual inoculation of *rhizobium* and PSB with different levels of phosphorus under groundnut (*viz.*, 25 and 50 kg ha^{-1}) and cowpea (*viz.*, 50 , 60 and 70 kg ha^{-1}), respectively.

4.2.2.4 DTPA-extractable Cu

Effect of phosphorus

At peg initiation stage, the application of phosphorus was found to be non-significant on DTPA-extractable Cu content (Table 4.25) and it ranged from 2.77 to 2.93 mg kg^{-1} and 3.87 to 3.99 mg kg^{-1} in the year 2017-18 and 2018-19, respectively. The DTPA-extractable Cu content recorded was highest (2.93 and 3.99 mg kg^{-1} during 2017-18 and 2018-19, respectively) with the application of phosphorus @ 15 kg ha^{-1} than the other treatments of phosphorus application, whereas the lowest DTPA-extractable Cu content (2.77 mg kg^{-1}) was observed with application of phosphorus @ 30 kg ha^{-1} in the year 2017-18 and with the application of phosphorus @ 45 kg ha^{-1} (3.87 mg kg^{-1}) in the year 2018-19.

The application of phosphorus did not influence significantly on DTPA-extractable Cu at pod formation stage, which varied from 3.63 to 4.05 mg kg⁻¹ and 5.09 to 5.69 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 30 kg ha⁻¹ noted highest DTPA-extractable Cu (4.05 mg kg⁻¹ and 5.69 mg kg⁻¹ during 2017-18 and 2018-19, respectively) than the other treatments however, the lowest DTPA-extractable Cu content (3.63 mg kg⁻¹ and 5.09 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) was observed with the application of phosphorus @ 60 kg ha⁻¹.

Application of graded levels of phosphorus brought about significant changes in DTPA-extractable Cu at harvest stage and varied from 3.63 to 4.05 and 5.09 to 5.69 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. Significantly higher DTPA-extractable Cu (4.13 mg kg⁻¹ and 4.66 mg kg⁻¹ during 2017-18 and 2018-19) was observed in the treatment receiving phosphorus @ 45 kg ha⁻¹ over all other treatments consisting application of phosphorus @ 30 kg ha⁻¹, @ 15 kg ha⁻¹ and @ 60 kg ha⁻¹ in the year 2017-18 and 2018-19.

Effect of biofertilizers

The inoculation of biofertilizers showed non-significant effect on DTPA-extractable Cu during peg initiation stage (Table 4.25) and it ranged from 2.78 to 2.93 and 3.84 to 4.01 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The inoculation of VAM @ 10 kg ha⁻¹ recorded the highest DTPA-extractable Cu (2.93 and 4.01 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively), while the application of PSB @ 10 kg ha⁻¹ (2.78 mg kg⁻¹) in the year 2017-18 and with no biofertilizers application (3.84 mg kg⁻¹) in the year 2018-19 noted lowest DTPA-extractable Cu content.

The inoculation of biofertilizers significantly increase DTPA-extractable Cu content at pod formation stage and varied from 3.59 to 4.20 and 5.05 to 5.91 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The DTPA-extractable Cu content was found to be significantly highest (4.20 mg kg⁻¹) with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄) over all other treatments of biofertilizers applications in both the years. However, inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄) treatment found to be at par with application of PSB @ 10 kg ha⁻¹ (B₂) in the year 2017-18 and treatment B₄ showed its superiority over all other treatments in the year 2018-19.

The alone or dual inoculation of biofertilizers could not reach the level of significance at harvest and DTPA-extractable Cu content ranged from 3.67 to 3.88 and 4.12 to 4.38 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The DTPA-extractable Cu was observed highest (3.88 mg kg⁻¹ and 4.38 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) with no biofertilizers application (B₀) over all other treatments of biofertilizers application consisting B₁, B₂, B₃ and B₄ and the lowest content was recorded with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (3.67 mg kg⁻¹ and 4.12 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively).

Interaction effect

Regarding the effects of different levels of phosphorus and biofertilizers presented in the Table 4.25, the results showed that the DTPA-extractable Cu at peg initiation stage varied from 2.23 to 3.12 mg kg⁻¹ and 3.06 to 4.28 mg kg⁻¹ during 2017-18 and 2018-19, respectively. Significantly highest DTPA-extractable Cu was observed with application of phosphorus @ 45 kg ha⁻¹ with inoculation of PSB @ 10 kg ha⁻¹ (B₂P₄₅) (3.12 mg kg⁻¹ and 4.28 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) over other treatment combinations and found to be at par with B₃P₃₀, B₂P₁₅, B₄P₁₅, B₀P₃₀, B₁P₆₀, B₁P₃₀, B₄P₆₀, B₄P₄₅ and B₃P₁₅ in the year 2017-18 and B₃P₃₀, B₄P₁₅, B₂P₁₅, B₁P₆₀, B₀P₃₀, B₁P₃₀ and B₄P₆₀ in the year 2018-19.

At pod formation stage, the application of phosphorus and biofertilizers significantly influenced DTPA-extractable Cu content and it ranged from 3.43 to 5.68 and 4.77 to 7.97 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The DTPA-extractable Cu was found to be significantly superior with application of phosphorus @ 30 kg ha⁻¹ alongwith dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₃₀) (5.68 mg kg⁻¹ and 7.97 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) over all other treatment combinations in the both the years.

Integration of phosphorus and biofertilizers did not showed significant effect on DTPA-extractable Cu content at harvest s and it varied from 3.18 to 4.60 and 3.57 to 5.17 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. Among the different treatment combinations, the application of phosphorus @ 45 kg ha⁻¹ with inoculation of PSB @ 10 kg ha⁻¹ (B₂P₄₅) was recorded highest DTPA-extractable Cu (4.60 and 5.17 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) and the lowest (3.18 and 3.57 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) was observed with application of phosphorus @ 60 kg ha⁻¹ with inoculation of PSB @ 10 kg ha⁻¹.

Similar ranges of DTPA extractable Cu content in lateritic soils of Konkan were reported by Pawar (2012) and Joshi (2012). The mean content of available copper content (4.17 mg kg^{-1}) was reported in soils of Konkan region (Anonymous 1990).

The scrutiny of two years data indicated that, the DTPA extractable Cu content increased over initial content of it irrespective of the treatments. Further, DTPA extractable Cu increased gradually from peg initiation to pod formation stage and thereafter decreased at harvest stage in both the years. The inoculation of biofertilizer does not indicated specific trend during the growth period in both the years. This may be attributed due to the root exudation in the rhizosphere, which increases its availability and plant uptake.

Babulkar *et al.* (2000) found significant increase in available Cu of soil after harvest of crop due to application of NPK ($15:30:00 \text{ kg N:P}_2\text{O}_5:\text{K}_2\text{O ha}^{-1}$) + biofertilizers under soybean crop in Vertisol.

In lateritic soils of Konkan, Gengaje (2013) and Mhalshi (2013) observed increase in DTPA extractable Cu with the dual inoculation of *rhizobium* and PSB with different levels of phosphorus under groundnut (*viz.*, 25 and 50 kg ha^{-1}) and cowpea (*viz.*, 50, 60 and 70 kg ha^{-1}), respectively.

4.3 Effect on growth parameters, yield attributing characters and yield of groundnut

4.3.1 Effect of phosphorus and biofertilizers levels on plant height of groundnut

Effect of phosphorus

The plant height at peg initiation stage, pod formation stage and at harvest stage, was significantly influenced by application of different levels of phosphorus and biofertilizers (Table 4.26). At peg initiation stage, increase in successive dose of added phosphorus from 15 to 60 kg ha^{-1} , plant height tended to increase from 19.82 to 23.01 cm in the year 2017-18 and 18.70 to 22.18 cm during 2018-19, respectively. The higher magnitudes of plant height (23.01 cm and 22.18 cm during 2017-18 and 2018-19, respectively) were observed with application of phosphorus @ 60 kg ha^{-1} , while the lowest (19.82 cm and 18.70 cm during 2017-18 and 2018-19, respectively) were recorded with application of phosphorus @ 15 kg ha^{-1} .

The plant height influenced significantly with application of phosphorus at pod formation stage and it ranged from 29.51 to 34.77 cm and 27.85 to 32.93 cm during 2017-18 and 2018-19 respectively. The lower dose of phosphorus @ 15 kg ha⁻¹ recorded significantly highest plant height (34.77 cm and 32.93 cm during 2017-18 and 2018-19, respectively) over all other treatments and it was found to be statistically superior and followed the order of P₃₀ < P₆₀ < P₄₅ < P₁₅.

The different levels of phosphorus brought about significant changes in plant height at harvest stage, which ranged from 31.23 to 35.81 cm and 29.87 to 34.88 cm in the year 2017-18 and 2018-19 respectively and followed the order of P₃₀ < P₆₀ < P₄₅ < P₁₅. The plant height (35.81 cm and 34.88 cm during 2017-18 and 2018-19, respectively) was found to be significantly superior with the application of phosphorus @ 15 kg ha⁻¹ during 2017-18 and 2018-19, respectively over all other treatments of phosphorus application.

From the data it is observed that, the increase in plant height might be due to the improvement in soil physical condition provided for plant growth and also due to increased availability of nutrients especially N, P₂O₅ and K₂O from the early stages of crop. Phosphorus fertilization might have improved the root system, which in turn helped more assimilation of nutrients resulting in increased growth.

Ramana *et al.* (2010) reported that the application of 75 per cent RDF (Recommended Dose of Fertilizer) + VAM (Vesicular Arbuscular Mycorrhizae) @ 2 kg ha⁻¹ + PSB (Phosphorus Solubilizing Bacteria) @ 2.5 kg ha⁻¹ significantly increased the plant height (cm), number of branches per plant, leaf area (cm²) and dry weight (g) of plant in the variety Arka suvidha (V2) followed by selection 9 and Arka komal. Similar results were obtained by Patil *et al.* (2018) due to application of fertilizers based on SSNM for target yield of 2.5 t ha⁻¹ + Sulphur + Boron + Zn recorded significantly higher growth parameters, yield parameters and yield of groundnut as compared to recommended dose of fertilizer.

Effect of biofertilizers

At peg initiation stage, the inoculation of biofertilizers alone or in combination was found to be non-significant and the plant height ranged from 21.00 to 23.18 and 20.04 to 21.35 cm during 2017-18 and 2018-19, respectively. The highest plant height (23.18 cm) was observed with the application of PSB @ 10 kg ha⁻¹ (B₂) during 2017-18 and with VAM +PSB @ 10 kg ha⁻¹ each i.e. B₄ (21.35cm) during 2018-19 as compared to all other treatments of biofertilizers application. The lowest plant height (21.00 cm and 20.04 cm during 2017-18 and 2018-19) was recorded with inoculation of VAM @ 10 kg ha⁻¹ (B₁) in both the years.

The application of biofertilizers influenced plant height significantly at pod formation stage (Table 4.26) and varied from 30.13 to 35.08 and 28.45 to 33.09 cm in 2017-18 and 2018-19 respectively. Dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each recorded plant height significantly highest (35.08 and 33.09 cm during 2017-18 and 2018-19, respectively) and found to be superior over all other treatments of biofertilizers application during both the years.

At harvest, the plant height tended to increase significantly due to application of biofertilizers and varied from 31.06 to 35.68 cm and 29.20 to 34.47 cm in 2017-18 and 2018-19, respectively. The plant height was recorded significantly highest (35.68 cm) with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄) and found to be significantly superior over all other treatments of biofertilizers application in the year 2017-18. The dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄) was found to be significantly highest (34.47 cm) and at par with no biofertilizers application (B₀) over all other treatments in the year 2018-19.

From the data it was observed that, the plant height increased gradually from peg initiation to harvest stage. The organic manures play an important role in root development and proliferation resulting in better nodules formation and nitrogen fixation by supplying assimilates to the root. They also increase water holding capacity and phosphate availability in soil thus provide better environment in rhizosphere for growth and development. VAM inoculation also plays significant and unique role in phosphate mobilization and uptake of phosphorus, zinc, sulphur and water by plant. The relatively higher availability of phosphorus in rhizosphere might have helped in *rhizobium* activity and resulted in more number of nodules per plant.

Ramana *et al.* (2010) reported that the application of 75 per cent RDF (Recommended Dose of Fertilizer) + VAM (Vesicular Arbuscular Mycorrhizae) @ 2 kg ha⁻¹ + PSB (Phosphorus Solubilizing Bacteria) @ 2.5 kg ha⁻¹ significantly increased the plant height (cm), number of branches per plant, leaf area (cm²) and dry weight (g) of plant in the variety Arka suvidha (V2) followed by selection 9 and Arka komal.

Rana *et al.* (2014) revealed that growth attributes of soybean increased with the application of 60 kg P₂O₅ ha⁻¹ along with *Rhizobium* and phosphorus solubilizing bacteria. Further, Pandey *et al.* (2016) reported that the application of phosphorus, sulphur and PSB proved effective in significantly enhancing the nodulation, yield attributes and seed yield of lentil.

Interaction effect

The integration of phosphorus and biofertilizers (Table 4.26) did not influence significantly on plant height at peg initiation stage and it ranged from 18.21 to 27.38 cm and 16.19 to 25.45 cm during 2017-18 and 2018-19 respectively. The application of phosphorus @ 45 kg ha⁻¹ alongwith inoculation of PSB @ 10 kg ha⁻¹ (B₂P₄₅) recorded the highest plant height (27.38 cm) as compared to other treatment combinations in the year 2017-18. Whereas, the plant height (25.45 cm) was found to be highest with the application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀) in all other treatment combinations in the year 2018-19.

At pod formation stage, the application of phosphorus and biofertilizers showed the significant effect on plant height and it varied from 23.15 to 41.48 cm and 21.85 to 39.14 cm in the year 2017-18 and 2018-19 respectively. The plant height (41.48 cm and 39.14 cm during 2017-18 and 2018-19, respectively) was found to be significantly highest due to application of phosphorus @ 15 kg ha⁻¹ alongwith application of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₁₅) over all other treatment combinations in both the years.

Application of phosphorus and biofertilizers significantly influenced the plant height at harvest, which ranged from 22.96 to 41.26 cm and 21.31 to 40.19 cm during the year 2017-18 and 2018-19, respectively. Significantly highest plant height (41.26 cm) was observed to be in the treatment receiving phosphorus @ 15 kg ha⁻¹

with no biofertilizers (B_0P_{15}) over all other treatment combinations in the year 2017-18, while, application of phosphorus @ 15 kg ha⁻¹ with inoculation of VAM @ 10 kg ha⁻¹ each i.e. B_1P_{15} (40.19 cm) in the year 2018-19.

When two years data was studied, it was observed that, the plant height increased gradually from peg initiation to harvest stage in both the years. The significant increase in plant height was recorded with application of phosphorus as well as dual inoculation of biofertilizers in both the years. The increase in plant height might be due to addition of organic manures as well as PSB might have helped in releasing P from native as well as protecting fixation of added phosphate by excretion of organic acid and enzymes, some of hydroxyl acid may form chelates with cation as Ca^{++} and Mg^{++} which resulted in effective solubilization of phosphates and rendered more available phosphorus for the plants leading to increased nutrient content of the plants which resulted in increased plant height.

In lateritic soils of Konkan, Gengaje (2013) and Mhalshi (2013) observed increase in plant height with the dual inoculation of *rhizobium* and PSB with different levels of phosphorus under groundnut (*viz.*, 25 and 50 kg ha⁻¹) and cowpea (*viz.*, 50, 60 and 70 kg ha⁻¹), respectively.

Rana *et al.* (2014) revealed that growth attributes of soybean increased with the application of 60 kg P₂O₅ ha⁻¹ along with *Rhizobium* and phosphorus solubilizing bacteria. This finding corroborates with the findings of Jangandi *et al.* (2017) in pigeon pea, Pandey *et al.* (2016) in lentil.

4.3. 2 Effect of phosphorus and biofertilizers on rachis

Effect of Phosphorus

The application of phosphorus Table 4.27 showed non-significant effect on number of rachis plant⁻¹ at peg initiation stage and it varied from 7.23 to 7.74 and 7.66 to 8.32 during 2017-18 and 2018-19, respectively. The number of rachis plant⁻¹ (7.74 and 8.32 during 2017-18 and 2018-19, respectively) were recorded highest with application of phosphorus @ 60 kg ha⁻¹ (RDF) as compared to all other treatments of phosphorus application while the lowest were noted with application of phosphorus @ 30 kg ha⁻¹ in both the years.

Successive addition of phosphorus from 15 to 60 kg ha⁻¹ significantly increased the number of rachis plant⁻¹ at pod formation stage and ranged from 5.28 to

6.53 and 7.34 to 9.08 in the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 30 kg ha⁻¹ recorded significantly superior number of rachis (6.53 and 9.08 during 2017-18 and 2018-19, respectively) plant⁻¹ over all other treatments of phosphorus. The increase in the number of rachis plant⁻¹ followed the order of P₆₀ < P₁₅ < P₄₅ < P₃₀.

At harvest stage, the application of phosphorus tended to increase number of rachis plant⁻¹ and it varied from 5.51 to 6.41 and 7.73 to 8.42 in the year 2017-18 and 2018-19, respectively. The number of rachis plant⁻¹ (6.41) was found to be significantly superior with application of phosphorus @ 30 kg ha⁻¹ over all other treatments of phosphorus application in the year 2017-18. While, the number of rachis (8.42) plant⁻¹ was found to be significantly highest with application of phosphorus @ 60 kg ha⁻¹ and found to be at par with application of @ 30 kg ha⁻¹ (8.41) over all other treatments of phosphorus application in the year 2018-19.

Analysis of the data indicated that, the number of rachis increased from peg initiation to harvest stage in both the years. This might be due to the better nutritional environment in root zone for growth and development. Phosphorus is a vital component of ADP and ATP, it plays an important role in conservation and transfer of energy in metabolic reaction and also improve nodulation and fixation by roots. These results are in accordance with Ramana *et al.* (2010) in French bean. Similar findings were reported Yadav *et al.* (2017).

Effect of biofertilizers

The application of biofertilizers did not influence significantly on number of rachis plant⁻¹ presented in Table 4.27, which ranged from 7.19 to 7.65 and 7.59 to 8.22 due to application of biofertilizers during 2017-18 and 2018-19, respectively. Dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄) noted highest number of rachis (7.65 and 8.22 during 2017-18 and 2018-19, respectively) plant⁻¹ whereas, the lowest (7.19 and 7.59 during 2017-18 and 2018-19 respectively) was noted with application of VAM @ 10 kg ha⁻¹ (B₁).

At the pod formation stage, the application of biofertilizers alone or in combination showed significant effect on the number of rachis plant⁻¹ and varied from 5.29 to 6.03 and 7.35 to 8.38 in the year 2017-18 and 2018-19, respectively. Among the different levels of biofertilizers, the application of VAM @ 10 kg ha⁻¹ i.e. B₁

showed significantly highest number of rachis (6.03 and 8.38) plant⁻¹ over all other treatments, however, it was found to be at par with B₃ (5.99 and 8.33), B₂ (5.92 and 8.23) and B₄ (5.66 and 7.87) in the year 2017-18 and 2018-19, respectively.

Inoculation of biofertilizers either or in combination showed significant effect on number of rachis plant⁻¹ at harvest stage and it ranged from 5.71 to 6.41 and 7.69 to 8.61 during 2017-18 and 2018-19, respectively due to inoculation of biofertilizers. The combine application of VAM + PSB @ 10 kg ha⁻¹ each i.e. B₄ in respect to number of rachis (6.41 and 8.61) plant⁻¹ was found to be significantly superior over no biofertilizers application i.e. B₀ (5.71 and 7.69) in the year 2017-18 and 2018-19, respectively.

The data indicated that, the number of rachis increased from peg initiation to harvest stage in both the years. The increase number of rachis may be due to dual inoculation with VAM + PSB which registered the maximum value of this parameter than rest of the treatment. It might also be due to the PSB that produce organic acids like gluconic, succinic and lactic acid etc. that solubilize insoluble phosphates from stable complex such as Ca⁺⁺ and Mg⁺⁺ phosphates, so as to increase the availability of phosphorus, which in turn indicate better growth and development of roots, increase photosynthesis and production of assimilates which led to increase the number of rachis and dry matter accumulation. The results are corroborated with the findings of Yadav *et al.* (2017).

Interaction effect

The interaction effect on number of rachis plant⁻¹ was found to be non-significant at peg formation stage (Table 4.27) and it ranged from 6.0 to 10.11 and 6.47 to 10.77 in the year 2017-18 and 2018-19, respectively. The highest number of rachis plant⁻¹ (10.11 and 10.77) was observed with lower dose of phosphorus alongwith application of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₁₅) and the lowest (6.0 and 6.47) was found with application of phosphorus @ 45 kg ha⁻¹ in combination with application of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₄₅) in the year 2017-18 and 2018-19, respectively.

The integration effect of different levels of phosphorus and different sources of biofertilizers showed significant variation in number of rachis plant⁻¹ at pod formation stage, and it ranged from 3.38 to 8.30 and 4.70 to 11.54 in the year 2017-18 and

2018-19 respectively. The application of phosphorus @ 30 kg ha⁻¹ with inoculation of VAM @ 10 kg ha⁻¹ (B₁P₃₀) was found to be significantly highest (8.30) which was at par with application of phosphorus @ 60 kg ha⁻¹ with inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃P₆₀) in the year 2017-18. While, the application of phosphorus @ 30 kg ha⁻¹ with inoculation of VAM @ 10 kg ha⁻¹ i.e. B₁P₃₀ (11.54) found to be significantly superior over all other treatment combinations in the year 2018-19.

At harvest stage, the number of rachis plant⁻¹ due to application of phosphorus and biofertilizers in combination ranged from 3.94 to 7.78 and 5.82 to 10.04 in the year 2017-18 and 2018-19, respectively. The number of rachis plant⁻¹ with application of phosphorus @ 30 kg ha⁻¹ with no biofertilizers i.e. B₀P₃₀ was found to be significantly superior (7.78 and 10.04) over all other treatment combinations in the year 2017-18. Whereas, significantly highest number of rachis (10.04) plant⁻¹ was observed with the application of phosphorus @ 45 kg ha⁻¹ with inoculation VAM + PSB @ 5 kg ha⁻¹ each (B₄P₄₅) which was at par with B₂P₆₀ and B₃P₆₀ in the year 2018-19.

When the data was studied, it was revealed that the number of rachis increases gradually from peg initiation to harvest stage in both the years. The significant increase was recorded with application of higher doses of phosphorus as well as dual inoculation of biofertilizers during peg initiation and harvest stage in both the years. Whereas, the phosphorus application with inoculation of VAM recorded the significant increase in number of rachis during pod formation stage in both the years.

Increase in number of rachis per plant due to inoculation could be due to the conversion of unavailable phosphorus to the available form particularly during the early crop growth phase, which would have helped in the absorption of all major and minor nutrients required for the plants to put forth early vigour in vegetative growth. Another mechanism by which phosphobacteria augment the number of branches due to the biosynthesis of growth promoting substances like vitamin-B₂ and auxin.

In lateritic soils of Konkan, Gengaje (2013) and Mhalshi (2013) observed increase in plant height with the dual inoculation of *rhizobium* and PSB with different

levels of phosphorus under groundnut (*viz.*, 25 and 50 kg ha⁻¹) and cowpea (*viz.*, 50, 60 and 70 kg ha⁻¹), respectively. Rana *et al.* (2014) also reported similar observations in soybean crop, Jangandi *et al.* (2016) in pigeon pea and Pandey *et al.* (2016) in lentil.

4.4 Effect on yield of groundnut

4.4.1 Pod Yield

Effect of phosphorus

The pod yield of groundnut presented in Table 4.28 was found to be graded and in the order of $P_{15} < P_{30} < P_{45} < P_{60}$ which varied from 22.86 to 35.67 q ha⁻¹ and 22.92 to 36.06 q ha⁻¹ during the year 2017-18 and 2018-19, respectively. The pod yield increased with increasing doses of phosphorus, where the increase was graded and the highest pod yield (35.67 q ha⁻¹ and 36.06 q ha⁻¹) was recorded with the application of phosphorus @ 60 kg ha⁻¹ (P₆₀), which was significantly highest over the lower doses of phosphorus (P₃₀ and P₁₅) and found to be at par with application of phosphorus @ 45 kg ha⁻¹ i.e. P₄₅ (31.43 and 32.49 q ha⁻¹ during 2017-18 and 2018-19, respectively), which indicated that the application of phosphorus @ 60 kg ha⁻¹ can be substituted by the application of phosphorus @ 45 kg ha⁻¹. It could therefore, be concluded that with application of phosphorus @ 45 kg ha⁻¹ could save 15 kg ha⁻¹ phosphorus and gave much yield as that of application of phosphorus @ 60 kg ha⁻¹ (RDF).

The results clearly indicated that only inorganic sources can not maintain instant flow of nutrients in increasing crop yield. There is need to use organic and chemical fertilizers in combination so, as to increase crop productivity.

The overall results indicated that, the pod yield increased with increase in the level of phosphorus. This could be attributed due to better root proliferation, higher root development, increased availability and uptake of nutrients, energy transformation and metabolic processes in plant. The higher crop growth with more supply of phosphorus might regulate starch / sucrose ratio in source leaves and reproductive organs. The beneficial effect of phosphorus on fruiting of plants and better translocation of desired metabolites to the yield contributing parts of the plant might attributed to more grain yield.

The above results are in accordance with the results reported by Pramanik and Bera (2003) in chickpea, Kausale *et al.* (2009) in groundnut, Sarawgi *et al.* (2012) in soybean, Pramanik and Bera (2013) in sunflower and Nadeem *et al.* (2018) in cowpea

crop. Significant increase in seed yield of cowpea due to application of graded doses of P with biofertilizers in lateritic soils of Konkan was also reported by Mhalshi (2013).

Effect of Biofertilizers

The pod yield of groundnut was not affected significantly due to the inoculation of biofertilizers alone or in combination (Table 4.28), however it varied from 27.43 to 31.42 q ha⁻¹ and 28.42 to 31.70 q ha⁻¹ in the year 2017-18 and 2018-19, respectively. Among the different treatments, the dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄) recorded maximum pod yield (31.42 q ha⁻¹ and 31.70 q ha⁻¹ during 2017-18 and 2018-19, respectively) than rest of the treatments, but statistically not differ than the application of PSB @ 10 kg ha⁻¹ i.e. B₂ (27.43 and 28.42 q ha⁻¹) during 2017-18 and 2018-19, respectively.

The increase in yield due to beneficial effects of VAM inoculation on crop yield are attributed to greater exploration of soil volume by its hyphal network. The VAM fungi might have bring many favourable changes in the crop rhizosphere by way of exudation / secretion of organic acids / chelating agents. It also have improves root morphology and Rhizoidal root nodulation in legumes due to more P availability and PSB helps in solubilization of insoluble soil phosphates, thereby encouraging better acquisition of nutrients and the strengthening root system. The dual inoculation recorded higher grain yield might be due to synergistic effect between PSB and VAM (Pramanik and Bera 2003).

The similar results were reported by Suri *et al.* (2011) in maize, Suri and Choudhary (2013) in soybean, Pramanik and Bera (2013) in sunflower and Poonia *et al.* (2014) in groundnut-pigeonpea intercropping,

Interaction effect

Regarding the effects of different levels of phosphorus and biofertilizers, the results showed that the pod yield of groundnut (Table 4.28) varied from 21.76 to 37.27 q ha⁻¹ and 22.14 to 37.06 q ha⁻¹ in 2017-18 and 2018-19, respectively. The dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each with higher dose of phosphorus @ 60 kg ha⁻¹ (B₄P₆₀) showed highest pod yield (37.27 and 37.06 q ha⁻¹) as compared to all treatment combinations. However, the lowest pod yield (21.76 and 22.14) was

recorded with application of phosphorus @ 30 kg ha⁻¹ with no biofertilizers application (B₀P₃₀) in the 2017-18 and 2018-19, respectively.

The pod yield increased due to interaction effect of phosphorus and biofertilizers in both the years. The higher grain yield due to PSB and VAM might be due to better growth and yield attributes. The PSB is known to produce vitamins and indole acetic acid and gibberellins like substances. These growth factors in combination with better nutritional condition due to increase in availability of phosphorus in soil might have played role in increasing the grain yield. On the other hand, VAM helped in supply of essential nutrients and water to plants resulted in better yield that led to increase in grain yield. The dual inoculation recorded higher grain yield might be due synergistic effect between PSB and VAM. This improvement in yield with increased supply of phosphorus might be due profuse nodulation leading to increase in nitrogen fixation which in turn had positive effect on photosynthetic organ resulted higher grain yield.

The similar results were reported by Sarawgi *et al.* (2012) and Munda *et al.* (2013) in soybean, Pramanik and Bera, (2013) in chickpea and sunflower and Poonia *et al.* (2014) in groundnut-pigeonpea intercropping. Solanki *et al.* (2018) the recorded the significantly highest seed yield of Indian mustard with application of higher dose of phosphorus (50 kg ha⁻¹), sulphur (50 kg ha⁻¹) alongwith inoculation of PSB.

From the data it was revealed that, the pod yield increases significantly with increasing levels of phosphorus and the interaction also noted the higher pod yield of groundnut in both the years. The increase in pod yield with inoculation of phosphate solubilizing microorganisms may be due to increase in P availability through solubilization of insoluble inorganic phosphate, decomposition of rich organic compounds and production of plant growth promoting substances.

In lateritic soils of Konkan, Gengaje (2013) and Mhalshi (2013) observed increase in yield with the dual inoculation of *rhizobium* and PSB with different levels of phosphorus under groundnut (*viz.*, 25 and 50 kg ha⁻¹) and cowpea (*viz.*, 50, 60 and 70 kg ha⁻¹), respectively.

4.4.2 Halum yield Phosphorus effect

The halum yield (Table 4.28) ranged from 47.13 to 50.55 q ha⁻¹ and 48.78 to 51.55 q ha⁻¹ during 2017-18 and 2018-19, respectively which indicated non-significant difference due to application of phosphorus. The maximum halum yield (50.55 q ha⁻¹ and 51.55 q ha⁻¹ during 2017-18 and 2018-19, respectively) was obtained with application of phosphorus @ 45 kg ha⁻¹ while, the lowest halum yield (47.13 q ha⁻¹ and 47.34 q ha⁻¹ during 2017-18 and 2018-19, respectively) was observed with application of phosphorus @ 15 kg ha⁻¹.

Biofertilizers effect

The sole or dual inoculation of biofertilizers did not influence significantly the halum yield of groundnut (Table 4.28) and it ranged from 47.51 to 51.50 q ha⁻¹ and 48.84 to 50.22 q ha⁻¹ in the year 2017-18 and 2018-19, respectively. The numerically highest value of the halum yield (51.50 q ha⁻¹ and 50.22 q ha⁻¹ during 2017-18 and 2018-19, respectively) was recorded with no biofertilizers application (B₀) and the lowest halum yield (290.28 q ha⁻¹ and 331.58 q ha⁻¹ during 2017-18 and 2018-19, respectively) was recorded due VAM + PSB @ 5 kg ha⁻¹ each (B₃).

Interaction effect

The integration effect of different doses of phosphorus and biofertilizers did not showed significant variation in halum yield of groundnut presented in Table 4.28, however it varied from 42.67 to 53.60 q ha⁻¹ and 43.21 to 54.36 q ha⁻¹ in the year 2017-18 and 2018-19, respectively. The highest halum yield of groundnut (53.60 and 54.36 q ha⁻¹ during 2017-18 and 2018-19, respectively) was noted with application of phosphorus @ 45 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₄₅) whereas, the lowest halum yield (42.67 q ha⁻¹ and 43.21 q ha⁻¹ during 2017-18 and 2018-19, respectively) was recorded with application of phosphorus @ 15 kg ha⁻¹ with inoculation of VAM @ 10 kg ha⁻¹ (B₁P₁₅).

From the data it was observed that the halum yield increased irrespective of the treatments in both the years. The improvement in halum yield might be due to the fact that, phosphorus tends to increased growth and development in terms of plant height, branches and dry matter by improving nutritional environment of rhizosphere and plant system leading to higher plant metabolism and photosynthetic activity. It

also indicated that applying larger amounts of P do not increased significantly the halum yield of the crop.

Similar results were reported by Patil *et al.* (2006) in french bean, Sarawgi *et al.* (2012) and Munda *et al.* (2013) in soybean, Melese and Dechassa (2017) in groundnut. Solanki *et al.* (2018) recorded the significantly highest stover yield of Indian mustard with application of higher dose of phosphorus (50 kg ha^{-1}), sulphur (50 kg ha^{-1}) alongwith inoculation of PSB.

4.4.3 Kernel yield

Effect of phosphorus

Graded increase in kernel yield of groundnut with graded doses of phosphorus was observed (Table 4.29) and varied from 15.14 to 24.65 and 14.92 to 25.74 q ha^{-1} in the year 2017-18 and 2018-19, respectively. The highest kernel yield (24.65 q ha^{-1} and 25.74 q ha^{-1} during 2017-18 and 2018-19, respectively) was found due to application of phosphorus @ 60 kg ha^{-1} (RDF), which was significantly superior over the lower doses of phosphorus. The increase in kernel yield followed the order $P_{15} < P_{30} < P_{45} < P_{60}$.

Effect of biofertilizers

The inoculation of biofertilizers alone or in combination does not show significant effect on kernel yield (Table 4.29) and it ranged from 18.83 to 21.26 q ha^{-1} and 19.70 to 22.33 q ha^{-1} in the year 2017-18 and 2018-19, respectively. The inoculation of VAM + PSB @ 10 kg ha^{-1} (B_4) showed the highest kernel yield (21.26 and 22.33 q ha^{-1} during 2017-18 and 2018-19, respectively) while, the application of VAM @ 10 kg ha^{-1} (B_1) and with no biofertilizers application (B_0) was recorded the lowest kernel yield (18.83 q ha^{-1}) in the year 2017-18 and (19.70 q ha^{-1}) in the year 2018-19, respectively.

Interaction effect

The interaction of phosphorus and biofertilizers could not reach the level of significance in respect of kernel yield presented in the Table 4.29 and it varied from 13.51 to 26.75 q ha^{-1} and 14.15 to 27.37 q ha^{-1} in the year 2017-18 and 2018-19, respectively. The highest kernel yield (26.75 q ha^{-1} and 27.37 q ha^{-1}) was observed with application of phosphorus @ 60 kg ha^{-1} with dual inoculation of VAM + PSB @ 10 kg ha^{-1} (B_4P_{60}) while, the application of phosphorus @ 15 kg ha^{-1} with no

biofertilizers (B₀P₁₅) showed the lowest kernel yield (13.51 q ha⁻¹ and 14.15 q ha⁻¹) of groundnut in the year 2017-18 and 2018-19, respectively.

Increase in dry matter yield of soybean with the *rhizobium* inoculation was also reported by many workers (Balsundaram 1971, Balsubramanian *et al.* (1980), Thakare *et al.* (1996), Singh *et al.* (2009). Balchandran *et al.* (2006) explained that the increase in grain yield of green gram might be due to availability of N and P in required amount through fertilizers and PSB. The higher values of kernel yield of groundnut was reported by Kharade (2009) with the application of 25:50:30 + BF in *Kharif* groundnut.

4.4.4 Test weight

Effect of phosphorus

The application of phosphorus showed non-significant effect on test weight (presented in Table 4.30) of groundnut pod and it ranged from 58.08 to 62.68 per cent and 56.12 to 61.36 per cent in 2017-18 and 2018-19, respectively. The application of phosphorus @ 30 kg ha⁻¹ recorded the highest test weight (62.68 % and 61.36 %), while the lowest test weight (58.08 % and 56.12 %) was noted with application of phosphorus @ 15 kg ha⁻¹ in the year 2017-18 and 2018-19, respectively.

Biofertilizers effect

The inoculation of biofertilizers alone or in combination had significant effect on test weight of groundnut (Table 4.30), which ranged from 55.33 to 64.36 and 53.56 to 62.56 per cent during 2017-18 and 2018-19, respectively. The significantly highest test weight was observed with the application of VAM + PSB @ 10 kg ha⁻¹ each (B₄) (64.36 % and 62.56 % during 2017-18 and 2018-19, respectively) over all other treatment combinations and it was found to be at par with B₂ and B₀ treatments.

The increase in test weight might be due to a strong positive synergistic effect that caused to improving photosynthesis by increasing water and nutrients absorption and this leading to producing more assimilates and improving plant growth, as a result 1000-seed weight increased). The similar results were reported by Hadwani and Gundalia (2005) in groundnut and Yadav *et al.* (2017) in urdbean.

Interaction effect

The application of phosphorus and biofertilizers significantly influenced the test weight of groundnut (Table 4.30) and it ranged from 47.63 to 69.20 per cent and 45.94 to 67.46 per cent in the year 2017-18 and 2018-19, respectively. The highest test weight (69.20 per cent and 67.46 per cent during the year 2017-18 and 2018-19, respectively) was found in the treatment combination with the application of phosphorus @ 60 kg ha⁻¹ alongwith dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀), indicating its superiority of higher dose of phosphorus and biofertilizers combination and it was at par with B₂P₄₅, B₀P₆₀, B₁P₃₀, B₂P₃₀, B₄P₃₀, B₂P₁₅, B₀P₁₅, B₄P₁₅ and B₃P₄₅ in the year 2017-18 and B₂P₄₅, B₀P₆₀, B₁P₃₀, B₂P₃₀, B₄P₃₀, B₂P₁₅, B₄P₁₅, B₀P₁₅, B₃P₄₅ and B₀P₃₀ in the year 2018-19.

As regard the influence of phosphorus on yield contributing characters, the increasing rates of phosphorus brought about a significant impact. All the yield attributing characters like pod yield, halum yield, plant height, number of rachis and weight of 1000-grains were positively influenced as the level of phosphorus increased. The cumulative effect of high doses of phosphorus on the yield attributing characters ultimately resulted in higher production of groundnut. The basic reason of increase in pod yield due to phosphorus application might be due to an adequate supply of phosphorus in the early stage of plant life, considered essential for the development of its reproductive process. Such favourable effects on yield and yield components could also be attributed to the stimulation effect of NPK on number and weight of nodules and nitrogen activity, which in turn reflected positively on groundnut yield attributes.

Phosphorus is an important nutrient for all the crops in general and legumes in particular, it is a key constituent of ATP and plays significant role in energy transformation in plant and also, in various roles in seed formation (Sanker *et al.* 1984). Patra *et al.* (1995) stated that addition of N fertilizer generally increases root-shoot ratio and pod yield of groundnut. Significant increase in 100 kernel weights with biofertilizers and levels of NPK application has been recorded by Kharade (2009).

In lateritic soils of Konkan, Gengaje (2013) and Mhalshi (2013) observed significant increase in yield with the dual inoculation of *rhizobium* and PSB with

different levels of phosphorus under groundnut (*viz.*, 25 and 50 kg ha⁻¹) and cowpea (*viz.*, 50, 60 and 70 kg ha⁻¹), respectively.

4.5 Effect on nutrient content (N, P, K, Zn, Fe, Mn and Cu)

4.5.1 Macronutrients content in halum

4.5.1.1 Nitrogen content

Effect of phosphorus

The nitrogen content was found to be non-significant with application of phosphorus (Table 4.31) and it varied from 0.65 to 0.81 and 0.64 to 0.79 per cent at peg initiation stage in the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 30 kg ha⁻¹ recorded the highest nitrogen content (0.81 % and 0.79 % during 2017-18 and 2018-19, respectively) and the lowest (0.65 % and 0.64 % during 2017-18 and 2018-19, respectively) was recorded with application of phosphorus @ 45 kg ha⁻¹.

At pod formation stage, the application of phosphorus could not reach the level of significance and the nitrogen content varied from 0.54 to 0.72 per cent and 0.47 to 0.59 per cent during the year 2017-18 and 2018-19, respectively. The nitrogen content found to be highest (0.72 % and 0.59 % during 2017-18 and 2018-19, respectively) with application of phosphorus @ 30 kg ha⁻¹ and lowest (0.54 % and 0.47 % during 2017-18 and 2018-19, respectively) observed due to application of phosphorus @ 15 kg ha⁻¹.

The graded doses of phosphorus significantly influenced the nitrogen content at harvest stage and it ranged from 1.74 to 2.14 and 1.84 to 2.33 per cent in the year 2017-18 and 2018-19, respectively. Significantly highest nitrogen content (2.14 % and 2.33 % during 2017-18 and 2018-19, respectively) was observed with application of phosphorus @ 60 kg ha⁻¹ and was found to be significantly superior over other all treatments. The increase in nitrogen content in halum followed the order of P₁₅ < P₃₀ < P₄₅ < P₆₀.

Effect of biofertilizers

The inoculation of biofertilizers did not influenced significantly on nitrogen content during peg initiation stage (Table 4.31) and ranged from 0.62 to 0.78 and 0.62 to 0.77 per cent in the year 2017-18 and 2018-19, respectively. The highest (0.78 % and 0.77 % during 2017-18 and 2018-19, respectively) nitrogen content was observed

with application of VAM @ 10 kg ha⁻¹ and the lowest (0.62 % and 0.62 % during the year 2017-18 and 2018-19, respectively) was noticed with application of PSB @ 10 kg ha⁻¹.

The inoculation of biofertilizers tended to increase significantly nitrogen content at pod formation stage, which varied from 0.45 to 0.92 per cent and 0.38 and 0.76 per cent in the year 2017-18 and 2018-19, respectively. The inoculation of VAM + PSB @ 10 kg ha⁻¹ each was found to be significantly superior (0.92 % and 0.76 % during 2017-18 and 2018-19, respectively) over inoculation of VAM @ 10 kg ha⁻¹ (0.45 % and 0.37 % during 2017-18 and 2018-19, respectively).

At harvest, the inoculation of biofertilizers had significant effect on nitrogen content of the groundnut and the nitrogen content varied from 1.654 to 2.084 per cent and 1.76 to 2.22 per cent in the year 2017-18 and 2018-19, respectively. The nitrogen content increase significantly (2.08 % and 2.22 % during 2017-18 and 2018-19, respectively) with dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each, which was found to be significantly superior over all other treatments.

Interaction effect

The application of phosphorus and inoculation of biofertilizers did not influenced significantly on nitrogen content at peg initiation stage (Table 4.31), however it ranged from 0.37 to 1.03 per cent and 0.35 to 1.00 per cent in the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 30 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₃₀) recorded the highest nitrogen content (1.025 % and 0.996 % during the year 2017-18 and 2018-19, respectively), while, the application of phosphorus @ 45 kg ha⁻¹ with inoculation of PSB @ 10 kg ha⁻¹ (B₂P₄₅) showed the lowest nitrogen content (0.374 % and 0.351 % during 2017-18 and 2018-19, respectively) in halum.

At pod formation stage, the application of phosphorus and inoculation of biofertilizers had significant effect on nitrogen content and it ranged from 0.23 to 1.07 per cent and 0.20 to 0.91 per cent during pod formation stage in the year 2017-18 and 2018-19, respectively. Significantly highest nitrogen content (1.07 and 0.91 % during 2017-18 and 2018-19, respectively) was recorded with application of phosphorus @ 15 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₁₅), however B₄P₁₅ was found to be at par with B₄P₃₀, B₃P₃₀, B₀P₄₅, B₄P₄₅ and

B₃P₆₀ in both the years.

Integration of phosphorus and biofertilizers significantly increased nitrogen content at harvest, which varied from 0.79 to 2.74 and 0.84 to 2.95 in the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃P₆₀) was found to be significantly superior (2.74 % and 2.95 % during 2017-18 and 2018-19, respectively) over application of phosphorus @ 15 kg ha⁻¹ with inoculation of PSB @ 10 kg ha⁻¹ i.e. B₂P₁₅ (0.79 % and 0.84 % during 2017-18 and 2018-19, respectively).

Application of biofertilizers increased the N content in plant and seed over sole use of different chemical fertilizer combinations. Further, data indicated that N content in plant and seed increased with the increasing doses of P and K. This may be due to symbiotic effect of mycorrhiza which might transfer N between crops via hyphal nets. The VAM inoculation leads to better exploration of rhizosphere by hyphal network, leading to greater nutrient use efficiencies by way of nutrient dynamics mechanisms in the soil-plant continuum. It also influences Rhizoidal-root nodulation behavior in legumes due to more P availability either by VAM or PSB supported P acquisition.

Rhizobium inoculation and addition of N probably enhanced the availability and absorption of N by plants which might have increased the N metabolism leading to high N content in seed. The marked improvement in nutritional status of grain and straw due to rhizobium + PSB inoculation may be ascribed to greater availability of nutrients in soil environment and increased their absorption by the roots and their transportation towards above ground parts and increased the N and P concentration in cell sap, which helped in various metabolic activities and resulted in greater dry matter production.

Mishra (2003) found that application of NPK (20:50:45 kg N:P₂O₅:K₂O ha⁻¹) + seed inoculation has significantly increased the N content of seed from 3.84 per cent to 4.17 per cent over control. The results of the present study are in agreement with those reported by Kharade (2009) who observed that application of NPK (30:50:45 kg N:P₂O₅:K₂O ha⁻¹) + seed inoculation of biofertilizers significantly increased the N content of kernel from 3.87 per cent to 4.97 per cent over control in lateritic soil.

In lateritic soils of Konkan, Gengaje (2013) and Mhalshi (2013) observed

significant increase in nitrogen content with the dual inoculation of *rhizobium* and PSB with different levels of phosphorus under groundnut (*viz.*, 25 and 50 kg ha⁻¹) and cowpea (*viz.*, 50, 60 and 70 kg ha⁻¹), respectively. Suri and Choudhary (2013) clearly indicate the existence of *Glycine max-Glomus*-PSB interactions having vital role in nutrient dynamics in soil-plant system which may lead to P economy in soybean in a P-deficient acidic Alfisol. Similar results were reported by Zohmingliana *et al.* (2018) in French bean.

4.5.1.2 Phosphorus

Effect of phosphorus

At peg initiation stage, the application of phosphorus significantly influenced the phosphorus content presented in Table 4.32, which ranged from 0.30 to 0.38 per cent and 0.19 to 0.31 per cent in the year 2017-18 and 2018-19, respectively and followed the order of P₆₀ < P₃₀ < P₄₅ < P₁₅. The application of phosphorus @ 15 kg ha⁻¹ showed significantly highest phosphorus content (0.38 % and 0.31 % during 2017-18 and 2018-19, respectively) and showed its superiority, which was found to be at par with phosphorus application @ 45 kg ha⁻¹ and @ 30 kg ha⁻¹ in both the years.

The phosphorus content was found to be significant due to application of phosphorus at pod formation stage and it varied from 0.42 to 0.59 per cent and 0.53 to 0.75 per cent in the year 2017-18 and 2018-19, respectively. Significantly highest phosphorus content (0.59 % during 2017-18) and @ 30 kg ha⁻¹ (0.75 % during the year 2018-19) was observed with the application of phosphorus @ 15 kg ha⁻¹, thereby indicating its superiority, which was found to be at par with @ 30 kg ha⁻¹ (0.55 %) and @ 60 kg ha⁻¹ (0.51 %) in the year 2017-18 and @ 15 kg ha⁻¹ (0.73 %) and @ 60 kg ha⁻¹ (0.71 %) in the year 2018-19. The increase in phosphorus content in halum followed the order of P₄₅ < P₆₀ < P₃₀ < P₁₅.

At harvest of the crop, the phosphorus application showed non-significant effect on phosphorus content and it varied from 0.04 to 0.04 and 0.04 to 0.05 per cent in the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 15 kg ha⁻¹ was recorded highest phosphorus content (0.04 % and 0.05 % during 2017-18 and 2018-19, respectively) and lowest (0.04 % and 0.0441 % during 2017-18 and 2018-19, respectively) was observed with application of phosphorus @ 45 kg ha⁻¹.

Effect of biofertilizers

The phosphorus content could not reach the level of significance due to inoculation of biofertilizers at peg initiation stage (Table 4.32), however it was ranged from 0.31 to 0.37 per cent and 0.25 to 0.30 per during the year 2017-18 and 2018-19, respectively. The highest (0.37 % and 0.30 % during 2017-18 and 2018-19, respectively) phosphorus content was observed with no biofertilizers application (B_0) and the lowest (0.31 % and 0.25 % during 2017-18 and 2018-19, respectively) were observed with inoculation of VAM @ 10 kg ha⁻¹.

At pod formation stage, the inoculation of biofertilizers does not showed significant effect on phosphorus content and it varied from 0.50 to 0.57 per cent and 0.55 to 0.79 per cent in the year 2017-18 and 2018-19, respectively. The inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B_4) was recorded the highest phosphorus content (0.57 % and 0.79 % during 2017-18 and 2018-19, respectively) and the lowest (0.50 and 0.55 % during 2017-18 and 2018-19, respectively) phosphorus content was observed with no biofertilizers application (B_0) in both the years.

Inoculation of biofertilizers alone or in combination was not affected significantly on phosphorus content and it varied from 0.04 to 0.04 per cent and 0.04 to 0.05 per cent in the year 2017-18 and 2018-19, respectively. The highest phosphorus content (0.04 % and 0.05 % during 2017-18 and 2018-19, respectively) was observed with no biofertilizers application (B_0) and the lowest (0.04 and 0.04 % during 2017-18 and 2018-19, respectively) was observed with inoculation of PSB @ 10 kg ha⁻¹.

Interaction effect

The data on phosphorus content as influenced by the application of phosphorus and inoculation of biofertilizers showed significant effect at peg initiation stage, which varied from 0.27 to 0.47 per cent and 0.14 to 0.38 per cent in the year 2017-18 and 2018-19, respectively. Significantly highest phosphorus content (0.47 % and 0.38 % during 2017-18 and 2018-19, respectively) was found with application of phosphorus @ 15 kg ha⁻¹ without biofertilizers (B_0P_{15}) over all other treatment combinations in both the years. However, the treatment combinations B_0P_{15} found to be at par with B_4P_{45} B_2P_{15} , B_4P_{30} , B_3P_{60} , and B_1P_{45} in the year 2017-18 and B_4P_{45} B_2P_{15} , B_4P_{30} , and B_0P_{45} in the year 2018-19, respectively.

The application of phosphorus and biofertilizers alone or in combination had significant effect on phosphorus content at pod formation stage presented in Table 4.32 and ranged from 0.28 to 0.70 per cent and 0.26 to 1.01 per cent in the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 60 kg ha⁻¹ without biofertilizers (B₀P₃₀) showed significantly higher phosphorus content in halum (0.70 %) and found to be at par with B₃P₁₅, B₂P₁₅, B₀P₃₀, B₄P₁₅, B₃P₄₅, B₂P₃₀, B₀P₁₅, B₃P₃₀, B₂P₆₀, and B₁P₆₀ in the year 2017-18. However, the application of phosphorus @ 30 kg ha⁻¹ with no biofertilizers application (B₀P₃₀) found to be significantly highest phosphorus content (1.01 %) in all other treatment combinations and found at par with B₀P₆₀, B₁P₆₀, B₃P₁₅, B₂P₁₅, B₃P₄₅, B₂P₃₀, B₂P₆₀, B₀P₁₅ and B₃P₃₀ in the year 2018-19.

At harvest stage, the integration of different doses of phosphorus and biofertilizers showed significant variations in phosphorus content and it ranged from 0.03 to 0.06 per cent and 0.03 to 0.06 per cent in the year 2017-18 and 2018-19, respectively. Significantly highest phosphorus content (0.06 % and 0.06 % during 2017-18 and 2018-19, respectively) was recorded with application of phosphorus @ 15 kg ha⁻¹ with no application of biofertilizers (B₀P₁₅) over all other treatment combinations and found to be at par with B₄P₃₀, B₁P₃₀, B₄P₃₀, B₀P₄₅, B₁P₆₀ and B₀P₆₀ in both the years.

Application of biofertilizers increased the P content in plant and seed over sole use of different chemical fertilizer combinations. Further, the data indicated that P content in plant and seed increased with the increasing doses of phosphorus. This might be due to involvement of phosphorus in energy transformation within plant system and cell division. Furthermore, phosphorus also help in better root development that resulted plant to better utilization of nutrients and moisture leading to better plant growth and development. The positive effect of inoculation in combination with organic matter i.e. FYM or interactive effect of two or more organisms increased uptake of phosphorus due to solubilization effect of phosphate solubilizing bacteria or better uptake under VAM-treated plots was also reported by Rao and Tarafdar (1993).

These results were in accordance with Kharade (2009) who reported an increase in phosphorus content might be due to adequate supply of phosphate to soil through fertilizer and PSB and thereby greater mobilization of insoluble phosphorus

along with enhanced transport of soil nutrients within the plant system.

Bio-inoculants application also increased the availability of phosphorus in the soil and favored higher absorption and utilization of phosphorus as well as other nutrients resulted positive effect on plant growth. Phosphorus and bio-inoculants application improved the root growth and nutrients availability resulted plant absorbed more nutrients from the soil for effective dry matter production and translocation of photosynthates from leaves to reproductive parts for better development of seeds. Similar results were reported by Zohmingliana *et al.* (2018).

In lateritic soils of Konkan, Gengaje (2013) and Mhalshi (2013) observed significant increase in phosphorus content with the dual inoculation of *rhizobium* and PSB with different levels of phosphorus under groundnut (*viz.*, 25 and 50 kg ha⁻¹) and cowpea (*viz.*, 50, 60 and 70 kg ha⁻¹), respectively.

4.5.1.3 Potassium

Effect of phosphorus

The application of graded doses of phosphorus increased potassium content significantly at peg initiation stage (Table 4.33), which ranged from 1.18 to 1.87 and 0.65 to 1.01 per cent in the year 2017-18 and 2018-19, respectively. The highest dose of phosphorus i.e. application of phosphorus @ 60 kg ha⁻¹ recorded significantly highest potassium content (1.87 % and 1.01 % during 2017-18 and 2018-19, respectively) indicating its superiority and found to be at par with phosphorus application @ 45 kg ha⁻¹ and @ 30 kg ha⁻¹ in the years 2017-18. The increase in potassium content in halum followed the order of P₁₅ < P₃₀ < P₄₅ < P₆₀.

At pod formation stage, the application of phosphorus showed significant effect on potassium content and it varied from 1.44 to 1.81 and 1.15 to 1.50 per cent in the year 2014-18 and 2018-19, respectively. The potassium content found to be significantly highest (1.81 % and 1.49 % during 2017-18 and 2018-19, respectively) with application of phosphorus @ 60 kg ha⁻¹ and showed its superiority, which was found to be at par with application of phosphorus @ 30 kg ha⁻¹ (1.67 % and 1.38 % during 2017-18 and 2018-19, respectively).

The phosphorus application showed non-significant effect on potassium at harvest and varied from 0.99 to 1.05 per cent and 1.03 to 1.09 per cent in the year 2017-18 and 2018-19, respectively. Among the phosphorus doses, the application of

phosphorus @ 60 kg ha⁻¹ was recorded highest potassium content (1.05 and 1.09 % during 2017-18 and 2018-19, respectively) whereas the application of phosphorus @ 45 kg ha⁻¹ (0.99 % and 1.03 % during 2017-18 and 2018-19, respectively) showed the lowest content of potassium.

Effect of biofertilizers

The sole or dual inoculation of biofertilizers influenced significantly on potassium content at peg initiation (Table 4.33) and it varied from 1.29 to 1.75 per cent and 0.75 to 1.05 per cent with application of phosphorus in the year 2017-18 and 2018-19, respectively. The application of PSB @ 10 kg ha⁻¹ was found to be significantly superior (1.75 % and 1.05 % during 2017-18 and 2018-19, respectively) over all other treatments of biofertilizers application in both the years.

The inoculation of biofertilizers does not showed significant effect on potassium content at pod formation stage and it ranged from 1.38 to 1.68 per cent and 1.25 to 1.39 per cent in the year 2017-18 and 2018-19, respectively. The highest potassium content was observed with application of VAM + PSB @ 10 kg ha⁻¹ each (1.68 %) and the lowest was recorded with no biofertilizers application (1.38 %) in the year 2017-18. However, the dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (1.39 %) showed highest magnitude of potassium content while the lowest (1.25 %) was observed with application of PSB @ 10 kg ha⁻¹ in the year 2018-19.

At harvest stage, the potassium content tended to increase significantly with the application of biofertilizers and ranged from 0.91 to 1.09 per cent and 0.95 to 1.14 per cent in the year 2017-18 and 2018-19, respectively. Significantly highest potassium content (1.09 % and 1.14 % during 2017-18 and 2018-19, respectively) was observed with no biofertilizers application (B₀) which was found to be at par with application of PSB @ 10 kg ha⁻¹ (1.08 % and 1.13 % during the year 2017-18 and 2018-19, respectively) and inoculation of VAM + PSB @ 10 kg ha⁻¹ each (1.06 and 1.09 % during 2017-18 and 2018-19, respectively).

Interaction effect

The application of phosphorus and biofertilizers showed significant effect on potassium content (presented in the Table 4.33) and it varied from 0.62 to 2.63 and 0.46 to 1.41 per cent during peg initiation stage in the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 60 kg ha⁻¹ with PSB @ 10 kg ha⁻¹

(B₂P₆₀) was found to be significantly superior in potassium content (2.63 %) in all other treatment combinations in the year 2017-18. However, significantly highest potassium content (1.41 %) was observed with application of phosphorus @ 60 kg ha⁻¹ alongwith PSB @ 10 kg ha⁻¹ (B₂P₆₀) which was found to be at par with application of phosphorus @ 60 kg ha⁻¹ with no biofertilizers application i.e. B₀P₃₀ (1.21 %) in the year 2018-19.

At pod formation, integrated use of phosphorus and biofertilizers significantly increased potassium content and it ranged from 0.97 to 2.38 per cent in the year 2017-18 and 0.79 to 1.71 per cent in the year 2018-19. Significantly highest potassium content (2.38 %) was noted with application of phosphorus @ 60 kg ha⁻¹ alongwith PSB @ 10 kg ha⁻¹ (B₂P₆₀) and showed its superiority, which was found to be at par with application of phosphorus @ 45 kg ha⁻¹ with inoculation of VAM @ 10 kg ha⁻¹ i.e. B₁P₄₅ (1.97 %) in the year 2017-18. But, in the year 2018-19, the application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each i.e. B₄P₆₀ (1.710 %) was recorded significantly highest potassium content and indicating its superiority which was found to be at par with B₀P₃₀, B₁P₆₀, B₄P₃₀, B₃P₁₅, B₃P₆₀ and B₂P₃₀ in the year 2018-19.

Application of phosphorus either alone or in combination with biofertilizers significantly influenced potassium content at harvest, which was ranged from 0.64 to 1.57 per cent and 0.67 to 1.61 per cent in the year 2017-18 and 2018-19, respectively. Significantly superior potassium content (1.57 %) was observed with application of phosphorus @ 30 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₃₀), which was found to be at par with application of phosphorus @ 15 kg ha⁻¹ with no biofertilizers application i.e. B₀P₁₅ (1.54 %) in the year 2017-18. However, the application of phosphorus @ 15 kg ha⁻¹ with no biofertilizers application (B₀P₁₅) noted significantly highest potassium content (1.61 %) and showed its superiority and which was found to be at par with application of phosphorus @ 30 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₃₀) i.e. 1.60 % in the year 2018-19.

From the data it was noticed that, similar to N and P content, application of biofertilizers increased the K content in plant over sole use of different chemical fertilizer combinations. Further, a graded increase in P content in halum was observed with the application of graded doses of potassium (from 15 to 60 kg ha⁻¹). At harvest,

the K concentration decreased as compared to flowering stage. An increase in K content can be attributed to the fact that in young stage plant may be able to uptake nutrients from the soil than the older ones and it might be due to better root establishment and thereby better uptake of nutrients. Increase in K content due to the application of potassium with biofertilizers was reported by Kharade (2009).

In lateritic soils of Konkan, Gengaje (2013) and Mhalshi (2013) observed significant increase in potassium content with the dual inoculation of *rhizobium* and PSB with different levels of phosphorus under groundnut (*viz.*, 25 and 50 kg ha⁻¹) and cowpea (*viz.*, 50, 60 and 70 kg ha⁻¹), respectively.

4.5.1.4 Nitrogen content in Kernel

Effect of phosphorus

The data on nitrogen content in kernel as influenced by phosphorus application presented in the Table 4.34, which varied from 3.74 to 4.80 per cent and 3.71 to 4.75 per cent during the year 2017-18 and 2018-19, respectively. Among the different doses of phosphorus, the application of phosphorus @ 45 kg ha⁻¹ (4.80 % and 4.75 % during 2017-18 and 2018-19, respectively) showed significantly superior nitrogen content in kernel over all other treatments of phosphorus application in both the years and followed the order of P₁₅ < P₃₀ < P₆₀ < P₄₅.

Effect of biofertilizers

The inoculation of biofertilizers either or in combination significantly increased nitrogen content in kernel and it ranged from 4.18 to 4.49 per cent and 4.14 to 4.45 per cent in the 2017-18 and 2018-19, respectively. Significantly highest nitrogen (4.49 % and 4.45 % during 2017-18 and 2018-19, respectively) content in kernel was observed with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄) and thereby indicating its superiority, which was found to be at par with B₃, B₂ and B₁ in the year 2018-19. However, in the year 2017-18, treatment was at par with the treatment B₃, B₂ and B₁.

Interaction effect

Regarding the effects of different levels of phosphorus and biofertilizers, the results showed that the nitrogen content, which varied from 3.575 to 5.06 per cent and 3.53 to 5.01 per cent with application of phosphorus and biofertilizers in the year 2017-18 and 2018-19, respectively. The nitrogen content in kernel noted significantly

highest content (5.06 % and 5.01 % during 2017-18 and 2018-19, respectively) was with the application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀) and which was found to be at par with B₃P₆₀ (5.02 % and 4.94 % during 2017-18 and 2018-19, respectively) and B₂P₄₅ (4.98 % and 4.94 % during 2017-18 and 2018-19, respectively).

From the data it is revealed that, *rhizobium* inoculation and addition of N probably enhanced the availability and absorption of N by plants which might have increased the N metabolism leading to high N content in seed. The marked improvement in nutritional status of grain due to *rhizobium* + PSB inoculation may be ascribed to greater availability of nutrients in soil environment and increased their absorption by the roots and their transportation towards above ground parts and increased the N and P concentration in cell sap, which helped in various metabolic activities and resulted in greater dry matter production (Meena 1999; Jain and Singh 2003).

In lateritic soils of Konkan, Gengaje (2013) observed significant increase in nitrogen content in kernel with the dual inoculation of *rhizobium* and PSB with different levels of phosphorus under groundnut (*viz.*, 25 and 50 kg ha⁻¹).

4.5.1.5 Phosphorus content in Kernel

Effect of phosphorus

The application of phosphorus influenced phosphorus content in kernel significantly (Table 4.34), which varied from 0.11 to 0.22 and 0.10 to 0.19 per cent with application of phosphorus in the year 2017-18 and 2018-19, respectively. Among the phosphorus doses, the application of phosphorus @ 60 kg ha⁻¹ was found to be significantly higher (0.22 %) which was found to be at par with P₁₅ (0.19 %) in the year 2017-18. However, the application of phosphorus @ 60 kg ha⁻¹ which was found to be significantly superior (0.19 %) over all treatments in the year 2018-19 and followed the order of P₄₅ < P₃₀ < P₁₅ < P₆₀.

Effect of biofertilizers

The inoculation of biofertilizers alone or in combination recorded significant effect on phosphorus content in kernel and varied from 0.10 to 0.11 and 0.09 to 0.18 per cent in the year 2017-18 and 2018-19, respectively. The dual inoculation of VAM

+ PSB @ 10 kg ha⁻¹ each (B₄) was found to be significantly higher in phosphorus (0.11 % and 0.18 % during 2017-18 and 2018-19, respectively) content in kernel and which was found at par with B₁, B₀, and B₂ during the year 2017-18. However, treatment B₄ was significantly higher and was at par with B₁ and B₀ treatment during the year 2018-19.

Interaction effect

Integrated use of phosphorus and inoculation of biofertilizers had a significant influence on phosphorus content in kernel, which ranged from 0.02 to 0.27 and 0.01 to 0.24 per cent in the year 2017-18 and 2018-19, respectively. Significantly higher phosphorus (0.27 % and 0.24 % during 2017-18 and 2018-19, respectively) content in kernel was registered with application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀), which was found to be at par with all the treatment combinations except B₃P₃₀ and B₃P₄₅ in the year 2017-18 and B₀P₆₀, B₁P₃₀, B₂P₃₀ and B₂P₁₅ in the year 2018-19.

From the two years data, it was observed that, the phosphorus content in kernel increases with increase in the phosphorus levels. The increase in phosphorus content might be due to adequate supply of phosphate to soil through fertilizer and PSB and thereby greater mobilization of insoluble phosphorus along with enhanced transport of soil nutrients within the plant system. It was observed that the P content in halum decreased at harvest as compared to halum at flowering stage, probably due to the fact that at vegetative period physiological and metabolic activities are at higher rate and this might be reason for increase in concentration of the nutrients.

Application of biofertilizers increased the P content in plant and seed over sole use of different chemical fertilizer combinations. Further, data indicated that P content in plant and seed increased with the increasing doses of P and K. These results were in accordance with Kharade (2009).

In lateritic soils of Konkan, Gengaje (2013) observed significant increase in phosphorus content in kernel with the dual inoculation of *rhizobium* and PSB with different levels of phosphorus under groundnut (*viz.*, 25 and 50 kg ha⁻¹).

4.5.1.6 Potassium content in Kernel

Effect of phosphorus

The application of phosphorus showed non-significant effect on potassium

content in kernel (Table 4.34) however, it varied from 0.70 to 0.77 per cent and 0.65 to 0.72 per cent in the year 2017-18 and 2018-19, respectively. The higher magnitude of potassium (0.77 % and 0.72 % during 2017-18 and 2018-19, respectively) content in kernel observed with application of phosphorus @ 45 kg ha⁻¹ while the lowest (0.70 % and 0.65 % during 2017-18 and 2018-19, respectively) was recorded with application of phosphorus @ 15 kg ha⁻¹.

Effect of biofertilizers

The alone or dual inoculation of biofertilizers did not influence significantly on potassium content in kernel and it ranged from 0.68 to 0.78 per cent and 0.63 to 0.73 per cent in the year 2017-18 and 2018-19, respectively. The potassium content (0.78 % and 0.73 % during 2017-18 and 2018-19, respectively) in kernel was recorded highest with no biofertilizers application and the inoculation of VAM + PSB @ 10 kg ha⁻¹ each showed the lowest content (0.68 % and 0.63 % during 2017-18 and 2018-19, respectively) of it.

Interaction effect

Application of phosphorus and biofertilizers could not reach the level of significance on potassium content in kernel, which varied from 0.61 to 0.83 per cent and 0.55 to 0.78 per cent in the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 45 kg ha⁻¹ with no biofertilizers application (B₀P₄₅) was recorded the highest potassium content (0.83 % and 0.78 % during 2017-18 and 2018-19, respectively) in kernel and lowest was recorded with B₄P₆₀ in the year 2017-18 and B₄P₁₅ in the year 2018-19.

The two years data showed that, similar to N and P content, application of biofertilizers increased the K content in seed over sole use of different chemical fertilizer combinations. Further, it was observed the potassium content in kernel increased with lower dose of phosphorus in both the years. The graded increase in K content in halum was observed with the application of graded doses of potassium (from 15 to 45 kg ha⁻¹). Increase in K content due to the application of potassium with biofertilizers was also reported by Kharade (2009). At harvest, the K concentration decreased as compared to flowering stage. An increase in K content can be attributed to the fact that in young stage plant may be able to uptake nutrients from the soil than the older ones and it might be due to better root establishment and thereby better

uptake of nutrients.

In lateritic soils of Konkan, Gengaje (2013) observed significant increase in potassium content in kernel with the dual inoculation of *rhizobium* and PSB with different levels of phosphorus under groundnut (*viz.*, 25 and 50 kg ha⁻¹).

4.5.1.7 Nitrogen content in shell

Effect of phosphorus

The application of phosphorus significantly increased the nitrogen content in shell (Table 4.35), which varied from 0.44 to 0.74 and 0.43 to 0.73 per cent during the 2017-18 and 2018-19, respectively. The treatment receiving the phosphorus @ 45 kg ha⁻¹ was found to be significantly superior (0.74 % and 0.73 % during 2017-18 and 2018-19, respectively) over all treatments of phosphorus application and followed the increasing order $P_{15} < P_{30} < P_{45} < P_{60}$.

Effect of biofertilizers

The nitrogen content in shell was significantly influenced with application of biofertilizers (Table 4.35) and ranged from 0.59 to 0.63 and 0.55 to 0.62 per cent in the 2017-18 and 2018-19, respectively. Significantly highest nitrogen (0.63 % and 0.62 % during 2017-18 and 2018-19, respectively) content in shell observed with the dual inoculation of VAM +PSB @ 5 kg ha⁻¹ each which was found to be at par with B₁ and B₄ in the year 2017-18 and B₁, B₄ and B₂ in the year 2018-19.

Interaction effect

Different levels of phosphorus alongwith biofertilizers significantly increased nitrogen content in shell at harvest stage (Table 4.35), which varied from 0.39 to 0.82 per cent and 0.39 to 0.81 per cent during 2017-18 and 2018-19, respectively. The application of phosphorus @ 45 kg ha⁻¹ with inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃P₄₅) in all treatment combinations and was found to be significantly highest (0.82 % and 0.81 % during 2017-18 and 2018-19, respectively) which was found to be at par with B₂P₄₅ treatment was 0.79 % and 0.79 % during 2017-18 and 2018-19, respectively.

4.5.1.8 Phosphorus content in shell

Effect of phosphorus

The application of phosphorus showed the significant effect on phosphorus content in shell (Table 4.35) and varied from 0.06 to 0.07 per cent and 0.05 to 0.05

per cent in the year 2017-18 and 2018-19, respectively. Significantly highest phosphorus (0.07 % and 0.05 % during 2017-18 and 2018-19, respectively) content in shell was recorded due to application of phosphorus @ 60 kg ha⁻¹ as compared to all treatments and it was found to be at par with application of phosphorus @ 15 kg ha⁻¹ (0.06 % and 0.05 % during 2017-18 and 2018-19, respectively). The increase in phosphorus content in shell followed the order P₃₀ < P₄₅ < P₁₅ < P₆₀ during both the years.

Effect of biofertilizers

The inoculation of biofertilizers alone or in combination did not affected the phosphorus content in shell (Table 4.35) and ranged from 0.06 to 0.06 per cent and 0.05 to 0.05 per cent in the year 2017-18 and 2018-19, respectively. The higher magnitude of phosphorus content (0.06 % and 0.05 % during 2017-18 and 2018-19, respectively) in shell was observed with no biofertilizers application, whereas the inoculation of VAM + PSB @ 10 kg ha⁻¹ each showed the lowest content (0.06 % and 0.05 % during 2017-18 and 2018-19, respectively) of it.

Interaction effect

The application of phosphorus and biofertilizers observed the significant effect on phosphorus content in shell (Table 4.35) and it varied from 0.04 to 0.08 and 0.04 to 0.06 per cent in the year 2017-18 and 2018-19, respectively. The treatment combination receiving application of phosphorus @ 45 kg ha⁻¹ with inoculation of PSB @ 10 kg ha⁻¹ was found to be significantly highest (0.08 % and 0.06 % during 2017-18 and 2018-19, respectively) overall treatment combinations and found to be at par with B₀P₁₅, B₀P₆₀, B₃P₆₀, B₂P₆₀, B₄P₆₀, B₄P₃₀, B₁P₆₀, and B₁P₃₀ in both the years.

4.5.1.9 Potassium content in shell

Effect of phosphorus

The data on potassium content in shell as influenced by application of phosphorus could not reach the level of significance (Table 4.35) and it varied from 0.72 to 0.85 per cent and 0.69 to 0.80 per cent in the year 2017-18 and 2018-19, respectively. Among the different phosphorus levels, the application of phosphorus @ 60 kg ha⁻¹ exhibit the highest potassium (0.85 % and 0.80 % during 2017-18 and 2018-19, respectively) content in shell, while the lowest (0.72 % and 0.69 % during 2017-18 and 2018-19, respectively) was recorded with application of phosphorus @

45 kg ha⁻¹.

Effect of biofertilizers

The inoculation of biofertilizers alone or in combination showed significant difference on potassium content in shell (Table 4.35), which ranged from 0.65 to 0.87 and 0.61 to 0.82 per cent in the year 2017-18 and 2018-19, respectively. Significantly highest potassium (0.87 % and 0.82 % during 2017-18 and 2018-19, respectively) content in shell was recorded with application of PSB @ 10 kg ha⁻¹ (B₂) which was found to be at par with B₀, B₁ and B₄ in the year 2017-18 and B₀ in the year 2018-19.

Interaction effect

The data (Table 4.35) on potassium content in shell as influenced by integrated application of phosphorus and biofertilizers had significant effect, which varied from 0.38 to 1.17 per cent and 0.36 to 1.10 per cent in the year 2017-18 and 2018-19, respectively. Significantly highest potassium (1.17 % and 1.10 % during 2017-18 and 2018-19, respectively) content in shell was observed in the treatment receiving application of phosphorus @ 60 kg ha⁻¹ with no biofertilizers application as compared to all treatment combinations. However, the same treatment was found to be at par B₁P₃₀, B₂P₆₀, B₂P₃, B₂P₁₅, B₃P₆₀, B₀P₄₅, and B₄P₄₅ in the year 2017-18 and B₁P₃₀ (1.03 %) in the year 2018-19.

4.5.2 Micronutrient content in halum

4.5.2.1 Fe Content in halum

Effect of phosphorus

The application of phosphorus tended to increase significantly the Fe content in halum (Table 4.36) and it varied from 492.44 to 1031.64 mg kg⁻¹ and 398.94 to 835.76 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively during peg initiation stage. Significantly highest Fe content (1031.64 mg kg⁻¹ and 835.76 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in halum was noted with application of phosphorus @ 45 kg ha⁻¹ which was found to be at par with application of phosphorus @ 60 kg ha⁻¹ (790.52 mg kg⁻¹ and 636.20 mg kg⁻¹ during 2017-18 and 2018-19, respectively). The increase in Fe content in halum followed the order of P₁₅ < P₃₀ < P₆₀ < P₄₅.

The application of phosphorus significantly influenced Fe content in halum at pod formation stage, which varied from 419.84 to 1091.52 mg kg⁻¹ and 457.26 to

1341.66 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 15 kg ha⁻¹ was found to be significantly superior in respect of Fe content (1091.52 mg kg⁻¹ and 1341.66 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively) in halum as compared to other treatments of phosphorus application.

The graded decrease in the Fe content in halum with graded doses of phosphorus at harvest stage, was significantly increased with successive dose of added phosphorus and ranged from 410.97 to 499.96 and 363.65 to 448.35 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively. There was graded decrease in Fe content in halum with the graded doses of phosphorus. The lower dose of phosphorus i.e. 15 kg ha⁻¹ recorded the significantly highest Fe content (499.96 mg kg⁻¹ and 448.35 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively), which was found to be significantly superior over the highest doses of phosphorus and followed the order P₆₀ < P₄₅ < P₃₀ < P₁₅.

Effect of biofertilizers

The inoculation of biofertilizers alone or on combination could not reach the level of significance and the Fe content in halum at peg initiation stage presented in the Table 4.36, ranged from 497.23 to 852.59 and 397.55 to 690.71 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The highest magnitude of Fe content in halum (852.59 mg kg⁻¹ and 690.71 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) was recorded due to inoculation of PSB @ 10 kg ha⁻¹ while lowest (497.23 mg kg⁻¹ and 397.55 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) was with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each.

At pod formation stage, the application of biofertilizers showed non-significant effect on Fe content in halum and varied from 548.68 to 896.74 mg kg⁻¹ and 575.66 to 1081.97 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The application of PSB @ 10 kg ha⁻¹ recorded the highest Fe content (896.74 mg kg⁻¹ and 1081.97 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively), while the lowest content (548.68 mg kg⁻¹ and 575.66 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) was observed with inoculation of VAM + PSB @ 5 kg ha⁻¹ each.

The inoculation of biofertilizers alone or in combination had significant effect on Fe content in halum at harvest stage and it ranged from 388.14 to 550.64 and 343.49 to 487.30 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The Fe

content was found to be significantly superior ($550.64 \text{ mg kg}^{-1}$ and $487.30 \text{ mg kg}^{-1}$ during the year 2017-18 and 2018-19, respectively) with dual inoculation of VAM + PSB @ 10 kg ha^{-1} each over all other treatments of biofertilizers application.

Interaction effect

The application of phosphorus and biofertilizers showed the significant effect on Fe content in halum at peg initiation stage (Table 4.36), which ranged from 135.22 to $1796.89 \text{ mg kg}^{-1}$ and 46.25 to $1455.71 \text{ mg kg}^{-1}$ in the year 2017-18 and 2018-19, respectively. Significantly higher Fe content (1796.89 and $1455.71 \text{ mg kg}^{-1}$ during the year 2017-18 and 2018-19, respectively) in halum was registered with the application of phosphorus @ 45 kg ha^{-1} with inoculation of VAM @ 10 kg ha^{-1} (B₁P₄₅). However, the same treatment combination found to be at par with B₂P₄₅ in the year 2017-18 and B₂P₄₅, B₃P₃₀, B₃P₆₀ and B₄P₆₀ in the year 2018-19.

The integration of phosphorus and biofertilizers significantly influenced the Fe content in halum at pod formation stage and it varied from 80.19 to 2209.22 and 110.87 to $2804.44 \text{ mg kg}^{-1}$ in the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 15 kg ha^{-1} with application of PSB @ 10 kg ha^{-1} (B₂P₁₅) was found to be significantly superior ($2209.22 \text{ mg kg}^{-1}$ and $2804.44 \text{ mg kg}^{-1}$ during the year 2017-18 and 2018-19, respectively) over all treatment combinations.

At harvest stage, the different levels of phosphorus and biofertilizers significantly increased Fe content in halum, which ranged from 267.39 to 687.04 and 236.63 to $608.02 \text{ mg kg}^{-1}$ during the year 2017-18 and 2018-19, respectively. The treatment comprising the application of phosphorus @ 15 kg ha^{-1} with dual inoculation of VAM + PSB @ 10 kg ha^{-1} each (B₄P₁₅) was found to be significantly superior ($687.04 \text{ mg kg}^{-1}$ and $608.02 \text{ mg kg}^{-1}$ during the year 2017-18 and 2018-19, respectively) over all treatment combinations.

From the data it was observed that, the Fe content increases with different levels of phosphorus. Further, it was observed that the Fe content decreases from peg initiation to harvest stage in both the years. The increase in the Fe content with higher levels of P may be due to increases in nutrients absorption resulting by more available nutrients in the soil solution and this probably promoted the well developed root system in upper zone. The Fe content ranges reported here are in agreement with Patil (2010).

Application of biofertilizers also increased the Fe content in plant and seed over the sole use of different chemical fertilizer combinations. Further, a graded increase in Fe content in halum and seed was observed with the application of graded doses of phosphorus. Singh *et al.* (1993) reported significant increase in Fe content of seed (382.5 mg kg^{-1}) in chickpea due to application of *rhizobium* and NPK (30:50:45 kg N:P₂O₅:K₂O ha⁻¹) over control. Increase in Fe content in cowpea due to the application of potassium levels with biofertilizers in lateritic soils was also reported by Patil (2010).

In lateritic soils of Konkan, Gengaje (2013) and Mhalshi (2013) observed significant increase in Fe content with the dual inoculation of *rhizobium* and PSB with different levels of phosphorus under groundnut (*viz.*, 25 and 50 kg ha⁻¹) and cowpea (*viz.*, 50, 60 and 70 kg ha⁻¹), respectively.

4.5.2.2 Mn content in halum

Effect of phosphorus

The application of different levels of phosphorus showed the significant differences on Mn content in halum at peg initiation stage (Table 4.37), which varied from 169.80 to 199.71 mg kg⁻¹ and 107.47 to 126.40 mg kg⁻¹ during peg initiation stage in the year 2017-18 and 2018-19, respectively. Significantly highest Fe content (199.71 and 126.40 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) in halum was recorded with the application of phosphorus @ 30 kg ha⁻¹, which was found to be at par with application of phosphorus @ 45 kg ha⁻¹ in the year 2017-18 and application of phosphorus @ 45 kg ha⁻¹ and @ 60 kg ha⁻¹ in the year 2018-19. The increase in Mn content in halum followed the order of P₁₅ < P₆₀ < P₄₅ < P₃₀.

At pod formation stage, the application of phosphorus showed non-significant effect on Mn content in halum and ranged from 156.12 to 182.16 mg kg⁻¹ and 156.83 to 183.00 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The higher magnitude of Mn content (182.16 mg kg⁻¹ and 183.00 mg kg⁻¹ during 2017-18 and 2018-19, respectively) was observed with application of phosphorus @ 45 kg ha⁻¹ while the lowest (156.12 mg kg⁻¹ and 156.83 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) Mn content was recorded with application of phosphorus @ 60 kg ha⁻¹.

The application of phosphorus was not affected significantly Mn content in

halum at harvest stage and it ranged from 193.04 to 228.23 mg kg⁻¹ and 201.08 to 237.76 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 30 kg ha⁻¹ recorded the highest Mn content (228.23 mg kg⁻¹ and 237.76 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively), whereas the application of phosphorus @ 60 kg ha⁻¹ was noted the lowest Mn content in halum i.e. 193.04 mg kg⁻¹ and 201.08 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively.

Effect of biofertilizers

At peg initiation stage, the inoculation of biofertilizers could not reach the level of significance in Mn content (Table 4.37) and it ranged from 174.86 to 195.42 and 110.67 to 123.68 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The highest Mn content (195.42 mg kg⁻¹ and 123.68 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) in halum was observed with no biofertilizers application (B₀) and the lowest (174.86 mg kg⁻¹ and 110.67 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) was recorded with application of VAM @ 10 kg ha⁻¹.

The application of biofertilizers either or in combination does not showed the significant effect on Mn content in halum at pod formation stage and varied from 151.19 to 183.54 mg kg⁻¹ and 151.88 to 184.39 mg kg⁻¹, respectively. The inoculation of PSB @ 10 kg ha⁻¹ showed the highest Mn content (183.54 and 184.39 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) in halum and the inoculation of VAM + PSB @ 10 kg ha⁻¹ each noted the lowest Mn content (151.19 mg kg⁻¹ and 151.88 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively).

The application of biofertilizers did not affected Mn content in halum at harvest stage, however it varied from 185.23 to 230.65 and 192.95 to 240.26 mg kg⁻¹, respectively. Among the biofertilizers application, the inoculation of PSB @ 10 kg ha⁻¹ was recorded the highest (230.65 mg kg⁻¹ and 240.26 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) Mn content, while the application of VAM @ 10 kg ha⁻¹ showed the lowest Mn content (185.23 mg kg⁻¹ and 192.95 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) in halum.

Interaction effect

Regarding the different levels of phosphorus and biofertilizers, the results (Table 4.37) showed that the Mn content in halum at peg initiation stage varied from 120.59 to 244.75 mg kg⁻¹ and 82.99 to 154.06 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. Significantly highest Mn content (244.75 and 154.06 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) was observed with the application of phosphorus @ 45 kg ha⁻¹ alongwith dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each over all other treatment combination. But, the same the treatment combinations was found to be at par with B₄P₃₀, B₃P₃₀ and B₀P₃₀ in the year 2017-18 and B₄P₃₀, B₃P₃₀, B₀P₃₀, B₂P₆₀, B₀P₄₅, B₁P₄₅ and B₂P₃₀ in the year 2018-19.

Application of phosphorus either alone or in combination with biofertilizers significantly influenced Mn content in halum at pod formation stage, which ranged from 127.07 to 231.15 mg kg⁻¹ and 127.66 to 232.22 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The treatment combination consisting application of phosphorus @ 45 kg ha⁻¹ with inoculation of PSB @ 10 kg ha⁻¹ was recorded significantly highest Mn content (231.15 mg kg⁻¹ and 232.22 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) in halum over all treatment combinations. However, the same treatment combination found to be at par with B₁P₄₅, B₃P₆₀, B₂P₁₅, B₁P₁₅, B₀P₁₅ and B₃P₃₀ during both the years.

At harvest, the integration of phosphorus and biofertilizers did not influenced significantly on Mn content in halum however, it ranged from 108.29 to 271.48 and 112.81 to 282.90 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The highest Mn content (271.48 mg kg⁻¹ and 282.90 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) in halum was recorded with application of phosphorus @ 30 kg ha⁻¹ with no biofertilizers application (B₀P₃₀), while the lowest Mn content (108.29 and 112.81 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) was recorded with application of phosphorus @ 15 kg ha⁻¹ with VAM @ 10 kg ha⁻¹ (B₁P₁₅).

The data revealed that the Mn content in halum decreases from flowering stage to harvest irrespective of different treatments. The probable reason behind decrease may be attributed to the dilution effect of dry matter production. The Mn content values obtained in the present investigation are similar to those reported by Patil (2010) in cowpea under lateritic soils.

Suthar and Patel (1992) reported significant increase in Mn content of stover (262 ppm) in groundnut due to application of *Rhizobium* and RDF over control. Singh *et al.* (1993) reported significant increase in Mn content of seed (28.71ppm) in chickpea due to application of *Rhizobium* and NPK (30:50:45 kg N:P₂O₅:K₂O ha⁻¹) over control.

In lateritic soils of Konkan, Gengaje (2013) and Mhalshi (2013) observed significant increase in Mn content with the dual inoculation of *rhizobium* and PSB with different levels of phosphorus under groundnut (*viz.*, 25 and 50 kg ha⁻¹) and cowpea (*viz.*, 50, 60 and 70 kg ha⁻¹), respectively.

4.5.2.3 Zn Content in halum

Effect of phosphorus

The Zn content in halum of groundnut was found to be graded and in the order of P₁₅ < P₃₀ < P₄₅ < P₆₀ at peg initiation stage presented in the Table 4.38, which varied from 88.30 to 102.00 mg kg⁻¹ and 55.89 to 64.69 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. Among the phosphorus levels, the application of phosphorus @ 60 kg ha⁻¹ was noted the highest Zn content(102.00 and 64.69 mg kg⁻¹ during 2017-18 and 2018-19, respectively), while the application of phosphorus @ 15 kg ha⁻¹ was recorded the lowest (88.30 mg kg⁻¹ and 59.89 mg kg⁻¹ during 2017-18 and 2018-19, respectively) content of Zn and the treatment differences were statistically non-significant.

At pod formation stage, the application of phosphorus did not influence significantly on Zn content and it ranged from 26.67 to 28.70 mg kg⁻¹ and 20.83 to 22.52 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The higher magnitude of Zn content (28.70 mg kg⁻¹ and 22.52 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in halum was observed with application of phosphorus @ 30 kg ha⁻¹, while, the lowest (26.67 mg kg⁻¹ and 20.83 mg kg⁻¹ during 2017-18 and 2018-19, respectively) was recorded with application of phosphorus @ 60 kg ha⁻¹ and the treatment differences were not found significant.

The application of phosphorus indicated the significant effect on Zn content in halum at harvest and it varied from 29.61 to 38.19 mg kg⁻¹ and 26.15 to 33.68 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively and followed the order of P₄₅ < P₆₀ < P₃₀ < P₁₅. Significantly highest Zn content was noted due to application of

phosphorus @ 45 kg ha⁻¹. Significantly higher Zn content was obtained to 38.19 and 33.68 mg kg⁻¹ during 2017-18 and 2018-19, respectively as compared to all other treatment of phosphorus application which was found to be at par with application of phosphorus @ 30 kg ha⁻¹ (35.43 mg kg⁻¹ and 31.29 mg kg⁻¹ during 2017-18 and 2018-19, respectively).

Effect of biofertilizers

At peg initiation, the inoculation of biofertilizers alone or in combination showed the significant effect on Zn content (Table 4.38) and it varied from 57.66 to 132.88 mg kg⁻¹ and 36.50 to 85.12 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The application of VAM @ 10 kg ha⁻¹ was found to be significantly superior (132.88 mg kg⁻¹ and 85.12 mg kg⁻¹ during 2017-18 and 2018-19, respectively) over all treatments of biofertilizers application and followed the order B₄ < B₂ < B₀ < B₃ < B₁.

The application of biofertilizers significantly influenced Zn content in halum at pod formation stage, which ranged from 23.56 to 35.67 and 18.49 to 28.01 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The highest Zn content (35.67 mg kg⁻¹ and 28.01 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in halum was observed with inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄) which was found to be significantly superior over all other treatments.

The inoculation of biofertilizers alone or in combination showed non-significant effect on Zn content in halum at harvest and it varied from 32.03 to 37.42 and 28.28 to 33.07 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each was recorded the highest (37.42 and 33.07 mg kg⁻¹ during 2017-18 and 2018-19, respectively) Zn content in halum, whereas the inoculation of VAM + PSB @ 5 kg ha⁻¹ each was showed the lowest Zn content (32.03 mg kg⁻¹ and 28.28 mg kg⁻¹ during 2017-18 and 2018-19, respectively).

Interaction effect

The data (Table 4.38) on Zn content in halum at peg initiation stage as influenced by integrated application of phosphorus and biofertilizers showed significant effect, which ranged from 35.50 to 229.94 and 22.47 to 147.43 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The treatment combination consisting application of phosphorus @ 60 kg ha⁻¹ with application of VAM @ 10 kg ha⁻¹ was

found to be significantly superior (229.94 mg kg⁻¹ and 147.43 mg kg⁻¹ during 2017-18 and 2018-19, respectively) over all other treatment combinations.

The application of phosphorus and biofertilizers alone or in combination does not influenced the Zn content in halum at pod formation stage and it ranged from 15.15 to 47.97 mg kg⁻¹ and 11.70 to 37.69 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. However, the application of phosphorus @ 60 kg ha⁻¹ alongwith dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀) showed the highest Zn content (47.97 mg kg⁻¹ and 37.69 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in halum, whereas the application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃P₆₀) was recorded the lowest (15.15 and 11.70 mg kg⁻¹ during 2017-18 and 2018-19, respectively) zinc content in halum.

At harvest stage, the integration of phosphorus and biofertilizers showed significant variations in Zn content in halum, which varied from 22.63 to 44.71 and 20.00 to 39.34 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. Significantly highest Zn content (44.71 mg kg⁻¹ and 39.34 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in halum was observed with application of phosphorus @ 30 kg ha⁻¹ with inoculation of VAM @ 10 kg ha⁻¹ in all treatment combinations. However, the same treatment combination found to be at par with B₄P₄₅, B₄P₆₀, B₂P₄₅, B₀P₃₀, B₀P₄₅, B₄P₃₀, B₁P₄₅, B₃P₁₅, B₃P₄₅, B₁P₆₀ and B₂P₁₅ in the year 2017-18 and B₄P₄₅, B₄P₆₀, B₂P₄₅, B₀P₃₀, B₀P₄₅, B₄P₃₀ and B₁P₄₅ in the year 2018-19.

The data showed that the Zn content in halum decreases from peg initiation to harvest stage irrespective of the treatments in both the year. Application of biofertilizers increased the Zn content in plant over the sole use of different chemical fertilizer combinations. Further, a graded increase in Zn content in halum was observed with the application of graded doses of phosphorus. The data revealed that the Zn content in halum showed decrease from flowering stage to harvest irrespective of different treatments. Increase in Zn content in cowpea plant due to the application of potassium levels with biofertilizers in lateritic soils was also reported by Patil (2010).

Zinc is less mobile as compared to P within the plant and therefore a large accumulation of Zn takes place in leaves, nodes and internodes. Application of P fertilizer in small doses results in higher concentration of Zn in the roots accompanied by large reduction in Zn concentration in the plant tops (Anonymous 2002). The

decrease in Zn concentration in plants may arise from the dilution effect resulting from marked increase in plant growth. Singh *et al.* (1992) also reported similar increase in the Zn content of stover from 13.50 ppm to 14.00 ppm in pea due to application of 30 kg K₂O ha⁻¹. Suthar and Patel (1992) reported significant increase in Zn content of stover (290 ppm) in groundnut due to application of *rhizobium* and RDF over control.

In lateritic soils of Konkan, Gengaje (2013) and Mhalshi (2013) observed significant increase in zinc content with the dual inoculation of *rhizobium* and PSB with different levels of phosphorus under groundnut (*viz.*, 25 and 50 kg ha⁻¹) and cowpea (*viz.*, 50, 60 and 70 kg ha⁻¹), respectively.

4.5.2.4 Cu content in halum

Effect of phosphorus

At peg initiation stage, increasing phosphorus level from 15 to 60 kg ha⁻¹ was associated with increase in Cu content in halum (Table 4.39), which ranged from 184.63 to 325.09 mg kg⁻¹ and 233.71 to 411.51 mg kg⁻¹ year 2017-18 and 2018-19, respectively, but the variations was not statistically significant and was in the order P₁₅ < P₃₀ < P₄₅ < P₆₀. The highest Cu content (325.09 mg kg⁻¹ and 411.51 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) in halum was observed with application of phosphorus @ 60 kg ha⁻¹ and with the application of phosphorus @ 15 kg ha⁻¹ was recorded the lowest Cu content (184.63 mg kg⁻¹ and 233.71 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) in halum.

The graded decrease with graded doses of phosphorus was significantly influenced the Cu content in halum at pod formation stage and it varied from 127.05 to 196.26 mg kg⁻¹ and 102.53 to 182.56 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. Among the different phosphorus doses, the application of phosphorus @ 15 kg ha⁻¹ exhibited significantly higher Cu content (196.26 and 182.56 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively) in halum and all the treatments found to be at par with each other and followed the increasing order P₆₀ < P₄₅ < P₃₀ < P₁₅.

The Cu content in halum of groundnut was in the order of P₆₀ < P₃₀ < P₁₅ < P₄₅ at harvest stage and varied from 75.54 to 101.04 and 40.32 to 53.46 mg kg⁻¹ due in the year 2017-18 and 2018-19, respectively. Significantly highest Cu content (101.04 and 53.46 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) in halum was noted with the application of phosphorus @ 45 kg ha⁻¹ as compared to all other

treatments of phosphorus application and found to be at par with application of phosphorus @ 15 (P₁₅) (94.94 mg kg⁻¹) and application of phosphorus @ 30 (P₃₀) (94.08 mg kg⁻¹) during both the years of observation.

Effect of biofertilizers

At peg formation stage, the Cu content in halum was found to be in the range from 117.42 to 436.33 mg kg⁻¹ and 148.63 to 552.32 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively presented in the Table 4.39. The Cu content in halum (436.33 and 552.32 mg kg⁻¹ during 2017-18 and 2018-19, respectively) was found to be significantly higher due to inoculation of VAM @ 10 kg ha⁻¹, which was found to be at par with B₃ i.e. VAM + PSB @ 5 kg ha⁻¹ each (357.37 mg kg⁻¹ and 452.37 mg kg⁻¹ during 2017-18 and 2018-19, respectively).

The variation in Cu content in halum at pod formation stage due to application of biofertilizers in different treatments were observed to be from 134.75 to 188.55 and 119.25 to 165.58 mg kg⁻¹ during 2017-18 and 2018-19, respectively. The inoculation of VAM + PSB @ 10 kg ha⁻¹ showed the highest Cu content (188.55 and 165.58 mg kg⁻¹ during 2017-18 and 2018-19, respectively), while application of VAM @ 10 kg ha⁻¹ was recorded the lowest content (134.75 and 119.25 mg kg⁻¹ during 2017-18 and 2018-19, respectively) of it and did not reach the level of significance.

Results of Cu content in halum at harvest stage revealed that it showed non-significant effect and ranged from 85.07 to 97.15 mg kg⁻¹ and 45.01 to 51.40 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively. The inoculation of PSB @ 10 kg ha⁻¹ showed the highest Cu content (97.15 mg kg⁻¹ and 51.40 mg kg⁻¹ during 2017-18 and 2018-19, respectively) and lowest content (85.07 mg kg⁻¹ and 45.01 mg kg⁻¹ during 2017-18 and 2018-19, respectively) was recorded with the application of VAM + PSB @ 5 kg ha⁻¹ each.

Interaction effect

The interaction between graded doses of phosphorus either alone or in combination increased Cu content in halum significantly at peg initiation stage and it ranged from 32.68 to 809.68 mg kg⁻¹ and 41.37 to 1025.37 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. Significantly highest Cu content (809.68 mg kg⁻¹ and 1025.37 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in halum was noted

with the application of phosphorus @ 60 kg ha⁻¹ with inoculation of VAM @ 10 kg ha⁻¹ (B₁P₆₀) over all other treatment combinations in both the years and which was found to be at par with B₁P₃₀ and B₃P₁₅ in the year 2017-18.

Application of graded levels of phosphorus in combination with biofertilizers along with recommended dose of N, K and FYM significantly influenced Cu content in halum at pod formation stage (Table 4.39) and it varied from 66.27 to 372.42 and 45.30 to 373.95 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The Cu content in halum recorded significantly highest (372.42 and 373.95 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in the treatment receiving the application of phosphorus @ 15 kg ha⁻¹ alongwith dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each over all other treatment combinations. However, the same treatment combination was found to be at par with all treatment combinations except B₂P₆₀ in the year 2017-18 and B₂P₆₀, B₃P₄₅, B₂P₄₅, B₁P₃₀ and B₁P₆₀, in the year 2018-19.

At harvest stage, the application of different levels of phosphorus and biofertilizers increased significantly the Cu content in halum and ranges from 39.38 to 126.06 mg kg⁻¹ and 22.60 to 66.70 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. Significantly highest Cu content (126.06 mg kg⁻¹ and 66.70 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in halum was observed due to application of phosphorus @ 15 kg ha⁻¹ with inoculation of PSB @ 10 kg ha⁻¹ in all treatment combination and found to be at par with B₀P₁₅, B₄P₃₀, and B₀P₄₅ in the year 2017-18 and B₀P₁₅, B₀P₄₅ and B₄P₃₀ 2018-19.

The obtained results in this investigation may be due to the beneficial effect of P and biofertilizers inoculation on metabolic processes and growth which in turn reflected positively on chemical content of groundnut plants and seeds.

These findings are in harmony with those obtained by Abou-El-Magd and Hoda (2003) in onion and Abou-El-Nour and Abdel-Maguid (2003) in corn who stated that higher values of micronutrients (Fe, Mn, Zn and Cu) content in onion bulb were obtained by the higher level of NPK (80:50:60) as compared with the lower one (40:25:30). Moreover, they added that decreasing NPK applied to soil than the recommended rate resulted generally, in reducing micro-nutrient concentration in corn plant. In lateritic soils of Konkan, Gengaje (2013) and Mhalshi (2013) observed significant increase in Cu content with the dual inoculation of *rhizobium* and PSB with different levels of phosphorus under groundnut (*viz.*, 25 and 50 kg ha⁻¹) and cowpea

(viz., 50, 60 and 70 kg ha⁻¹), respectively.

4.5.2.5 Fe content in Kernel

Effect of phosphorus

Application of different levels of phosphorus brought about significant changes in Fe content in kernel (Table 4.40) and varied from 121.17 to 188.97 and 127.55 to 198.92 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 60 kg ha⁻¹ was found to be significantly higher in respect of Fe content (188.97 and 198.92 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in kernel and found at par with P @ 30 kg ha⁻¹ in both the years. The increase in the Fe content in kernel followed the order of P₁₅ < P₄₅ < P₃₀ < P₆₀.

Effect of biofertilizers

The inoculation of biofertilizers alone or in combination could not reach the level of significance in respect of Fe content in kernel (Table 4.40), however, it ranged from 119.03 to 182.56 mg kg⁻¹ and 125.29 to 192.17 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The higher magnitude of Fe content (182.56 and 192.17 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in kernel was observed with inoculation of VAM @ 10 kg ha⁻¹ while the dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each showed the lowest Fe content (119.03 mg kg⁻¹ and 125.29 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in kernel.

Interaction effect

The interaction effect between graded doses of phosphorus and biofertilizers either alone or in combination significantly increased Fe content in kernel presented in the Table 4.40, which varied from 69.24 to 273.03 and 72.89 to 287.40 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively. Significantly highest Fe content (273.03 mg kg⁻¹ to 287.04 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in kernel was noted in the treatment receiving application of phosphorus @ 30 kg ha⁻¹ with inoculation of PSB @ 10 kg ha⁻¹. The same treatment combination was found to be at par with B₁P₆₀, B₀P₆₀, B₁P₃₀, B₀P₄₅, B₄P₆₀ and B₄P₃₀ in both the years.

4.5.2.6 Mn content in Kernel

Effect of phosphorus

The application of phosphorus did not showed any significant effect on Mn content in kernel (Table 4.41) however, it varied from 18.07 to 21.79 mg kg⁻¹ and 18.45 to 22.23 mg kg⁻¹ during 2017-18 and 2018-19, respectively. The application of phosphorus @ 30 kg ha⁻¹ recorded the highest Mn content (21.79 and 22.23 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in kernel and application of phosphorus @ 45 kg ha⁻¹ showed the lowest Mn content (18.07 mg kg⁻¹ and 18.45 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in kernel and the treatment difference was statistically non-significant.

Effect of biofertilizers

The inoculation of biofertilizers significantly influenced Mn content in kernel and it ranged from 14.78 to 27.88 mg kg⁻¹ and 15.08 to 28.45 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each was found to be significantly superior (27.88 mg kg⁻¹ and 28.45 mg kg⁻¹ during 2017-18 and 2018-19, respectively) over all treatments of biofertilizers application.

Interaction effect

The application of different levels of phosphorus and biofertilizers significantly increased Mn content in kernel (Table 4.41), which varied from 5.97 to 55.31 mg kg⁻¹ and 6.09 to 56.44 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 30 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each was found to be significantly superior (55.31 mg kg⁻¹ and 56.44 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in respect to Mn content in kernel over all treatment combinations.

4.5.2.7 Zn content in Kernel

Effect of phosphorus

The application of phosphorus did not showed significant effect on Zn content in kernel of groundnut (Table 4.42) and varied from 37.82 to 44.84 mg kg⁻¹ and 37.17 to 44.65 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively. Among the different phosphorus doses, the application of phosphorus @ 30 kg ha⁻¹ exhibited highest Zn content (44.84 mg kg⁻¹ and 44.65 mg kg⁻¹ during 2017-18 and 2018-19,

respectively) in kernel and the lowest content (37.82 and 37.17 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) was recorded with application of phosphorus @ 60 kg ha⁻¹.

Effect of biofertilizers

The variations in Zn content in kernel due to inoculation of biofertilizers was found to be non-significant effect (Table 4.42), and it ranged from 36.27 to 44.32 and 35.97 to 43.79 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each registered highest Zn content (44.32 and 43.79 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in kernel while the dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each showed the lowest content (36.27 and 35.97 mg kg⁻¹ during 2017-18 and 2018-19, respectively) of it.

Interaction effect

The interaction between graded doses of phosphorus either alone or in combination significantly increased Zn content in kernel (Table 4.42), which varied from 16.64 to 56.72 mg kg⁻¹ and 16.53 to 56.18 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. Significantly higher magnitude of Zn (56.72 and 56.18 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in kernel was observed due to application of phosphorus @ 30 kg ha⁻¹ with inoculation of VAM @ 10 kg ha⁻¹ (B₁P₃₀), and found to be at par with B₁P₄₅, B₃P₃₀, B₄P₄₅, B₄P₃₀, B₂P₆, B₀P₁₅, B₂P₁₅ and B₃P₁₅ in the year 2017-18 and 2018-19.

Singh *et al.* (1992) also reported similar increase in the Zn content of seed from 28.00 ppm to 29.00 ppm in pea due to application of *rhizobium* and NPK (25:50:30 kg N:P₂O₅:K₂O ha⁻¹) over control. In lateritic soils of Konkan, Gengaje (2013) and Mhalshi (2013) observed significant increase in Zn content with the dual inoculation of *rhizobium* and PSB with different levels of phosphorus under groundnut (*viz.*, 25 and 50 kg ha⁻¹) and cowpea (*viz.*, 50, 60 and 70 kg ha⁻¹), respectively.

4.5.2.8 Cu content in kernel

Effect of phosphorus

The Cu content in kernel tended to increase significantly, which ranged from 7.10 to 11.30 mg kg⁻¹ and 7.24 to 10.99 mg kg⁻¹ during 2017-18 and 2018-19, respectively presented in the Table 4.43. Significantly higher Cu content in kernel (11.30 mg kg⁻¹ and 10.99 mg kg⁻¹ during 2017-18 and 2018-19, respectively) was

noted with the application of phosphorus @ 15 kg ha⁻¹ which was found to be at par with application of phosphorus @ 30 kg ha⁻¹ in the year 2017-18 and @ 30 kg ha⁻¹ and @ 60 kg ha⁻¹ in the year 2018-19. The increase in the Cu content in kernel followed the order of P₄₅ < P₆₀ < P₃₀ < P₁₅.

Effect of biofertilizers

The Cu content in kernel with application of phosphorus was found to be non-significant (Table 4.43) and it varied from 8.03 to 10.11 and 7.86 to 10.65 mg kg⁻¹ during 2017-18 and 2018, respectively. Numerically, the highest Cu content (10.11 and 10.65 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in kernel was recorded with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each, whereas, the lowest Cu content (8.03 mg kg⁻¹) was observed with no biofertilizers application (B₀) in the year 2017-18 and (7.86 mg kg⁻¹) with the inoculation of PSB @ 10 kg ha⁻¹ (B₂) in the year 2018-19.

Interaction effect

The application of different levels of phosphorus and biofertilizers significantly increased the Cu content in kernel (Table 4.43) and it ranged from 3.97 to 20.09 mg kg⁻¹ and 4.05 to 20.51 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 15 kg ha⁻¹ with dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃P₁₅) was found to be significantly superior (20.09 and 20.51 mg kg⁻¹ during 2017-18 and 2018-19, respectively) over all treatment combinations.

4.5.2.9 Fe content in shell

Effect of phosphorus

The Fe content in shell due to application of phosphorus showed the significant difference (Table 4.44) and it ranged from 1976.02 to 4140.34 mg kg⁻¹ and 1829.65 to 3833.65 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The treatment consisting application of phosphorus @ 60 kg ha⁻¹ was recorded significantly highest Fe content (4140.34 mg kg⁻¹ and 3833.65 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) in shell and found to be at par with application of phosphorus @ 30 kg ha⁻¹. The increase in the Fe content in shell followed the order of P₃₀ < P₁₅ < P₆₀ < P₄₅.

Effect of biofertilizers

The application of biofertilizers alone or in combination was not affected

significantly on Fe content in shell (Table 4.44), which ranged from 2647.74 to 3189.04 mg kg⁻¹ and 2451.61 to 2952.81 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The higher magnitude of Fe content (3189.04 and 2952.81 mg kg⁻¹ during 2017-18 and 2018-19, respectively) was noted with dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each whereas, with no biofertilizers application was recorded the lowest Fe content (2647.74 and 2451.61 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in shell.

Interaction effect

The combine application of phosphorus and biofertilizers could not reach the level of significance in respect of Fe content in shell (Table 4.44) and varied from 837.45 to 6439.44 mg kg⁻¹ and 775.42 to 5962.95 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The highest Fe content (6439.44 mg kg⁻¹ and 5962.95 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in shell was observed due to application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀), while the lowest (837.45 mg kg⁻¹ and 775.42 mg kg⁻¹ during 2017-18 and 2018-19, respectively) was recorded with the application of phosphorus @ 45 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₄₅).

4.5.2.10 Mn content in shell

Effect of phosphorus

The application of phosphorus was found to be significant on Mn content in shell presented in the Table 4.45, which was varied from 54.72 to 99.76 mg kg⁻¹ and 61.43 to 113.47 mg kg⁻¹ with application of phosphorus in the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 30 kg ha⁻¹ was found to be significantly superior (99.76 mg kg⁻¹ and 113.47 mg kg⁻¹ during 2017-18 and 2018-19, respectively) over all other treatments of phosphorus application. The increase in the Mn content in shell followed the order of P₄₅ < P₁₅ < P₆₀ < P₃₀.

Effect of biofertilizers

The individual or dual inoculation of biofertilizers increased significantly the Mn content in shell (Table 4.45) and it ranged from 43.71 to 96.77 mg kg⁻¹ and 49.89 to 109.97 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively. The Mn content in shell was recorded significantly highest (96.77 mg kg⁻¹ and 109.97 mg kg⁻¹ during 2017-18 and 2018-19, respectively) with inoculation of VAM @ 10 kg ha⁻¹

which was found to be significantly superior all other treatments of biofertilizers application.

Interaction effect

The integration of graded doses of phosphorus and biofertilizers showed significant variation in Mn content in shell (Table 4.45) and it varied from 25.15 to 181.02 mg kg⁻¹ and 28.58 to 205.69 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 30 kg ha⁻¹ with dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃P₃₀) was found to be significantly superior (181.02 and 205.69 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in all treatment combinations.

4.5.2.11 Zn content in shell

Effect of phosphorus

The different treatments of application of phosphorus significantly influenced Zn content in shell (Table 4.46) and varied from 19.79 to 29.51 mg kg⁻¹ and 19.12 to 28.90 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively. In the year 2017-18, the application of phosphorus @ 45 kg ha⁻¹ was registered significantly superior Zn content (29.51 mg kg⁻¹) over all other treatments of phosphorus application. During 2018-19, Significantly highest Zn content (28.90 mg kg⁻¹) in shell was recorded with application of phosphorus @ 45 kg ha⁻¹ and found at par with application of phosphorus @ 60 kg ha⁻¹. The increase in the Zn content in shell followed the order of P₃₀ < P₁₅ < P₆₀ < P₄₅.

Effect of biofertilizers

The inoculation of biofertilizers alone or in combination did not showed significant effect on Zn content in shell (Table 4.46) and it ranged from 22.45 to 25.91 mg kg⁻¹ and 20.53 to 25.92 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. The Zn content in shell was found to be non significant however, it noted (25.91 mg kg⁻¹) the highest value of it with no biofertilizers application in the year 2017-18 and with application of VAM @ 5 kg ha⁻¹ (25.92 mg kg⁻¹) in the year 2018-19. But, the lowest Zn content (22.45 mg kg⁻¹ and 20.53 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) in shell was observed with application of VAM + PSB @ 5 kg ha⁻¹ each in both the years.

Interaction effect

The interaction effect between graded doses of phosphorus alone or in combination increased Zn content in shell significantly and it ranged from 14.03 to 47.02 mg kg⁻¹ and 13.11 to 43.15 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively presented in the Table 4.46. The application of phosphorus @ 45 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each was found to be significantly superior (47.02 mg kg⁻¹) over all other treatment combinations in the year 2017-18. While, Significantly higher Zn content (43.15 mg kg⁻¹) in shell was observed with application of phosphorus @ 45 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each and found at par with B₀P₆₀ in the year 2018-19.

4.5.2.12 Cu content in shell

Effect of phosphorus

The application of phosphorus tended to increase Cu content in shell significantly (Table 4.47), which ranged from 12.09 to 24.48 mg kg⁻¹ and 12.34 to 24.98 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. Significantly higher Cu content (24.48 and 24.98 mg kg⁻¹ during 2017-18 and 2018-19, respectively) was observed with the application of phosphorus @ 30 kg ha⁻¹ which was found to be at par with application of phosphorus @ 45 kg ha⁻¹ and @ 60 kg ha⁻¹ in both the years. The increase in the Cu content in shell followed the order of P₁₅ < P₆₀ < P₄₅ < P₃₀.

Effect of biofertilizers

The inoculation of biofertilizers alone or in combination does not showed significant effect on Cu content in shell (Table 4.47) however, it varied from 14.69 to 24.53 mg kg⁻¹ and 14.99 to 25.03 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively. The inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) was recorded the lowest Cu content (14.69 mg kg⁻¹ and 14.99 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in shell while with no biofertilizers application (B₀) showed the highest Cu content (24.53 mg kg⁻¹ and 25.03 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in shell.

Interaction effect

The integrated use of phosphorus and individual or dual inoculation of biofertilizers showed significant influence on Cu content in shell (Table 4.47) and it varied from 8.64 to 47.70 mg kg⁻¹ and 8.82 to 48.67 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively. Significantly highest Cu content (47.70 and 48.67 mg kg⁻¹

during 2017-18 and 2018-19, respectively) was observed with application of phosphorus @ 30 kg ha⁻¹ with application of VAM @ 10 kg ha⁻¹ and which was found to be at par with B₀P₄₅ (43.14 mg kg⁻¹ and 44.02 mg kg⁻¹ during 2017-18 and 2018-19, respectively).

4.6 Effect on uptake of nutrients (N, P, K, Zn, Fe, Mn and Cu) in plant by groundnut

4.6.1 Uptake by macronutrients

4.6.1.1 Total uptake of Nitrogen

Effect of phosphorus

Graded doses of phosphorus application significantly influenced the nitrogen uptake and ranged from 109.40 to 208.85 and 153.14 to 251.86 kg ha⁻¹ in the year 2017-18 and 2018-19, respectively presented in the Table 4.48. Among the different levels of phosphorus, the application of phosphorus @ 60 kg ha⁻¹ noted the significantly highest nitrogen uptake (208.85 kg ha⁻¹), which was found to be significantly superior over all treatments of phosphorus in the year 2017-18. However, the significantly highest nitrogen uptake (251.86 kg ha⁻¹) was recorded with application of phosphorus @ 60 kg ha⁻¹ and which was found at par with application of phosphorus @ 45 kg ha⁻¹ (231.79 kg ha⁻¹) in the year 2018-19. The increase in the total uptake of nitrogen followed the order of P₁₅ < P₃₀ < P₄₅ < P₆₀.

Effect of biofertilizers

The variations in nitrogen uptake (Table 4.48) ranged from 152.88 to 180.00 and 190.32 and 221.86 kg ha⁻¹ in the year 2017-18 and 2018-19, respectively, but the differences were statistically non-significant. Application of VAM + PSB @ 10 kg ha⁻¹ each noted the highest nitrogen uptake (180.00 kg ha⁻¹ and 221.86 kg ha⁻¹ during 2017-18 and 2018-19, respectively), while the lowest uptake (152.88 kg ha⁻¹) was recorded with no biofertilizers application in the year 2017-18 and 190.32 kg ha⁻¹ with PSB@ 10 kg ha⁻¹ in the year 2018-19.

Interaction effect

The data presented in the Table 4.48 regarding nitrogen uptake as influenced by various treatment combinations indicated that nitrogen uptake varied from 98.74 to 253.08 kg ha⁻¹ and 120.16 to 286.35 kg ha⁻¹ in the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of

VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀) noted significantly highest nitrogen uptake (253.08 kg ha⁻¹ and 286.35 kg ha⁻¹ during 2017-18 and 2018-19, respectively) over all other treatment combinations, which was at par with B₃P₆₀ in the year 2017-18 and with B₃P₆₀, B₄P₄₅ and B₁P₄₅ in the year 2018-19.

The data revealed that, the total N uptake increased with increase in the level of phosphorus as well as inoculation of biofertilizers in both the years. The inoculation with phosphate solubilizing microorganisms also significantly increased the uptake of nitrogen which may be due to enhanced availability and uptake of phosphorus which is known to be positively related with nitrogen uptake. The total nitrogen uptake increased considerably due to the improvement in symbiotic N₂ fixation. Further, it is well established that if the P nutrition of plants is improved, either through fertilization or biological means, symbiotic N₂ fixation and the plant N content improved. A similar trend was also reported by Tanwar and Shaktawat (2003) and Despande *et al.* (2015).

4.6.1.2 Total uptake of phosphorus

Effect of phosphorus

The application of phosphorus tended to increase significantly the total uptake of phosphorus (Table 4.48) and it varied from 4.84 to 8.34 and 3.92 to 6.76 kg ha⁻¹ in the year 2017-18 and 2018-19, respectively. Significantly highest phosphorus uptake (8.34 kg ha⁻¹ and 6.76 kg ha⁻¹ during 2017-18 and 2018-19, respectively) was observed with the application of phosphorus @ 60 kg ha⁻¹ was found to be significantly superior over all treatments of phosphorus application. The increase in the total uptake of phosphorus followed the order of P₄₅ < P₁₅ < P₃₀ < P₆₀.

Effect of biofertilizers

The phosphorus uptake was found to be increased from 4.95 to 7.01 and 4.30 to 5.68 kg ha⁻¹ in the year 2017-18 and 2018-19, respectively (Table 4.48). The phosphorus uptake was found to be significantly highest (7.01 and 5.68 kg ha⁻¹ during 2017-18 and 2018-19, respectively) with no biofertilizers application (B₀) and it was found to be at par with B₄ and B₁ treatments in both the years.

Interaction effect

The interaction effect consisting the application of graded doses of phosphorus and application of biofertilizers either or in combinations increased

phosphorus uptake significantly (Table 4.48) and it ranged from 3.14 to 9.51 kg ha⁻¹ and 2.55 to 7.70 kg ha⁻¹ during the year 2017-18 and 2018-19, respectively. Significantly highest phosphorus uptake (9.51 kg ha⁻¹ and 7.70 kg ha⁻¹ during 2017-18 and 2018-19, respectively) was observed due to the treatment receiving phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀) and found to be at par with B₀P₆₀ and B₁P₃₀ during both the years.

The two years data showed that, the total P uptake increased with increase in the level of phosphorus as well as inoculation of biofertilizers in both the years. This may be due to increased concentration of phosphorus in soil solution with increasing phosphorus application. The increase in P uptake may be attributed to higher P content as well as grain and straw yields with higher dose of P. It also might be due to dissolution of phosphorus in single super phosphate mixture in the presence of farmyard manure along with phosphorus solubilizing bacteria, which may be resulted and increased its absorption by the crop which ultimately reflected in increased seed yield. The similar results were also reported by Tanwar and Shaktawat (2003).

Further, the *rhizobium* inoculation together with PSB increased the nodulation and N₂ fixation and also the availability of phosphorus to chickpea which might have resulted in the increased N and P uptake (Gupta 2006).

The inoculation with phosphate solubilizing microorganisms also enhanced the phosphorus uptake to a level of significance compared to uninoculated plots due to microbial activity that could have resulted in quantitative and qualitative alterations of root exudates composition due to the degradation of exudates compounds and the release of microbial metabolites. Microbial activity is a central factor in the soil organic P cycle and affects the transformations of inorganic P which influence of P status on uptake efficiency could be attributed to the change in root parameters of the plant. Similar findings were also reported by Sharma *et al.* (2012). Yawalkar *et al.* (2002) reported that the application of VAM enhance uptake of P leading to uniform crop growth and increased yield.

4.6.1.3 Total uptake of potassium

Effect of phosphorus

Graded doses of phosphorus significantly influenced the potassium uptake (Table 4.48) and it ranged from 67.25 to 85.51 kg ha⁻¹ and 66.56 and 84.59 kg ha⁻¹ in

the year 2017-18 and 2018-19, respectively. The potassium uptake increased with increasing doses of phosphorus and the highest (85.51 kg ha⁻¹ and 84.59 kg ha⁻¹ during 2017-18 and 2018-19, respectively) was recorded with the application of phosphorus @ 60 kg ha⁻¹ was found to be significantly superior over all other treatments of phosphorus application. The increase in the total uptake of potassium followed the order of P₁₅ < P₃₀ < P₄₅ < P₆₀.

Effect of biofertilizers

The individual or dual inoculation biofertilizers was not affected significantly on total uptake of potassium (Table 4.48) and it varied from 69.01 to 83.87 kg ha⁻¹ and 67.63 to 83.01 kg ha⁻¹ in the year 2017-18 and 2018-19, respectively. The higher magnitude of total uptake of potassium (83.87 kg ha⁻¹ and 83.01 kg ha⁻¹ during the year 2017-18 and 2018-19, respectively) was recorded with no biofertilizers application (B₀) and the lowest potassium uptake (69.01 kg ha⁻¹ and 67.63 kg ha⁻¹ during 2017-18 and 2018-19, respectively) was observed with dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each.

Interaction effect

Application of graded levels of phosphorus in combination with biofertilizers along with recommended dose of N, K and FYM significantly influenced the potassium uptake (Table 4.48) and it varied from 68.92 to 96.89 kg ha⁻¹ and 67.54 to 96.51 kg ha⁻¹ during 2017-18 and 2018-19, respectively. The highest potassium uptake (96.89 kg ha⁻¹) was found due to the treatment combination application of phosphorus @ 60 kg ha⁻¹ with inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃P₆₀), which was found to be at par with B₂P₆₀, B₀P₁₅, B₄P₃₀, B₀P₄₅, B₁P₆₀, B₁P₄₅, B₂P₃₀ and B₀P₃₀ in the year 2017-18. However, application of phosphorus @ 60 kg ha⁻¹ with inoculation of PSB @ 10 kg ha⁻¹ i.e. B₂P₆₀ was found highest (96.51 kg ha⁻¹) in respect of potassium uptake and was at par with B₀P₁₅, B₃P₆₀, B₄P₃₀, B₀P₄₅, B₁P₆₀ and B₁P₄₅ in the year 2018-19.

The data showed that, the total K uptake increased with increase in the level of phosphorus as well as inoculation of biofertilizers in both the years. The increases potassium uptake by grain and straw might be due to the synergistic effect between phosphorus and potassium and better root growth. The beneficial effect of organic matter on yield might also be attributed to the availability of sufficient amounts of nutrients throughout the growth periods of crops resulting in better uptake. Hadwania

and Gundalia (2005) reported that total uptake of N, P and K increased due to combined application of various levels of N, P and K.

4.6.2 Uptake by micronutrients

4.6.2.1 Total Fe uptake

Effect of phosphorus

The phosphorus application significantly influenced the total Fe uptake (Table 4.49) and it ranged from 2462.96 to 2613.21 and 4903.92 to 10167.76 g ha⁻¹ in the year 2017-18 and 2018-19, respectively. The total Fe uptake (2613.21 g ha⁻¹) was significantly higher with the application of phosphorus @ 15 kg ha⁻¹ which found to be at par with application of phosphorus @ 60 kg ha⁻¹ in the year 2017-18. During 2018-19, the higher magnitude of Fe uptake (10167.76 g ha⁻¹) was recorded with the application of phosphorus @ 60 kg ha⁻¹ and which was found to be statistically superior over all other treatments. The increase in the total uptake of Fe followed the order of P₄₅ < P₃₀ < P₆₀ < P₁₅ in the year 2017-18 and P₁₅ < P₄₅ < P₃₀ < P₆₀ in the year 2018-19.

Effect of biofertilizers

An alone or dual inoculation of biofertilizers showed significant effect on the total Fe uptake presented in the Table 4.49 and it ranged from 2215.35 to 3005.60 and 6290.10 to 7668.36 g ha⁻¹ in the year 2017-18 and 2018-19, respectively. The application of VAM + PSB @ 10 kg ha⁻¹ each was found to be significantly highest (3005.60 g ha⁻¹ and 7668.36 g ha⁻¹ during 2017-18 and 2018-19, respectively) in respect of Fe uptake indicating its superiority over all other the treatments.

Interaction effect

The interaction between graded doses of phosphorus and biofertilizers application alone or in combination increased total Fe uptake significantly presented in the Table 4.49 and ranged from 1438.71 to 3392.37 and 2494.43 to 14405.11 g ha⁻¹ in the year 2017-18 and 2018-19, respectively. Significantly highest total Fe uptake (3392.37 g ha⁻¹) was observed with the treatment receiving phosphorus @ 15 kg ha⁻¹ with no biofertilizers (B₀P₁₅) and found to be at par with B₄P₁₅ in the year 2017-18. During 2018-19, the application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀) was found to be significantly superior in respect of total Fe uptake (14405.11 g ha⁻¹) in all treatment combinations.

The total Fe uptake increased with increase in the level of phosphorus as well as inoculation of biofertilizers in both the years. This means that the uptake of the nutrient showed more increment by applying the higher rate of soil P combined with inoculation of biofertilizers. This may be due to positive effect of NPK application with inoculation of biofertilizers on plant root growth and hence, promoting nutrient uptake.

In lateritic soils of Konkan, Gengaje (2013) and Mhalshi (2013) observed significant increase in Fe content with the dual inoculation of *rhizobium* and PSB with different levels of phosphorus under groundnut (*viz.*, 25 and 50 kg ha⁻¹) and cowpea (*viz.*, 50, 60 and 70 kg ha⁻¹), respectively.

4.6.2.2 Total Mn uptake

Effect of phosphorus

The application of phosphorus could not reach the level of significance presented in the Table 4.50 in respect of Mn uptake and it ranged from 1125.22 to 1306.00 g ha⁻¹ and 1183.20 to 1371.48 g ha⁻¹ in the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 30 kg ha⁻¹ was recorded the highest total Mn uptake (1306.00 g ha⁻¹ and 1371.48 g ha⁻¹ during 2017-18 and 2018-19, respectively), whereas the application of phosphorus @ 15 kg ha⁻¹ showed the lowest total Mn uptake (1125.22 g ha⁻¹ and 1183.20 g ha⁻¹ during 2017-18 and 2018-19, respectively).

Effect of biofertilizers

The application of biofertilizers does not showed the significant effect on total Mn uptake (Table 4.50) and it varied from 1077.74 to 1261.27 g ha⁻¹ and 1171.81 to 1314.63 g ha⁻¹ in the year 2017-18 and 2018-19, respectively. The total Fe uptake (1261.27 g ha⁻¹ and 1314.63 g ha⁻¹ during 2017-18 and 2018-19, respectively) noted highest due to inoculation of PSB @ 10 kg ha⁻¹ (and the lowest (1077.74 g ha⁻¹ and 1171.81 g ha⁻¹ during 2017-18 and 2018-19, respectively) was recorded with application of VAM @ 10 kg ha⁻¹.

Interaction effect

The application of phosphorus and biofertilizers did not influence significantly the total Mn uptake presented in the Table 4.50, which ranged from 538.36 to 1530.48 g ha⁻¹ and 571.06 to 1610.05 g ha⁻¹ during the year 2017-18 and

2018-19, respectively. The application of phosphorus @ 30 kg ha⁻¹ with inoculation of PSB @ 10 kg ha⁻¹ was recorded the highest total Mn uptake (1530.48 g ha⁻¹ and 1527.97 g ha⁻¹ during 2017-18 and 2018-19, respectively) and application of phosphorus @ 15 kg ha⁻¹ with inoculation of VAM @ 10 kg ha⁻¹ (538.36 g ha⁻¹ and 571.06 g ha⁻¹ during 2017-18 and 2018-19, respectively) recorded the lowest uptake of it.

The total Mn uptake increased with increase in the level of phosphorus as well as inoculation of biofertilizers in both the years, which was attributed to the prevention of rapid oxidation of added Mn by phosphate and thereby maintaining a sustained supply of Mn in available form for the plant. Prasad and Dey (1979) observed higher uptake of Mn due to P application.

In this concern, Tisdale *et al.* (1995) explained that increasing soil temperature during the crop growing season improves Mn uptake, presumably because of greater plant growth and root activity.

4.6.2.3 Total Zn Uptake

Effect of phosphorus

The Zn uptake ranged from 230.33 to 312.23 and 210.45 to 308.71 g ha⁻¹ in the year 2017-18 and 2018-19, respectively (Table 4.51) and followed the order P₁₅ < P₃₀ < P₆₀ < P₄₅. The application of phosphorus @ 45 kg ha⁻¹ recorded the significantly highest Zn uptake (312.23 g ha⁻¹ and 308.72 g ha⁻¹ during 2017-18 and 2018-19, respectively), which was found to be at par with P₆₀ (300.41 g ha⁻¹) and P₃₀ (281.10 g ha⁻¹) in the year 2017-18 and P₆₀ (287.95 g ha⁻¹) in the year 2018-19.

Effect of biofertilizers

The variations in Zn uptake due to application of biofertilizers in different treatments were observed to be ranged from 251.46 to 311.17 g ha⁻¹ and 240.98 to 302.15 g ha⁻¹ during the year 2017-18 and 2018-19 respectively (Table 4.51). Significantly highest Zn uptake (311.17 g ha⁻¹ and 302.15 in the year 2017-18 and 2018-19, respectively) was noted with the application of VAM + PSB @ 10 kg ha⁻¹ each which was found to be at par with B₁ (290.69 g ha⁻¹), B₂ (278.53 g ha⁻¹) and B₀ (273.23 g ha⁻¹) in the year 2017-18 and B₁ (279.00 g ha⁻¹) in the year 2018-19.

Interaction effect

The integration of phosphorus doses and biofertilizers application showed significant variation in total uptake of Zn (Table 4.51) and it ranged from 167.54 to 423.06 g ha⁻¹ and 154.03 to 396.48 g ha⁻¹ in the year 2017-18 and 2018-19, respectively. The Zn uptake found to be significantly highest (423.06 g ha⁻¹ and 396.48 g ha⁻¹ during 2017-18 and 2018-19, respectively) due to treatment consisting application of phosphorus @ 45 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₄₅) over all treatment combination and the same treatment combination was found to be at par with B₁P₃₀ in the year 2017-18 and with B₁P₃₀, B₁P₄₅ and B₄P₆₀ in the year 2018-19.

The data revealed that, the total Zn uptake increased with increase in the level of phosphorus as well as inoculation of biofertilizers in both the years. In this concern, Tandon (1992) stated that the acidic nature of N fertilizers enhances availability of micronutrient cations in soils, in addition to the luxuriant vegetative growth due to N itself. In the process, nutrient concentration of plant components get reduced on account of dilution effect, but overall nutrient uptake by plants is increased. Yawalkar *et al.* (2002) reported that the application of VAM enhance uptake of Zn leading to uniform crop growth and increased yield. In this context, Tandon (1992) reported that potassium application promotes Zn absorption and/or its translocation in the plant as the concentration of Zn was found to be higher in grain, straw and roots of wheat in the presence of K than in its absence.

4.6.2.4 Total Cu uptake Effect of phosphorus

The total Cu uptake ranged from 79.23 to 103.20 and 57.90 to 81.08 g ha⁻¹ in the year 2017-18 and 2018-19, respectively (Table 4.52). The higher magnitude of total Cu uptake (103.20 g ha⁻¹ and 81.08 g ha⁻¹ during 2017-18 and 2018-19, respectively) was observed with application phosphorus @ 60 kg ha⁻¹ and lowest Cu uptake (79.23 g ha⁻¹ and 57.90 g ha⁻¹ during 2017-18 and 2018-19, respectively) was recorded with application of phosphorus @ 15 kg ha⁻¹. The increase in total uptake of Cu followed the order P₁₅ < P₄₅ < P₃₀ < P₆₀. The significant difference was not observed within the treatment.

Effect of biofertilizers

The application of biofertilizers did not influence the total Cu uptake

(Table 4.52), however, it ranged from 79.31 to 105.91 g ha⁻¹ and 63.82 to 83.88 g ha⁻¹ during the year 2017-18 and 2018-19. The dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄) and with no biofertilizers application (B₀) showed highest total Cu uptake (105.91 g ha⁻¹ and 83.88 g ha⁻¹ during 2017-18 and 2018-19, respectively) while dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) (79.31 and 63.82 g ha⁻¹ during 2017-18 and 2018-19, respectively) was recorded the lowest Cu uptake.

Interaction effect

The interaction effect between graded doses of phosphorus alone or in combination increased total Cu uptake significantly (Table 4.52) and varied from 47.24 to 161.89 g ha⁻¹ and 37.03 to 128.21 g ha⁻¹ in the year 2017-18 and 2018-19, respectively. Significantly highest total Cu uptake (161.89 g ha⁻¹) was registered with the application of phosphorus @ 30 kg ha⁻¹ with inoculation of VAM @ 10 kg ha⁻¹ (B₁P₃₀) over all other treatment combinations and found at par with B₄P₆₀ and B₀P₄₅ in the year 2017-18. However, the application of phosphorus @ 45 kg ha⁻¹ with no biofertilizers application showed significantly highest Cu uptake (128.21 g ha⁻¹) over all other treatment combinations, which was found to be at par with B₁P₃₀, B₄P₆₀, B₄P₃₀ and B₀P₆₀ in the year 2018-19.

The data revealed that, the total Cu uptake increased with increase in the different levels of phosphorus as well as inoculation of biofertilizers in both the years. The increase in the availability of Cu with inoculation of biofertilizers and P and K application, which reflected a good utilization of nutrients which gave a good growth and biological yield.

In general, the beneficial effect of soil fungi on nutrient uptake which may be attributed to three factors: increased absorption of available nutrients from soil, increasing the availability by solubilizing insoluble nutrients like P and increasing the nutrient mobility due to faster intracellular nutrient mobility and mobilizing nutrients from the soil mass.

4.7 Effect on quality parameters

4.7.1 Oil Content

Phosphorus effect

The application of graded doses of phosphorus increased oil content of groundnut significantly (Table 4.53) and varied from 45.62 to 50.23 per cent and 46.36 to 50.23 per cent during 2017-18 and 2018-19, respectively. Among the

different levels of phosphorus, the application of phosphorus @ 60 kg ha⁻¹ noted the significantly highest oil content (50.23 % and 50.23 % during 2017-18 and 2018-19, respectively), which followed the order P₁₅ < P₃₀ < P₄₅ < P₆₀ and showed its superiority over all other doses of phosphorus.

Biofertilizers effect

The oil content could not reach the level of significance with inoculation of biofertilizers alone or in combination (Table 4.53) however, it varied from 46.91 to 48.47 per cent and 46.96 to 48.74 per cent in the year 2017-18 and 2018-19, respectively. Dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄) during 2017-18 and application of VAM +PSB @ 5 kg ha⁻¹ each (B₃) during 2018-19 registered highest oil content (48.47 % and 48.74 %, respectively), while inoculation of VAM @ 10 kg ha⁻¹ recorded the lowest oil content (46.91 and 46.96 % during 2017-18 and 2018-19, respectively).

Interaction effect

The combine application of phosphorus and biofertilizers showed significant effect on oil content (Table 4.53) and it ranged from 44.50 to 51.21 per cent and 44.40 to 50.55 per cent during the year 2017-18 and 2018-2019. Significantly highest oil content (51.21 % and 50.55 % during the year 2017-18 and 2018-19, respectively) was recorded due to the treatment receiving phosphorus @ 60 kg ha⁻¹ with VAM + PSB @ 10 kg ha⁻¹ each and no biofertilizers application (B₄P₆₀ and B₀P₆₀ during the year 2017-18 and 2018-19, respectively), which were found at par with B₂P₆₀, B₄P₄₅, B₀P₆₀, B₃P₆₀, B₃P₄₅, B₂P₄₅, B₀P₃₀ and B₁P₃₀ in the year 2017-18 and B₂P₆₀, B₄P₄₅, B₃P₄₅, B₁P₆₀, B₄P₆₀, B₂P₄₅, B₀P₃₀, B₃P₃₀ and B₁P₃₀ in the year 2018-19.

The oil content increases with higher doses of phosphorus and also inoculation of biofertilizers in both the years. This may be due to the better availability of phosphorus through a readily available source (single super phosphate) caused better root development resulting in higher uptake of phosphorus and other nutrients and higher biological nitrogen fixation.

The significant increased in oil content was also reported by Hadwani and Gundalia (2005) in ground nut with higher doses of N, P and K, Zalate and Padmani (2009) under groundnut crop, Pramanik and Bera (2013) in sunflower due to application of VAM + PSB + *Azotobacter*.

In lateritic soils of Konkan, Gengaje (2013) and Mhalshi (2013) observed significant increase oil content with the dual inoculation of *rhizobium* and PSB with different levels of phosphorus under groundnut (*viz.*, 25 and 50 kg ha⁻¹). Significant increase in oil content also reported by Kamdi *et al.* (2014).

4.7.2 Protein content

Phosphorus effect

The variation in protein content due to application of phosphorus in different treatments were observed and ranged from 23.39 to 30.01 per cent and 23.86 to 30.61 per cent in the year 2017-18 and 2018-19, respectively (Table 4.53). Among the different levels of phosphorus, the application of phosphorus @ 45 kg ha⁻¹ noted the significantly highest protein content (30.01 % and 30.61 % during 2017-18 and 2018-19, respectively) and followed the increasing order P₁₅ < P₃₀ < P₆₀ < P₄₅ in both the years.

Biofertilizers effect

The protein content tended to increased significantly with application of biofertilizers (Table 4.53) and it ranged from 26.15 to 28.07 per cent and 26.67 to 28.63 per cent in the year 2017-18 and 2018-19, respectively. The dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each registered significantly highest protein content (28.07 and 28.63 % during 2017-18 and 2018-19, respectively) as compared to other treatments and showed its superiority over all treatments. However, the treatment B₃ consisting dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each was at par with B₄ treatment during both the years. The increase in protein content followed the order B₀ < B₁ < B₂ < B₃ < B₄ in both the years.

Interaction effect

The interaction effect between graded doses of phosphorus and biofertilizers application either alone or in combination increased protein content significantly (Table 4.53), which ranged from 22.28 to 31.62 per cent and 22.73 to 32.25 per cent during the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 60 kg ha⁻¹ with VAM + PSB @ 10 kg ha⁻¹ each recorded significantly highest protein content (31.62 % and 32.25 % during 2017-18 and 2018-19, respectively) over all other treatment combinations and it was found to be at par with the treatment combinations of B₃P₆₀ (31.38 % and 32.01 % during 2017-18 and 2018-19,

respectively) and B₂P₄₅ (31.15% and 31.77 % during 2017-18 and 2018-19, respectively).

The protein content increases with higher doses of phosphorus and also inoculation of biofertilizers in both the years. The increased in protein content may be due to the combined application of various VAM cultures and PSB, which was additionally effective in enhancing protein content, indicating a synergistic interaction between VAM and PSB biofertilizers. Beside this, the phosphorus has important role in formation of protein, particular amino acid, phosphate form, nucleic acid, phospholipids, co-enzyme NAD, NADP, ATP, cell growth, chromosome form and stimulate the root growth. This macronutrient also has a significant role in the synthesis of nucleic acid co-enzyme and some protein as well as in the substrate metabolism.

The increased protein content of cowpea as result of 45:50:45 + BF application in lateritic soils of Konkan was also reported by Patil *et al.* (2011). The increased in protein content due to beneficial effect of biofertilizers in soybean was also reported by Munda *et al.* (2013). The similar results were reported by Pramanik and Bera (2013) in sunflower due to application of VAM + PSB + *Azotobacter*.

4.7.3 Methionine content **Phosphorus effect**

The methionine content showed significant differences due to application of phosphorus (Table 4.53) and it varied from 0.23 to 0.44 and 0.23 to 0.45 per cent in the year 2017-18 and 2018-19, respectively. Among the graded levels of phosphorus, application of phosphorus @ 45 kg ha⁻¹ showed significantly highest methionine content (0.44 % and 0.45 % during 2017-18 and 2018-19, respectively), which was at par with application of phosphorus @ 60 kg ha⁻¹ (0.43 per cent and 0.44 per cent during 2017-18 and 2018-19, respectively).

Biofertilizers effect

The individual or dual inoculation of biofertilizers showed significant effect regarding methionine content (Table 4.53) and it varied from 0.33 to 0.39 per cent and 0.34 to 0.39 per cent in the year 2017-18 and 2018-19, respectively. The significantly highest methionine content (0.39 % and 0.39 % during 2017-18 and 2018-19, respectively) was recorded with application of VAM + PSB @ 10 kg ha⁻¹ each, which was found to be at par with application of VAM + PSB @ 5 kg ha⁻¹ each (0.38 % and

0.38 % during 2017-18 and 2018-19, respectively) in both the years.

Interaction effect

Different levels of phosphorus and biofertilizers significantly increased methionine content presented in the Table 4.53, which ranged from 0.18 to 0.49 and 0.19 to 0.49 per cent in the year 2017-18 and 2018-19, respectively. The application of phosphorus @ 15 kg ha⁻¹ with no biofertilizers application (B₀P₁₅) noted significantly highest methionine content (0.49 % and 49 % during 2017-18 and 2018-19, respectively) over all other treatment combinations, which were at par with B₄P₄₅, B₃P₄₅, B₁P₆₀, and B₄P₆₀ in the year 2017-18 and with B₄P₄₅, B₃P₄₅, B₁P₆₀, B₄P₆₀, B₃P₆₀, and B₂P₆₀ in the year 2018-19

In general, the application of biofertilizers increased the methionine content over sole use of different chemical fertilizer combinations. A close look on the data indicated that methionine increased with the increasing doses of phosphorus. Bhikane (2007) observed significant increase in the methionine content of cowpea grain due to application of 100 per cent NPK (25:50:50 kg N:P₂O₅:K₂O ha⁻¹) + biofertilizers over control from 0.190 to 0.310 per cent. Gadade (2007) reported significant increase in methionine content due to application of 100 per cent N and P (25:50 kg N:P ha⁻¹) + biofertilizers over control from 0.188 to 0.212 per cent.

The above results also find support with the investigation of Kharade (2009) with groundnut in lateritic soil and Patil *et al.* (2011) with cowpea.

4.7.4 Shelling percentage

Effect of phosphorus

The shelling percentage followed the order P₁₅ < P₃₀ < P₆₀ and < P₄₅ due to application of phosphorus (Table 4.54), which influenced significantly and varied from 63.16 to 69.71 per cent and 64.98 to 71.80 per cent during 2017-18 and 2018-19, respectively. The application of phosphorus @ 45 kg ha⁻¹ registered significantly higher shelling percentage (69.71 % and 71.80 % during 2017-18 and 2018-19, respectively), which was found to be significantly superior over all other treatments of phosphorus application.

Effect of biofertilizers

The shelling percentage significantly increased with inoculation of biofertilizers alone or in combination (Table 4.54) and it varied from 65.99 to 67.91

and 67.98 to 69.95 per cent during 2017-18 and 2018-19, respectively. The shelling percentage was found to be significantly higher (67.91 % and 69.95 % during 2017-18 and 2018-19, respectively) with inoculation of VAM + PSB @ 10 kg ha⁻¹ each over no biofertilizers (65.99 % and 67.98 % during 2017-18 and 2018-19, respectively) in both the years.

Interaction effect

The application of phosphorus and inoculation of biofertilizers influenced significantly on shelling percentage presented in the Table 4.54, which ranged from 62.13 to 71.62 per cent and 63.66 to 73.77 per cent in the year 2017-18 and 2018-19, respectively. The treatment combination consisting application of phosphorus @ 60 kg ha⁻¹ along with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each i.e. B₄P₆₀ was found to be significantly superior in respect of shelling percentage (71.62 and 73.77 % during 2017-18 and 2018-19, respectively) over all other treatment combinations and found to be at par with the application of phosphorus @ 45 kg ha⁻¹ alongwith VAM + PSB @ 5 kg ha⁻¹ each i.e. B₃P₄₅ (70.92 % and 73.08 % during 2017-18 and 2018-19, respectively).

The increase in shelling percentage might be due to high dose of phosphorus fertilizer, which tends to form nutrient interaction and may affect the availability of other nutrients, which are essential for growth of the groundnut. Similar findings were also reported by Zalate and Padmani (2009), Kamdi *et al.* (2014) and (Sibhatu *et al.* 2016) in groundnut crop.

4.8 Relationship between soil properties and pod yield of groundnut

The knowledge of total soil content of an element or of its available form provides only limited information about the chemical behaviour of it and its availability to the plants. In soils, several chemical reactions are going on simultaneously and it is difficult to separate out one reaction from the other. Therefore, an attempt has been made to find out the relationship between chemical and biological properties of soil with the available nutrients and to understand the chemistry of the element.

As there are 62 variables, the correlation matrix of 62 variables can not be accommodated in single page, therefore the variables were grouped according to physico-chemical properties of soil, biological properties of soil, available nutrient

status, available micronutrients and soil enzymes activities and their correlation matrices with pod yield are presented in Table 4.55 to 4.57.

4.8.1 Correlation between chemical properties and available nutrients of soil with each other and yield of groundnut

Soil pH

Soil pH was positively correlated with DTPA-extractable Fe, Mn and pod yield of groundnut. It showed non-significant negative relationship with organic carbon, available N, available P₂O₅ and available K₂O content of soil. However, the soil pH indicated significant and negative correlation and non-significant correlation with DTPA-extractable Zn and Cu content of soil, respectively.

Joshi (2012) reported non-significant negative relationships for available Fe, Mn, Cu and Zn with pH of soil in lateritic soils of Konkan. The inverse effect of pH on available Mn might be due conversion of divalent form (Mn²⁺) into insoluble and unavailable trivalent form (Mn³⁺) as a result of increase in soil pH (Waghmare *et al.* 2008).

Organic carbon

The organic carbon content was observed to be significantly and positively related with available K₂O content and negatively related with DTPA-extractable Zn and Cu content, while the soil pH, available N, available P₂O₅ and DTPA-extractable Fe and Mn content showed negative and non-significant relationship. Joshi (2012) and Pawar (2012) also reported positive correlation between organic carbon and available Fe, Mn, Cu and Zn in lateritic soils of Konkan.

Available N

A significant and positive co-relationship was observed between available N with available P₂O₅, K₂O and Zn content, but non-significant relationship with pod yield and the negative non-significant results were observed with pH, organic carbon as well as with DTPA- extractable Cu content. However, it showed significant negative relationship with DTPA-extractable Fe ($r = -0.278^{**}$) and Mn ($r = -0.580^{**}$) content. In lateritic soils of Konkan, Joshi (2012) and Pawar (2012) also reported positive correlation between available N and available Fe, Mn, Cu and Zn content.

Available P₂O₅

The available P₂O₅ showed significant and positive relation with available N as well as with DTPA-extractable Zn content. However, it showed negative and non-significant co-relation with soil pH, organic carbon content as well as with DTPA-extractable Fe and Cu content except available K₂O and pod yield of groundnut, which was observed non-significant relationship.

Available K₂O

Available K₂O recorded significant positive co-relation with organic carbon and available N content and significant negative correlations observed with DTPA extractable Fe, Mn ($r = -0.622^{**}$), and Cu content. However, available K₂O content observed non-significant with available P₂O₅ and DTPA-extractable Zn content and pod yield of groundnut, while, it was negative and non-significant relationship with soil pH.

DTPA-extractable micronutrients

DTPA extractable Fe content observed significant and positive correlation with DTPA extractable Mn ($r = 0.553^{**}$), Cu, soil pH and pod yield of groundnut, while, it was significantly and negatively related with available N and available K₂O content. The DTPA-extractable Fe showed negative and non-significant with organic carbon, available P₂O₅ and DTPA-extractable Zn content.

DTPA-extractable Mn was found to be significantly and positively related with soil pH, DTPA-extractable Fe ($r = 0.553^{**}$) and Cu content and negative but significant co-relation with available N ($r = -0.580^{**}$), available K₂O ($r = -0.622^{**}$) and DTPA-extractable Zn content. However, the non-significant correlation was observed with pod yield and negatively but non-significant relationship with organic carbon content.

DTPA-extractable Zn was observed to be positively and significantly correlated with available N and available P₂O₅ content and negatively related with soil pH, organic carbon, DTPA-extractable Mn content and pod yield of groundnut, while, it was found to be non-significantly correlated with available K₂O and negative but non-significant relationship with DTPA-extractable Fe and Cu content.

DTPA-extractable Cu showed positive relation with DTPA-extractable Fe and Mn and negative relationship with organic carbon and available K₂O content. DTPA-

extractable Cu content observed non-significant correlation with soil pH and pod yield of groundnut and negative but non-significant relation with available N, available P₂O₅ and DTPA-extractable Zn content.

4.8.2 Relationship between biological properties of soil with each other and with yield of groundnut

The data regarding relationship between biological properties of soil with each other and with yield of groundnut are presented in Table 4.56. It was observed from the data that, all the biological properties of soil were observed to be significantly and positively co-related with each other. The CO₂ evolution ($r= 0.534^{**}$), dehydrogenase activity ($r= 0.524^{**}$), urease activity ($r= 0.531^{**}$), alkaline phosphatase activity ($r= 0.531^{**}$) and acid phosphatase activity ($r=0.514^{**}$) were observed to be positively and significantly correlated with pod yield of groundnut.

All the biological properties of soil were found to be significantly and positively correlated with each other *viz.*, bacterial population, actinomycetes, fungi population, CO₂ evolution, dehydrogenase activity, urease activity, alkaline phosphatases activity, acid phosphatases activity and soil microbial biomass carbon. Bedi *et al.* (2009) reported highly significant positive relation of microbial population with microbial respiration. A positive significant co-relationship was observed with different biological properties.

The dehydrogenase activity was strongly co-related with all biological properties due to accumulation of nitrification products (NO₃⁻ and NO₂⁻) or some other compounds that have inhibitory effect on dehydrogenase activity (Masciandaro *et al.* 1997) or likely be the consequence of decreased availability of easily degradable compounds in the organic amendments.

The SMBC was strongly correlated with microbial populations and soil enzymes, which signified the role of microbial biomass as it represents the main sources of soil enzymes and nutrient pools, which regulates in protecting and maintaining soil enzymes in their active forms in soil matrix (Saha *et al.* 2008).

The SMBC was also related positively with dehydrogenase which might be due to addition of organic manure, which provide a more favourable environment for the accumulation of enzymes in the soil matrix, since soil organic constituents stable complexes with free enzymes (Srinivas *et al.* 2015).

Nath *et al.* (2015) also reported significant correlation between soil enzymes exhibited the prevalence of both intracellular and extracellular enzymes that offer steady biological activity and soil functionality under integrated nutrient management.

4.8.3 Inter-relationship between chemical and biological properties of soil with each other and with yield of groundnut

From the data presented in Table 4.57 it was observed that the soil pH showed significant and positive relation with pod yield of groundnut as well as with, actinomycetes and fungal population and showed non-significant relation with bacterial population and dehydrogenase activity. The properties like organic carbon, available N, available P₂O₅, available K₂O showed negative and non-significant co-relationship with soil pH.

The organic carbon content showed positive relation with available K₂O while bacteria, actinomycetes, fungi, dehydrogenase activity, pod yield of groundnut were found to be non-significant co-relationship. However, the soil pH, available N and available P₂O₅ were observed to be negatively and non-significantly co-related with organic carbon content of soil.

The available N was found to be significantly and positively co-related with available P₂O₅ and K₂O content and non-significant and negative co-relationship was observed with soil pH, organic carbon, actinomycetes and fungal population. However, it showed non-significant relation with bacteria, dehydrogenase as well as with pod yield of groundnut.

The available P₂O₅ content was observed to be positively and significantly co-related with available N, bacteria and actinomycetes population and dehydrogenase activity and it showed non-significant relationship with available K₂O, fungi and pod yield. The soil properties like soil pH and organic carbon content showed found to be negative and non-significant relationship with available P₂O₅.

The available K₂O content indicated significant and positive relation with organic carbon, available N and negative correlation with actinomycetes and fungal population. The soil pH showed negative but non-significant relationship while the available P₂O₅, bacteria, dehydrogenase activity and pod yield of groundnut indicated non-significant relationship.

As far as bacterial population was concerned, it showed positive and significant co-relationship with available P₂O₅, pod yield of groundnut, actinomycetes

($r = 0.917^{**}$), fungi ($r = 0.879^{**}$) and dehydrogenase activity ($r = 0.983^{**}$) and soil pH, organic carbon, available N, available K_2O content showed non-significant relationship.

A positive and significant co-relationship was observed with soil pH, available P_2O_5 content, bacteria ($r = 0.917^{**}$), fungi ($r = 0.993$), dehydrogenase activity ($r = 0.928^{**}$) and pod yield of groundnut with actinomycetes population. The organic carbon content was observed to be non-significant whereas, available N content showed negative but non-significant relation with actinomycetes population.

The fungal population showed significant and positive relation with soil pH, bacteria ($r = 0.879^{**}$), actinomycetes ($r = 0.993^{**}$), dehydrogenase activity ($r = 0.894^{**}$) and pod yield of groundnut and showed negative relation with available K_2O content and non-significant relation with organic carbon, available P_2O_5 content and negative but non-significant relation with available N content.

The dehydrogenase activities indicated the positive but significant relationship with available P_2O_5 content, bacteria ($r = 0.983^{**}$), actinomycetes ($r = 0.928^{**}$), fungi ($r = 0.894^{**}$) and with pod yield ($r = 0.524^{**}$) of groundnut and showed non-significant relation with soil pH, organic carbon content, available N and available K_2O content.

There was a significant and positive correlation observed between fungi, bacteria and actinomycetes population. However, the microbial population showed positive correlation with microbial respiration, dehydrogenase and phosphatase activity may be because of all these sources were considered truly as being of microbial origin (Tabatabai 1994). Urease activity, SMBC, Alkaline and acid phosphatase activity were positively and significantly related to microbial population i.e. fungi, bacteria and actinomycetes activities.

Nath *et al.* (2015) reported the positive correlation of organic carbon with dehydrogenase activities, which indicates the improvement in soil quality under the environment-friendly nutrient management.

In literature, it was also reported that the concentration of phosphorus in microbial cells was higher as compared to the other nutrients (Bedi *et al.* 2009). Micro-organisms cause immobilization of phosphorus in soil, if the concentration of phosphorus in soil decreased to less than the concentration of microbial cells (Mark

1999). Hence, the phosphorus present in the soil showed positive correlation with microbial biomass.

4.9 Effect of different levels of phosphorus and biofertilizers on economics of groundnut

Data presented in Table 4.58 and 4.59 indicated that the economic analysis of different levels of phosphorus, biofertilizers and their combinations in respect of groundnut crop showed the differences in B:C ratio and it ranged from 0.89 to 1.30 and 0.93 to 1.34 in the year 2017-18 and 2018-19, respectively.

The scrutiny of data indicated that the higher B:C ratio (1.30) was obtained due to the treatment receiving the application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀) in the year 2017-18. However, the higher similar B: C ratio (1.34) was observed (B₄P₄₅) as well as with application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀) in the year 2018-19. It was clearly indicated that the earlier treatment (B₄P₄₅) is beneficial for saving of 15 kg phosphorus ha⁻¹, thereby increasing net returns (₹ 63048/-) from the groundnut cultivation. The maximum net returns (₹ 55883/- and ₹ 63048/-) was received due to the treatment B₄P₆₀ in the year 2017-18 and B₄P₄₅ in the year 2018-19, respectively.

In B: C ratio was in the decreasing order of (B₄P₄₅) > (B₃P₆₀) > (B₃P₄₅) > (B₄P₁₅) > (B₃P₃₀) > (B₂P₄₅) > (B₂P₆₀) > (B₂P₃₀) > (B₂P₁₅) and > (B₃P₁₅) in the year 2017-18. However, in the year 2018-19 the B:C ration followed the order of (B₄P₆₀) > (B₄P₃₀) > (B₃P₆₀) > (B₃P₄₅) > (B₄P₁₅) > (B₃P₃₀) > (B₂P₄₅) > (B₂P₆₀) > (B₂P₃₀) > (B₃P₁₅) and > (B₂P₁₅).

In general, the dual inoculation of biofertilizers such as Vesicular Arbuscular Mycorrhiza (VAM) as well as phosphate solubilizing bacteria (PSB) and individual inoculation of phosphate solubilizing bacteria with graded levels of phosphorus recorded the highest B:C ratio . In the decreasing order, the application of phosphorus @ 15 kg ha⁻¹ with dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃P₁₅) in the year 2017-18 and application of phosphorus @ 15 kg ha⁻¹ with dual inoculation of PSB @ 10 kg ha⁻¹ each (B₂P₁₅) recorded the lowest (1.04 and 1.13) B:C ratio in the year 2018-19, respectively.

Thus, keeping in view the optimum net return with good B:C (1.30) ratio the treatment receiving the application of phosphorus @ 60 kg ha⁻¹ with dual inoculation

of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀) in the year 2017-18 and B:C ratio (1.34) application of phosphorus @ 45 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₄₅) and B:C (1.34) application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀) in the year 2018-19 can be used for enhancing groundnut production with increased profit.

Table 4.58 Effect of different levels of phosphorus and biofertilizers on economics of groundnut (2017-18)

Treatment combinations	Pod Yield (q ha ⁻¹)	Halum Yield (q ha ⁻¹)	Gross Returns (₹ ha ⁻¹)	Total Cost of cultivation (₹ ha ⁻¹)	Net Returns (₹ ha ⁻¹)	B:C Ratio	
						Input cost	Total cost
B ₀ P ₁	21.76	51.67	143478	160914	-17437	1.19	0.89
B ₀ P ₂	22.81	42.67	1475285	162362	-14834	1.22	0.90
B ₀ P ₃	22.63	51.67	148698	163329	-14632	1.22	0.91
B ₀ P ₄	24.00	44.53	155133	165174	-10048	1.26	0.93
B ₁ P ₁	28.59	45.13	150003	163341	-13338	1.23	0.91
B ₁ P ₂	31.28	51.12	160440	165853	-5413	1.31	0.97
B ₁ P ₃	31.63	50.67	167648	167827	-179	1.36	0.99
B ₁ P ₄	31.66	51.40	160030	167330	-7299	1.29	0.95
B ₂ P ₁	23.12	43.03	182298	167693	14604	1.51	1.08
B ₂ P ₂	24.61	44.25	198743	171207	27536	1.64	1.16
B ₂ P ₃	25.83	51.60	202680	172636	30045	1.66	1.17
B ₂ P ₄	24.53	48.67	202128	173316	28812	1.64	1.16
B ₃ P ₁	27.20	46.43	174808	166907	7848	1.44	1.04
B ₃ P ₂	32.64	52.47	208958	173424	35533	1.71	1.20
B ₃ P ₃	34.00	53.60	217400	175604	41796	1.77	1.23
B ₃ P ₄	35.25	51.60	224400	177543	46857	1.82	1.26
B ₄ P ₁	34.00	49.20	216300	174700	41601	1.77	1.23
B ₄ P ₂	35.37	49.77	224663	176866	47697	1.83	1.27
B ₄ P ₃	36.44	50.00	231140	178718	52422	1.87	1.29
B ₄ P ₄	37.27	50.40	236220	180337	55883	1.90	1.30

Note: Input cost

Manure (FYM) cost ₹ t ⁻¹	= 5000/-	Rhizobium ₹ kg ⁻¹	=20/-
Seed ₹ kg ⁻¹	=92/-	VAM ₹ kg ⁻¹	= 130/-
Urea ₹ kg ⁻¹	= 5.36/-	PSB ₹ kg ⁻¹	= 30/-
S. S. P. ₹ kg ⁻¹	= 8.00/-	Labour charges ₹ day ⁻¹	= 206/-
M. O. P. ₹ kg ⁻¹	= 18.00/-	Price of groundnut ₹ kg ⁻¹	=6000/-
		Price of Halum ₹ kg ⁻¹	=250/-

Note: Treatments details

B ₀ - No biofertilizer application	P ₁ - Application Phosphorus @ 15 kg ha ⁻¹
B ₁ - VAM @ 10 kg ha ⁻¹	P ₂ - Application Phosphorus @ 30 kg ha ⁻¹
B ₂ -PSB @ 10 kg ha ⁻¹	P ₃ - Application Phosphorus @ 45 kg ha ⁻¹
B ₃ -VAM + PSB @ 5 kg ha ⁻¹ each	P ₄ - Application Phosphorus @ 60 kg ha ⁻¹
B ₄ -VAM + PSB @ 5 kg ha ⁻¹ each	

Table 4.59 Effect of different levels of phosphorus and biofertilizers on economics of groundnut (2018-19)

Treatment combinations	Pod Yield (q ha ⁻¹)	Halum Yield (q ha ⁻¹)	Gross Returns (₹ ha ⁻¹)	Total Cost of cultivation (₹ ha ⁻¹)	Net Returns (₹ ha ⁻¹)	B:C Ratio	
						Input cost	Total cost
B ₀ P ₁	22.14	52.36	151465	162437	-10972	1.25	0.93
B ₀ P ₂	22.18	43.21	149428	132966	-13539	1.23	0.91
B ₀ P ₃	22.31	52.37	152530	164352	-11822	1.25	0.92
B ₀ P ₄	24.45	45.14	164098	167149	-3052	1.33	0.98
B ₁ P ₁	23.54	43.60	158025	164869	-6844	1.30	0.95
B ₁ P ₂	24.97	44.86	167278	167280	-2.69	1.36	0.99
B ₁ P ₃	26.22	52.16	176915	169756	7159	1.43	1.04
B ₁ P ₄	24.94	49.29	168198	169172	-974	1.35	0.99
B ₂ P ₁	29.12	45.71	193428	169740	23688	1.60	1.13
B ₂ P ₂	31.73	51.87	211280	173584	37696	1.74	1.21
B ₂ P ₃	32.18	51.19	213923	174894	39029	1.75	1.22
B ₂ P ₄	32.27	52.07	214705	175893	38812	1.74	1.22
B ₃ P ₁	30.45	47.03	202070	171695	30375	1.66	1.17
B ₃ P ₂	33.08	53.10	220025	175556	44769	1.80	1.25
B ₃ P ₃	34.48	54.36	229090	177936	51154	1.86	1.28
B ₃ P ₄	35.77	52.21	236615	180060	56555	1.91	1.31
B ₄ P ₁	34.42	49.81	227578	176770	50807	1.86	1.28
B ₄ P ₂	36.00	50.43	237608	179311	58297	1.93	1.32
B ₄ P ₃	37.04	51.41	244353	181304	63048	1.97	1.34
B ₄ P ₄	37.06	51.05	244388	182179	62209	1.96	1.34

Note: Input cost

Manure (FYM) cost ₹ t ⁻¹	= 5000/-	Rhizobium ₹ kg ⁻¹	=20/-
Seed ₹ kg ⁻¹	= 92/-	VAM ₹ kg ⁻¹	= 130/-
Urea ₹ kg ⁻¹	= 6.00/-	PSB ₹ kg ⁻¹	= 30/-
S. S. P. ₹ kg ⁻¹	= 9.00/-	Labour charges ₹ day ⁻¹	= 206/-
M. O. P. ₹ kg ⁻¹	= 19.00/-	Price of groundnut ₹ kg ⁻¹	=6250/-
		Price of Halum ₹ kg ⁻¹	=250/-

Note: Treatments details

B ₀ - No biofertilizer application	P ₁ - Application Phosphorus @ 15 kg ha ⁻¹
B ₁ - VAM @ 10 kg ha ⁻¹	P ₂ - Application Phosphorus @ 30 kg ha ⁻¹
B ₂ -PSB @ 10 kg ha ⁻¹	P ₃ - Application Phosphorus @ 45 kg ha ⁻¹
B ₃ -VAM + PSB @ 5 kg ha ⁻¹ each	P ₄ - Application Phosphorus @ 60 kg ha ⁻¹
B ₄ -VAM + PSB @ 5 kg ha ⁻¹ each	

CHAPTER V

SUMMARY AND CONCLUSION

The field investigation pertaining to the “Effect of different levels of phosphorus and biofertilizers on soil properties, yield, quality and uptake of nutrients by groundnut (*Arachis hypogaea* L.)” was undertaken during *Rabi* season of 2017-18 and 2018-19. The field trial was conducted in plot No. 14 (1) at Botany Farm, College of Agriculture, Dapoli.

The effect of different levels of phosphorus and biofertilizers on yield, nutrients content and uptake by groundnut as well as changes in physico-chemical properties, biological properties and nutrient status of soil was studied. The field experiments were laid out in Factorial Randomized Block Design with twenty treatment combinations, which were replicated thrice. The periodical observations at peg initiation stage, pod formations stage and at harvest of the crop were recorded.

The important findings evolved from the present investigation are summarized below:

5.1 Soil Properties

5.1.1 Chemical properties

The pH of the soil (4.66 and 4.71 during 2017-18 and 2018-19, respectively) was found to be significantly superior with application of phosphorus @ 15 kg ha⁻¹ as well as @ 60 kg ha⁻¹ i.e. RDF (4.66 and 4.69 during 2017-18 and 2018-19, respectively). The treatment with no biofertilizers application i.e. B₀ (4.69 and 4.74 during 2017-18 and 2018-19, respectively) was found to be significantly superior. The application of phosphorus @ 30 kg ha⁻¹ with inoculation of VAM @ 10 kg ha⁻¹ was found to be significantly superior in increasing soil pH (4.88) and application of phosphorus @ 30 kg ha⁻¹ with inoculation of VAM @ 10 kg ha⁻¹ was found to be significantly superior over all treatments in the year 2017-18 and 2018-19.

At pod formation stage, the application of phosphorus @ 15 kg ha⁻¹ (4.66 and 4.97 during 2017-18 and 2018-19, respectively) was found to be significantly superior. The dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄) was found to be significantly superior in increasing soil pH (4.70 and 5.02 during 2017-18 and 2018-19, respectively) as compared all other treatments. The application of phosphorus @ 15 kg ha⁻¹ alongwith dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₁₅) was found to be significantly superior over all other

treatment combinations.

At harvest stage, the application of phosphorus @ 60 kg ha⁻¹ (RDF) showed its superiority in increasing soil pH (5.19 and 5.41 during 2017-18 and 2018-19, respectively). The application of phosphorus @ 60 kg ha⁻¹ (RDF) with inoculation of VAM @ 10 kg ha⁻¹ i.e. B₁P₆₀ was found to be significantly superior in increasing the soil pH (5.53 and 5.79 during 2017-18 and 2018-19, respectively) over all other treatment combinations.

The soil EC (0.18 dS m⁻¹ during *rabi* 2017-18 and 0.42 dS m⁻¹ during *rabi* 2018-19) was found to be significantly superior due to application of phosphorus @ 45 kg ha⁻¹. The EC was found to be significantly superior with inoculation of VAM + PSB @ 10 kg ha⁻¹ each i.e. B₄ (0.17 dS m⁻¹ during 2017-18 and 0.40 dS m⁻¹ during 2018-19) over all the treatments. The highest EC values (0.22 dS m⁻¹ during 2017-18 and 0.51 dS m⁻¹ during 2018-19) were noted with the application of phosphorus @ 30 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₃₀) which was found to be at par with the application of phosphorus @ 45 kg ha⁻¹ with inoculation of PSB @ 10 kg ha⁻¹ each (B₂P₄₅).

At pod formation stage, the EC (0.44 dS m⁻¹ during 2017-2018 and 0.47 dS m⁻¹ during 2018-2019) of soil was found to be significantly superior with dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each i.e. B₃ among all treatments. The highest EC of soil (0.70 dS m⁻¹ and 0.56 dS m⁻¹ during 2017-18 and 2018-19, respectively) was observed with application of phosphorus @ 30 kg ha⁻¹ with dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃P₃₀).

At harvest stage, the EC (0.17 dS m⁻¹ during 2017-18 and 0.33 dS m⁻¹ during 2018-19) of soil was found to be significantly superior with application of phosphorus @ 30 kg ha⁻¹ over all other treatments in both the years. The EC was found to be significantly superior with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄) which indicated that the EC was 0.17 dS m⁻¹ during 2017-18 and 0.33 dS m⁻¹ during 2018-19 over all the treatments. The application of phosphorus @ 45 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₄₅) recorded significantly superior EC (0.21 dS m⁻¹ and 0.53 dS m⁻¹ during 2017-18 and 2018-19, respectively) over all other treatment combinations.

At peg initiation stage, the application of phosphorus @ 45 kg ha⁻¹ with

no biofertilizers application (B_0P_{45}) noted significantly highest soil organic carbon content (12.63 g kg^{-1} and 14.63 g kg^{-1} during 2017-18 and 2018-19, respectively) over all treatment combinations.

At pod formation stage, the soil organic carbon content (11.77 g kg^{-1} and 12.70 g kg^{-1} during 2017-18 and 2018-19, respectively) was found to be significantly superior with no inoculation of biofertilizers (B_0) over all other treatments. The soil organic carbon (13.30 g kg^{-1} and 14.23 g kg^{-1} during 2017-18 and 2018-19, respectively) was found to be significantly superior with application of phosphorus @ 15 kg ha^{-1} with inoculation of PSB @ 10 kg ha^{-1} each over all other treatment combinations.

At harvest stage, significantly highest organic carbon content (12.08 and 11.51 g kg^{-1} during 2017-18 and 2018-19, respectively) was recorded with application of phosphorus @ 60 kg ha^{-1} . The dual inoculation of VAM + PSB @ 5 kg ha^{-1} each showed significantly highest carbon content (12.32 and 11.70 g kg^{-1} during 2017-18 and 2018-19, respectively) in soil. The treatment combination consisting application of phosphorus @ 45 kg ha^{-1} with dual inoculation of VAM + PSB @ 10 kg ha^{-1} each was recorded significantly highest soil organic carbon content (14.03 g kg^{-1} and 13.43 g kg^{-1} during 2017-18 and 2018-19, respectively) over all treatment combinations.

5.1.2 Biological properties at harvest

The higher dose of phosphorus and dual inoculation of VAM + PSB @ 10 kg ha^{-1} each individual and in combination recorded significantly highest soil biological properties at all growth stages of groundnut, but recorded highest at pod formation stage as compared to peg initiation stage and at harvest stage.

The treatment combination B_4P_{60} at pod formation stage recorded highest bacterial population ($133.87 \times 10^5 \text{ cfu g}^{-1}$ soil and $143.70 \times 10^5 \text{ cfu g}^{-1}$ soil), actinomycetes (85.13 to $117.73 \times 10^5 \text{ cfu g}^{-1}$ soil and 86.83 to $120.16 \times 10^5 \text{ cfu g}^{-1}$ soil), fungi ($24.65 \times 10^3 \text{ cfu g}^{-1}$ soil and $28.89 \times 10^3 \text{ cfu g}^{-1}$ soil), CO_2 evolution ($76.73 \text{ mg } 100\text{g}^{-1}$ soil 24 hr^{-1} and $77.51 \text{ mg } 100\text{g}^{-1}$ soil 24 hr^{-1}), dehydrogenase activity ($83.52 \text{ } \mu\text{g TPF g}^{-1}$ soil 24 hr^{-1} and $90.26 \text{ } \mu\text{g TPF g}^{-1}$ soil 24 hr^{-1}), urease activity ($96.75 \text{ } \mu\text{g NH}_4\text{-N g}^{-1}$ soil 24 hr^{-1} and $96.00 \text{ } \mu\text{g NH}_4\text{-N g}^{-1}$ soil 24 hr^{-1}), alkaline phosphatase ($39.89 \times 10^5 \text{ cfu g}^{-1}$ soil and $38.59 \times 10^5 \text{ cfu g}^{-1}$ soil), acid phosphatase ($112.72 \text{ } \mu\text{g p-NP g}^{-1}$ soil hr^{-1} and $109.77 \text{ } \mu\text{g p-NP g}^{-1}$ soil hr^{-1}), microbial biomass carbon (266.73

and 262.76 ug g⁻¹ soil) and soil microbial biomass nitrogen (46.76 ug g⁻¹ soil and 50.07 ug g⁻¹ soil) over all other treatment combinations in the year 2017-18 and 2018-19, respectively.

5. 2 Available soil nutrients

The application of phosphorus @ 45 kg ha⁻¹ alongwith VAM @ 10 kg ha⁻¹ i.e. B₁P₄₅ was found to be significantly superior over all other treatments in recording available nitrogen (376.82 kg ha⁻¹ and 432.77 kg ha⁻¹ during 2017-18 and 2018-19, respectively) content in soil.

At pod formation stage, the application of phosphorus @ 15 kg ha⁻¹ recorded the significantly highest soil available nitrogen (366.39 and 380.40 kg ha⁻¹ during 2017-18 and 2018-19, respectively) content in soil.

At harvest, the treatment B₀ i.e. with no biofertilizers application was found to be significantly superior in respect of available nitrogen (365.82 kg ha⁻¹ and 295.78 kg ha⁻¹ during 2017-18 and 2018-19, respectively) content in soil after harvest of groundnut crop. The application of phosphorus @ 30 kg ha⁻¹ and inoculation of VAM @ 10 kg ha⁻¹ (i.e. B₁P₃₀) was found to be significantly superior over other remaining treatments in respect of available nitrogen (401.41 and 325.14 kg ha⁻¹ during 2017-18 and 2018-19, respectively) content in soil at harvest.

At peg initiation, the significantly superior and highest available phosphorus (i.e. 14.46 kg ha⁻¹) was found with the application of phosphorus @ 30 kg ha⁻¹ during 2017-18 and @ 45 kg ha⁻¹ during 2018-19 (i.e. 19.37 kg ha⁻¹). Among the different biofertilizers, the inoculation of PSB @ 10 kg ha⁻¹ (B₂) exhibited higher soil available phosphorus (15.42 kg ha⁻¹ and 20.84 kg ha⁻¹ during 2017-18 and 2018-19, respectively), which was significantly superior over all treatments of biofertilizers. The soil available phosphorus (18.40 kg ha⁻¹ and 25.52 kg ha⁻¹ during 2017-18 and 2018-19, respectively) was found to be significantly highest with application of phosphorus @ 30 kg ha⁻¹ along with individual inoculation of PSB @ 10 kg ha⁻¹ (B₂P₃₀) over all treatment combinations.

At pod formation stage, the application of VAM + PSB @ 10 kg ha⁻¹ each registered significantly higher soil available phosphorus (17.57 and 17.86 kg ha⁻¹ during 2017-18 and 2018-19, respectively) as compared to the other treatments. Application of phosphorus @ 30 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10

kg ha⁻¹ each (B₄P₃₀) recorded significantly highest soil available phosphorus (18.13 and 18.43 kg ha⁻¹ during 2017-18 and 2018-19, respectively).

At harvest stage, application of phosphorus @ 60 kg ha⁻¹ noted significantly highest available phosphorus (16.63 kg ha⁻¹ and 19.97 kg ha⁻¹ during 2017-18 and 2018-19, respectively). The significantly highest soil available phosphorus (24.58 and 20.39 kg ha⁻¹ during 2017-18 and 2018-19, respectively) content was found with application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃P₆₀).

The soil available potassium to the tune of 453.02 and 294.61 kg ha⁻¹ during 2017-18 and 2018-19, respectively was found to be significantly superior with application of phosphorus @ 60 kg ha⁻¹ over all treatments. 449.00 kg K₂O ha⁻¹ and 293.16 kg K₂O ha⁻¹ during 2017-18 and 2018-19, respectively was found significantly highest with dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) over all treatments. The soil available potassium with the value of 576.44 and 390.88 kg ha⁻¹ during 2017-18 and 2018-19, respectively was found to be significantly superior with application of phosphorus @ 60 kg ha⁻¹ along with VAM + PSB @ 5 kg ha⁻¹ each (B₃P₆₀) over all treatment combinations.

At pod formation stage, dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃) during 2017-18 and no biofertilizers application (B₀) during 2018-19 registered significantly highest soil available potassium (404.60 kg ha⁻¹ and 304.86 kg ha⁻¹, during 2017-18 and 2018-19, respectively) over all treatments.

At harvest stage, the soil available potassium (349.06 and 275.52 kg ha⁻¹ during 2017-18 and 2018-19, respectively) was found to be significantly highest with application of phosphorus @ 30 kg ha⁻¹ along with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₃₀), which was found to be at par with B₃P₃₀, B₂P₁₅, B₁P₆₀ and B₁P₁₅ over rest of the treatment combinations in both the years.

Significantly highest DTPA-extractable Fe (104.41 and 132.17 mg kg⁻¹ during 2017-18 and 2018-19, respectively) was recorded due to application of phosphorus @ 15 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₃P₁₅) over all treatment combinations.

At pod formation, significantly highest DTPA-extractable Fe (76.97 and 99.98 mg kg⁻¹ during 2017-18 and 2018-19, respectively) was recorded with inoculation of PSB @ 10 kg ha⁻¹ over all treatments of biofertilizers. The application

of phosphorus @ 15 kg ha⁻¹ alongwith PSB @ 10 kg ha⁻¹ (B₂P₁₅) showed significantly highest DTPA extractable Fe (82.14 mg kg⁻¹ and 106.61 mg kg⁻¹ during 2017-18 and 2018-19, respectively).

At harvest stage, the DTPA-extractable Fe (59.92 and 67.33 mg kg⁻¹ during 2017-18 and 2018-19, respectively) was found highest with application of phosphorus @ 45 kg ha⁻¹. The dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each was found to be significantly highest DTPA-extractable Fe (61.62 and 69.24 mg kg⁻¹ during 2017-18 and 2018-19, respectively) over all treatments of biofertilizers application. The DTPA-extractable Fe (64.15 mg kg⁻¹ and 72.08 mg kg⁻¹ during 2017-18 and 2018-19, respectively) found to be highest with application of phosphorus @ 45 kg ha⁻¹ alongwith dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₄₅).

Significantly higher DTPA-extractable Mn (65.39 and 94.77 mg kg⁻¹ during 2017-18 and 2018-19, respectively) was recorded with application of phosphorus @ 60 kg ha⁻¹ over all treatments of phosphorus. Significantly highest DTPA-extractable Mn (78.37 mg kg⁻¹ and 113.58 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively) was observed with application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀) over all treatment combinations.

At pod formation, the DTPA-extractable Mn (65.40 mg kg⁻¹) was found to be significantly superior with application of phosphorus @ 60 kg ha⁻¹ over all treatments in the year 2017-18. However, significantly highest DTPA-extractable Mn (93.80 mg kg⁻¹) was recorded with application of phosphorus @ 60 kg ha⁻¹ in the year 2018-19. The application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃P₆₀) noted significantly superior DTPA-extractable Mn (98.39 mg kg⁻¹ and 135.11 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively).

At harvest stage, significantly highest DTPA-extractable Mn (93.96 and 126.00 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) was recorded with no biofertilizers application (B₀) in all treatments. The DTPA-extractable Mn from 96.25 mg kg⁻¹ and 128.34 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively was found to be significantly highest with application of phosphorus @ 30 kg ha⁻¹ with no biofertilizers application (B₀P₃₀) over all treatment combinations in both the years.

The inoculation of PSB @ 10 kg ha⁻¹ was recorded significantly highest DTPA-extractable Zn (1.40 mg kg⁻¹) in all treatments of biofertilizers application and found to be at par with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (1.36 mg kg⁻¹) in the year 2017-18. The inoculation of VAM + PSB @ 10 kg ha⁻¹ each noted significantly highest DTPA-extractable Zn (1.58 mg kg⁻¹) in the year 2018-19. The DTPA-extractable Zn (1.73 mg kg⁻¹) during the year 2017-18 was found significantly highest with application of phosphorus @ 45 kg ha⁻¹ with application of PSB @ 10 kg ha⁻¹ over all treatment combinations. While, application of phosphorus @ 15 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each recorded significantly highest DTPA-extractable Zn (1.97 mg kg⁻¹) over all treatment combinations in the year 2018-19.

At pod formation stage, significantly highest DTPA-extractable Zn (1.17 mg kg⁻¹) was observed with application of phosphorus @ 45 kg ha⁻¹ and with application of phosphorus @ 15 kg ha⁻¹ (1.21 mg kg⁻¹) during 2017-18 and 2018-19.

During the year 2017-18, the DTPA-extractable Zn (1.14 mg kg⁻¹) was found to be significantly highest with inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄) and application of PSB @ 10 kg ha⁻¹ (B₂) recorded significantly highest DTPA-extractable Zn (1.25 mg kg⁻¹) over all treatments of biofertilizers application in the year 2017-18 and 2018-19, respectively.

The significantly highest DTPA-extractable Zn (1.29 mg kg⁻¹) was recorded with application of phosphorus @ 15 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₁₅) in all treatments in the year 2017-18. While the application of phosphorus @ 45 kg ha⁻¹ with individual inoculation of PSB @ 10 kg ha⁻¹ found significantly highest in respect of DTPA-extractable Zn (1.55 mg kg⁻¹) in the year 2018-19 over all treatment combinations.

At harvest stage, significantly highest DTPA-extractable Zn (1.04 mg kg⁻¹ and 0.89 mg kg⁻¹ during 2017-18 and 2018-19, respectively) was observed with application of phosphorus @ 15 kg ha⁻¹ over all treatments of phosphorus application in both the years.

Significantly highest DTPA-extractable Zn (1.05 mg kg⁻¹) was observed with individual application of VAM @ 10 kg ha⁻¹ (B₁) in the year 2017-18 and the DTPA-extractable Zn (0.88 mg kg⁻¹) was found to be significantly higher with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄) (0.88 mg kg⁻¹) during 2018-19.

The application of phosphorus @ 15 kg ha⁻¹ with dual inoculation of

VAM + PSB @ 10 kg ha⁻¹ each (B₄P₁₅) recorded significantly highest DTPA-extractable Zn (1.32 mg kg⁻¹) over all treatment combinations in both the years.

Significantly highest DTPA-extractable Cu (3.12 and 4.28 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) was observed with application of phosphorus @ 45 kg ha⁻¹ with inoculation of PSB @ 10 kg ha⁻¹ (B₂P₄₅) over all treatment combinations.

At pod formation stage, the DTPA-extractable Cu (4.20 mg kg⁻¹) was found to be significantly highest with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄) over all treatments of biofertilizers in both the years. The DTPA-extractable Cu was found to be significantly superior with application of phosphorus @ 30 kg ha⁻¹ alongwith dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (5.68 and 7.97 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) over all treatment combinations in the both the years.

At harvest stage, significantly higher DTPA-extractable Cu (4.13 mg kg⁻¹ and 4.66 mg kg⁻¹ during 2017-18 and 2018-19) was observed in the treatment receiving phosphorus @ 45 kg ha⁻¹ over all treatments consisting application of phosphorus @ 30 kg ha⁻¹, @ 15 kg ha⁻¹ and @ 60 kg ha⁻¹ in the year 2017-18 and 2018-19.

5.3 Growth parameters

At peg initiation stage, significantly highest plant height (23.01 cm and 22.18 cm during 2017-18 and 2018-19, respectively) was observed with application of phosphorus @ 60 kg ha⁻¹. At pod formation stage, the lower dose of phosphorus application @ 15 kg ha⁻¹ recorded significantly highest 34.77 cm and 32.93 cm during 2017-18 and 2018-19, respectively plant height. Dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each recorded significantly highest plant height (35.08 cm and 33.09 cm during 2017-18 and 2018-19, respectively). However, the application of phosphorus @ 15 kg ha⁻¹ alongwith application of VAM + PSB @ 10 kg ha⁻¹ each i.e. B₄P₁₅ treatment recorded significantly highest (41.48 cm and 39.14 cm during 2017-18 and 2018-19, respectively) plant height over all other treatment combinations in both the years.

At harvest stage, significantly highest plant height (35.81 cm and 34.88 cm during 2017-18 and 2018-19, respectively) was observed with the application of phosphorus @ 15 kg ha⁻¹ in both the years. The plant height was recorded

significantly highest (35.68 cm and 34.47 cm during 2017-18 and 2018-19, respectively) with inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄).

In treatment combination, the significantly highest plant height (41.26 cm) was observed due to the treatment receiving phosphorus @ 15 kg ha⁻¹ with no biofertilizers application (B₀P₁₅) in the year 2017-18, while with application of phosphorus @ 15 kg ha⁻¹ with inoculation of VAM @ 10 kg ha⁻¹ each recorded (40.19 cm) plant height in the year 2018-19.

At pod formation stage, the application of phosphorus @ 30 kg ha⁻¹ recorded significantly highest number of rachis (6.53 and 9.08 in the year 2017-18 and 2018-19, respectively plant⁻¹) over all treatments of phosphorus application. The significantly highest rachis (8.30) plant⁻¹ were observed with application of phosphorus @ 30 kg ha⁻¹ with inoculation of VAM @ 10 kg ha⁻¹ in the year 2017-18 and with application of phosphorus @ 30 kg ha⁻¹ with inoculation of VAM @ 10 kg ha⁻¹ (11.54) in the year 2018-19. At harvest stage, significantly highest number of rachis plant⁻¹ (6.41) were observed due to application of phosphorus @ 30 kg ha⁻¹ over all other treatments of phosphorus application in the year 2017-18 and with application of phosphorus @ 60 kg ha⁻¹ (8.42) in the year 2018-19.

The combine application of VAM + PSB @ 10 kg ha⁻¹ each (B₄) recorded significantly highest number of rachis (6.41 and 8.61) plant⁻¹ in the year 2017-18 and 2018-19. The significantly highest numbers of rachis (7.78 and 10.04 in the year 2017-18 and 2018-19, respectively) plant⁻¹ were recorded with application of phosphorus @ 30 kg ha⁻¹ with no biofertilizers application (B₀P₃₀).

5.4 Yield of groundnut

The application of phosphorus @ 60 kg ha⁻¹ recorded significantly highest pod yield (35.67 q ha⁻¹ and 36.06 q ha⁻¹) and was found to be at par with application of phosphorus @ 45 kg ha⁻¹ (31.43 q ha⁻¹ and 32.49 q ha⁻¹) during the year 2017-18 and 2018-19, respectively. Further, it indicates that the application of phosphorus @ 60 kg ha⁻¹ can be substituted by the application of phosphorus @ 45 kg ha⁻¹. It could therefore, be concluded that with application of phosphorus @ 45 kg ha⁻¹ could save 15 kg ha⁻¹ phosphorus and gave much yield as that of application of phosphorus @ 60 kg ha⁻¹.

The halum yield observed to be non-significant, but the maximum halum yield (50.55 q ha⁻¹ and 51.55 q ha⁻¹ during 2017-18 and 2018-19, respectively) was obtained with application of phosphorus @ 45 kg ha⁻¹. In the interaction, the highest

halum yield (53.60 q ha⁻¹ and 54.36 q ha⁻¹ during 2017-18 and 2018-19, respectively) of groundnut was noted with application of phosphorus @ 45 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each i.e. B₄P₄₅ treatment.

5.5 Nutrient content in plant

Among the different levels of phosphorus and biofertilizers with recommended dose of N and K, the N content in halum at pod formation stage recorded was significantly highest. With the inoculation of VAM + PSB @ 10 kg ha⁻¹ each N content in halum was observed to be significantly highest i.e. 0.92 per cent and 0.76 per cent during 2017-18 and 2018-19, respectively. Significantly highest nitrogen content (1.07 % and 0.91 % during 2017-18 and 2018-19, respectively) was recorded with application of phosphorus @ 15 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₁₅) in the interaction.

At harvest stage, significantly highest nitrogen content (2.14 and 2.33 % during 2017-18 and 2018-19, respectively) was observed with application of phosphorus @ 60 kg ha⁻¹. The nitrogen content increased significantly with dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (2.08 % and 2.22 % during 2017-18 and 2018-19, respectively). The application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃P₆₀) was found to be significantly highest in nitrogen content (2.74 % and 2.95 % during 2017-18 and 2018-19, respectively).

N content recorded in kernel was significantly highest (4.801 and 4.753 during the year 2017-18 and 2018-19, respectively) with application of phosphorus @ 45 kg ha⁻¹, due to application of biofertilizers i.e. VAM + PSB @ 10 kg ha⁻¹ each (4.49 % and 4.45 % during the year 2017-18 and 2018-19, respectively). However, the treatment combination consisting application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each recorded significantly highest N content (5.06 % and 5.01 % during the year 2017-18 and 2018-19, respectively) and found to be at par with B₃P₆₀ and B₂P₄₅ in both the years.

The N content in shell was observed to be significantly highest (0.74 % and 0.73 % during 2017-18 and 2018-19, respectively) with treatment receiving phosphorus @ 45 kg ha⁻¹. The significantly highest nitrogen content (0.63 and 0.62 % during 2017-18 and 2018-19, respectively) in shell was observed with the dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each. The application of phosphorus @

45 kg ha⁻¹ with inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃P₄₅) showed highest N content (0.82 % and 0.81 % during 2017-18 and 2018-19, respectively) in all treatment combinations and was found to be at par with B₂P₄₅.

The highest phosphorus content (0.37 % and 0.30 % during 2017-18 and 2018-19, respectively) were observed with no biofertilizers application (B₀). The significantly highest phosphorus content (0.47 % and 0.38 % during 2017-18 and 2018-19, respectively) was observed with application of phosphorus @ 15 kg ha⁻¹ with no biofertilizers application (B₀P₁₅) over all other treatment combinations in both the years.

At pod formation stage, the significantly highest phosphorus content was observed with the application of phosphorus @ 15 kg ha⁻¹ i.e. 0.59 per cent during 2017-18, which was found at par with P₃₀ and P₆₀ and application of phosphorus @ 30 kg ha⁻¹ i.e. 0.751 per cent during 2018-19, which was found at par with P₁₅ and P₆₀ in the year 2018-19.

In treatment combination, the application of phosphorus @ 60 kg ha⁻¹ with no biofertilizers application (0.70 %) and application of phosphorus @ 30 kg ha⁻¹ with no biofertilizers application (1.01 %) in the year 2017-18 and 2018-19, respectively recorded significantly highest P content in halum.

During harvest stage, significantly highest P content (0.06 % and 0.06 % during the year 2017-18 and 2018-19, respectively) was recorded in halum with the treatment combination receiving phosphorus @ 15 kg ha⁻¹ with no biofertilizers application i.e. B₀P₁₅.

The phosphorus content recorded in kernel was significantly higher (0.22 and 0.19 % in the year 2017-18 and 2018-19, respectively) with application of phosphorus @ 60 kg ha⁻¹. The dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄) showed significantly highest phosphorus content (0.20 % and 0.18 % during 2017-18 and 2018-19, respectively) in kernel. The significantly higher phosphorus content (0.27 % and 0.24 % during 2017-18 and 2018-19, respectively) in kernel registered with application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀).

The P content in groundnut shell was found to be significant with application of phosphorus @ 60 kg ha⁻¹ (0.07 % and 0.05 % during 2017-18 and 2018-19, respectively). The treatment combination receiving application of phosphorus @ 45 kg ha⁻¹ with inoculation of PSB @ 10 kg ha⁻¹ recorded highest P

content (0.08 % and 0.06 % during 2017-18 and 2018-19, respectively) in shell.

Potassium content recorded in halum was significantly highest (1.87 % and 1.01 % during 2017-18 and 2018-19, respectively) with application of phosphorus @ 60 kg ha⁻¹. The treatment combination consisting application of phosphorus @ 60 kg ha⁻¹ with PSB @ 10 kg ha⁻¹ (2.63 %) in the year 2017-18 and with application of phosphorus @ 60 kg ha⁻¹ alongwith PSB @ 10 kg ha⁻¹ (1.41 %) in the year 2018-19 recorded significantly highest K content in halum.

At pod formation stage, application of phosphorus @ 60 kg ha⁻¹ showed significantly highest K content (1.81 % and 1.49 % during 2017-18 and 2018-19, respectively) in halum and was observed to be at par with application of phosphorus @ 30 kg ha⁻¹. The application of phosphorus @ 60 kg ha⁻¹ alongwith PSB @ 10 kg ha⁻¹ (2.38 %) in the year 2017-18 and application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (1.71 %) in the year 2018-19 recorded significantly highest K content in halum.

At harvest stage, significantly highest potassium content in halum was noted with application of phosphorus @ 60 kg ha⁻¹ i.e. 1.05 per cent and 1.09 per cent during 2017-18 and 2018-19, respectively. The treatment combinations receiving application of phosphorus @ 30 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each i.e. B₄P₃₀ (1.57 %) in the year 2017-18 and the application of phosphorus @ 15 kg ha⁻¹ with no biofertilizers application i.e. B₀P₁₅ (1.61 %) in the year 2018-19 showed the significantly highest K content in halum.

The potassium content recorded in kernel was highest (0.78 % and 0.73 % during 2017-18 and 2018-19, respectively) with no biofertilizers application (B₀). The K content in shell was found significantly highest (0.87 % and 0.82 % during 2017-18 and 2018-19, respectively) due to application of PSB @ 10 kg ha⁻¹ (B₂). The significantly highest potassium content in (1.17 % and 1.10 % during 2017-18 and 2018-19, respectively) shell was observed in the treatment receiving application of phosphorus @ 60 kg ha⁻¹ with no biofertilizers application in all treatment combinations.

At peg initiation, significantly highest Fe content (1031.64 mg kg⁻¹ and 835.76 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in halum was recorded with application of phosphorus @ 45 kg ha⁻¹. Significantly higher Fe content (1796.89 and 1455.71 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) in halum

was registered with the application of phosphorus @ 45 kg ha⁻¹ with inoculation of VAM @ 10 kg ha⁻¹ (B₁P₄₅).

At pod formation stage, the application of phosphorus @ 15 kg ha⁻¹ (1091.52 mg kg⁻¹ and 1341.66 mg kg⁻¹ in the year 2017-18 and 2018-19, respectively) showed significantly highest Fe content in halum. Significantly higher Fe content in halum was registered with the application of phosphorus @ 45 kg ha⁻¹ with inoculation of VAM @ 10 kg ha⁻¹ (1796.89 mg kg⁻¹ and 1455.71 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively).

At harvest stage, the lower dose of phosphorus i.e. 15 kg ha⁻¹ was recorded significantly highest Fe content (499.96 mg kg⁻¹ and 448.35 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively). The Fe content was found to be significantly superior with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (550.64 mg kg⁻¹ and 487.30 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively). The treatment comprising the application of phosphorus @ 15 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (687.04 mg kg⁻¹ and 608.02 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) showed significant increase in Fe content in halum.

The application of phosphorus @ 60 kg ha⁻¹ (188.97 and 198.92 mg kg⁻¹ during 2017-18 and 2018-19, respectively) significantly highest Fe content in kernel was recorded. The significantly highest Fe content in kernel was noted in the treatment receiving application of phosphorus @ 30 kg ha⁻¹ with inoculation of PSB @ 10 kg ha⁻¹ (273.03 mg kg⁻¹ to 287.04 mg kg⁻¹ during 2017-18 and 2018-19, respectively).

The treatment consisting application of phosphorus @ 60 kg ha⁻¹ (4140.34 and 3833.65 mg kg⁻¹ during 2017-18 and 2018-19, respectively) recorded significantly highest Fe content in shell.

At peg initiation stage, significantly highest Mn content in halum was recorded with the application of phosphorus @ 30 kg ha⁻¹ (199.71 and 126.40 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively). Significantly highest Mn content was observed with the application of phosphorus @ 45 kg ha⁻¹ alongwith dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (244.75 mg kg⁻¹ and 154.06 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively).

At pod formation stage, the treatment combination consisting application of phosphorus @ 45 kg ha⁻¹ with inoculation of PSB @ 10 kg ha⁻¹ recorded

significantly highest Mn content (231.15 mg kg⁻¹ and 232.22 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) in halum.

The dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each highest Mn content (27.88 mg kg⁻¹ and 28.45 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in kernel was recorded. The application of phosphorus @ 30 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each was observed highest significant Mn content (55.31 and 56.44 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in kernel.

The application of phosphorus @ 30 kg ha⁻¹ recorded significantly highest Mn content (99.76 mg kg⁻¹ and 113.47 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in shell. It was also recorded significantly highest (96.77 mg kg⁻¹ and 109.97 mg kg⁻¹ during 2017-18 and 2018-19, respectively) with inoculation of VAM @ 10 kg ha⁻¹. The application of phosphorus @ 30 kg ha⁻¹ with dual inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃P₃₀) observed significantly highest Mn content (181.02 mg kg⁻¹ and 205.69 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in shell.

The application of VAM @ 10 kg ha⁻¹ recorded significantly highest Zn content (132.88 mg kg⁻¹ and 85.12 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in halum at peg initiation stage. The application of phosphorus @ 60 kg ha⁻¹ with application of VAM @ 10 kg ha⁻¹ observed significantly highest Zn content (229.94 mg kg⁻¹ and 147.43 mg kg⁻¹ during 2017-18 and 2018-19, respectively) over all treatment combinations.

The significantly highest Zn content (35.67 mg kg⁻¹ and 28.01 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in halum was observed at pod formation stage with inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄). The treatment combination where, application of phosphorus @ 60 kg ha⁻¹ alongwith dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀) recorded significantly highest Zn content (47.97 and 37.69 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in halum over all other treatment combinations.

At harvest, significantly highest Zn content (38.19 and 33.68 mg kg⁻¹ during 2017-18 and 2018-19, respectively) was noted with the application of phosphorus @ 45 kg ha⁻¹. However, significantly highest Zn content (44.71 mg kg⁻¹ and 39.34 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in halum was observed with application of phosphorus @ 30 kg ha⁻¹ with inoculation of VAM @ 10 kg ha⁻¹

in all treatment combinations.

The Zn content in kernel was observed significantly highest (56.72 and 56.18 mg kg⁻¹ during 2017-18 and 2018-19, respectively) due to application of phosphorus @ 30 kg ha⁻¹ with inoculation of VAM @ 10 kg ha⁻¹ (B₁P₃₀). The application of phosphorus @ 45 kg ha⁻¹ (29.51 mg kg⁻¹) was registered significantly highest Zn content in the year 2017-18 and with application of phosphorus @ 45 kg ha⁻¹ (28.90 mg kg⁻¹) in the year 2018-19.

At peg initiation stage, the highest Cu content in halum was observed with application of phosphorus @ 60 kg ha⁻¹ (325.09 mg kg⁻¹ and 411.51 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively). The Cu content in halum (436.33 and 552.32 mg kg⁻¹ during 2017-18 and 2018-19, respectively) was found to be significantly higher due to inoculation of VAM @ 10 kg ha⁻¹. Significantly highest Cu content in halum was noted with the application of phosphorus @ 60 kg ha⁻¹ with inoculation of VAM @ 10 kg ha⁻¹ (809.68 mg kg⁻¹ and 1025.37 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) in all treatment combinations.

At pod formation stage, the application of phosphorus @ 15 kg ha⁻¹ exhibited significantly higher Cu content (196.26 mg kg⁻¹ and 182.56 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) in halum. The Cu content in halum recorded significantly highest in the treatment receiving the application of phosphorus @ 15 kg ha⁻¹ alongwith dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (372.42 and 373.95 mg kg⁻¹ during 2017-18 and 2018-19, respectively).

At harvest stage, significantly highest Cu content (101.04 mg kg⁻¹ and 53.46 mg kg⁻¹ during the year 2017-18 and 2018-19, respectively) in halum was noted with the application of phosphorus @ 45 kg ha⁻¹. The significantly highest Cu content (122.19 mg kg⁻¹ and 66.70 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in halum was observed due to application of phosphorus @ 15 kg ha⁻¹ with inoculation of PSB @ 10 kg ha⁻¹ over all other treatment combinations.

The significantly higher Cu content (11.30 mg kg⁻¹ and 10.99 mg kg⁻¹ during 2017-18 and 2018-19, respectively) in kernel was observed with the application of phosphorus @ 15 kg ha⁻¹. The application of phosphorus @ 30 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (20.09 and 20.51 mg kg⁻¹ during 2017-18 and 2018-19, respectively) showed significantly highest Cu content in kernel and found superior over all treatment combinations.

Significantly highest Cu content (24.48 mg kg⁻¹ and 24.98 mg kg⁻¹ during

2017-18 and 2018-19, respectively) in shell was observed with the application of phosphorus @ 30 kg ha⁻¹ which was found to be at par with application of phosphorus @ 45 kg ha⁻¹ and @ 60 kg ha⁻¹ in both the years. The significantly highest Cu content was observed with application of phosphorus @ 30 kg ha⁻¹ with application of VAM @ 10 kg ha⁻¹ (47.70 mg kg⁻¹ and 48.67 mg kg⁻¹ during 2017-18 and 2018-19, respectively) and found to be at par with B₀P₄₅.

5.6 Nutrient uptake by plant

The application of phosphorus @ 60 kg ha⁻¹ noted the significantly highest nitrogen uptake (208.85 kg ha⁻¹ and 251.86 kg ha⁻¹ during 2017-18 and 2018-19, respectively) in both the years.

The application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀) noted significantly highest nitrogen uptake (253.08 and 286.35 kg ha⁻¹ during 2017-18 and 2018-19, respectively) over all treatment combinations, which was at par with B₃P₆₀ in the year 2017-18 and with B₃P₆₀, B₄P₄₅ and B₁P₄₅ in the year 2018-19.

Significantly highest phosphorus uptake (8.34 kg ha⁻¹ and 6.76 kg ha⁻¹ during 2017-18 and 2018-19, respectively) was observed with the application of phosphorus @ 60 kg ha⁻¹. The phosphorus uptake (7.01 kg ha⁻¹ and 5.68 kg ha⁻¹ during 2017-18 and 2018-19, respectively) was found to be significantly highest with no biofertilizers application (B₀).

Significantly highest phosphorus uptake (9.51 kg ha⁻¹ and 7.70 kg ha⁻¹ during 2017-18 and 2018-19, respectively) was recorded in the treatment receiving phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀) and found to be at par with B₀P₆₀ and B₁P₃₀.

The potassium uptake (85.51 kg ha⁻¹ and 84.59 kg ha⁻¹ during 2017-18 and 2018-19, respectively) significantly highest were recorded with the application of phosphorus @ 60 kg ha⁻¹. The highest potassium uptake (96.89 kg ha⁻¹) found in the treatment combination consisting application of phosphorus @ 15 kg ha⁻¹ with inoculation of VAM + PSB @ 5 kg ha⁻¹ each (B₃P₆₀), which was found to be at par with B₂P₆₀, B₀P₁₅, B₄P₃₀, B₀P₄₅, B₁P₆₀, B₁P₄₅, B₂P₃₀ and B₀P₃₀ in the year 2017-18. However, application of phosphorus @ 60 kg ha⁻¹ with inoculation of PSB @ 10 kg ha⁻¹ (B₂P₆₀) found highest in respect of potassium uptake (96.51 kg ha⁻¹) and was at par with B₀P₁₅, B₃P₆₀, B₄P₃₀, B₀P₄₅, B₁P₆₀ and B₁P₄₅ in the year 2018-19.

The total Fe uptake was significantly highest (2613.208 g ha⁻¹) with the

application of phosphorus @ 15 kg ha⁻¹ and with the application of phosphorus @ 60 kg ha⁻¹ (10167.761 g ha⁻¹) in the year 2017-18 and 2018-19, respectively. The application of VAM + PSB @ 10 kg ha⁻¹ each showed significantly highest Fe uptake (3005.598 g ha⁻¹ and 7668.361 g ha⁻¹ during 2017-18 and 2018-19, respectively). The significantly highest Fe uptake (3392.370 g ha⁻¹) was observed to be in the treatment receiving phosphorus @ 15 kg ha⁻¹ with no biofertilizers (B₀P₁₅) and found to be at par with B₄P₁₅ in the year 2017-18. However, the application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀) showed significantly highest Fe uptake (14405.113 g ha⁻¹) in the year 2018-19.

The application of different levels of phosphorus and biofertilizers did not show any significant effect on total Mn uptake in both the years.

The application of phosphorus @ 45 kg ha⁻¹ recorded significantly highest Zn uptake (312.225 g ha⁻¹ and 308.715 g ha⁻¹ during 2017-18 and 2018-19, respectively). However, significantly highest Zn uptake (311.170 and 302.152 g ha⁻¹ during 2017-18 and 2018-19, respectively) was noted with the application of VAM + PSB @ 10 kg ha⁻¹ each. The Zn uptake (423.063 g ha⁻¹ and 396.475 g ha⁻¹ during 2017-18 and 2018-19, respectively) found to be significantly highest due to treatment consisting application of phosphorus @ 45 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₄₅).

Significantly highest total Cu uptake (161.890 g ha⁻¹) was registered with the application of phosphorus @ 30 kg ha⁻¹ with inoculation of VAM @ 10 kg ha⁻¹ (B₁P₃₀) in the year 2017-18. The treatment combination consisting application of phosphorus @ 15 kg ha⁻¹ with inoculation of VAM @ 10 kg ha⁻¹ (B₁P₁₅) showed significantly highest Cu uptake (47.244 g ha⁻¹) in all treatment combinations.

5.7 Quality parameters of groundnut

Significantly highest oil content (51.21 % and 50.55 % during the year 2017-18 and 2018-19, respectively) was recorded in the treatment receiving phosphorus @ 60 kg ha⁻¹ with VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀ and B₀P₆₀ during the year 2017-18 and 2018-19, respectively).

The application of phosphorus @ 45 kg ha⁻¹ was recorded significantly highest protein content (30.01 % and 30.61 % during 2017-18 and 2018-19, respectively) and followed the increasing order P₁₅ < P₃₀ < P₆₀ < P₄₅ in both the years.

The dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each registered

significantly highest protein (28.07 % and 28.63 % during 2017-18 and 2018-19, respectively) content. The application of phosphorus @ 60 kg ha⁻¹ with VAM + PSB @ 10 kg ha⁻¹ each (31.62 % and 32.25 % during 2017-18 and 2018-19, respectively) recorded significantly highest protein content over all treatment combinations.

Application of phosphorus @ 45 kg ha⁻¹ showed significantly highest methionine content (0.44 % and 0.45 % during 2017-18 and 2018-19, respectively). The significantly highest methionine content was recorded with application of VAM + PSB @ 10 kg ha⁻¹ each (0.39 % and 0.39 % during 2017-18 and 2018-19, respectively). The application of phosphorus @ 15 kg ha⁻¹ with no biofertilizers application (B₀P₁₅) noted significantly highest methionine content (0.49 % and 49 % during 2017-18 and 2018-19, respectively) over all treatment combinations.

5.8. Economics

The application of different levels of phosphorus and biofertilizers influenced the B:C ratio. The optimum net return with higher B:C (1.30 and 1.34 during 2017-18 and 2018-19, respectively) ratio was recorded with the application of phosphorus @ 60 kg ha⁻¹ with dual inoculation of VAM + PSB @ 10 kg ha⁻¹ each (B₄P₆₀) in both the years. The same treatment found to be at par with application of phosphorus @ 45 kg ha⁻¹ with higher B:C (1.34), which indicated that the application of phosphorus @ 60 kg ha⁻¹ can be substituted by the application of phosphorus @ 45 kg ha⁻¹ for enhancing groundnut production with increased profit.

CONCLUSIONS

On the basis of data obtained from the present investigation, the following conclusions may be drawn:

1. Collation of data on soil fertility indicated that, the application of phosphorus @ 60 kg ha⁻¹ along with VAM + PSB @ 10 kg ha⁻¹ each followed by application of phosphorus @ 45 kg ha⁻¹ alongwith VAM + PSB @ 10 kg ha⁻¹ each resulted in a significant increase in soil pH, soil organic carbon, available macronutrients (N, P and K), micronutrients (Fe, Mn, Zn and Cu) contents and decline in electrical conductivity indicating build up of soil fertility.
2. Application of phosphorus @ 60 kg ha⁻¹ along with VAM + PSB @ 10 kg ha⁻¹ each with recommended dose of N and potassium was found beneficial for improving biological properties which includes microbial count (bacteria, fungi and actinomycetes), CO₂ evolution, dehydrogenase activity, urease activity, alkaline and acid phosphatase activity, soil microbial biomass carbon and soil microbial biomass nitrogen of the soils.
3. In groundnut, yield contributing characters, seed and halum yield, quality parameters *viz.*, protein content, crude fibre and methionine content and nutrient uptake by plants, the application of phosphorus @ 60 kg ha⁻¹ along with VAM + PSB @ 10 kg ha⁻¹ each followed by application of phosphorus @ 45 kg ha⁻¹ alongwith VAM + PSB @ 10 kg ha⁻¹ each had recorded the highest favourable parameters.
4. Considering the yield and other parameters stated above, the application of phosphorus @ 45 kg ha⁻¹ alongwith VAM + PSB @ 10 kg ha⁻¹ each was found to be at par with the application of phosphorus @ 60 kg ha⁻¹ along with VAM + PSB @ 10 kg ha⁻¹ each in general indicating the requirement of more P₂O₅ and seed inoculation of biofertilizers.
5. The higher B: C ratio (1.34) was obtained with the application of phosphorus @ 60 kg ha⁻¹.

The study suggested that, for getting maximum yield of groundnut, fetching highest net returns as well as for improving the soil health application of phosphorus @ 60 kg ha⁻¹ along with VAM + PSB @ 10 kg ha⁻¹ each followed application of phosphorus @ 45 kg ha⁻¹ alongwith VAM + PSB @ 10 kg ha⁻¹ each, was be beneficial during *rabi* season in soils of Konkan.

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Table 4.55 Relationship between chemical properties of soil and yield of groundnut

0	pH	OC	Avail N	Avail P₂O₅	Avail K₂O	DTPA Zn	DTPA Fe	DTPA Mn	DTPA Cu	Pod Yield
pH	1	-0.051	-0.097	-0.037	-0.131	-0.225 *	0.190 *	0.332 **	0.115	0.186 *
OC	-0.051	1	-0.118	-0.042	0.227 *	-0.227 *	-0.055	-0.167	-0.354 **	0.111
Avail N	-0.097	-0.118	1	0.366 **	0.347 **	0.328 **	-0.278 **	-0.580 **	-0.073	0.062
Avail P₂O₅	-0.037	-0.042	0.366 **	1	0.100	0.414 **	-0.166	-0.439 **	-0.142	0.114
Avail K₂O	-0.131	0.227 *	0.347 **	0.100	1	0.152	-0.441 **	-0.622 **	-0.478 **	0.026
DTPA Zn	-0.225 *	-0.227 *	0.328 **	0.414 **	0.152	1	-0.105	-0.464 **	-0.023	-0.212 *
DTPA Fe	0.190 *	-0.055	-0.278 **	-0.166	-0.441 **	-0.105	1	0.553 **	0.387 **	0.180 *
DTPA Mn	0.332 **	-0.167	-0.580 **	-0.439 **	-0.622 **	-0.464 **	0.5535 **	1	0.439 **	0.040
DTPA Cu	0.115	-0.354 **	-0.0731	-0.142	-0.478**	-0.023	0.387 **	0.439 **	1	0.046
Pod Yield	0.186 *	0.111	0.062	0.114	0.026	-0.212 *	0.180 *	0.040	0.046	1

Table 4.56 Relationship between biological properties of soil and yield of groundnut

0	Bacteria	Actinomycetes	Fungi	CO ₂ evol.	Dehydro.	Urease	Alk. Phosph	Alk Phosph	SMBC	Pod Yield
Bacteria	1	0.917 **	0.879 **	0.889 **	0.983 **	0.893 **	0.965 **	0.987 **	0.820 **	0.485 **
Actinomycetes	0.917 **	1	0.993 **	0.978 **	0.928 **	0.981 **	0.969 **	0.916 **	0.931 **	0.496 **
Fungi	0.879 **	0.993 **	1	0.978 **	0.894 **	0.981 **	0.947 **	0.880 **	0.936 **	0.483 **
CO₂ evol.	0.889 **	0.978 **	0.978 **	1	0.925 **	0.995 **	0.964 **	0.910 **	0.917 **	0.534 **
Dehydro.	0.983 **	0.928 **	0.894 **	0.925 **	1	0.925 **	0.986 **	0.996 **	0.828 **	0.524 **
Urease	0.893 **	0.981 **	0.981 **	0.995 **	0.925 **	1	0.965 **	0.913 **	0.919 **	0.531 **
Alk Phosph	0.965 **	0.969 **	0.947 **	0.964 **	0.986 **	0.965 **	1	0.978 **	0.874 **	0.531 **
Alk Phosph	0.987 **	0.916 **	0.880 **	0.910 **	0.996 **	0.913 **	0.978 **	1	0.814 **	0.514 **
SMBC	0.820 **	0.931 **	0.936 **	0.917 **	0.828 **	0.919 **	0.874 **	0.814 **	1	0.417 **
Pod Yield	0.485 **	0.496 **	0.483 **	0.534 **	0.524 **	0.531 **	0.531 **	0.514 **	0.417 **	1

Table 4.57 Inter-Relationship between chemical properties and biological properties of soil with yield of groundnut

0	pH	OC	Avail N	Avail P₂O₅	Avail K₂O	Bacteria	Actino.	Fungi	Dehyd.	Pod Yield
pH	1	-0.051	-0.097	-0.037	-0.131	0.085	0.202 *	0.227 *	0.129	0.186 *
OC	-0.051	1	-0.118	-0.042	0.227 *	0.163	0.078	0.049	0.120	0.111
Avail N	-0.097	-0.118	1	0.366 **	0.347 **	0.144	-0.104	-0.156	0.134	0.062
Avail P₂O₅	-0.037	-0.042	0.366 **	1	0.100	0.360 **	0.204 *	0.175	0.379 **	0.114
Avail K₂O	-0.131	0.227 *	0.347 **	0.100	1	0.088	-0.185 *	-0.244 **	0.037	0.026
Bacteria	0.085	0.163	0.144	0.360 **	0.088	1	0.917 **	0.879 **	0.983 **	0.485 **
Actino.	0.202 *	0.078	-0.104	0.204 *	-0.185 *	0.917 **	1	0.993 **	0.928 **	0.496 **
Fungi	0.227 *	0.049	-0.156	0.175	-0.244 **	0.879 **	0.993 **	1	0.894 **	0.483 **
Dehyd.	0.129	0.120	0.134	0.379 **	0.037	0.983 **	0.928 **	0.894 **	1	0.524 **
Pod Yield	0.186 *	0.111	0.062	0.114	0.026	0.485 **	0.496 **	0.483 **	0.524 **	1

Table 4.1 Effect of different levels of phosphorus and biofertilizers on soil pH under groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	4.70	4.58	4.72	4.59	4.72	4.66	4.62	4.65	4.62	4.54	4.88	4.66	4.63	4.67	4.88	5.15	4.75	4.82
P₃₀	4.70	4.88	4.53	4.46	4.46	4.60	4.78	4.53	4.61	4.25	4.75	4.58	5.10	5.08	4.80	5.06	4.99	5.00
P₄₅	4.64	4.48	4.50	4.69	4.62	4.58	4.44	4.60	4.57	4.45	4.53	4.52	4.81	4.93	5.22	5.11	4.81	4.98
P₆₀	4.73	4.62	4.65	4.65	4.66	4.66	4.72	4.60	4.63	4.62	4.62	4.64	5.45	5.53	4.70	5.06	5.22	5.19
Mean	4.69	4.64	4.60	4.59	4.61	4.63	4.64	4.59	4.60	4.46	4.70	4.60	5.00	5.05	4.90	5.10	4.94	5.00
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.007		0.008		0.016		0.009		0.011		0.021		0.045		0.050		0.101	
C.D. @ 5%	0.020		0.022		0.044		0.027		0.030		0.060		0.129		NS		0.289	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	4.73	4.60	4.77	4.62	4.82	4.71	4.92	4.95	4.92	4.84	5.25	4.97	4.84	4.86	5.09	5.39	5.29	5.09
P₃₀	4.73	4.91	4.55	4.49	4.48	4.63	5.08	4.83	4.91	4.55	5.05	4.88	5.21	5.05	4.95	4.95	5.32	5.10
P₄₅	4.67	4.51	4.53	4.72	4.65	4.61	4.73	4.90	4.87	4.75	4.84	4.82	5.30	4.97	5.20	5.19	4.99	5.13
P₆₀	4.85	4.65	4.67	4.68	4.59	4.69	5.02	4.90	4.93	4.92	4.92	4.94	5.71	5.79	4.89	5.23	5.45	5.41
Mean	4.74	4.67	4.63	4.62	4.64	4.66	4.93	4.89	4.90	4.76	5.02	4.90	5.27	5.17	5.03	5.19	5.26	5.18
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.010		0.011		0.022		0.010		0.011		0.021		0.057		0.064		0.128	
C.D. @ 5%	0.029		0.032		0.064		0.027		0.030		0.061		0.164		NS		0.367	

Table 4.2 Effect of different levels of phosphorus and biofertilizers on electrical conductivity (dSm^{-1}) of soil under groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	0.09	0.17	0.10	0.16	0.17	0.14	0.19	0.15	0.18	0.60	0.17	0.26	0.14	0.15	0.13	0.11	0.16	0.14
P₃₀	0.10	0.10	0.13	0.17	0.22	0.14	0.16	0.23	0.22	0.70	0.17	0.30	0.16	0.17	0.16	0.16	0.19	0.17
P₄₅	0.18	0.19	0.21	0.12	0.19	0.18	0.13	0.16	0.28	0.14	0.27	0.20	0.11	0.13	0.14	0.12	0.21	0.14
P₆₀	0.14	0.10	0.11	0.12	0.10	0.11	0.13	0.35	0.20	0.31	0.08	0.21	0.16	0.12	0.15	0.17	0.14	0.15
Mean	0.13	0.14	0.14	0.14	0.17	0.14	0.15	0.22	0.22	0.44	0.17	0.24	0.14	0.14	0.14	0.14	0.17	0.15
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.003		0.004		0.008		0.043		0.048		0.096		0.007		0.007		0.015	
C.D. @ 5%	0.010		0.011		0.022		NS		0.138		NS		0.019		0.021		0.043	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	0.19	0.36	0.23	0.38	0.41	0.31	0.32	0.25	0.29	0.55	0.28	0.34	0.30	0.30	0.21	0.22	0.25	0.26
P₃₀	0.24	0.23	0.31	0.41	0.51	0.34	0.27	0.38	0.36	0.56	0.29	0.37	0.30	0.34	0.38	0.33	0.32	0.33
P₄₅	0.43	0.45	0.50	0.27	0.44	0.42	0.20	0.27	0.52	0.24	0.37	0.32	0.15	0.16	0.18	0.23	0.53	0.25
P₆₀	0.33	0.23	0.25	0.28	0.23	0.27	0.21	0.44	0.33	0.51	0.10	0.32	0.35	0.21	0.27	0.30	0.24	0.27
Mean	0.30	0.31	0.32	0.33	0.40	0.33	0.25	0.33	0.38	0.47	0.26	0.34	0.27	0.25	0.26	0.27	0.33	0.28
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.005		0.006		0.012		0.041		0.046		0.092		0.011		0.012		0.024	
C.D. @ 5%	0.015		0.017		0.033		NS		0.131		NS		0.031		0.035		0.070	

Table 4.3 Effect of different levels of phosphorus and biofertilizers on soil organic carbon (g kg⁻¹) content of soil under groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	11.17	11.90	10.88	10.15	11.76	11.17	11.78	10.40	13.30	11.01	11.31	11.56	12.23	13.00	12.23	11.16	10.86	11.90
P₃₀	9.41	10.29	11.02	10.44	10.00	10.23	11.01	11.28	11.25	10.24	10.24	10.80	11.16	10.18	9.33	11.77	11.16	10.72
P₄₅	12.63	9.56	9.85	10.88	11.17	10.82	11.62	10.24	10.09	12.01	11.39	11.07	10.44	9.24	8.66	13.81	14.03	11.23
P₆₀	11.61	11.02	10.00	10.25	11.02	10.78	12.69	10.24	10.24	11.32	10.70	11.04	13.46	12.08	12.23	12.54	10.09	12.08
Mean	11.21	10.70	10.44	10.43	10.99	10.75	11.77	10.54	11.22	11.14	10.91	11.12	11.82	11.12	10.61	12.32	11.53	11.48
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.233		0.260		0.521		0.199		0.222		0.444		0.131		0.146		0.292	
C.D. @ 5%	NS		NS		1.491		NS		0.636		1.272		0.374		0.419		0.837	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	13.50	13.90	12.88	12.15	13.76	13.24	12.71	11.33	14.23	11.94	12.24	12.49	11.65	12.38	11.65	10.63	10.34	11.33
P₃₀	11.41	12.29	13.02	12.44	12.00	12.23	11.94	11.18	12.78	11.68	11.88	11.89	10.63	9.70	8.88	11.08	10.63	10.18
P₄₅	14.63	11.56	11.85	12.88	13.17	12.82	12.55	11.17	11.02	13.27	12.32	12.06	9.94	8.80	8.24	13.15	13.43	10.71
P₆₀	13.61	13.02	12.00	12.59	13.02	12.85	13.62	11.17	11.17	12.25	11.63	11.97	12.82	11.50	11.65	11.95	9.61	11.51
Mean	13.29	12.70	12.44	12.51	12.99	12.78	12.70	11.21	12.30	12.28	12.02	12.10	11.26	10.60	10.11	11.70	11.00	10.93
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.253		0.283		0.566		0.177		0.198		0.396		0.122		0.136		0.272	
C.D. @ 5%	NS		NS		1.621		NS		0.567		1.133		0.348		0.390		0.779	

Table 4.6 Effect of different levels of phosphorus and biofertilizers on soil porosity (%) of soil after harvest of groundnut

Treat.	2017-18						2018-19					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P ₁₅	48.19	48.14	48.19	48.13	48.19	48.17	48.19	48.19	48.19	48.19	48.85	48.32
P ₃₀	47.53	48.73	48.85	48.19	49.52	48.56	48.19	49.27	49.50	48.19	49.46	48.92
P ₄₅	47.07	48.85	48.19	48.14	48.73	48.20	47.83	48.85	48.19	48.19	48.19	48.25
P ₆₀	49.50	48.14	48.19	48.89	48.19	48.58	48.19	48.19	48.19	49.14	48.19	48.38
Mean	48.07	48.47	48.35	48.34	48.66	48.38	48.10	48.62	48.52	48.43	48.67	48.47
	P		B		P x B		P		B		P x B	
S.E.±	0.297		0.332		0.665		0.195		0.218		0.437	
C.D. @ 5%	NS		NS		NS		NS		NS		NS	

Table 4.7 Effect of different levels of phosphorus and biofertilizers on maximum water holding capacity (%) of soil after harvest of groundnut

Treat.	2017-18						2018-19					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P ₁₅	43.46	42.94	43.25	42.73	42.63	43.00	43.04	43.19	42.83	42.99	43.22	43.05
P ₃₀	43.88	42.00	42.23	43.25	41.59	42.59	42.84	42.62	42.83	42.83	43.22	42.87
P ₄₅	43.67	42.21	42.42	43.15	42.42	42.77	43.25	43.47	42.68	43.06	43.04	43.10
P ₆₀	42.92	42.83	42.63	42.91	42.94	42.85	42.87	43.06	42.99	43.18	42.86	42.99
Mean	43.48	42.50	42.63	43.01	42.39	42.80	43.00	43.09	42.83	43.02	43.08	43.00
	P		B		P x B		P		B		P x B	
S.E.±	0.269		0.301		0.601		0.305		0.341		0.682	
C.D. @ 5%	0.019		0.021		0.042		0.040		0.045		0.090	

Table 4.8 Effect of different levels of phosphorus and biofertilizers on cation exchange capacity [c mol (p⁺) kg⁻¹] of soil after harvest of groundnut

Treat.	2017-18						2018-19					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P₁₅	9.06	7.71	9.88	8.54	11.59	9.35	9.23	8.18	10.08	8.73	11.72	9.59
P₃₀	9.06	12.53	13.02	10.68	10.74	11.21	9.32	12.47	12.97	12.65	11.23	11.73
P₄₅	9.88	11.51	10.69	8.65	11.53	10.45	10.07	11.82	10.87	8.86	12.36	10.80
P₆₀	9.06	10.29	11.53	11.54	13.24	11.13	9.09	10.49	11.76	12.03	13.43	11.36
Mean	9.26	10.51	11.28	9.85	11.77	10.54	9.43	10.74	11.42	10.57	12.19	10.87
	P		B		P x B		P		B		P x B	
S.E.±	0.007		0.007		0.015		0.014		0.016		0.031	
C.D. @ 5%	0.019		0.021		0.042		0.040		0.045		0.090	

Table 4.9 Effect of different levels of phosphorus and biofertilizers on bacterial population ($\times 10^5$ cfu g^{-1} soil) in soil under groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P ₁₅	43.17	46.82	43.50	46.82	47.16	45.49	97.47	105.72	98.24	105.72	101.71	101.77	28.01	30.38	28.23	30.08	28.95	29.13
P ₃₀	48.17	47.51	49.48	47.83	45.83	47.76	103.94	102.48	106.77	103.19	98.88	104.10	30.14	29.38	30.52	29.59	29.29	29.78
P ₄₅	47.50	50.86	49.17	53.47	52.82	50.76	102.14	109.68	106.10	115.48	113.99	108.35	29.67	31.52	30.49	33.18	32.76	31.52
P ₆₀	50.50	54.37	62.00	56.17	62.30	57.07	109.00	117.93	133.77	121.27	133.87	123.17	31.32	33.75	38.44	34.84	38.79	35.43
Mean	47.33	49.89	51.04	51.07	52.03	50.27	103.14	108.95	111.22	111.41	112.11	109.37	29.78	31.26	31.92	31.92	32.45	31.47
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E. \pm	0.095		0.106		0.213		0.113		0.126		0.252		0.066		0.074		0.148	
C.D. @ 5%	0.273		0.305		0.610		0.323		0.361		0.721		0.189		0.212		0.424	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P ₁₅	46.62	50.57	46.98	50.57	50.93	49.13	99.06	107.51	99.88	107.51	108.28	104.45	26.61	28.86	26.81	28.83	27.78	27.78
P ₃₀	52.02	51.29	53.44	51.65	49.49	51.58	110.57	109.08	113.65	109.81	105.21	109.66	28.38	27.98	29.15	28.17	26.99	28.13
P ₄₅	51.30	54.90	53.10	57.79	57.05	54.83	109.05	116.72	112.88	122.87	121.33	116.57	27.98	29.95	28.96	31.52	31.12	29.91
P ₆₀	54.54	58.72	66.96	60.66	68.03	61.78	115.91	124.58	142.36	129.01	143.70	131.11	29.75	32.03	36.52	33.17	37.68	33.83
Mean	51.12	53.87	55.12	55.17	56.37	54.33	108.65	114.47	117.19	117.30	119.63	115.45	28.18	29.70	30.36	30.42	30.89	29.91
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E. \pm	0.102		0.114		0.227		0.117		0.131		0.261		0.060		0.067		0.134	
C.D. @ 5%	0.291		0.325		0.650		0.335		0.374		0.748		0.172		0.192		0.385	

Table 4.10 Effect of different levels of phosphorus and biofertilizers on actinomycetes population ($\times 10^5$ cfu g^{-1} soil) in soil under groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P₁₅	42.56	46.17	42.89	46.16	44.44	44.45	85.13	92.34	85.78	92.34	88.88	88.89	27.02	29.31	27.23	29.28	28.21	28.21
P₃₀	45.39	44.75	46.63	45.07	43.18	45.00	90.78	89.51	93.25	90.14	86.36	90.01	28.82	28.42	29.60	28.62	27.41	28.57
P₄₅	44.76	47.91	46.33	50.43	49.78	47.84	89.52	95.81	92.67	100.85	99.55	95.68	28.42	30.42	29.42	32.02	31.60	30.37
P₆₀	47.59	51.23	58.42	52.95	58.07	53.65	95.18	102.47	116.83	105.89	117.73	107.62	30.21	32.53	37.09	33.62	39.89	34.67
Mean	45.08	47.52	48.57	48.65	48.87	47.74	90.15	95.03	97.13	97.31	98.13	95.55	28.62	30.17	30.84	30.88	31.78	30.46
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.096		0.107		0.214		0.125		0.140		0.280		0.063		0.071		0.142	
C.D. @ 5%	0.274		0.307		0.614		0.358		0.400		0.801		0.182		0.203		0.406	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P₁₅	43.84	47.55	44.18	47.55	45.77	45.78	86.83	94.18	87.50	94.18	90.65	90.67	27.84	30.19	28.05	30.19	29.06	29.07
P₃₀	46.75	46.10	48.02	46.42	44.47	46.35	92.60	91.29	95.12	91.94	88.08	91.81	29.68	29.27	30.49	29.47	28.24	29.43
P₄₅	46.10	49.34	47.72	51.94	51.27	49.28	91.31	97.73	94.52	102.87	101.55	97.59	29.27	31.33	30.30	32.98	32.55	31.29
P₆₀	49.01	52.77	60.17	54.54	62.51	55.80	97.08	104.51	119.17	108.01	120.16	109.79	31.12	33.49	38.20	34.63	38.59	35.21
Mean	46.43	48.94	50.02	50.11	51.01	49.30	91.95	96.93	99.08	99.25	100.11	97.46	29.48	31.07	31.76	31.82	32.11	31.25
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.093		0.104		0.208		0.159		0.178		0.356		0.062		0.070		0.139	
C.D. @ 5%	0.267		0.298		0.597		0.455		0.509		1.018		0.179		0.200		0.399	

Table 4.11 Effect of different levels of phosphorus and biofertilizers on fungal population ($\times 10^3$ cfu g^{-1} soil) in soil under groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	9.01	9.77	9.08	9.77	9.40	9.41	17.75	19.25	17.88	19.25	18.53	18.53	8.83	9.58	8.90	9.58	9.22	9.22
P₃₀	9.61	9.47	9.87	9.54	9.14	9.53	18.92	18.66	19.44	18.79	18.00	18.76	9.42	9.28	9.67	9.35	8.96	9.34
P₄₅	9.47	10.14	9.81	10.67	10.53	10.12	18.66	19.97	19.32	21.02	20.75	19.95	9.28	9.93	9.61	10.46	10.33	9.92
P₆₀	10.07	10.84	12.36	11.21	12.59	11.41	19.81	21.36	24.36	22.07	24.65	22.45	9.87	10.63	12.12	10.99	13.26	11.37
Mean	9.54	10.06	10.28	10.30	10.42	10.12	18.79	19.81	20.25	20.28	20.48	19.92	9.35	9.86	10.07	10.09	10.44	9.96
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.021		0.024		0.048		0.032		0.036		0.072		0.019		0.021		0.043	
C.D. @ 5%	0.061		0.068		0.136		0.092		0.103		0.206		0.055		0.061		0.123	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	10.00	10.84	10.08	10.85	10.44	10.44	20.23	21.94	20.39	21.94	21.05	21.11	9.27	10.06	9.34	10.05	9.68	9.68
P₃₀	10.67	10.51	10.95	10.59	10.14	10.57	21.57	21.27	22.16	21.42	20.52	21.39	9.88	9.75	10.16	9.82	9.40	9.80
P₄₅	10.51	11.25	10.88	11.85	11.69	11.24	21.27	22.77	22.02	23.97	23.66	22.74	9.75	10.44	10.09	10.98	10.84	10.42
P₆₀	11.18	12.04	13.72	12.44	14.69	12.81	22.62	24.35	27.76	25.17	28.89	25.76	10.37	11.16	12.72	11.53	13.12	11.78
Mean	10.59	11.16	11.41	11.43	11.74	11.27	21.42	22.58	23.08	23.12	23.53	22.75	9.82	10.35	10.58	10.60	10.76	10.42
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.018		0.021		0.041		0.049		0.054		0.109		0.021		0.023		0.047	
C.D. @ 5%	0.053		0.059		0.118		0.139		0.155		0.311		0.060		0.067		0.134	

Table 4.12 Effect of different levels of phosphorus and biofertilizers on CO₂ evolution (mg 100 g⁻¹ soil 24 hr⁻¹) in soil under groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	33.67	36.52	33.93	36.54	36.78	35.49	51.85	56.25	52.25	56.24	56.64	54.65	29.56	32.06	29.78	32.06	32.29	31.15
P₃₀	37.57	36.67	38.33	37.48	36.27	37.26	57.86	57.05	59.43	57.45	55.04	57.36	32.98	32.52	33.88	32.75	31.37	32.70
P₄₅	36.78	39.65	38.36	41.74	41.20	39.55	57.09	61.06	59.06	64.27	63.45	60.99	32.52	34.77	33.66	36.64	36.17	34.75
P₆₀	39.39	42.47	48.36	43.82	48.82	44.57	60.96	65.30	74.47	67.49	76.73	68.99	34.58	37.22	42.41	38.47	43.45	39.23
Mean	36.85	38.83	39.74	39.89	40.77	39.22	56.94	59.91	61.30	61.36	62.96	60.50	32.41	34.14	34.93	34.98	35.82	34.46
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.079		0.089		0.177		0.123		0.137		0.275		0.070		0.078		0.157	
C.D. @ 5%	0.227		0.254		0.507		0.352		0.393		0.786		0.201		0.224		0.448	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	36.36	39.44	36.64	39.78	39.72	38.39	52.89	57.37	53.30	57.37	57.78	55.74	30.74	33.34	30.98	33.34	33.58	32.39
P₃₀	40.58	40.00	41.68	40.29	38.60	40.23	59.01	58.18	60.62	58.60	56.14	58.51	34.30	33.82	35.23	34.05	32.63	34.01
P₄₅	40.01	42.82	41.42	45.08	44.50	42.77	58.20	62.29	60.24	65.56	64.72	62.20	33.82	36.15	35.01	38.10	37.61	36.14
P₆₀	42.54	45.80	52.23	47.33	53.40	48.26	61.87	66.61	75.97	68.17	77.51	70.03	35.96	38.85	44.12	40.01	44.73	40.73
Mean	39.87	42.02	42.99	43.12	44.05	42.41	57.99	61.11	62.53	62.43	64.04	61.62	33.70	35.54	36.33	36.38	37.14	35.82
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.086		0.096		0.192		0.095		0.106		0.212		0.076		0.085		0.169	
C.D. @ 5%	0.246		0.275		0.551		0.271		0.303		0.606		0.217		0.243		0.485	

Table 4.13 Effect of different levels of phosphorus and biofertilizers on dehydrogenase activity ($\mu\text{g TPF g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$) in soil under groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P ₁₅	42.56	46.16	42.89	46.16	46.50	44.85	57.46	62.32	57.90	62.32	62.77	60.55	36.77	39.89	37.06	39.89	40.17	38.75
P ₃₀	47.49	46.82	48.78	47.16	45.17	47.09	64.11	63.21	65.86	63.66	60.99	63.56	41.03	40.46	42.15	40.74	39.03	40.68
P ₄₅	46.83	50.12	48.48	52.76	52.08	50.05	63.22	67.66	65.44	71.22	70.31	67.57	40.46	43.31	41.88	45.58	45.00	43.25
P ₆₀	49.79	53.60	61.13	55.40	61.16	56.22	67.22	72.36	82.52	74.79	83.52	76.08	43.02	46.29	52.82	47.86	53.21	48.64
Mean	46.67	49.18	50.32	50.37	51.23	49.55	63.00	66.39	67.93	68.00	69.39	66.94	40.32	42.48	43.48	43.52	44.35	42.83
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.100		0.112		0.223		0.140		0.156		0.313		0.085		0.095		0.190	
C.D. @ 5%	0.286		0.320		0.640		0.401		0.448		0.896		0.243		0.272		0.543	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P ₁₅	42.99	46.63	43.32	46.63	46.96	45.30	62.05	67.31	62.53	67.31	68.12	65.46	35.30	38.29	35.57	38.29	38.56	37.20
P ₃₀	47.96	47.29	49.27	47.63	45.63	47.56	69.24	68.27	71.12	68.75	65.87	68.65	39.39	38.84	40.46	39.11	37.47	39.05
P ₄₅	47.30	50.62	48.96	53.29	52.60	50.55	68.28	73.08	70.68	76.92	75.93	72.98	38.84	41.57	40.21	43.76	43.20	41.52
P ₆₀	50.32	54.14	61.74	55.95	62.75	56.98	72.59	78.15	89.13	80.77	90.26	82.18	41.30	44.46	50.70	45.95	51.24	46.73
Mean	47.14	49.67	50.82	50.87	51.99	50.10	68.04	71.70	73.36	73.44	75.04	72.32	38.71	40.79	41.74	41.78	42.62	41.13
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.094		0.105		0.209		0.146		0.163		0.326		0.074		0.083		0.165	
C.D. @ 5%	0.268		0.299		0.599		0.417		0.467		0.933		0.212		0.237		0.473	

Table 4.14 Effect of different levels of phosphorus and biofertilizers on urease activity ($\mu\text{g NH}_4\text{-N g}^{-1}$ soil 24 hr⁻¹) in soil under groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P ₁₅	41.93	45.48	42.26	45.48	45.81	44.19	65.83	71.41	66.34	71.41	71.92	69.38	36.87	39.99	37.15	39.99	40.27	38.85
P ₃₀	46.79	46.13	48.06	46.46	44.51	46.39	73.46	72.43	75.46	72.94	69.88	72.83	41.14	40.56	42.26	40.84	39.13	40.79
P ₄₅	46.14	49.38	47.76	51.98	51.31	49.31	72.44	77.53	74.98	81.61	80.56	77.42	40.57	43.42	41.99	45.70	45.11	43.36
P ₆₀	49.05	52.81	60.22	54.58	61.81	55.70	77.01	82.91	94.56	85.69	96.75	87.38	43.13	46.43	52.95	47.99	55.37	49.18
Mean	45.98	48.45	49.58	49.63	50.86	48.90	72.19	76.07	77.83	77.91	79.78	76.76	40.42	42.60	43.59	43.63	44.97	43.04
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.101		0.113		0.226		0.155		0.173		0.346		0.087		0.097		0.194	
C.D. @ 5%	0.289		0.323		0.646		0.443		0.495		0.990		0.248		0.277		0.554	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P ₁₅	40.67	44.12	40.99	44.12	44.43	42.87	66.49	72.12	67.00	72.12	72.63	70.07	38.34	41.59	38.64	41.59	41.88	40.41
P ₃₀	45.38	44.75	46.62	45.06	43.17	45.00	74.19	73.15	76.21	73.67	70.58	73.56	42.78	42.18	43.95	42.48	40.69	42.41
P ₄₅	44.76	47.90	46.33	50.42	49.77	47.83	73.17	78.30	75.73	82.42	81.36	78.20	42.19	45.15	43.67	47.53	46.92	45.09
P ₆₀	47.58	51.22	58.42	52.94	61.20	54.27	77.79	83.74	95.50	86.55	96.00	87.91	44.85	48.29	55.20	49.90	57.45	51.14
Mean	44.60	47.00	48.09	48.14	49.64	47.49	72.91	76.83	78.61	78.69	80.14	77.44	42.04	44.30	45.36	45.37	46.74	44.76
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.096		0.107		0.214		0.161		0.180		0.359		0.093		0.103		0.207	
C.D. @ 5%	0.274		0.306		0.612		0.460		0.514		1.028		0.265		0.296		0.592	

Table 4.15 Effect of different levels of phosphorus and biofertilizers on alkaline phosphatase activity ($\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$) in soil under groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P ₁₅	87.88	95.33	88.56	95.33	96.01	92.62	113.37	122.97	114.25	122.97	123.85	119.48	77.09	83.62	77.69	83.62	84.22	81.25
P ₃₀	98.06	96.69	100.73	97.37	93.28	97.23	126.50	124.73	129.95	125.61	120.34	125.42	86.02	84.81	88.36	85.41	81.82	85.29
P ₄₅	96.71	103.50	100.10	108.95	107.54	103.36	124.75	133.51	129.13	140.54	138.73	133.33	84.83	90.79	87.81	95.57	94.34	90.67
P ₆₀	102.81	110.69	126.23	114.39	129.18	116.66	132.63	143.45	162.84	147.57	171.92	151.68	90.19	97.10	110.73	100.34	117.68	103.21
Mean	96.37	101.55	103.91	104.01	106.50	102.47	124.31	131.16	134.04	134.17	138.71	132.48	84.53	89.08	91.15	91.24	94.51	90.10
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.142		0.158		0.317		0.137		0.153		0.306		0.117		0.131		0.263	
C.D. @ 5%	0.406		0.454		0.908		0.391		0.438		0.875		0.336		0.376		0.752	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P ₁₅	84.37	91.51	85.02	91.51	92.17	88.92	114.50	124.20	115.39	124.20	125.09	120.68	76.32	82.78	76.91	82.78	83.34	80.43
P ₃₀	94.14	93.49	96.70	93.47	89.55	93.47	127.77	125.98	131.25	126.86	121.54	126.68	85.16	83.97	87.48	84.56	81.01	84.43
P ₄₅	92.84	99.36	96.10	104.59	103.24	99.22	126.00	134.85	130.42	141.94	140.12	134.67	83.98	89.89	86.93	94.61	93.39	89.76
P ₆₀	98.70	106.26	121.18	109.82	122.58	111.71	133.96	144.88	164.46	149.04	164.18	151.31	89.29	96.46	109.62	99.34	110.44	101.03
Mean	92.51	97.65	99.75	99.85	101.89	98.33	125.56	132.48	135.38	135.51	137.73	133.33	83.69	88.27	90.23	90.32	92.05	88.91
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.127		0.142		0.284		0.152		0.170		0.340		0.114		0.127		0.254	
C.D. @ 5%	0.363		0.406		0.813		0.436		0.487		0.975		0.326		0.364		0.728	

Table 4.16 Effect of different levels of phosphorus and biofertilizers on acid phosphatase activity ($\mu\text{g p-NP g}^{-1} \text{ soil hr}^{-1}$) in soil under groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	50.11	54.35	50.50	54.35	54.74	52.81	74.66	80.99	75.24	80.99	81.56	78.69	38.83	42.11	39.13	42.11	42.41	40.92
P₃₀	55.91	55.13	57.44	55.52	53.19	55.44	83.31	82.14	85.58	82.72	79.25	82.60	43.29	42.71	44.50	43.02	41.21	42.95
P₄₅	55.14	59.01	57.08	62.12	61.32	58.93	82.16	87.93	85.04	92.56	91.36	87.81	42.72	45.76	44.22	48.13	47.51	45.67
P₆₀	58.62	63.44	71.97	65.23	72.49	66.35	87.35	94.04	107.24	97.18	112.72	99.71	45.49	48.90	55.76	50.54	55.99	51.33
Mean	54.95	57.99	59.25	59.30	60.44	58.38	81.87	86.27	88.28	88.36	91.22	87.20	42.58	44.87	45.90	45.95	46.78	45.22
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.\pm	0.108		0.121		0.241		0.145		0.162		0.325		0.091		0.102		0.203	
C.D. @ 5%	0.309		0.346		0.691		0.416		0.465		0.930		0.261		0.291		0.583	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	47.60	51.63	47.97	51.63	52.00	50.17	76.16	82.61	76.75	82.61	83.20	80.26	36.88	40.01	37.17	40.01	40.29	38.87
P₃₀	53.12	52.37	54.57	52.74	50.53	52.67	84.98	83.79	87.29	84.38	80.84	84.25	41.16	40.58	42.27	40.86	39.15	40.80
P₄₅	52.38	56.06	54.22	59.01	58.25	55.99	83.80	89.69	86.74	94.41	93.19	89.57	40.59	43.44	42.01	45.72	45.13	43.38
P₆₀	55.69	59.96	68.37	61.96	69.34	63.06	89.10	95.91	109.38	99.13	109.77	100.66	43.15	46.45	52.98	48.01	55.11	49.14
Mean	52.20	55.01	56.28	56.34	57.53	55.47	83.51	88.00	90.04	90.13	91.75	88.69	40.44	42.62	43.61	43.65	44.92	43.05
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.\pm	0.105		0.117		0.234		0.155		0.174		0.347		0.075		0.084		0.169	
C.D. @ 5%	0.299		0.335		0.669		0.445		0.497		0.994		0.216		0.241		0.483	

Table 4.17 Effect of different levels of phosphorus and biofertilizers on soil microbial biomass carbon ($\mu\text{g g}^{-1}$ soil)in soil under groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P₁₅	173.06	187.71	174.37	187.71	177.47	180.07	211.05	228.92	212.68	228.92	216.48	219.61	156.17	169.40	157.38	169.40	160.19	162.51
P₃₀	181.31	178.77	186.25	178.94	175.53	180.16	221.11	218.01	227.13	215.98	215.91	219.63	170.26	161.33	168.08	159.82	156.42	163.18
P₄₅	176.30	188.58	182.07	198.15	195.60	188.14	214.51	229.57	222.03	241.66	238.54	229.26	158.73	169.88	164.30	178.82	176.52	169.65
P₆₀	187.24	186.35	212.51	192.59	213.64	198.46	228.06	227.25	259.16	234.86	266.73	243.21	168.76	168.17	191.78	173.86	192.96	179.11
Mean	179.48	185.35	188.80	189.35	190.56	186.71	218.68	225.94	230.25	230.35	234.42	227.93	163.48	167.19	170.38	170.48	171.52	168.61
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.232		0.259		0.519		0.440		0.490		0.983		0.256		0.287		0.573	
C.D. @ 5%	0.664		0.742		1.485		1.259		1.407		2.815		0.734		0.820		1.641	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P₁₅	171.33	185.84	172.65	185.84	175.73	178.28	213.16	231.21	214.83	231.21	218.64	221.81	160.86	174.48	162.10	174.48	165.00	167.38
P₃₀	179.39	176.98	184.38	176.33	174.75	178.37	223.32	220.19	229.40	218.14	219.19	222.05	168.53	166.17	173.12	164.62	165.50	167.59
P₄₅	174.14	186.69	180.24	196.17	193.65	186.18	216.65	231.86	224.25	244.07	240.93	231.55	163.50	174.98	169.23	184.19	181.82	174.74
P₆₀	185.36	184.48	210.39	190.66	211.61	196.50	230.34	229.53	261.75	237.21	262.76	244.32	173.82	173.21	197.53	179.08	198.64	184.46
Mean	177.55	183.50	186.92	187.25	188.94	184.83	220.87	228.20	232.56	232.66	235.38	229.93	166.68	172.21	175.50	175.59	177.74	173.54
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.157		0.175		0.350		0.351		0.393		0.786		0.182		0.204		0.407	
C.D. @ 5%	0.448		0.501		1.002		1.006		1.125		2.249		0.522		0.583		1.166	

Table 4.18 Effect of different levels of phosphorus and biofertilizers on soil microbial biomass nitrogen ($\mu\text{g g}^{-1}$ soil) in soil under groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P ₁₅	31.23	33.88	31.48	33.88	32.04	32.50	36.23	40.99	38.09	41.00	39.41	39.14	30.61	33.21	31.61	34.03	32.18	32.33
P ₃₀	32.72	32.59	33.62	31.97	31.62	32.50	40.25	39.04	40.68	38.64	38.00	39.32	32.87	32.40	33.76	32.10	30.76	32.38
P ₄₅	31.75	33.97	32.86	35.76	35.30	33.93	38.41	41.07	39.76	43.27	42.72	41.05	31.88	34.12	33.00	35.92	35.46	34.08
P ₆₀	33.75	33.63	38.36	34.76	39.62	36.02	40.84	40.69	46.41	42.06	46.76	43.35	33.90	33.74	38.52	34.91	39.86	36.19
Mean	32.36	33.52	34.08	34.09	34.65	33.74	38.93	40.45	41.23	41.24	41.72	40.72	32.31	33.37	34.22	34.24	34.56	33.74
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.072		0.080		0.160		0.101		0.113		0.227		0.071		0.079		0.158	
C.D. @ 5%	0.205		0.229		0.458		0.290		0.325		0.649		0.202		0.226		0.452	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P ₁₅	30.92	33.54	31.16	33.54	31.72	32.18	40.06	43.45	40.37	43.46	41.09	41.69	32.00	34.71	32.24	34.71	32.82	33.29
P ₃₀	32.40	31.94	33.28	31.64	31.94	32.24	41.97	41.38	43.11	41.00	42.61	42.02	33.52	33.05	34.43	32.74	32.95	33.34
P ₄₅	31.43	33.64	32.53	35.41	34.95	33.59	40.72	43.58	42.15	45.87	45.28	43.52	32.52	34.80	33.66	36.63	36.16	34.76
P ₆₀	33.41	33.30	37.97	34.41	38.08	35.43	43.29	43.14	49.19	44.58	50.07	46.06	34.57	34.46	39.29	35.61	39.97	36.78
Mean	32.04	33.11	33.74	33.75	34.17	33.36	41.51	42.89	43.71	43.73	44.76	43.32	33.15	34.25	34.91	34.92	35.48	34.54
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.065		0.073		0.145		0.090		0.101		0.202		0.064		0.072		0.143	
C.D. @ 5%	0.186		0.208		0.416		0.258		0.289		0.578		0.183		0.205		0.410	

Table 4.19 Effect of different levels of phosphorus and biofertilizers on soil available nitrogen (kg ha⁻¹) under groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P ₁₅	296.08	265.66	279.65	322.29	305.06	293.75	387.07	350.37	351.41	354.69	388.42	366.39	362.40	283.81	338.69	301.06	360.64	329.32
P ₃₀	294.10	283.94	325.86	324.73	366.28	318.99	342.92	383.42	361.54	347.64	343.10	355.72	363.78	401.41	282.24	329.28	324.58	340.26
P ₄₅	242.32	376.82	282.26	281.51	293.43	295.27	334.60	353.68	386.19	410.54	335.71	364.14	389.00	352.80	395.14	301.06	349.66	357.53
P ₆₀	328.61	327.30	287.23	305.35	314.62	312.62	364.50	353.08	337.19	373.00	378.88	361.33	348.10	355.94	343.39	330.85	359.07	347.47
Mean	290.28	313.43	293.75	308.47	319.85	305.16	357.27	360.14	359.08	371.47	361.53	361.90	365.82	348.49	339.86	315.56	348.49	343.64
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	7.881		8.811		17.622		3.162		3.536		7.071		7.083		7.919		15.838	
C.D. @ 5%	NS		NS		50.450		NS		NS		20.244		NS		22.671		45.343	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P ₁₅	335.35	304.19	319.87	368.48	349.66	335.51	401.41	363.78	365.34	368.48	402.98	380.40	291.07	229.64	274.61	243.94	292.06	266.26
P ₃₀	337.12	324.58	373.36	371.62	420.22	365.38	355.94	398.27	374.75	362.21	355.94	369.42	294.83	325.14	228.41	266.38	262.88	275.53
P ₄₅	277.54	432.77	323.01	323.01	335.55	338.37	348.10	368.48	401.41	426.50	348.10	378.52	315.21	286.09	320.39	243.94	282.88	289.70
P ₆₀	376.32	374.75	327.71	349.66	360.64	357.82	377.89	366.91	349.66	387.30	392.00	374.75	282.02	287.94	278.35	267.93	290.92	281.43
Mean	331.58	359.07	335.99	353.19	366.52	349.27	370.83	374.36	372.79	386.12	374.75	375.77	295.78	282.20	275.44	255.55	282.18	278.23
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	8.712		9.740		19.480		6.826		7.632		15.264		6.426		7.184		14.368	
C.D. @ 5%	NS		NS		55.770		NS		NS		43.700		NS		20.567		41.135	

Table 4.20 Effect of different levels of phosphorus and biofertilizers on soil available phosphorus (kg ha⁻¹) under groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	7.63	7.82	16.59	12.02	12.94	11.40	16.04	16.10	17.92	15.33	17.97	16.67	16.83	13.73	14.25	15.73	20.66	16.24
P₃₀	11.49	18.31	18.40	13.75	10.34	14.46	17.16	15.45	11.72	14.21	18.13	15.33	17.47	18.36	21.81	19.42	17.00	18.81
P₄₅	17.74	17.36	17.17	8.77	10.31	14.27	14.64	14.99	14.49	16.28	17.06	15.49	16.28	16.98	16.98	16.40	17.09	16.74
P₆₀	9.35	14.27	9.54	8.96	11.06	10.64	15.17	15.14	15.34	16.63	17.11	15.88	18.41	18.03	16.98	24.58	21.86	19.97
Mean	11.55	14.44	15.42	10.88	11.16	12.69	15.75	15.42	14.87	15.61	17.57	15.84	17.25	16.77	17.50	19.04	19.15	17.94
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.041		0.045		0.091		0.354		0.396		0.791		0.608		0.680		1.360	
C.D. @ 5%	0.116		0.130		0.260		NS		1.133		2.266		1.741		NS		3.893	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	10.61	10.87	23.07	16.71	18.03	15.86	16.32	16.35	18.26	15.59	18.26	16.96	14.01	11.47	11.86	13.03	17.17	13.51
P₃₀	16.44	25.46	25.52	15.12	13.26	19.16	17.44	15.75	11.90	14.50	18.43	15.60	16.42	15.32	18.14	14.65	15.34	15.98
P₄₅	24.66	24.13	21.53	12.20	14.32	19.37	14.93	15.24	14.74	16.54	17.37	15.76	13.62	14.08	14.13	13.64	14.26	13.95
P₆₀	12.99	19.89	13.26	12.46	15.38	14.80	15.42	15.42	15.62	16.95	17.39	16.16	15.40	14.96	14.18	20.39	18.21	16.63
Mean	16.18	20.09	20.84	14.12	15.25	17.30	16.03	15.69	15.13	15.89	17.86	16.12	14.86	13.96	14.58	15.43	16.25	15.01
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.045		0.051		0.102		0.369		0.412		0.824		0.567		0.634		1.267	
C.D. @ 5%	0.130		0.146		0.291		NS		1.180		2.360		1.622		NS		3.628	

Table 4.21 Effect of different levels of phosphorus and biofertilizers on soil available potassium (kg ha⁻¹) under groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P ₁₅	432.43	437.67	434.18	440.29	415.83	432.08	431.51	332.70	274.76	398.10	248.71	337.16	248.17	311.46	323.59	296.58	272.36	290.43
P ₃₀	381.76	455.15	406.22	378.27	545.13	433.31	294.00	386.87	411.67	403.54	296.39	358.49	264.87	277.37	255.54	331.29	349.06	295.62
P ₄₅	421.08	446.41	337.21	400.98	352.06	391.55	423.85	264.25	253.16	473.52	196.27	322.21	285.41	273.57	272.82	274.65	253.35	271.96
P ₆₀	368.66	442.92	464.76	576.44	412.34	453.02	297.72	260.86	304.60	343.24	273.05	295.89	295.37	315.73	293.09	278.54	269.10	290.37
Mean	400.98	445.54	410.59	449.00	431.34	427.49	361.77	311.17	311.05	404.60	253.60	328.44	273.45	294.53	286.26	295.26	285.97	287.10
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	3.248		3.631		7.263		19.710		22.036		44.072		7.880		8.811		17.621	
C.D. @ 5%	9.299		10.397		20.793		NS		63.088		NS		NS		NS		50.448	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P ₁₅	277.20	280.56	278.32	282.24	266.56	276.98	360.08	275.26	223.99	323.06	199.15	276.31	196.00	245.84	255.36	233.52	214.48	229.04
P ₃₀	244.72	291.76	260.52	242.48	349.44	277.78	237.85	287.57	298.07	294.86	242.83	272.24	208.88	218.96	201.04	260.96	275.52	233.07
P ₄₅	269.92	286.16	216.16	257.04	225.68	250.99	355.95	220.99	197.93	333.97	251.37	272.04	225.55	216.16	215.04	217.28	199.92	214.79
P ₆₀	236.32	283.59	297.92	390.88	264.32	294.61	265.55	216.16	235.69	244.38	277.65	247.89	233.52	248.08	231.84	220.64	211.68	229.15
Mean	257.04	285.52	263.23	293.16	276.50	275.09	304.86	250.00	238.92	299.07	242.75	267.12	215.99	232.26	225.82	233.10	225.40	226.51
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	3.648		4.078		8.157		15.039		16.814		33.628		5.527		6.180		12.359	
C.D. @ 5%	10.444		11.676		23.353		NS		48.137		NS		NS		NS		35.383	

Table 4.22 Effect of different levels of phosphorus and biofertilizers on DTPA extractable Fe (mg kg⁻¹) in soil under groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	79.34	66.98	79.54	66.27	104.41	79.31	78.47	74.36	82.14	69.20	76.75	76.19	62.16	57.15	55.10	49.39	62.32	57.22
P₃₀	95.78	67.93	76.02	77.21	42.34	71.85	71.80	74.34	71.91	67.50	74.79	72.07	56.99	55.17	52.32	58.95	55.88	55.86
P₄₅	59.79	62.99	98.54	66.44	74.37	72.43	70.84	80.97	79.69	66.15	73.18	74.16	55.37	61.28	61.51	57.30	64.15	59.92
P₆₀	68.03	91.92	73.28	71.43	74.64	75.86	80.30	74.00	74.13	75.08	73.47	75.39	61.51	56.49	50.23	59.26	64.12	58.32
Mean	75.73	72.46	81.85	70.34	73.94	74.86	75.35	75.92	76.97	69.48	74.55	74.45	59.01	57.52	54.79	56.22	61.62	57.83
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	2.606		2.913		5.827		1.245		1.392		2.783		1.280		1.431		2.863	
C.D. @ 5%	NS		NS		16.681		NS		3.984		NS		NS		4.098		NS	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	100.42	84.79	100.68	83.89	132.17	100.39	101.94	96.61	106.61	90.06	99.85	99.01	69.85	64.21	61.91	55.49	70.02	64.30
P₃₀	121.24	85.99	96.23	97.73	53.59	90.95	93.36	96.58	93.49	87.74	97.07	93.65	64.04	61.98	58.79	66.24	62.79	62.77
P₄₅	75.68	79.74	124.74	83.68	94.14	91.59	92.02	105.12	103.64	86.07	95.01	96.37	62.21	68.85	69.11	64.38	72.08	67.33
P₆₀	86.11	116.36	92.76	90.42	94.48	96.03	104.30	95.87	96.19	97.55	95.51	97.88	69.12	63.47	56.44	66.58	72.05	65.53
Mean	95.86	91.72	103.60	88.93	93.59	94.74	97.91	98.55	99.98	90.35	96.86	96.73	66.30	64.63	61.56	63.17	69.24	64.98
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	3.254		3.638		7.276		1.826		2.042		4.084		1.443		1.614		3.228	
C.D. @ 5%	NS		NS		20.832		NS		5.846		NS		NS		4.620		NS	

Table 4.23 Effect of different levels of phosphorus and biofertilizers on DTPA extractable Mn (mg kg⁻¹) in soil under groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P ₁₅	76.68	58.19	53.65	55.07	43.90	57.50	65.98	52.15	44.79	48.17	60.38	54.29	94.70	91.63	86.16	92.35	90.72	91.11
P ₃₀	34.03	57.25	59.08	67.68	42.70	52.15	41.38	46.64	59.40	39.23	31.80	43.69	96.25	82.97	81.17	95.64	88.15	88.84
P ₄₅	50.89	66.26	47.82	42.17	52.99	52.02	52.34	53.38	42.51	41.86	49.09	47.84	94.93	90.21	95.42	89.86	89.14	91.91
P ₆₀	49.01	66.26	55.26	78.04	78.37	65.39	43.18	59.40	63.76	98.39	62.27	65.40	89.96	89.88	85.54	88.16	95.67	89.84
Mean	52.65	61.99	53.95	60.74	54.49	56.76	50.72	52.89	52.61	56.91	50.88	52.80	93.96	88.67	87.07	91.50	90.92	90.43
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	2.461		2.752		5.503		1.507		1.685		3.370		0.849		0.949		1.899	
C.D. @ 5%	7.046		NS		15.756		4.315		NS		9.648		NS		2.718		5.436	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P ₁₅	111.13	84.34	77.75	79.81	63.62	83.33	107.80	87.67	77.75	79.81	98.08	90.22	125.83	122.17	114.88	123.13	120.95	121.39
P ₃₀	49.32	82.97	85.63	98.08	61.89	75.58	61.89	84.68	84.37	54.67	62.45	69.61	128.34	110.62	108.23	127.52	117.54	118.45
P ₄₅	73.75	96.03	69.30	61.11	76.79	75.40	85.52	81.60	54.83	73.30	80.74	75.20	126.24	120.28	127.23	119.81	118.85	122.48
P ₆₀	71.03	96.03	80.09	113.10	113.58	94.77	78.32	85.57	85.40	135.11	84.59	93.80	123.61	119.83	114.06	117.55	127.56	120.52
Mean	76.31	89.84	78.19	88.03	78.97	82.27	83.38	84.88	75.59	85.72	81.47	82.21	126.00	118.23	116.10	122.00	121.22	120.71
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	3.612		4.039		8.077		2.517		2.815		5.629		1.120		1.252		2.504	
C.D. @ 5%	10.342		NS		23.125		7.207		NS		16.116		NS		3.585		7.170	

Table 4.24 Effect of different levels of phosphorus and biofertilizers on DTPA extractable Zn (mg kg⁻¹) in soil under groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	1.06	0.94	1.67	1.47	1.62	1.35	1.07	0.96	1.01	1.15	1.29	1.10	1.03	1.04	0.87	0.92	1.32	1.04
P₃₀	1.24	1.31	1.22	1.17	1.17	1.22	1.14	1.08	1.11	1.21	1.03	1.11	0.89	1.11	1.24	1.03	0.80	1.02
P₄₅	0.85	1.01	1.73	1.10	1.53	1.24	1.20	1.19	1.19	1.15	1.12	1.17	0.93	1.05	0.97	0.86	0.86	0.93
P₆₀	1.31	1.63	0.98	1.34	1.14	1.28	1.09	1.05	0.94	1.07	1.12	1.05	0.92	0.98	0.84	0.97	1.18	0.98
Mean	1.12	1.22	1.40	1.27	1.36	1.27	1.12	1.07	1.06	1.14	1.14	1.11	0.94	1.05	0.98	0.95	1.04	0.99
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.034		0.038		0.077		0.019		0.021		0.043		0.021		0.024		0.047	
C.D. @ 5%	NS		0.110		0.220		0.055		0.061		0.122		0.061		0.068		0.135	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	1.56	1.56	1.30	1.37	1.97	1.55	0.95	0.84	1.49	1.31	1.44	1.21	0.80	0.95	0.75	0.85	1.08	0.89
P₃₀	1.33	1.65	1.66	1.54	1.20	1.48	1.11	1.17	1.09	1.04	1.04	1.09	0.85	0.85	0.94	0.90	0.76	0.86
P₄₅	1.38	1.57	1.45	1.29	1.28	1.39	0.76	0.90	1.55	0.98	1.36	1.11	0.89	0.88	0.88	0.85	0.86	0.87
P₆₀	1.37	1.47	1.25	1.44	1.86	1.48	1.16	1.45	0.87	1.20	1.04	1.14	0.80	0.75	0.70	0.81	0.83	0.78
Mean	1.41	1.56	1.41	1.41	1.58	1.47	1.00	1.09	1.25	1.13	1.22	1.14	0.84	0.86	0.82	0.85	0.88	0.85
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.044		0.050		0.099		0.028		0.032		0.064		0.012		0.013		0.026	
C.D. @ 5%	NS		0.142		0.284		0.081		0.091		0.182		0.033		0.037		0.075	

Table 4.25 Effect of different levels of phosphorus and biofertilizers on DTPA extractable Cu (mg kg⁻¹) in soil under groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	2.80	2.83	3.07	2.90	3.05	2.93	3.65	3.60	4.01	3.53	3.80	3.72	3.68	3.71	3.33	3.35	3.88	3.59
P₃₀	3.05	3.01	2.46	3.11	2.23	2.77	3.56	3.69	3.61	3.73	5.68	4.05	3.80	3.80	3.86	3.82	3.44	3.74
P₄₅	2.68	2.83	3.12	2.60	2.91	2.83	3.49	3.75	3.83	3.43	3.88	3.68	4.26	4.02	4.60	3.97	3.82	4.13
P₆₀	2.84	3.05	2.47	2.85	2.96	2.83	3.74	3.73	3.57	3.70	3.43	3.63	3.77	3.56	3.18	3.62	3.52	3.53
Mean	2.84	2.93	2.78	2.86	2.79	2.84	3.61	3.69	3.76	3.59	4.20	3.77	3.88	3.77	3.74	3.69	3.67	3.75
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.040		0.044		0.088		0.136		0.152		0.304		0.084		0.094		0.187	
C.D. @ 5%	NS		NS		0.253		NS		0.435		0.871		0.240		NS		NS	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	3.63	3.88	4.21	3.98	4.25	3.99	5.11	5.05	5.63	4.95	5.45	5.24	4.14	4.17	3.75	3.77	4.36	4.04
P₃₀	4.15	4.12	3.83	4.25	3.06	3.88	5.00	5.18	5.07	5.24	7.97	5.69	4.26	4.26	4.33	4.30	3.87	4.20
P₄₅	3.67	3.87	4.28	3.56	3.98	3.87	4.90	5.27	5.38	4.82	5.45	5.16	4.87	4.52	5.17	4.46	4.29	4.66
P₆₀	3.90	4.17	3.48	3.90	4.06	3.90	5.25	5.24	5.01	5.19	4.77	5.09	4.24	4.00	3.57	4.10	3.96	3.97
Mean	3.84	4.01	3.95	3.92	3.84	3.91	5.07	5.19	5.27	5.05	5.91	5.30	4.38	4.24	4.20	4.16	4.12	4.22
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.043		0.048		0.097		0.196		0.219		0.438		0.107		0.119		0.238	
C.D. @ 5%	NS		NS		0.278		NS		0.627		1.253		0.305		NS		NS	

Table 4.26 Effect of different levels of phosphorus and biofertilizers on plant height (cm) of groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	18.21	19.42	19.55	22.19	19.71	19.82	33.08	34.55	34.65	30.07	41.48	34.77	41.26	39.22	31.09	31.09	36.39	35.81
P₃₀	22.28	21.77	22.81	22.39	22.46	22.34	30.76	30.07	31.79	23.15	31.79	29.51	31.09	31.07	36.74	22.96	34.28	31.23
P₄₅	21.28	19.15	27.38	23.49	21.85	22.63	34.56	29.72	29.38	32.83	36.63	32.62	33.21	33.17	33.21	34.52	37.80	34.38
P₆₀	23.68	23.65	22.98	22.28	22.44	23.01	30.41	34.22	33.18	34.46	30.41	32.54	31.80	33.92	32.86	35.68	34.27	33.71
Mean	21.36	21.00	23.18	22.59	21.62	21.95	32.20	32.14	32.25	30.13	35.08	32.36	34.34	34.34	33.47	31.06	35.68	33.78
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.857		0.959		1.917		0.189		0.211		0.422		0.199		0.223		0.446	
C.D. @ 5%	NS		NS		NS		0.541		0.604		1.209		0.571		0.638		1.276	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	16.19	18.77	15.90	21.73	20.93	18.70	31.86	32.61	32.68	28.37	39.14	32.93	37.94	40.19	30.36	30.36	35.53	34.88
P₃₀	24.80	19.66	22.11	20.78	18.69	21.21	29.02	28.37	30.00	21.85	30.00	27.85	30.36	30.02	35.88	21.31	31.81	29.87
P₄₅	22.59	21.54	21.93	20.66	20.34	21.41	32.61	28.04	27.71	30.97	34.56	30.78	30.82	30.16	29.66	33.13	33.92	31.54
P₆₀	21.69	20.17	22.58	21.01	25.45	22.18	28.69	32.28	30.97	32.60	28.69	30.64	38.18	27.81	26.94	32.02	36.62	32.31
Mean	21.32	20.04	20.63	21.04	21.35	20.88	30.55	30.33	30.34	28.45	33.09	30.55	34.33	32.05	30.71	29.20	34.47	32.15
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.893		0.998		1.997		0.183		0.205		0.410		0.225		0.251		0.502	
C.D. @ 5%	NS		NS		NS		0.525		0.587		1.174		0.643		0.719		1.438	

Table 4.27 Effect of different levels of phosphorus and biofertilizers on rachis of groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	6.44	6.66	6.77	6.44	10.11	7.28	5.52	6.17	5.52	4.92	5.44	5.51	5.91	5.89	4.59	5.89	5.25	5.51
P₃₀	7.66	8.00	7.44	6.55	6.51	7.23	6.42	8.30	5.90	6.13	5.89	6.53	7.78	6.56	5.25	6.90	5.58	6.41
P₄₅	7.55	7.55	7.44	8.22	6.00	7.35	5.83	5.02	5.83	5.55	6.72	5.79	5.19	5.28	5.91	4.93	7.22	5.71
P₆₀	8.11	6.55	8.22	7.85	7.96	7.74	3.38	4.63	6.44	7.36	4.61	5.28	3.94	5.58	7.22	7.22	7.58	6.31
Mean	7.44	7.19	7.47	7.26	7.65	7.40	5.29	6.03	5.92	5.99	5.66	5.78	5.71	5.83	5.74	6.23	6.41	5.98
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.369		0.413		0.825		0.120		0.134		0.269		0.017		0.019		0.037	
C.D. @ 5%	NS		NS		NS		0.344		0.385		0.769		0.048		0.054		0.107	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	6.86	7.09	7.21	6.93	10.77	7.77	7.68	8.57	7.68	6.83	7.56	7.66	8.21	8.21	6.38	8.21	7.62	7.73
P₃₀	8.18	8.35	7.79	7.04	6.92	7.66	8.92	11.54	8.20	8.53	8.19	9.08	8.97	8.44	8.32	7.95	8.36	8.41
P₄₅	8.00	7.84	8.04	8.66	6.47	7.80	8.11	6.97	8.11	7.72	9.34	8.05	7.76	7.30	8.21	6.85	10.04	8.03
P₆₀	8.87	7.08	8.53	8.40	8.72	8.32	4.70	6.44	8.95	10.22	6.40	7.34	5.82	7.75	10.04	10.04	8.43	8.42
Mean	7.98	7.59	7.89	7.76	8.22	7.89	7.35	8.38	8.23	8.33	7.87	8.03	7.69	7.93	8.24	8.26	8.61	8.15
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.373		0.417		0.834		0.167		0.187		0.373		0.080		0.090		0.180	
C.D. @ 5%	NS		NS		NS		0.478		0.534		1.069		0.230		0.257		0.514	

Table 4.28 Effect of different levels of phosphorus and biofertilizers on pod and haulm yield (q ha⁻¹) of groundnut

2017-18												
Treat.	Pod yield (q ha ⁻¹)						Haulm yield (q ha ⁻¹)					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P₁₅	21.76	22.81	22.63	24.00	23.12	22.86	51.67	42.67	51.67	44.53	45.13	47.13
P₃₀	24.61	25.83	24.53	28.59	31.28	26.97	51.12	50.67	51.40	43.03	44.25	48.09
P₄₅	31.63	31.66	27.20	32.64	34.00	31.43	51.60	48.67	46.43	52.47	53.60	50.55
P₆₀	35.25	34.00	35.37	36.44	37.27	35.67	51.60	49.20	49.77	50.00	50.40	50.19
Mean	28.31	28.58	27.43	30.42	31.42	29.23	51.50	47.80	49.82	47.51	48.35	48.99
	P		B		P x B		P		B		P x B	
S.E.±	1.601		1.790		3.580		1.633		1.826		3.651	
C.D. @ 5%	4.584		NS		NS		NS		NS		NS	
2018-19												
Treat.	Pod yield (q ha ⁻¹)						Haulm yield (q ha ⁻¹)					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P₁₅	22.14	22.18	22.31	24.45	23.54	22.92	52.36	43.21	52.37	45.14	43.60	47.34
P₃₀	24.97	26.22	24.94	29.12	31.73	27.39	44.86	52.16	49.29	45.71	51.87	48.78
P₄₅	32.18	32.27	30.45	33.08	34.48	32.49	51.19	52.07	47.03	53.10	54.36	51.55
P₆₀	35.77	34.42	36.00	37.04	37.06	36.06	52.21	49.81	50.43	51.41	51.05	50.98
Mean	28.76	28.77	28.42	30.92	31.70	29.72	50.16	49.31	49.78	48.84	50.22	49.66
	P		B		P x B		P		B		P x B	
S.E.±	1.606		1.795		3.591		1.652		1.847		3.693	
C.D. @ 5%	4.597		NS		NS		NS		NS		NS	

Table 4.29 Effect of different levels of phosphorus and biofertilizers on kernel yield (q ha⁻¹) of groundnut

Treat.	2017-18						2018-19					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P₁₅	13.51	14.31	14.32	15.27	18.31	15.14	14.15	14.33	14.54	16.03	15.55	14.92
P₃₀	20.24	20.67	20.89	15.35	16.48	18.73	16.64	17.65	16.91	19.95	21.83	18.59
P₄₅	17.43	17.25	19.27	23.11	23.49	20.11	22.39	23.38	22.16	24.28	24.59	23.36
P₆₀	24.54	23.11	23.75	25.08	26.75	24.65	25.61	24.17	25.25	26.28	27.37	25.74
Mean	18.93	18.83	19.56	19.70	21.26	19.66	19.70	19.88	19.71	21.63	22.33	20.65
	P		B		P x B		P		B		P x B	
S.E.±	0.767		0.857		1.714		0.688		0.769		1.538	
C.D. @ 5%	2.195		NS		NS		1.970		NS		NS	

Table 4.30 Effect of different levels of phosphorus and biofertilizers on test weight (%) of groundnut

Treat.	2017-18						2018-19					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P₁₅	64.42	49.41	64.61	47.63	64.31	58.08	61.94	47.93	62.42	45.94	62.38	56.12
P₃₀	58.49	67.16	66.59	55.31	65.86	62.68	59.97	64.64	64.59	53.65	63.93	61.36
P₄₅	55.54	55.34	68.02	63.80	58.08	60.16	53.62	53.61	65.98	61.71	56.46	58.28
P₆₀	67.85	57.54	54.01	54.57	69.20	60.63	65.84	55.91	52.38	52.94	67.46	58.91
Mean	61.57	57.36	63.31	55.33	64.36	60.39	60.34	55.52	61.34	53.56	62.56	58.67
	P		B		P x B		P		B		P x B	
S.E.±	1.127		1.260		2.519		1.293		1.446		2.892	
C.D. @ 5%	NS		3.606		7.212		NS		4.139		8.278	

Table 4.31 Effect of different levels of phosphorus and biofertilizers on nitrogen content (%) in halum of groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	0.83	0.59	0.61	0.81	0.80	0.73	0.39	0.37	0.23	0.66	1.07	0.54	2.21	1.29	0.79	2.45	1.99	1.74
P₃₀	0.68	0.73	0.81	0.79	1.03	0.81	0.55	0.44	0.61	0.91	1.07	0.72	1.61	2.23	2.36	1.88	1.14	1.84
P₄₅	0.70	0.95	0.37	0.72	0.52	0.65	0.84	0.58	0.57	0.51	0.83	0.66	1.83	2.22	1.78	1.27	2.30	1.88
P₆₀	0.66	0.86	0.70	0.49	0.71	0.68	0.40	0.39	0.54	0.81	0.69	0.57	1.75	2.02	1.69	2.74	2.48	2.14
Mean	0.72	0.78	0.62	0.70	0.76	0.72	0.54	0.45	0.49	0.72	0.92	0.62	1.85	1.94	1.65	2.08	1.98	1.90
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.053		0.059		0.119		0.052		0.058		0.117		0.017		0.019		0.038	
C.D. @ 5%	NS		NS		NS		NS		0.167		0.334		0.049		0.055		0.110	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	0.90	0.59	0.62	0.80	0.80	0.74	0.39	0.31	0.20	0.56	0.91	0.47	2.37	1.35	0.84	2.55	2.08	1.84
P₃₀	0.68	0.73	0.78	0.77	1.00	0.79	0.46	0.38	0.52	0.78	0.83	0.59	1.73	2.36	2.53	2.02	1.22	1.97
P₄₅	0.70	0.93	0.35	0.69	0.53	0.64	0.71	0.48	0.55	0.33	0.70	0.55	1.95	2.42	1.89	1.36	2.52	2.03
P₆₀	0.67	0.84	0.71	0.50	0.70	0.69	0.34	0.34	0.46	0.69	0.59	0.48	1.88	2.14	1.79	2.95	2.88	2.33
Mean	0.74	0.77	0.62	0.69	0.76	0.71	0.47	0.38	0.43	0.59	0.76	0.53	1.98	2.07	1.76	2.22	2.18	2.04
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.051		0.057		0.115		0.035		0.039		0.077		0.011		0.012		0.024	
C.D. @ 5%	NS		NS		NS		NS		0.111		0.222		0.031		0.034		0.069	

Table 4.32 Effect of different levels of phosphorus and biofertilizers on phosphorus content (%) in halum of groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	0.47	0.35	0.41	0.34	0.32	0.38	0.58	0.44	0.65	0.67	0.63	0.59	0.06	0.04	0.04	0.04	0.05	0.04
P₃₀	0.36	0.28	0.35	0.33	0.40	0.35	0.64	0.51	0.60	0.57	0.42	0.55	0.04	0.06	0.04	0.03	0.05	0.04
P₄₅	0.36	0.37	0.29	0.35	0.46	0.36	0.37	0.40	0.28	0.61	0.43	0.42	0.05	0.03	0.04	0.04	0.03	0.04
P₆₀	0.31	0.22	0.29	0.39	0.27	0.30	0.70	0.55	0.55	0.41	0.36	0.51	0.03	0.04	0.04	0.04	0.04	0.04
Mean	0.37	0.31	0.34	0.35	0.36	0.35	0.57	0.47	0.52	0.57	0.46	0.52	0.04	0.04	0.04	0.04	0.04	0.04
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.017		0.019		0.038		0.031		0.035		0.069		0.002		0.002		0.005	
C.D. @ 5%	0.049		NS		0.109		0.089		NS		0.198		NS		NS		0.013	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	0.38	0.29	0.34	0.28	0.26	0.31	0.76	0.57	0.85	0.87	0.61	0.73	0.06	0.04	0.04	0.04	0.05	0.05
P₃₀	0.29	0.23	0.29	0.27	0.33	0.28	1.01	0.67	0.79	0.75	0.54	0.75	0.05	0.06	0.05	0.03	0.05	0.05
P₄₅	0.29	0.30	0.24	0.28	0.37	0.30	0.49	0.52	0.26	0.80	0.56	0.53	0.05	0.03	0.04	0.04	0.03	0.04
P₆₀	0.25	0.18	0.17	0.22	0.14	0.19	0.91	0.88	0.77	0.54	0.48	0.71	0.04	0.05	0.04	0.05	0.05	0.04
Mean	0.30	0.25	0.26	0.26	0.27	0.27	0.79	0.66	0.67	0.74	0.55	0.68	0.05	0.05	0.04	0.04	0.05	0.05
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.012		0.014		0.027		0.052		0.058		0.116		0.002		0.003		0.005	
C.D. @ 5%	0.035		NS		0.078		0.149		NS		0.332		NS		NS		0.015	

Table 4.33 Effect of different levels of phosphorus and biofertilizers on potassium content (%) in halum of groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P ₁₅	1.88	1.10	0.87	0.94	0.98	1.15	1.23	0.97	1.40	1.69	1.91	1.44	1.54	1.13	0.64	0.71	0.97	1.00
P ₃₀	0.94	0.62	1.45	1.60	1.30	1.18	1.45	1.91	1.61	1.73	1.67	1.67	0.93	0.84	0.90	0.79	1.57	1.01
P ₄₅	0.96	2.48	2.02	2.14	1.54	1.83	1.57	1.98	1.04	1.39	1.32	1.46	1.18	1.15	0.85	0.97	0.80	0.99
P ₆₀	1.40	1.94	2.63	1.67	1.72	1.87	1.28	1.69	2.38	1.88	1.81	1.81	0.71	1.20	1.25	1.20	0.89	1.05
Mean	1.29	1.54	1.75	1.59	1.39	1.51	1.38	1.64	1.61	1.67	1.68	1.60	1.09	1.08	0.91	0.92	1.06	1.01
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.022		0.024		0.048		0.070		0.078		0.156		0.017		0.019		0.038	
C.D. @ 5%	0.062		0.069		0.139		0.200		NS		0.446		NS		0.055		0.110	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P ₁₅	0.72	0.82	0.85	0.79	1.08	0.85	1.07	1.09	0.97	1.60	1.02	1.15	1.61	1.18	0.67	0.74	1.01	1.04
P ₃₀	0.46	0.52	0.89	0.83	0.54	0.65	1.66	1.12	1.46	1.05	1.61	1.38	0.97	0.88	0.93	0.83	1.60	1.04
P ₄₅	0.82	0.81	1.05	0.79	0.69	0.83	1.05	1.32	1.23	1.39	0.79	1.15	1.23	1.20	0.88	1.01	0.84	1.03
P ₆₀	1.21	0.91	1.41	0.86	0.69	1.01	1.27	1.61	1.35	1.52	1.71	1.49	0.74	1.25	1.30	1.25	0.93	1.09
Mean	0.80	0.77	1.05	0.82	0.75	0.84	1.26	1.29	1.25	1.39	1.28	1.29	1.14	1.13	0.95	0.96	1.09	1.05
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.035		0.040		0.079		0.043		0.048		0.097		0.017		0.019		0.038	
C.D. @ 5%	0.101		0.113		0.226		0.124		NS		0.278		NS		0.054		0.108	

Table 4.34 Effect of different levels of phosphorus and biofertilizers on nitrogen, phosphorus and potassium content (%) in kernel of groundnut

2017-18																		
Treat.	Nitrogen						Phosphorus						Potassium					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	3.57	3.66	3.77	3.84	3.88	3.74	0.22	0.18	0.22	0.18	0.15	0.19	0.70	0.70	0.74	0.73	0.62	0.70
P₃₀	3.97	4.12	4.19	4.22	4.30	4.16	0.15	0.25	0.23	0.03	0.20	0.17	0.81	0.63	0.74	0.78	0.73	0.74
P₄₅	4.80	4.88	4.98	4.62	4.72	4.80	0.14	0.14	0.02	0.07	0.17	0.11	0.83	0.81	0.75	0.70	0.76	0.77
P₆₀	4.41	4.50	4.52	5.02	5.06	4.70	0.27	0.21	0.21	0.14	0.27	0.22	0.78	0.66	0.73	0.76	0.61	0.71
Mean	4.18	4.29	4.37	4.42	4.49	4.35	0.19	0.20	0.17	0.10	0.20	0.17	0.78	0.70	0.74	0.74	0.68	0.73
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.023		0.026		0.051		0.013		0.014		0.029		0.028		0.032		0.063	
C.D. @ 5%	0.066		0.073		0.147		0.037		0.041		0.082		NS		NS		NS	
2018-19																		
Treat.	Nitrogen						Phosphorus						Potassium					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	3.53	3.62	3.73	3.80	3.84	3.71	0.20	0.17	0.20	0.16	0.14	0.17	0.66	0.66	0.70	0.69	0.55	0.65
P₃₀	3.93	4.08	4.15	4.18	4.26	4.12	0.13	0.22	0.21	0.03	0.18	0.16	0.76	0.59	0.70	0.73	0.69	0.69
P₄₅	4.75	4.83	4.94	4.57	4.68	4.75	0.13	0.13	0.02	0.06	0.15	0.10	0.78	0.76	0.70	0.65	0.71	0.72
P₆₀	4.36	4.45	4.47	4.97	5.01	4.65	0.23	0.19	0.19	0.13	0.24	0.19	0.73	0.61	0.68	0.71	0.58	0.66
Mean	4.14	4.25	4.32	4.38	4.45	4.31	0.17	0.18	0.15	0.09	0.18	0.15	0.73	0.65	0.70	0.70	0.63	0.68
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.015		0.017		0.034		0.006		0.007		0.014		0.023		0.026		0.052	
C.D. @ 5%	0.043		0.048		0.096		0.017		0.019		0.039		NS		NS		NS	

Table 4.35 Effect of different levels of phosphorus and biofertilizers on nitrogen, phosphorus and potassium content (%) in shell of groundnut

2017-18																		
Treat.	Nitrogen						Phosphorus						Potassium					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	0.39	0.42	0.43	0.46	0.48	0.44	0.07	0.06	0.04	0.06	0.06	0.06	0.63	0.80	0.89	0.81	0.73	0.77
P₃₀	0.50	0.53	0.55	0.56	0.59	0.55	0.05	0.06	0.05	0.05	0.07	0.06	0.81	1.08	0.92	0.38	0.68	0.77
P₄₅	0.61	0.78	0.79	0.82	0.71	0.74	0.06	0.06	0.08	0.05	0.05	0.06	0.86	0.71	0.70	0.51	0.84	0.72
P₆₀	0.73	0.76	0.64	0.66	0.70	0.70	0.07	0.06	0.07	0.07	0.07	0.07	1.17	0.54	0.95	0.89	0.68	0.85
Mean	0.56	0.62	0.60	0.63	0.62	0.61	0.06	0.06	0.06	0.06	0.06	0.06	0.86	0.79	0.87	0.65	0.73	0.78
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.006		0.007		0.014		0.002		0.003		0.005		0.048		0.053		0.107	
C.D. @ 5%	0.018		0.020		0.041		0.006		NS		0.014		NS		0.153		0.305	
2018-19																		
Treat.	Nitrogen						Phosphorus						Potassium					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	0.39	0.42	0.43	0.45	0.47	0.43	0.06	0.05	0.04	0.05	0.05	0.05	0.59	0.76	0.84	0.77	0.73	0.74
P₃₀	0.50	0.53	0.55	0.55	0.58	0.54	0.04	0.05	0.04	0.04	0.05	0.05	0.76	1.03	0.87	0.36	0.65	0.73
P₄₅	0.60	0.77	0.79	0.81	0.70	0.73	0.05	0.05	0.06	0.04	0.04	0.05	0.81	0.68	0.66	0.48	0.80	0.69
P₆₀	0.72	0.75	0.64	0.66	0.69	0.69	0.06	0.05	0.05	0.05	0.05	0.05	1.10	0.52	0.90	0.84	0.64	0.80
Mean	0.55	0.61	0.60	0.62	0.61	0.60	0.05	0.05	0.05	0.05	0.05	0.05	0.82	0.74	0.82	0.61	0.70	0.74
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.007		0.008		0.016		0.002		0.002		0.004		0.031		0.034		0.068	
C.D. @ 5%	0.020		0.023		0.045		0.005		NS		0.012		NS		0.098		0.195	

Table 4.36 Effect of different levels of phosphorus and biofertilizers on iron content (mg kg⁻¹) in halum of groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P ₁₅	176.37	680.96	464.24	421.59	719.01	492.44	980.08	583.59	2209.22	574.52	1110.23	1091.52	618.66	341.26	372.60	480.26	687.04	499.96
P ₃₀	748.29	135.22	568.37	999.54	172.21	524.73	1127.92	895.37	381.28	605.64	935.24	789.09	378.83	526.72	418.85	352.39	518.57	439.07
P ₄₅	640.87	1796.89	1701.27	819.09	200.10	1031.64	474.46	749.51	494.79	80.19	300.27	419.84	472.29	267.39	448.85	452.64	511.26	430.48
P ₆₀	673.80	738.26	676.49	966.44	897.60	790.52	656.17	179.76	501.67	934.38	469.16	548.23	346.28	417.20	424.76	380.70	485.68	410.92
Mean	559.83	837.83	852.59	801.67	497.23	709.83	809.66	602.06	896.74	548.68	703.72	712.17	454.01	388.14	416.26	416.50	550.64	445.11
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	95.147		106.378		212.755		79.961		89.399		178.798		0.837		0.936		1.872	
C.D. @ 5%	272.399		NS		609.102		228.922		NS		511.886		2.397		2.680		5.359	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P ₁₅	142.89	551.67	376.09	341.55	582.49	398.94	1290.13	645.12	2804.44	724.76	1243.84	1341.66	547.49	302.00	329.74	454.52	608.02	448.35
P ₃₀	606.21	46.25	460.46	809.76	139.52	412.44	1162.08	1222.49	377.87	611.38	853.28	845.42	335.25	466.13	373.61	311.85	458.92	389.15
P ₄₅	519.19	1455.71	1378.25	663.57	162.11	835.76	582.91	725.09	542.51	110.87	324.91	457.26	417.95	236.63	397.06	400.57	452.45	380.93
P ₆₀	545.87	598.09	548.05	782.94	706.08	636.20	735.97	212.98	603.08	855.65	557.60	593.06	306.44	369.20	375.90	336.91	429.81	363.65
Mean	453.54	662.93	690.71	649.45	397.55	570.83	942.77	701.42	1081.97	575.66	744.91	809.35	401.78	343.49	369.08	375.96	487.30	395.52
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	74.592		83.396		166.792		126.146		141.036		282.071		1.754		1.961		3.923	
C.D. @ 5%	213.551		NS		477.514		361.147		NS		807.549		5.022		5.615		11.230	

Table 4.37 Effect of different levels of phosphorus and biofertilizers on manganese content (mg kg⁻¹) in halum of groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P ₁₅	179.12	144.91	193.16	168.66	163.17	169.80	184.47	187.02	189.59	174.32	127.07	172.49	262.68	108.29	193.35	270.29	240.21	214.97
P ₃₀	209.67	164.75	194.47	209.92	219.74	199.71	170.29	141.20	165.89	180.56	150.50	161.69	271.48	229.08	271.39	158.08	211.14	228.23
P ₄₅	201.06	200.72	120.59	244.75	182.25	189.87	134.69	223.66	231.15	149.91	171.40	182.16	171.48	176.60	266.15	224.75	200.81	207.95
P ₆₀	191.82	189.07	201.44	127.15	185.07	178.91	129.46	144.17	147.53	203.66	155.77	156.12	155.30	226.96	191.73	211.46	179.74	193.04
Mean	195.42	174.86	177.41	187.62	187.56	184.57	154.73	174.01	183.54	177.11	151.19	168.11	215.24	185.23	230.65	216.14	207.97	211.05
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	5.950		6.652		13.304		8.196		9.164		18.327		17.046		19.058		38.115	
C.D. @ 5%	17.034		NS		38.088		NS		NS		52.470		NS		NS		NS	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P ₁₅	113.37	91.72	122.25	106.75	103.28	107.47	185.33	187.88	190.47	175.13	127.66	173.29	273.63	112.81	201.41	281.56	250.22	223.92
P ₃₀	132.71	104.28	123.08	132.86	139.08	126.40	171.08	141.85	166.66	181.39	151.20	162.43	282.90	238.62	282.70	164.67	219.94	237.76
P ₄₅	127.25	127.04	82.99	154.06	115.35	121.34	135.31	224.70	232.22	150.60	172.19	183.00	178.62	183.96	277.24	234.11	209.18	216.62
P ₆₀	121.41	119.67	129.61	80.48	117.14	113.66	130.06	144.84	148.22	204.60	156.47	156.83	161.78	236.42	199.72	220.27	187.23	201.08
Mean	123.68	110.67	114.48	118.54	118.71	117.22	155.44	174.82	184.39	177.93	151.88	168.89	224.23	192.95	240.26	225.15	216.64	219.85
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	4.795		5.360		10.721		8.038		8.987		17.974		21.592		24.140		48.280	
C.D. @ 5%	13.726		NS		30.693		NS		NS		51.460		NS		NS		NS	

Table 4.38 Effect of different levels of phosphorus and biofertilizers on zinc content (mg kg⁻¹) in halum of groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	81.66	67.24	62.39	167.05	63.17	88.30	28.76	29.37	24.73	22.70	30.55	27.22	26.27	23.11	35.11	35.38	28.16	29.61
P₃₀	82.10	160.28	92.71	88.84	35.57	91.90	26.42	22.09	31.86	35.11	28.04	28.70	39.36	44.71	22.63	32.88	37.60	35.43
P₄₅	142.45	74.07	90.04	102.49	64.53	94.71	26.97	22.69	29.69	21.84	36.12	27.46	38.08	35.99	39.47	35.22	42.20	38.19
P₆₀	90.80	229.94	35.50	86.39	67.39	102.00	27.06	20.10	23.08	15.15	47.97	26.67	26.00	35.19	34.00	24.64	41.74	32.31
Mean	99.25	132.88	70.16	111.19	57.66	94.23	27.30	23.56	27.34	23.70	35.67	27.51	32.43	34.75	32.80	32.03	37.42	33.89
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	3.515		3.930		7.861		2.155		2.409		4.818		1.516		1.695		3.391	
C.D. @ 5%	NS		11.252		22.504		NS		6.897		NS		4.341		NS		9.707	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	51.69	42.56	39.49	105.73	39.98	55.89	22.25	23.77	19.35	17.81	23.96	21.43	23.15	20.50	30.96	31.25	24.91	26.15
P₃₀	51.96	103.60	62.01	56.23	22.51	59.26	20.88	17.12	25.36	27.38	21.88	22.52	34.84	39.34	20.00	28.99	33.28	31.29
P₄₅	90.16	46.88	56.99	64.87	40.84	59.95	21.30	17.77	23.47	17.08	28.50	21.62	33.40	31.80	34.86	31.13	37.21	33.68
P₆₀	56.24	147.43	22.47	54.68	42.66	64.69	20.96	15.77	18.05	11.70	37.69	20.83	23.06	31.06	30.04	21.76	36.89	28.56
Mean	62.51	85.12	45.24	70.37	36.50	59.95	21.35	18.60	21.56	18.49	28.01	21.60	28.61	30.68	28.97	28.28	33.07	29.92
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	2.583		2.888		5.777		1.742		1.947		3.894		1.239		1.386		2.771	
C.D. @ 5%	NS		8.269		16.538		NS		5.575		NS		3.548		NS		7.934	

Table 4.39 Effect of different levels of phosphorus and biofertilizers on copper content (mg kg⁻¹) in halum of groundnut

2017-18																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	69.47	56.69	150.81	547.48	98.72	184.63	139.22	154.92	141.93	172.83	372.42	196.26	122.19	47.68	126.06	88.26	90.53	94.94
P₃₀	166.31	568.99	239.43	277.18	83.45	267.07	153.40	117.97	243.57	163.06	143.23	164.25	84.67	99.89	95.63	69.65	120.58	94.08
P₄₅	485.77	309.66	268.76	255.03	82.92	280.43	196.00	138.65	105.20	104.24	131.42	135.10	120.11	97.05	89.59	98.09	100.36	101.04
P₆₀	228.38	809.98	32.68	349.80	204.60	325.09	150.29	127.46	66.27	184.08	107.12	127.05	39.38	102.91	77.30	84.29	73.80	75.54
Mean	237.48	436.33	172.92	357.37	117.42	264.31	159.73	134.75	139.24	156.05	188.55	155.66	91.59	86.88	97.15	85.07	96.32	91.40
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	45.156		50.486		100.971		43.749		48.913		97.825		3.149		3.520		7.041	
C.D. @ 5%	NS		144.537		289.073		125.250		NS		280.067		9.014		NS		20.157	
2018-19																		
Treat.	Peg Initiation						Pod Formation						At Harvest					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	87.94	71.77	190.90	693.02	124.96	233.71	123.20	137.10	125.60	152.95	373.95	182.56	64.65	25.23	66.70	46.70	47.90	50.24
P₃₀	210.52	720.24	303.07	350.86	105.63	338.06	135.75	104.40	215.55	144.30	126.75	145.35	44.80	52.85	50.60	36.85	60.47	49.11
P₄₅	614.90	391.98	340.21	322.82	104.96	354.97	173.45	122.70	93.10	92.25	116.30	119.56	63.55	51.35	47.40	51.90	53.10	53.46
P₆₀	289.09	1025.30	41.37	442.79	258.99	411.51	133.00	112.80	58.65	162.90	45.30	102.53	22.60	54.45	40.90	44.60	39.05	40.32
Mean	300.61	552.32	218.89	452.37	148.63	334.56	141.35	119.25	123.23	138.10	165.58	137.50	48.90	45.97	51.40	45.01	50.13	48.28
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	46.094		51.534		103.068		39.326		43.967		87.935		1.892		2.116		4.232	
C.D. @ 5%	NS		147.539		295.077		112.587		NS		251.751		5.418		NS		12.115	

Table 4.40 Effect of different levels of phosphorus and biofertilizers on iron content (mg kg⁻¹) in kernel of groundnut

Treat.	Iron (2017-18)						Iron (2018-19)					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P₁₅	110.42	134.85	131.56	134.41	94.63	121.17	116.24	141.95	138.48	141.48	99.62	127.55
P₃₀	151.72	198.03	273.03	69.24	183.51	175.10	159.70	208.46	287.40	72.89	193.17	184.32
P₄₅	190.14	162.95	121.32	106.02	125.99	141.28	200.15	171.53	127.70	111.61	132.62	148.72
P₆₀	230.83	234.41	127.31	166.44	185.85	188.97	242.98	246.75	134.01	175.20	195.64	198.92
Mean	170.78	182.56	163.30	119.03	147.50	156.63	179.77	192.17	171.90	125.29	155.26	164.88
	P		B		P x B		P		B		P x B	
S.E.±	14.014		15.669		31.337		14.723		16.461		32.922	
C.D. @ 5%	40.122		NS		89.716		42.151		NS		94.252	

Table 4.41 Effect of different levels of phosphorus and biofertilizers on manganese content (mg kg⁻¹) in kernel of groundnut

Treat.	Manganese (2017-18)						Manganese (2018-19)					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P₁₅	34.58	15.07	16.99	16.63	9.28	18.51	35.29	15.38	17.34	16.97	9.47	18.89
P₃₀	12.57	14.52	20.58	5.97	55.31	21.79	12.83	14.82	21.00	6.09	56.44	22.23
P₄₅	17.58	13.26	11.40	15.69	32.41	18.07	17.94	13.53	11.63	16.08	33.08	18.45
P₆₀	20.34	16.28	21.86	24.26	14.53	19.45	20.75	16.61	22.31	24.76	14.83	19.85
Mean	21.27	14.78	17.70	15.64	27.88	19.45	21.70	15.08	18.07	15.97	28.45	19.86
	P		B		P x B		P		B		P x B	
S.E.±	1.042		1.165		2.331		1.047		1.171		2.342	
C.D. @ 5%	NS		3.337		6.673		NS		3.353		6.705	

Table 4.42 Effect of different levels of phosphorus and biofertilizers on zinc content (mg kg⁻¹) in kernel of groundnut

Treat.	Zinc (2017-18)						Zinc (2018-19)					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P₁₅	46.14	25.08	46.06	43.62	36.89	39.56	46.25	25.81	45.75	43.33	36.77	39.58
P₃₀	26.91	56.72	38.26	52.61	49.70	44.84	25.71	56.18	39.73	52.56	49.09	44.65
P₄₅	38.77	56.49	36.80	16.64	52.31	40.20	39.25	55.75	38.05	16.53	51.95	40.30
P₆₀	37.96	33.86	46.71	32.23	38.37	37.82	36.80	33.85	46.40	31.46	37.37	37.17
Mean	37.45	43.04	41.95	36.27	44.32	40.61	37.00	42.90	42.48	35.97	43.79	40.43
	P		B		P x B		P		B		P x B	
S.E.±	2.055		2.297		4.594		2.035		2.275		4.551	
C.D. @ 5%	NS		NS		13.153		NS		NS		13.028	

Table 4.43 Effect of different levels of phosphorus and biofertilizers on copper content (mg kg⁻¹) in kernel of groundnut

Treat.	Copper (2017-18)						Copper (2018-19)					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P₁₅	9.83	7.75	12.14	20.09	6.66	11.30	10.04	7.91	9.72	20.51	6.80	10.99
P₃₀	4.57	11.01	11.61	4.31	14.12	9.12	4.66	11.24	11.85	4.40	14.41	9.31
P₄₅	7.41	9.33	5.69	4.68	8.36	7.10	7.57	9.52	5.81	4.78	8.53	7.24
P₆₀	10.29	7.47	3.97	9.16	11.29	8.44	10.50	7.63	4.05	9.35	12.85	8.88
Mean	8.03	8.89	8.35	9.56	10.11	8.99	8.19	9.07	7.86	9.76	10.65	9.11
	P		B		P x B		P		B		P x B	
S.E.±	0.970		1.085		2.169		0.934		1.045		2.089	
C.D. @ 5%	2.777		NS		6.211		2.675		NS		5.982	

Table 4.44 Effect of different levels of phosphorus and biofertilizers on iron content (mg kg⁻¹) in groundnut shell

Treat.	Iron (2017-18)						Iron (2018-19)					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P₁₅	2926.39	846.00	1596.99	1700.29	2810.44	1976.02	2709.62	783.34	1478.69	1574.35	2602.26	1829.65
P₃₀	1685.97	4182.55	1933.33	5855.39	2068.72	3145.19	1561.08	3872.73	1790.12	5421.66	1915.49	2912.21
P₄₅	1965.11	1740.63	4777.78	2714.70	837.45	2407.13	1819.55	1611.69	4423.87	2513.62	775.42	2228.83
P₆₀	4013.49	4619.99	3142.47	2485.77	6439.99	4140.34	3716.19	4277.77	2909.70	2301.64	5962.95	3833.65
Mean	2647.74	2847.29	2862.64	3189.04	3039.15	2917.17	2451.61	2636.38	2650.59	2952.81	2814.03	2701.09
	P		B		P x B		P		B		P x B	
S.E.±	542.672		606.726		1213.452		499.276		558.208		1116.415	
C.D. @ 5%	1553.630		NS		NS		1429.390		NS		NS	

Table 4.45 Effect of different levels of phosphorus and biofertilizers on manganese content (mg kg⁻¹) in groundnut shell

Treat.	Manganese (2017-18)						Manganese (2018-19)					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P₁₅	90.05	46.73	34.32	29.79	80.76	56.33	102.34	53.10	39.00	33.86	91.78	64.01
P₃₀	37.86	127.16	51.04	181.02	101.71	99.76	42.69	144.50	58.87	205.69	115.59	113.47
P₄₅	84.73	62.31	44.74	25.15	56.67	54.72	92.50	70.81	50.84	28.58	64.40	61.43
P₆₀	116.45	150.90	44.73	49.71	100.75	92.51	132.33	171.48	50.83	56.45	114.49	105.11
Mean	82.27	96.77	43.71	71.42	84.98	75.83	92.46	109.97	49.89	81.14	96.56	86.00
	P		B		P x B		P		B		P x B	
S.E.±	0.099		0.111		0.222		0.319		0.357		0.714	
C.D. @ 5%	0.284		0.318		0.636		0.914		1.022		2.045	

Table 4.46 Effect of different levels of phosphorus and biofertilizers on zinc content (mg kg⁻¹) in groundnut shell

Treat.	Zinc (2017-18)						Zinc (2018-19)					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P₁₅	24.92	23.30	16.14	23.78	22.27	22.08	24.88	21.77	15.52	22.87	21.52	21.31
P₃₀	14.03	28.71	19.92	22.27	14.03	19.79	13.11	28.70	19.17	21.52	13.11	19.12
P₄₅	28.71	19.92	29.95	21.94	47.02	29.51	28.70	19.17	32.53	20.93	43.15	28.90
P₆₀	35.98	24.19	25.32	21.81	20.03	25.47	35.54	34.04	24.35	16.80	19.28	26.00
Mean	25.91	24.03	22.83	22.45	25.84	24.21	25.55	25.92	22.89	20.53	24.26	23.83
	P		B		P x B		P		B		P x B	
S.E.±	1.013		1.133		2.266		1.226		1.371		2.742	
C.D. @ 5%	2.901		NS		6.487		3.511		NS		7.850	

Table 4.47 Effect of different levels of phosphorus and biofertilizers on copper content (mg kg⁻¹) in groundnut shell

Treat.	Copper (2017-18)						Copper (2018-19)					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P₁₅	15.59	11.48	9.04	11.27	13.06	12.09	15.91	11.72	9.22	11.51	13.33	12.34
P₃₀	14.92	47.70	15.23	28.08	16.46	24.48	15.22	48.67	15.55	28.66	16.80	24.98
P₄₅	43.14	9.23	29.53	8.64	11.43	20.39	44.02	9.42	30.13	8.82	11.66	20.81
P₆₀	24.47	20.39	11.76	10.76	30.77	19.63	24.97	20.81	12.00	10.98	31.40	20.03
Mean	24.53	22.20	16.39	14.69	17.93	19.15	25.03	22.65	16.72	14.99	18.30	19.54
	P		B		P x B		P		B		P x B	
S.E.±	2.267		2.535		5.070		2.401		2.685		5.369	
C.D. @ 5%	6.491		NS		14.515		6.875		NS		15.372	

Table 4.48 Effect of different levels of phosphorus and biofertilizers on total uptake of nitrogen, phosphorus and potassium (kg ha⁻¹) by groundnut

2017-18																		
Treat.	Nitrogen						Phosphorus						Potassium					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	100.39	98.74	110.53	111.20	126.14	109.40	6.77	5.14	5.66	5.24	5.76	5.71	93.66	68.92	54.38	54.34	64.96	67.25
P₃₀	147.06	154.69	160.04	125.99	136.15	144.78	5.96	9.10	7.95	3.36	6.28	6.53	77.22	76.17	77.77	50.88	89.19	74.25
P₄₅	173.13	173.96	184.00	207.32	204.63	188.61	5.88	4.66	3.14	4.28	6.26	4.84	87.80	79.52	63.59	73.92	74.42	75.85
P₆₀	190.95	186.77	192.53	220.91	253.08	208.85	9.42	7.94	7.95	6.91	9.51	8.34	76.82	82.72	95.14	96.89	75.99	85.51
Mean	152.88	153.54	161.77	166.36	180.00	162.91	7.01	6.71	6.17	4.95	6.95	6.36	83.87	76.83	72.72	69.01	76.14	75.72
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	6.209		6.942		13.883		0.156		0.175		0.350		3.194		3.571		7.142	
C.D. @ 5%	17.775		NS		39.746		0.448		0.501		1.001		9.144		NS		20.447	
2018-19																		
Treat.	Nitrogen						Phosphorus						Potassium					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	184.42	120.16	109.46	185.19	166.49	153.14	5.49	4.16	4.58	4.24	4.66	4.63	95.05	67.54	53.30	53.25	63.66	66.56
P₃₀	166.89	205.36	215.50	182.91	163.63	186.86	4.83	7.37	6.44	3.91	5.09	5.52	75.67	74.65	76.22	49.87	87.41	72.76
P₄₅	220.60	249.79	216.53	201.04	270.97	231.79	4.76	3.78	2.55	3.46	5.07	3.92	86.05	77.93	62.32	72.44	72.93	74.33
P₆₀	228.31	232.31	219.81	292.53	286.35	251.86	7.63	6.43	6.44	5.60	7.70	6.76	75.28	81.06	96.51	94.95	75.12	84.59
Mean	200.06	201.90	190.32	215.42	221.86	205.91	5.68	5.43	5.00	4.30	5.63	5.21	83.01	75.29	72.09	67.63	74.78	74.56
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	7.134		7.976		15.952		0.185		0.207		0.414		3.154		3.527		7.054	
C.D. @ 5%	20.423		NS		45.668		0.530		0.593		1.186		9.031		NS		20.194	

Table 4.51 Effect of different levels of phosphorus and biofertilizers on total uptake (g ha⁻¹) of zinc by groundnut

Treat.	Zinc (2017-18)						Zinc (2018-19)					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P₁₅	228.62	167.54	267.81	259.11	228.57	230.33	215.05	154.03	246.77	242.97	193.44	210.45
P₃₀	274.13	390.80	224.96	251.13	264.46	281.10	212.63	339.60	195.00	262.62	294.40	260.85
P₄₅	295.82	299.40	290.01	252.83	423.06	312.23	299.28	327.74	287.60	232.48	396.48	308.72
P₆₀	294.33	305.00	331.33	242.78	328.59	300.41	280.93	294.65	314.04	225.86	324.29	287.95
Mean	273.23	290.69	278.53	251.46	311.17	281.01	251.97	279.00	260.85	240.98	302.15	266.99
	P		B		P x B		P		B		P x B	
S.E.±	12.011		13.429		26.858		12.609		14.097		28.194	
C.D. @ 5%	34.387		38.446		76.892		36.097		40.358		80.716	

Table 4.52 Effect of different levels of phosphorus and biofertilizers on total uptake (g ha⁻¹) of copper by groundnut

Treat.	Copper (2017-18)						Copper (2018-19)					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P₁₅	95.93	47.24	93.69	87.27	72.04	79.23	67.82	37.03	63.65	71.36	49.63	57.90
P₃₀	77.05	161.89	100.16	72.88	98.86	102.17	49.95	118.02	67.87	63.92	91.00	78.15
P₄₅	132.39	75.60	95.68	70.58	92.16	93.28	128.12	65.67	79.10	50.60	68.54	78.41
P₆₀	97.78	100.32	70.81	86.50	160.59	103.20	89.61	79.64	54.46	69.39	112.28	81.08
Mean	100.79	96.26	90.08	79.31	105.91	94.47	83.88	75.09	66.27	63.82	80.36	73.88
	P		B		P x B		P		B		P x B	
S.E.±	7.171		8.018		16.035		6.718		7.511		15.022	
C.D. @ 5%	NS		NS		45.907		NS		NS		43.007	

Table 4.53 Effect of different levels of phosphorus and biofertilizers on oil, protein and methionine content (%) in groundnut

2017-18																		
Treat.	Oil content						Protein content						Methionine					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	44.50	44.81	45.57	46.41	46.82	45.62	22.28	22.87	23.57	23.98	24.27	23.39	0.18	0.21	0.24	0.26	0.27	0.23
P₃₀	48.84	48.61	48.18	47.37	45.59	47.72	24.79	25.73	26.19	26.37	26.89	25.99	0.28	0.31	0.32	0.35	0.37	0.33
P₄₅	45.63	44.81	49.38	49.75	50.26	47.97	29.98	30.51	31.15	28.88	29.52	30.01	0.49	0.39	0.40	0.47	0.47	0.44
P₆₀	50.14	49.44	50.33	50.05	51.21	50.23	27.53	28.12	28.23	31.38	31.62	29.38	0.38	0.46	0.43	0.44	0.45	0.43
Mean	47.28	46.91	48.37	48.40	48.47	47.88	26.15	26.80	27.29	27.65	28.07	27.19	0.33	0.34	0.35	0.38	0.39	0.36
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.452		0.505		1.010		0.143		0.160		0.320		0.006		0.007		0.014	
C.D. @ 5%	1.293		NS		2.891		0.410		0.458		0.917		0.017		0.019		0.039	
2018-19																		
Treat.	Oil content						Protein content						Methionine					
	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean	B₀	B₁	B₂	B₃	B₄	Mean
P₁₅	46.38	45.39	45.54	47.05	47.46	46.36	22.73	23.32	24.04	24.45	24.75	23.86	0.19	0.21	0.24	0.26	0.27	0.23
P₃₀	49.19	47.90	47.64	47.96	46.23	47.78	25.29	26.24	26.72	26.89	27.43	26.51	0.29	0.31	0.33	0.35	0.37	0.33
P₄₅	46.27	44.40	50.03	50.40	50.55	48.33	30.58	31.12	31.77	29.45	30.11	30.61	0.49	0.40	0.40	0.47	0.48	0.45
P₆₀	50.81	50.16	50.63	49.54	50.03	50.23	28.08	28.68	28.80	32.01	32.25	29.96	0.39	0.46	0.44	0.45	0.45	0.44
Mean	48.16	46.96	48.46	48.74	48.57	48.18	26.67	27.34	27.83	28.20	28.63	27.74	0.34	0.35	0.35	0.38	0.39	0.36
	P		B		P x B		P		B		P x B		P		B		P x B	
S.E.±	0.473		0.529		1.058		0.146		0.163		0.327		0.006		0.007		0.014	
C.D. @ 5%	1.354		NS		3.028		0.418		0.468		0.935		0.018		0.020		0.039	

Table 4.54 Effect of different levels of phosphorus and biofertilizers on shelling percentage of groundnut

Treat.	2017-18						2018-19					
	B ₀	B ₁	B ₂	B ₃	B ₄	Mean	B ₀	B ₁	B ₂	B ₃	B ₄	Mean
P₁₅	62.13	62.67	63.24	63.68	64.08	63.16	63.66	64.55	65.10	65.59	66.00	64.98
P₃₀	64.79	65.34	65.91	66.43	66.88	65.87	66.74	67.30	67.89	68.42	68.89	67.85
P₄₅	67.50	70.36	70.72	70.92	69.07	69.71	69.53	72.47	72.77	73.08	71.14	71.80
P₆₀	69.55	67.93	68.11	68.84	71.62	69.21	71.64	69.97	70.15	70.84	73.77	71.27
Mean	65.99	66.58	67.00	67.47	67.91	66.99	67.89	68.57	68.98	69.48	69.95	68.98
	P		B		P x B		P		B		P x B	
S.E.±	0.134		0.150		0.300		0.141		0.158		0.316	
C.D. @ 5%	0.384		0.430		0.859		0.405		0.452		0.905	

APPENDIX – I

ABBREVIATIONS USED

AF	: At flowering
AH	: At harvest
BF	: Biofertilizers
C.D.	: Critical Difference
cfu	: colony forming unit
cm	: Centimeter(s)
Cv.	: Cultivar
DAS	: days after sowing
DMA	: Dry matter accumulaton
DTPA	: Di-ethylene Tri-amine Penta Acetic Acid
E.C.	: Electrical conductivity
EDTA	: Ethylene Di-amine Tetra Acetic Acid
Fig.	: Figure(s)
FRBD	: Factorial Randomized Block Design
FYM	: Farm Yard Manure
MBC	: Microbial biomass carbon
m	: meter
M.O.P	: Muriate of potash
M.S.	: Maharashtra State
M.T.	: Metric tonnes
MRP	: Mussoorie rock phosphate
N.S.	: Non-significant
no.	: Number
nm	: Nano metre
PI	: Peg initiation stage
Plant ⁻¹	: per plant
pp	: particular page
ppm	: parts per millions
PSB	: Phosphate Solubilizing Bacteria
PNP	: Para nitro phenol
RBD	: Randomized Block Design
RDF	: recommended dose of fertilizer
S.E. (m)	: Standard error of mean
S.S.P	: Single super phosphate
T	: tonnes(s)
TEA	: Tri ethanol amine
TTC	: Triphenyl Tetrazolium chloride
Tr.	: Treatments
TPF	: Tri phenyl formazon
VAM	: Vesicular ArbuscularMycorrhizal
var.	: Variety
viz.	: Namely
wt.	: weight

APPENDIX – II

A) Ratings given by Banger and Zende (1978)

1) Soil pH :

pH	Ratings
Extremely alkaline	< 9.0
Strongly alkaline	8.4-9.0
Moderately alkaline	7.6-8.3
Slightly alkaline	7.1-7.5
Nearly Neutral	7.6-7.0
Slightly acid	6.0-6.5
Moderately acid	5.3-5.8
Strongly acid	4.5-5.2
Extremely acid	< 4.5

2) Organic carbon content of soil :

Organic carbon	Ratings [g kg⁻¹]
Very low	< 0.20
Low	0.21-0.40
Medium	0.41-0.60
Moderately low	0.61-0.80
High	0.81-1.00
Very High	>1.00

3) Available nitrogen content of soil :

Nitrogen	Ratings [kg ha⁻¹]
Very low	< 140
Low	141-280
Medium	281-420
Moderately low	421-560
High	561-700
Very High	>701

4) Available phosphorous content of soil :

Phosphorus	Ratings [kg ha⁻¹]
Very low	< 7
Low	7.1-14
Medium	14.1-21
Moderately low	21.1-28
High	28.1-35
Very High	>35

5) Available potassium content of soil :

Potassium	Ratings [kg ha⁻¹]
Very low	< 100
Low	101-150
Medium	151-200
Moderately low	201-250
High	251-300
Very High	>300

B) Critical limits (Linsay and Norvell, 1978)

Available micronutrients	Critical limit (mg kg⁻¹)
Fe	4.5
Mn	1.0
Cu	0.2
Zn	0.8

Fig. 4.1 Effect of different levels of phosphorus and biofertilizers on soil pH under groundnut at different growth stages

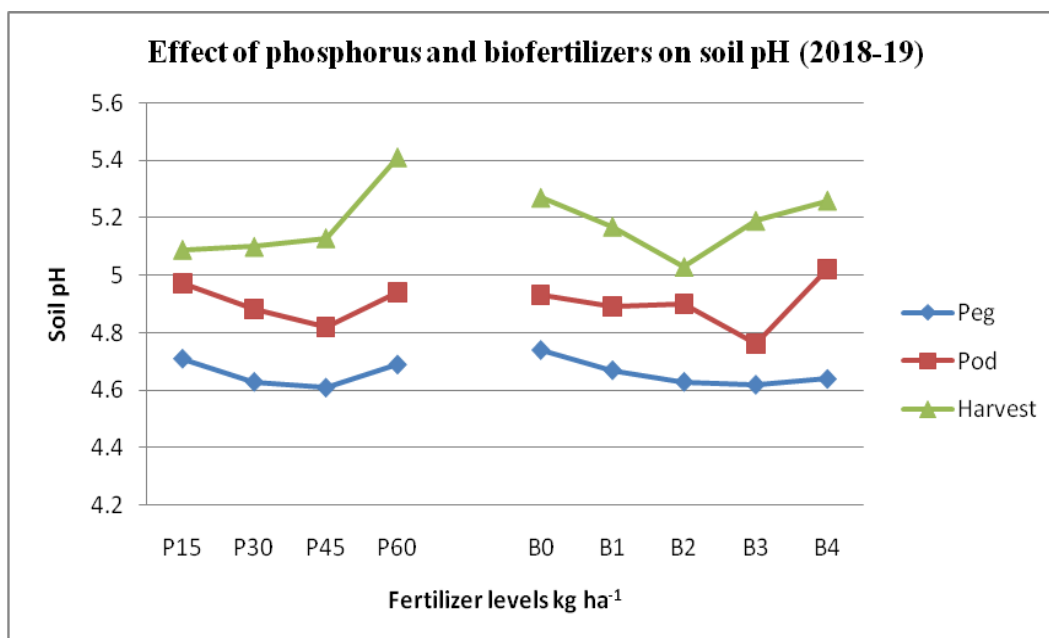
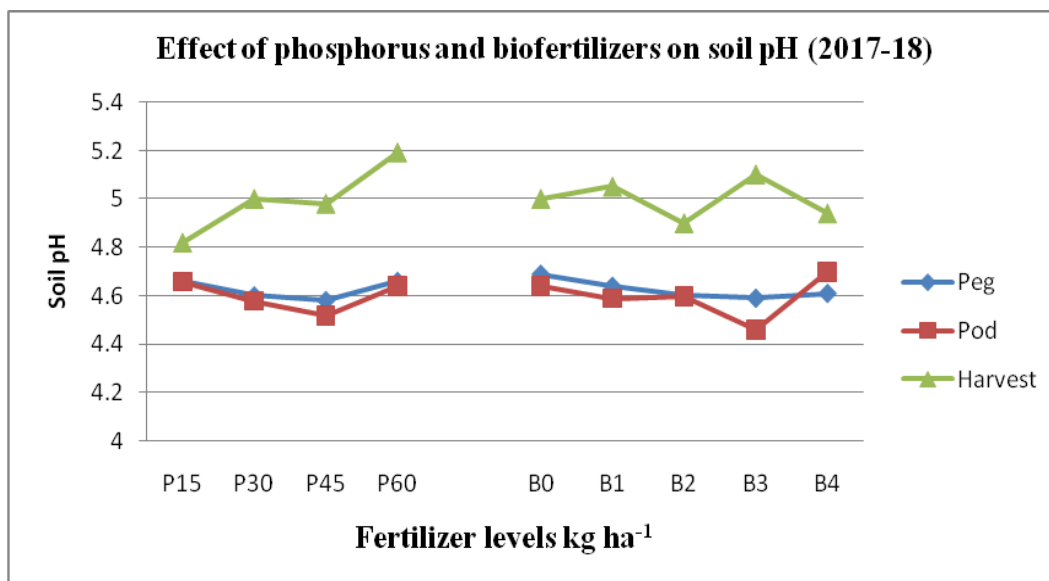


Fig. 4.2 Effect of different levels of phosphorus and biofertilizers on soil organic carbon content (kg ha^{-1}) under groundnut at different growth stages

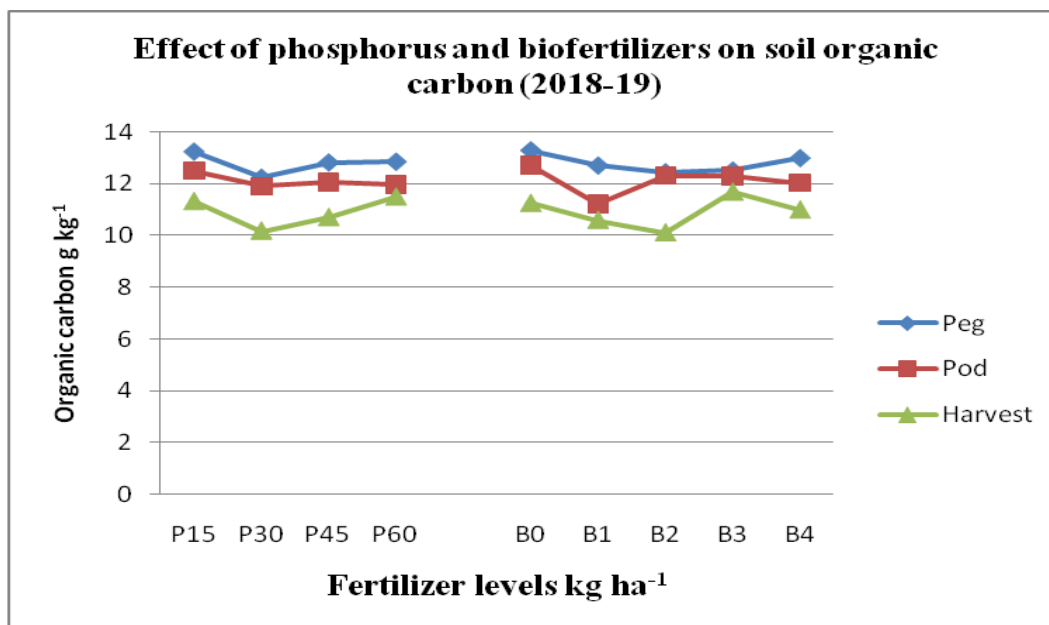
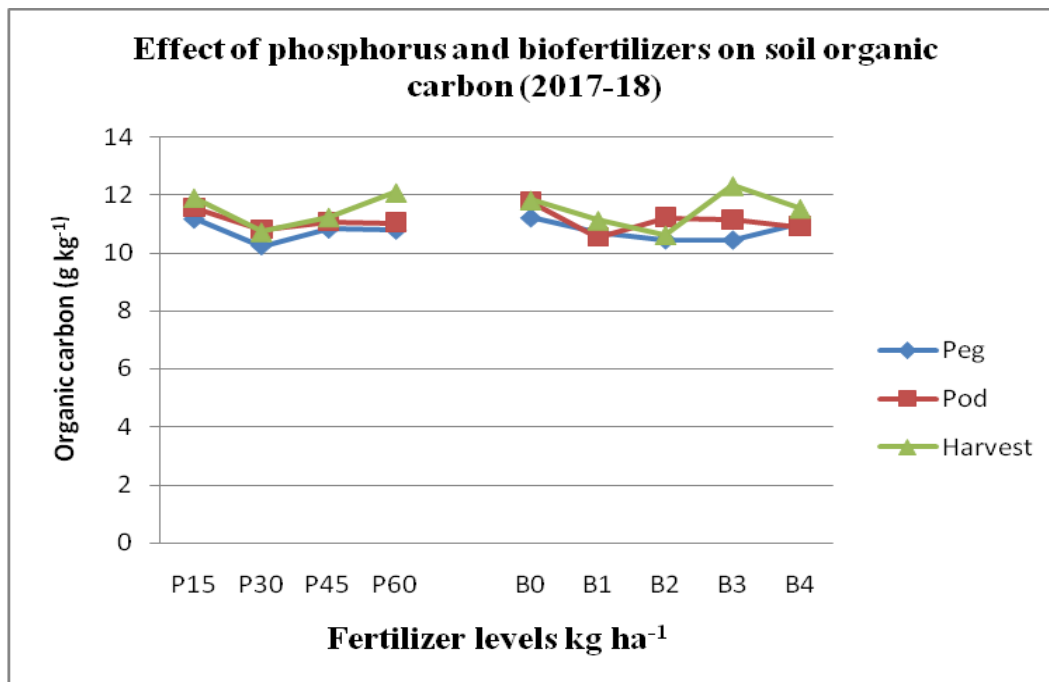


Fig. 4.3 Effect of different levels of phosphorus and biofertilizers on soil available phosphorus content (kg ha^{-1}) under groundnut at different growth stages

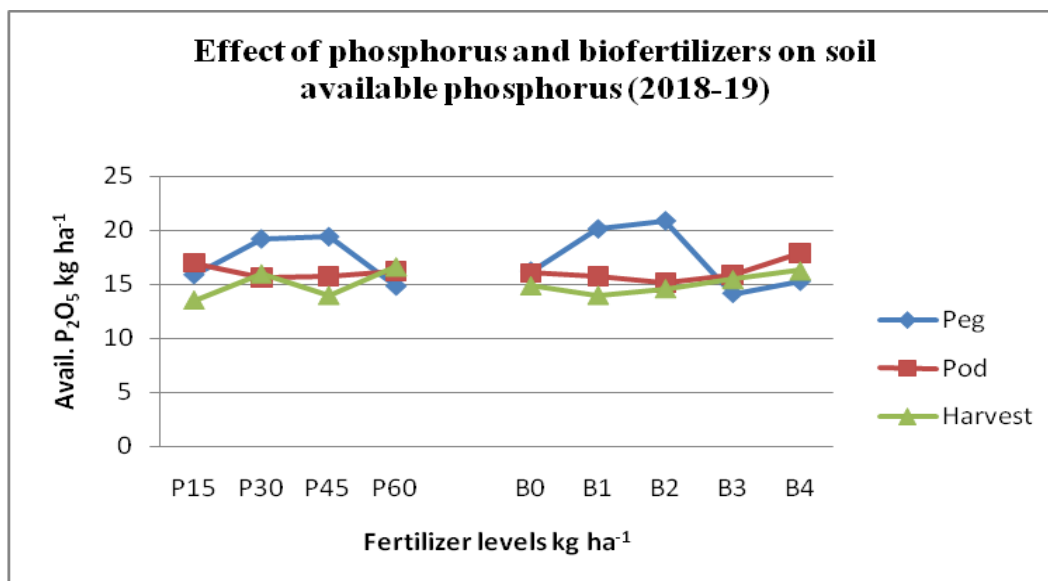
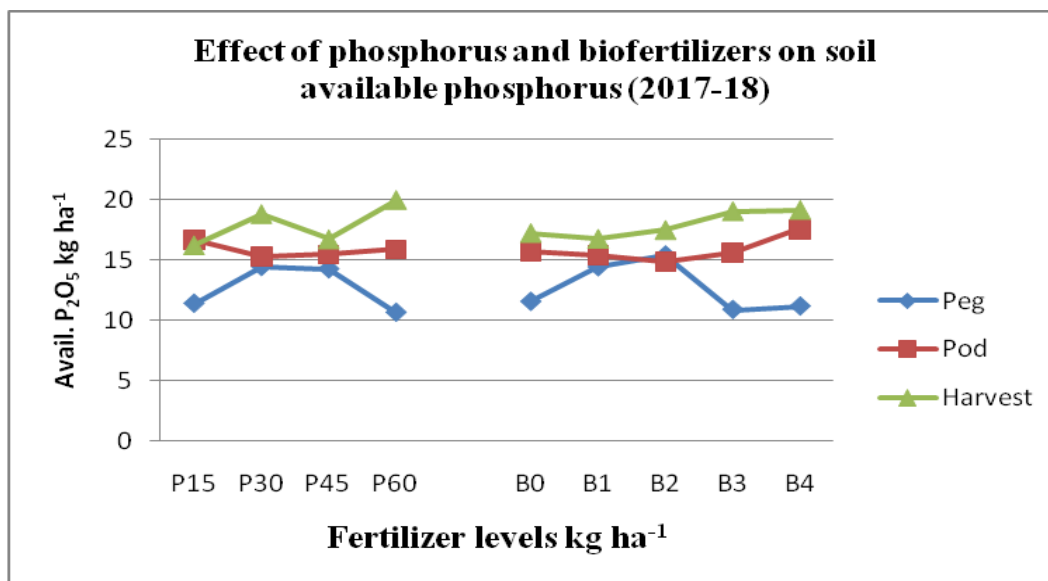


Fig. 4.4 Effect of different levels of phosphorus and biofertilizers on pod and halum yield ($q\ ha^{-1}$) of groundnut

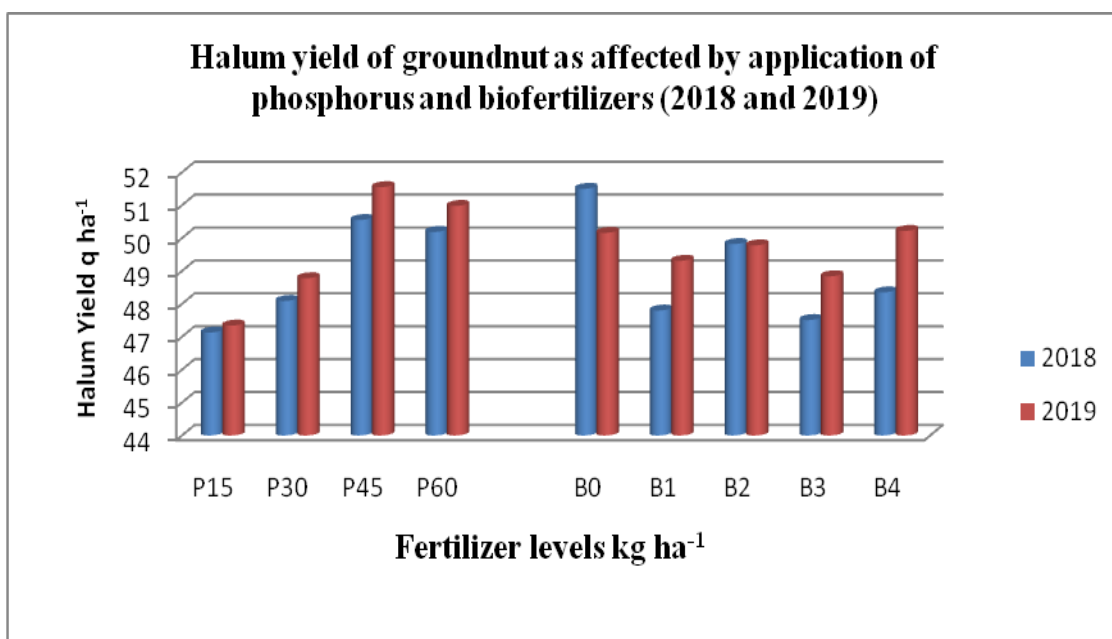
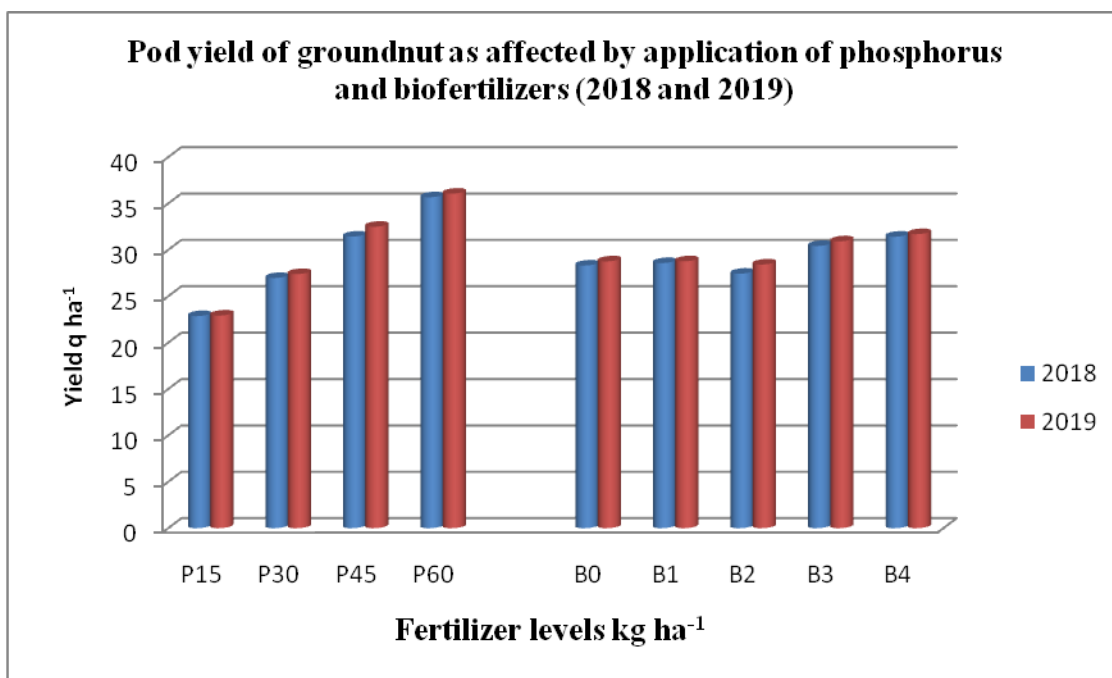




Plate 1 : General view of the experimental plot



Actinomycete count



Bacterial count

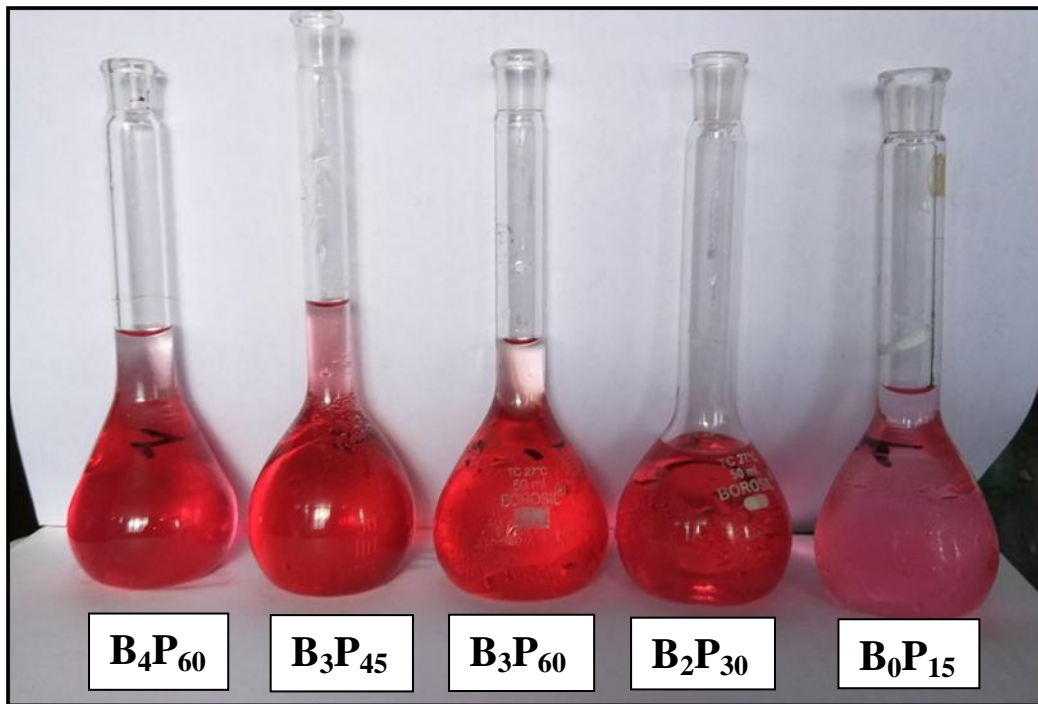


Fungal count

Plate 2 : Microbial count at pod formation stage



Dehydrogenase activity



Urease activity

Plate 3 : Enzyme activity at pod formation stage

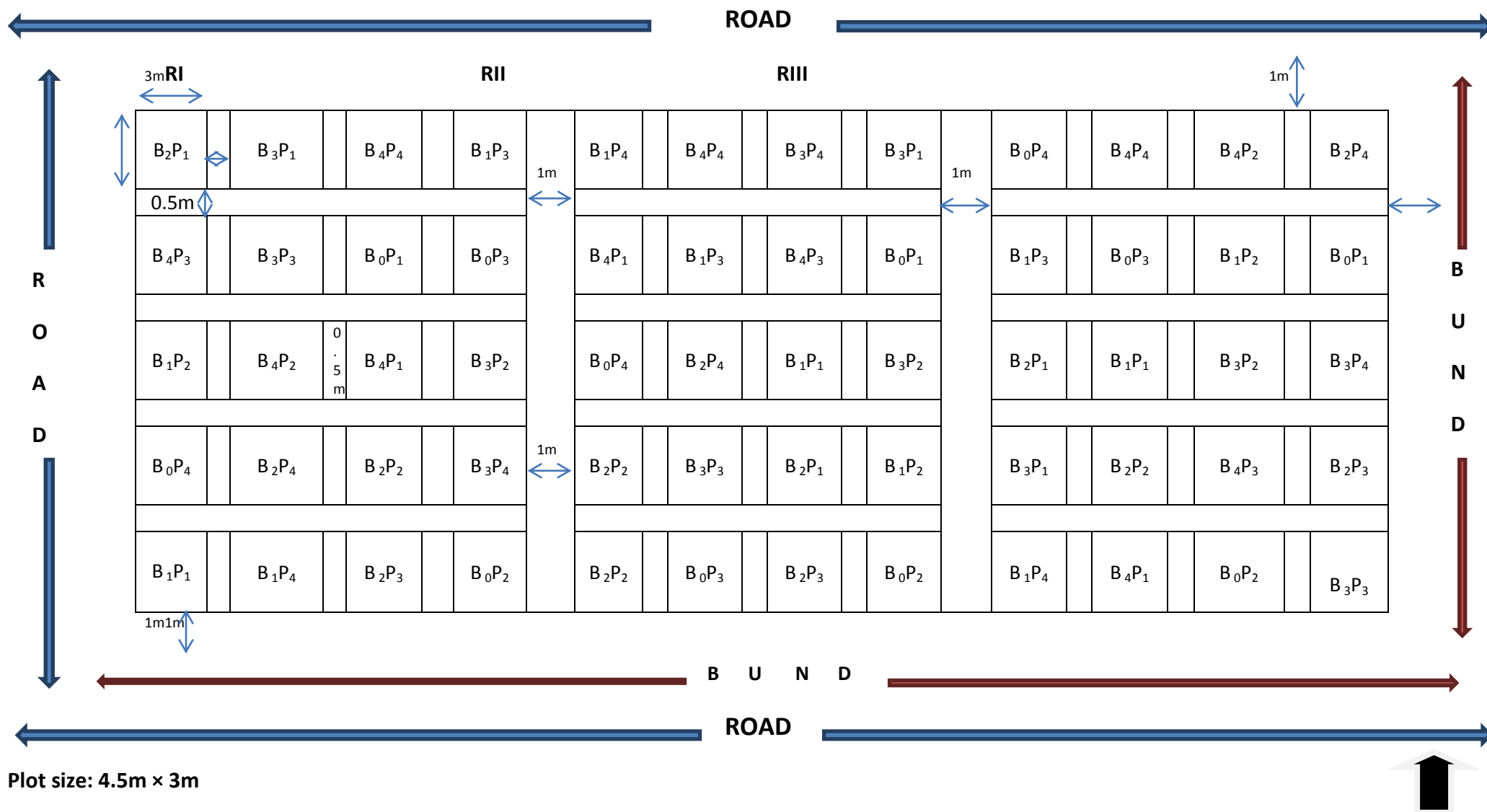


Fig. 1 : Layout plan of experimental plot