

**EFFECT OF CONSORTIUM OF PHOSPHATE SOLUBILIZING  
BACTERIA ON PHOSPHORUS AVAILABILITY, NUTRIENT CONTENT  
AND YIELD OF SOYBEAN (*Glycine max. L.*)**

by

**Mr. Gaikwad Dilip Hari**

(Reg. No. K-17/106)



**DIVISION OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY**

**RAJARSHEE CHHATRAPATI SHAHU MAHARAJ  
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RAHURI-413722, DIST-AHMEDNAGAR  
MAHARASHTRA, INDIA  
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A Thesis submitted to the  
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RAHURI- 413 722, DIST- AHMEDNAGAR,  
MAHARASHTRA, INDIA.**

In partial fulfilment of the requirements for the degree

of

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in

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MAHARASHTRA, INDIA**

**2019**

## CANDIDATE'S DECLARATION

I hereby declare that this thesis or part  
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other University or Institute  
for a Degree or  
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## CERTIFICATE

This is to certify that the thesis entitled, “**Effect of consortium of phosphate solubilizing bacteria on phosphorus availability, nutrient content and yield of soybean (*Glycine max. L.*)**” submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar (Maharashtra) in partial fulfilment of the requirement for the award of the degree of **MASTER OF SCIENCE (AGRICULTURE) in SOIL SCIENCE AND AGRICULTURAL CHEMISTRY**, embodies the result of a piece of bonafide research work carried out by **Mr. Gaikwad Dilip Hari** under my guidance and supervision and that no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been duly acknowledged.

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Date:

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## ABBREVIATIONS AND SYMBOLES

%	:	Per cent
<sup>0</sup> C	:	Degree Celsius
@	:	At the rate of
Agril.	:	Agricultural
cm	:	Centimeter (s)
Ca	:	Calcium
DAS	:	Days after sowing
DAP	:	Diammonium phosphate
dS m <sup>-1</sup>	:	DeciSiemens per metre
EC	:	Electrical conductivity
EDTA	:	Ethelene di-amine tetra acetic acid
et al.	:	And other (et alli)
etc.	:	Et cetera
Fig.	:	Figure
G	:	Gram
ha <sup>-1</sup>	:	Per hectare
i.e.	:	That is (id est)
K	:	Potassium
KUE	:	Potassium use efficiency
kg ha <sup>-1</sup>	:	Kilogram per hectare
Mg	:	Milli gram
mL	:	Milli liter
mm	:	Milli meter
Mg	:	Magnesium
N	:	Nitrogen
NUE	:	Nitrogen use efficiency
O.C.	:	Organic carbon
Plant <sup>-1</sup>	:	per plant
P	:	Phosphorus
PUE	:	Phosphorus use efficiency
pH	:	Poissionus dehydrogeous ratio

PNP	:	P-nitrophenyl phosphate
P <sub>2</sub> O <sub>5</sub>	:	Phosphate
pp.	:	Particular page
q ha <sup>-1</sup>	:	Quintal per hectare
RDF	:	recommended dose of fertilizer
S	:	Sulphur
t ha <sup>-1</sup>	:	Tonne (s) per hectare
TPF	:	Triphenyl formazan
TTC		Triphenyl tetrazolium chloride
<i>viz.</i>	:	Namely (videlicent)

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**ABSTRACT**


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**“EFFECT OF CONSORTIUM OF PHOSPHORUS SOLUBILIZING BACTERIA ON PHOSPHORUS AVAILABILITY, NUTRIENT CONTENT AND YIELD OF SOYBEAN (*Glycine max.L.*)”**

by

**Mr. Gaikwad Dilip Hari**

A Candidate for the degree

of

**MASTER OF SCIENCE (AGRICULTURE)**

in

**Soil Science and Agricultural Chemistry**

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Research Guide	:	Dr. P. N. Gajbhiye
Division	:	Soil Science and Agricultural Chemistry

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The field experiment entitled “Effect of consortium of phosphate solubilizing bacteria on phosphorus availability, nutrient content and yield of soybean (*Glycine max. L.*)” was conducted during *Kharif*, 2018 at Agronomy Farm, Rajarshee Chhatrapati Shahu Maharaj College of Agriculture, Kolhapur. The experiment comprised of eight treatments replicated thrice and statistically tested using randomized block design. The present investigation was carried out to evaluate the effect of consortium of phosphate solubilizing bacteria on phosphorus availability, growth, yield attributes, yield, nutrient uptake, quality parameter and nodulation characteristics of soybean. The hypothesis, behind the expected enhancement in yield and growth attributes of soybean was the ability of consortium of *Bacillus subtilis*, *Pseudomonas fluorescens* and *Bacillus megaterium* (PSBs) to mitigate the complexity involved with soil phosphorus availability. The treatment consisted 100 percent of recommended dose of fertilizer for soybean and two lower level of phosphorus as 75 and 50 percent P<sub>2</sub>O<sub>5</sub> with and without consortium of PSB. Application of 10 tonnes FYM ha<sup>-1</sup> was common to all treatments except the absolute control.

Inoculation with consortium of PSB in conjunction with inorganic fertilizer unveiled positive effect on all the parameters under study. The 100 seed weight was found to be statistically non-significant but higher values were reflected by treatment (T<sub>7</sub>) consortium of PSB + 75 % P<sub>2</sub>O<sub>5</sub> + 100 % N and K<sub>2</sub>O (19.52 g plant<sup>-1</sup>) followed by T<sub>8</sub> i.e. consortium of PSB + 100 % GRDF. Maximum plant height was recorded in T<sub>8</sub> (48.9 cm) which was statistically significant over control and was at par with all other treatments with and without PSB inoculation. The total number of pods was observed to be significantly higher in T<sub>8</sub> (89.3 plant<sup>-1</sup>) which was statistically at par with T<sub>7</sub> and T<sub>4</sub> (100 % GRDF without inoculation.)

The applied P along with PSB played an imperative role in enhancing the grain yield of soybean. Significant highest grain yield was recorded by treatment T<sub>8</sub> (36.9 q ha<sup>-1</sup>) which was found to be statistically at par with T<sub>7</sub> (36.2 q ha<sup>-1</sup>). The straw yield followed the similar trend to that of grain yield.

Protein and oil content values in soybean seed differed numerically within the treatments but were found to be statistically non-significant. The highest protein content was recorded by treatment T<sub>7</sub> (42.2 %) which was followed by T<sub>8</sub>, however, both of these treatments recorded numerically identical highest value of oil content (21.2 %). Thus, though non-significant but the

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**Abstract contd....**

**Mr. Gaikwad Dilip Hari**

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quality parameters were positively influenced by inoculation treatments.

The major and micronutrient content in soybean grain and straw did not differ much within the treatments and was found to be statistically non-significant. There was a slight increment in nutrient contents in the PSB inoculated treatments indicating the enhanced availability of both major nutrient (NPK) and micronutrients. The uptake of these nutrients by soybean crop however, varied significantly with maximum values being recorded in T<sub>8</sub> treatment which were statistically at par with T<sub>7</sub>.

The soil pH and EC remained unaffected due to the various treatments. The organic carbon content also did not varied to major extent between the treatment with and without PSB inoculation but significant highest value was recorded by T<sub>8</sub> (0.62 %) over control. The overall status of available major and micronutrient was positively influenced by conjunct use of consortium of PSB and inorganic fertilizer. The treatment consortium of PSB + 100 % GRDF (T<sub>8</sub>) recorded significant higher values of available N, P, K, Cu, Fe, Zn and Mn (252 kg ha<sup>-1</sup>, 37.8 kg ha<sup>-1</sup>, 379 kg ha<sup>-1</sup>, 2.97 mg kg<sup>-1</sup>, 6.03 mg kg<sup>-1</sup>, 0.97 mg kg<sup>-1</sup> and 7.82 mg kg<sup>-1</sup> respectively) and these values were statistically at par with treatment T<sub>7</sub> consisting PSB + 75 % P<sub>2</sub>O<sub>5</sub>+ 100 % N and K<sub>2</sub>O.

The phosphorus availability pattern at different days of incubation (0, 15, 30, 45, 60, 90 DAI) revealed that the Olsen's P concentration at 0 and 15 DAI did not vary significantly within the treatments whereas, at 30, 45, 60 and 90 DAI the P concentration was observed to be significantly varying. The significantly highest value of available P at 90 DAI was recorded by treatment T<sub>8</sub> (41.70 mg kg<sup>-1</sup>) which was at par with T<sub>7</sub>.

The significant and highest DHA activity (4.21 µg TPF g Soil<sup>-1</sup> hr<sup>-1</sup>), acid phosphatase (150.6 µg PNP g Soil<sup>-1</sup> hr<sup>-1</sup>) and alkaline phosphatase (253.9 µg PNP g Soil<sup>-1</sup> hr<sup>-1</sup>) was recorded by T<sub>8</sub> which was statistically at par with treatment T<sub>7</sub>.

## 1. INTRODUCTION

Soybean (*Glycine max.* L) is one of the most important oilseed crops in the world. It is reported to have originated in Eastern Asian countries and the cultivated soybean originated in China during 2800 BC. The Eastern half of North China has been believed to be the primary centre and Manchuria, the secondary centre of origin. The utilization of soybean has been mentioned almost 6000 years back in the medical compilations of China. For centuries together this crop has been meant meat, milk, cheese, bread and oil to the people of China, Japan, Korea, Manchuria, the Philippines and Indonesia. This could well be the reason, why in these countries, it has earned sobriquets like “Cow of the field” or “Gold from soil”. The western world has been a late entry into soybean production which can be illustrated by the fact that even during 1921, China was the leading producer of soybean with almost 80 % of world’s soybean production. The western countries gradually recognized the potential of soybean for food, feed and numerous industrial products which in particular revolutionized the agricultural economy of the USA. Historically, soybean is not a new crop to India. It was grown in India long before it was introduced to the USA in the early 1800s. Black soybean has been grown for ages in low Himalayan hills as well as in the foothills and some scattered pockets of central India (Bisaliah 1986).

Despite, this historical background the development of soybean crop was delayed in India and eventually after recognizing the importance of soybean as commercial crop with immense potential for food and feed. In india, it was introduced in to the mainstream agriculture during seventies of the 20<sup>th</sup> century.

At present, globally, area under soybean cultivation is around 121 million hectares and five major producing countries (USA, Brazil, Argentina, India and China) account for more than 85% of global soybean area and 88.5% of production. The record production of soybean was estimated during 2016-17 as 349 million tonnes (Sharma and Patel 2017).

India ranks fifth in area and production of soybean after USA, Brazil, Argentina, and China and second in Asia. It accounts for 3.95 per cent of global soybean production according to Statista. From the 2004-05 season to the 2012-13 season, there has been a compound annual growth rate of 9.6 per cent for soybean production in the country, according to the (FICCI) Federation of Indian Chambers of Commerce and Industry (worldatlas). The estimated production of soybean during *kharif* 2016 was 13.79 million tones from an area of 11.39 million hectares with the productivity of over 1.2 t ha<sup>-1</sup>. The growth in area and production of soybean in India since, 1970-71 is highly noteworthy. Acreage under soybean has increased at an annual compound growth rate of 13.3% for the period from 1970-71 to 2016-17 and 4.5% from 2000-

01. Production of soybean in India increased at an annual growth rate of 14.8% for 1970-71 to 2016-17 and 5.5% for 2000-01 to 2016-17 (Sharma and Patel 2017).

In the Indian subcontinent, the area under soybean is spread in latitudinal belt of about 15°–25°N comprising the states of Madhya Pradesh, Maharashtra, Rajasthan, Chhattisgarh, Andhra Pradesh, and Karnataka. The per cent contribution of these states together accounted to be 98 % of the total soybean production in the country. In recent years, rapid growth in area under soybean cultivation has been noticed in the southern part of the country particularly in the states of Maharashtra, Andhra Pradesh, and Karnataka. Madhya Pradesh since beginning has been the major contributor to the soybean area and production, currently Madhya Pradesh is contributing 59% of area and production followed by Maharashtra with a contribution of 28 and 26% in terms of total area and production of the country (Agrawal *et al.* 2013)

In Maharashtra soybean is mainly cultivated as rainfed crop from June to November. Satara, Sangli, Kolhapur, Solapur, Pune, Ahmednagar, etc. are major soybean cultivating districts of Maharashtra state. In Maharashtra, soybean is cultivated on an area of 3.8 M ha with production of 3.07 m ton with second rank in India. (Jaybhay *et al.* 2018)

Soybean has not only gained the vital importance in agriculture, but also plays a decisive role in oil economy of India. It has the highest protein content (40-42 %) of all other food crops and is second only to groundnut in terms among food legumes (Robert, 1986). It is basically a pulse crop and gained the importance as an oil seed crop as it contains 20% cholesterol free oil and high quality protein due to this reason, soybean is known as ‘poor man’s meat’. Soybean played a key role in the yellow revolution. Generally, it is used in the industry for flour, oil cookies candy, milk, vegetable cheese, lecithin and many other products. Only 2% of soybean protein is consumed directly by humans in the form of soy food products such as tofu, soy hamburger, or soy milk analogs. All but a very small percentage of the other 98% is processed into soybean meal and fed to livestock, such as poultry and pigs. Soybean contains a class of phytochemicals called flavonoids which are thought to have certain health benefits and have potential to prevent some diseases such as heart disease, osteoporosis and certain cancers (Aparicio *et al.*, 2008).

In the recent years, the soybean yield across the country has been declining or stagnant. The plausible reasons for this may be the climatic conditions, cultivars, cropping system or management practices. Nutrient management in soybean is one of aspects which needs prime consideration in soybean production. Soybean, being a legume has the inherent ability to fix atmospheric nitrogen (N<sub>2</sub>) in symbiotic association N fixing bacteria. It forms a symbiotic relationship with soil borne rhizobia bacteria (*Bradyrhizobium japonicum*) to convert, or ‘fix’ atmospheric N gas to ammonia (NH<sub>3</sub>) N, a form usable by the plant. The rhizobia bacterium

attaches to new soybean roots just behind the root tip then colonizes the plant. In response to bacterial chemical signals, plant root cells form nodules, help to protect the bacteria from oxygen. Nodules grow very rapidly and continue to supply N to the plant for approximately six weeks. Nodules begin supplying N during the early vegetative growth (McGrath *et al.* 2013). Potassium not only improves yields but also benefits various aspects of quality (oil and protein content, larger seed size). Potassium increases nodulation in soybean's roots and also provides resistance against pest and diseases. Besides, nitrogen and potassium, phosphorus is the second most important nutrient in soybean production after nitrogen.

Phosphorus is a major growth-limiting nutrient, and unlike the case for nitrogen, there is no large atmospheric source that can be made it biologically available. Root development, stalk and stem strength, flower and seed formation, crop maturity and production, N-fixation in legumes, crop quality, and resistance to plant diseases are the attributes associated with phosphorus nutrition. The soil phosphorus, despite, being abundant in soil in both inorganic and organic forms however, 'P' content in average soil is about 0.05 % (w/w) but only 0.1% of the total P is available to plants because of its low solubility and its fixation in soil. To circumvent the problem of 'P' deficiency, chemical fertilizers are added to the soil. The utilization efficiency of phosphatic fertilizers by plants is only 20 to 25 % largely due to its chemical fixation in soil (Hedley *et al.*, 1995)

In the context of soil test phosphorus, two apprehensions are of paramount importance i) augmenting available soil phosphorus ii) utilization of accumulated soil test phosphorus due to over application of fertilizer P. Phosphorus unlike nitrogen does not get leached down with the water but it get fixed in the soil. The phosphorus fixation is mainly governed by soil reaction (pH). In soil with higher pH most phosphorus is in the form of calcium compounds while in soils with lower pH, phosphorus is combined with iron and aluminum compounds. Maximum phosphorus availability occurs at a soil pH between 6.5 to 7.0. Large amount of P applied as fertilizer enters in to the immobile pools through precipitation reaction with highly reactive  $\text{Al}^{3+}$  and  $\text{Fe}^{3+}$  in acidic, and  $\text{Ca}^{2+}$  in calcareous or normal soil (Goldstein, 1986) this could be the plausible explanation why it necessary to enhance soil phosphorus availability. While on the other hand, accumulation of unnecessary high soil test P levels is being observed which needs to be addressed. The high value of soil test phosphorus is substantially causing ecological anomalies by mean of eutrophication and other concern is, use of phosphate rock to manufacture P fertilizer which is a critical raw material. The unnecessary accumulation of soil test P in agricultural soils is due to over-application of P. Utilization of P store and reducing the soil test P concentration could prove

effective strategy to mitigate the pressure on critical phosphorus rock and eutrophication, (Sattari *et al.* 2012). Rowe *et al.* 2016

Suggested two strategies in this context, first by omitting either wholly or partially P inputs where feasible and second to reduce the soil test P concentration without loss in production by adopting advance technologies like precision farming, plant breeding, microbial engineering etc. to recover and recycle P.

There has been long standing interest to manipulate soil microorganisms to improve P nutrition of plants. Phosphorus bio-fertilizers in the form of microorganisms can help in increasing the availability of accumulated phosphate for plant growth by solubilization. Apart from fertilization and enzymatic decomposition of organic compounds, microbial immobilization would be the only possible way to answer plant available 'P' (Illmer, and Schinner, 1992). The organisms possessing a phosphate solubilizing ability can also convert the insoluble phosphatic compounds into soluble form in soil and make them available to the plant (Kang *et al.*, 2002<sup>b</sup>). Phosphate solubilizing bacteria such as *Bacillus, megaterium, var phosphaticum, Pseudomonas, Aspergillus and penicillium etc* in the rhizosphere of crop and soils has been reported to help increasing phosphorus availability in soil. These bacteria can be effectively used as bio-inoculants in soybean, wheat, rice, Bengal gram and other crops and due emphasize is needed to be given to evaluate efficient strains individually and in consortium to achieve greater phosphorus availability and higher yield in legume like soybean (Gaur, 1990). The phosphate solubilizing bacteria in combination with inorganic fertilizer or alone has substantiated the beneficial effect on crop growth and yield. For instance, inoculation with *Bradyrhizobia* inoculant and phosphate solubilizing bacteria with varied N levels enhances the nodulation in soybean and soil available nutrients (Tran *et al.* 2006). Inoculation with *Rhizobium* and phosphate solubilizing bacteria has positive impact on nodulation in chickpea and also enhances the soil nutrient status (Tagore *et al.* 2013). The combination of PSB and poultry manure with rock phosphate could be the feasible option for releasing P from insoluble rock phosphate for a longer period (Abbasi *et al.* 2015). Rock phosphate inoculated with PSB and organic manure is most beneficial in P release. Phosphate solubilizing bacteria in conjunction to rock phosphate releases equivalent amount of phosphorus to that Di ammonium phosphate (Sharma *et al.* 2016).

There are numerous studies that evidently proved the role and mechanism of phosphate solubilizing bacteria in promoting plant growth. The mechanisms by which these solubilizers can exert a positive effect on plant growth can be of two types: direct and indirect (Glick 1995). Indirect growth promotion is the decrease or prevention of deleterious effect of pathogenic microorganisms, mostly due to the synthesis of antibiotics or siderophores by the bacteria (Sivan

and Chet I. 1992; Leong J. 1986). Direct growth promotion can be through the synthesis of phytohormones, N<sub>2</sub> fixation, reduction of membrane potential of the roots, synthesis of some enzymes (such as ACC deaminase) that modulate the level of plant hormones (Glick *et al.* 1995), as well as the solubilization of inorganic phosphate and mineralization of organic phosphate, which makes phosphorous available to the plants (Awasthi *et al.* 2011).

Considering the factual about limitation of phosphorus availability in soybean crop, The present investigation was designed to evaluate effect of consortium of *Bacillus subtilis*, *Pseudomonas fluorescens* and *Bacillus megaterium* (PSBs) on growth and yield attributes, quality, nodulation, availability of phosphorus, soil phosphatase activity, nutrient uptake, soil properties and yield of soybean. The objectives of the present investigation are abridged as under Objectives:

1. To study the effect of consortium of phosphate solubilizing bacteria on phosphorus availability in soil.
2. To study the effect of consortium of phosphate solubilizing bacteria on yield, quality, enzyme activity and nutrient uptake by soybean.

## 2. REVIEW OF LITERATURE

The present investigation was conducted on “Effect of consortium of phosphate solubilizing bacteria on phosphorus availability, nutrient content and yield of soybean (*Glycine max.L.*)” In this chapter, efforts have been made to review the work done in India and abroad on soybean and other related crops in relation to study the effect of different kinds of phosphate solubilizing bacteria applications. The relevant literature is presented under the following suitable headlines:

- 2.1 Mechanism of phosphate solubilization
- 2.2 Effect of P solubilizers on growth parameters
- 2.3 Effect of P solubilizers on yield and yield contributing characters
- 2.4 Effect of P solubilizers on uptake of nutrients by crops
- 2.5 Effect of P solubilizers on nodulation
- 2.6 Effect of P solubilizers on soil properties
- 2.7 Effect of P solubilizers on soil enzymatic activity
- 2.8 Effect of P solubilizers on release of phosphorus
- 2.9 Effect of P solubilizers on nutrient use efficiency

### 2.1 Mechanism of phosphate solubilization:

Khan *et al.* (2009<sup>a</sup>) studied the mechanism and role of phosphorus solubilizing bacteria in crop production. They explained that the phosphorus solubilizing bacteria play vital role in phosphorus nutrition by enhancing its availability through release from inorganic and organic soil P pools by solubilization and mineralization. The principal mechanism in soil for mineral phosphate solubilization is lowering soil pH by microbial production of organic acids and mineralization of organic P by acid phosphatase. Further, they concluded that PSB *viz.* *Bacillus*, *pseudomonas* and *Enterobacter* are very effective for increasing the plant available P in soil.

Park *et al.* (2009) investigated the ability of *Pseudomonas fluorescens* to solubilize insoluble P via two mechanisms *viz.* proton excretion by ammonium assimilation and organic acid production. The results of high performance liquid chromatography analysis showed that *Ps. fluorescens* produced mainly gluconic and tartaric acid with small amounts of 2-ketogluconic, formic and acetic acid. They reported that during the culture, the pH was reduced with increase in gluconic acid production and was inversely proportional to soluble P concentration. *Ps. fluorescens* showed the properties related to plant promotion such as pectinase, protease, lipase, siderophore, hydrogen cyanide and indoleacetic acid production.

Awasthi *et al.* (2011) reviewed the work various researchers and stated that PSB solubilize phosphate by production of organic acids. There are various heterotrophic

microorganisms, which help in excretion of organic acids, they dissolve phosphatic minerals or chelate cationic partners of the phosphate ions i.e.  $\text{PO}_4^{3-}$  and directly release phosphorous into the soil. In soil, these organic acids reduce the pH of their surroundings. These acids can either dissolve the phosphorous directly by lowering the pH of soil, which can help in ion exchange of  $\text{PO}_4^{2-}$  by acid ions or they can chelate heavy metal ions such as Ca, Al and Fe and release associated phosphorous with them.

## 2.2 Effect of P Solubilizers on growth parameters

Freitas *et al.* (1997) isolated one hundred and eleven P solubilizing bacteria and in vitro screened these bacteria for their P solubilizing efficiency. The best P solubilizer were studied for their effect on growth and phosphorus uptake by canola plants in the phosphorus deficient soil amended with rock phosphate. The results revealed that the some of the P- solubilizing rhizobacteria significantly increased plant height and number pod but not the total P uptake. They emphasized that use of P solubilizing bacteria as inoculants certainly has potential but also indicated that P solubilization is not the only mechanism responsible for positive growth of plant.

Rudresh *et al.* (2005) studied the tricalcium phosphate solubilizing abilities of *Trichoderma* spp. in relation to growth parameters of chickpea (*Cicerarietinum*L.). They reported that PSB + *Trichoderma* spp along with rock phosphate significantly improved the growth parameters such as germination (90-100%), plant height (29-32 cm), number of branches per plant (4.3-7.0) and biomass (0.99-3.19 g plant<sup>-1</sup>) as compared to control.

Fatima *et al.* (2006) investigated the effect of different *Rhizobium* strains and phosphorus on growth of soybean. They further, reported that the dry weight of root, dry weight of shoot, shoot per plant and fresh weight of roots significant increased due to conjunct use of *Rhizobium* inoculum and phosphorus fertilizer in soybean.

Fernandez *et al.* (2007) studied the efficiency of different phosphate-solubilizing bacteria species by evaluating soil phosphorus availability under greenhouse conditions. These inoculants were also studied for their effect on growth and nutrient uptake of soybean. They reported that the plants inoculated with *Burkhoderia* sp. exhibited highest aerial height and showed appropriate N:P ratio. Further, they concluded that the selection of efficient PSB strain as inoculants is of prime importance for P deficient soil.

Elkoca *et al.* (2008) evaluated the effect of single, dual and triple combination of nitrogen fixing and phosphorus solubilizing bacteria on nodulation, plant growth and yield of chickpea crop. Their results revealed that bacterial inoculation significantly influenced all the growth parameter. All the inoculation treatment showed significantly higher plant height as compared to control. Amongst all the treatment, dual combination of *Rhizobium* and *Bacillus subtilis* (OSU-142) revealed highest plant height to the tune of 47.3 cm.

Shahid *et al.* (2009) conducted an experiment to evaluate effect of different levels of phosphorus (0, 25, 50, 75, 100 kg ha<sup>-1</sup>) and seed inoculation with *Rhizobium japonicum* on growth performance of soybean. They reported that higher level of phosphorus i.e. 75 and 100 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> was found to be beneficial in terms plant growth. The treatment receiving 75 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> showed significantly highest plant height (51.07 cm) which was at par with 100 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> and seed inoculation. However, the parameters viz. number of pod bearing branches per plant (4.94), number of pods per plant (42.68) and pod length (4.09 cm) was found to be highest in treatment 100 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>. They found that compared to non-inoculated seed, inoculation with *Rhizobium japonicum* proved to be significantly superior in terms of all the growth parameters.

Ramana *et al.* (2010) studied the effect of VAM and PSB along with graded levels of fertilizer on growth of french bean during *rabi* season. The results of their study revealed that the application of 75 % RDF + VAM @ 2 kg ha<sup>-1</sup> + PSB @ 2.5 kg ha<sup>-1</sup> significantly increased the plant height (49.56 cm), number of branches per plant (10.13), leaf area (1041.50 cm<sup>2</sup>), dry weight (21.14 g) at 60 DAS in variety Araka Suvidha. However, these results were followed by 50% RDF + VAM @ 2 kg ha<sup>-1</sup> + PSB @ 2.5 kg ha<sup>-1</sup>.

Singh *et al.* (2010) evaluated the effect of phosphate solubilizing bacteria on growth attributes of soybean crop. The results of their study showed significant impact of PSB on root length, plant height and number of branches. They observed that the phosphate solubilizing bacterial inoculation showed maximum increment in root length, plant height and number of branches per plant by 64.79, 26.89 and 32.69 per cent respectively.

Singh *et al.* (2011) studied the influence of phosphate solubilizing bacteria for enhancement of plant growth and seed yield in lentil. The result of their investigation revealed that treatment of phosphate solubilizing bacteria strain RPB3 significantly increased the growth parameters such as field emergence (73.50%), root length (11.93 cm), plant height (33.69 cm), Number of branch (3.95 plant<sup>-1</sup>), Nodule (11.12 plant<sup>-1</sup>) compared to others strain viz, RMV1, RMV4 and control.

Wahyudi *et al.* (2011) identified 90 bacillus sp. on the basis of their capabilities to produce phytohormone like indole acetic acid (IAA). Out of these, they selected 12 isolates to study their use in plant growth promotion. The results of their study revealed significant and positive enhancement in growth attributing characters due to application of these 12 bacillus sp. as inoculants. The increased in root length ranged from 12.21 to 22.25 cm, length of shoot ranged from 9.57 to 24.47 cm while number of lateral roots ranged from 65.00 to 96.86.

Rana *et al.* (2014) evaluated the effect of *Rhizobium* and phosphorus solubilizing bacteria on growth attributes in soybean crop. They opined that inoculation of soybean seed with *Rhizobium* and PSB significantly influenced the growth parameters viz. plant height and dry

matter production. The magnitude of increase in plant height due to rhizobium and PSB were to the extent of 3.56 to 4.93 % respectively over control.

Daravath and Takankhar (2017) carried out an experiment to evaluate the effect of liquid biofertilizer on growth characters of soybean. They studied the effect of four levels of *Bradyrhizobium* and PSB (0, 5ml, 10 ml, 15 ml kg<sup>-1</sup> seed) on plant height, number of functional leave, root length and dry matter yield of soybean. The data depicted significant increase due to dual inoculation with 10 ml of *Bradyrhizobium* + PSB kg<sup>-1</sup> seed in plant height, number of functional leave, root length and dry matter yield. The combine treatment i.e. 10 ml of *Bradyrhizobium* + PSB kg<sup>-1</sup> seed recorded significant maximum plant height (24.88 cm), number of functional leave (15.35) and root length (13.87 cm) over rest of the treatments.

Jayashree and Jagadeesh (2017) studied the effect of the microbial consortium on growth of vegetable seedlings in a farmer's Nursery. They used microbial consortium consisting of *Azospirillum*, phosphate solubilizing bacterium (*Pseudomonas striata*), potassium solubilizing bacterium, PGPR strain (*Pseudomonas* sp. B15) and lactic acid bacterium with antifungal activities in their study. The outcome of their research revealed that the plant height and girth of tomato seedling increased to the tune of 57.48 and 47.61% respectively. However, in brinjal seedlings increase in plant height and girth was to the magnitude of 42.10 to 53.60% and in chilli up to 76.50 and 28.05 respectively. Furthermore, they opined that the microbial consortium consisting of strain with multiple functions can be used to treat cocopeat to produce quality seedlings.

### 2.3 Effect of PSB on yield and yield contributing character

Athul *et al.* (2008) conducted a pot culture experiment to study the influenced of phosphate solubilizing bacteria on the yield of soybean. The combination treatments of phosphate solubilizing microorganism and rock phosphate were compared with treatment receiving super phosphate alone. The results of their study highlighted that PSB inoculation along with rock phosphate increased the straw yield, seed yield and pod yield of soybean per pot as compared to super phosphate alone. The data revealed that combination treatment i.e. *P. Vermiculosum* along with rock phosphate recorded significantly highest straw yield (39.51 g pot<sup>-1</sup>), seed yield (18.18 g pot<sup>-1</sup>) and pod yield (32.29 g pot<sup>-1</sup>).

Elkoca *et al.* (2008) evaluated the effect of single, dual and triple combination of nitrogen fixing and phosphorus solubilizing bacteria on nodulation, plant growth and yield of chickpea crop. Their results revealed that bacterial inoculation significantly influenced all the yield parameters. Their experimental data divulged that the treatment receiving N and P alone recorded highest number of pod, seed yield, biomass yield, 1000-seed weight which was almost equal or at par to triple combination of *Rhizobium*, *Bacillus subtilis* (OSU-142) and *Bacillus*

*Megaterium* (M-3) in terms of number of pod (25.3 nu.plant<sup>-1</sup>), seed yield (1701.5 kg ha<sup>-1</sup>), biomass yield (3291.0 kg ha<sup>-1</sup>), 1000-seed weight (494.6 g).

Dhage and Kachhave (2008) studied the effect of dual inoculation of rhizobium and PSB on yield, protein and oil content of soybean. The results revealed that the significantly highest grain yield (15.46 q ha<sup>-1</sup>), straw yield (26.66 q ha<sup>-1</sup>) and biological yield (36.12 q ha<sup>-1</sup>) was recorded due to interaction of rhizobium +PSB with 100% RDF over rest of the treatments.

Aftab *et al.* (2008) carried out both pot and field experiments to studied the effect of inoculation of *Bradyrhizobium* and *Pseudomonas*, or both, in presence and absence of phosphate fertilizeron soybean yield. Their results showed that the co-inoculation of *Bradyrhizobium* and *Pseudomonas* strain along with the P<sub>2</sub>O<sub>5</sub>treatment resulted in increased grain yield of 38 % in pot experiments and 12% in field experiments as compared to P<sub>2</sub>O<sub>5</sub> treatment alone.

Shahid *et al.* (2009) conducted an experiment to evaluate effect of different levels of phosphorus (0, 25, 50, 75, 100 kg ha<sup>-1</sup>) and seed inoculation with *Rhizobium japonicum* of growth performance of soybean. They reported that higher level of phosphorus i.e. 75 and 100 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> was found to be beneficial in seed yield and oil yield of soybean. The treatment receiving 100 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>recorded significantly highest seed yield (1963.8 kg ha<sup>-1</sup>) and oil yield (380.1 kg ha<sup>-1</sup>) which was at par with 75 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>and seed inoculation. When compared to non-inoculated seed, inoculation with *Rhizobium japonicum* recorded highest seed and oil yields.

Singh *et al.* (2010) studied comparative evaluation of three phosphate solubilizing bacteria viz., RMV1, MRV4 and RPB3 for the P solubilizing capacity. Their results revealed that, by virtue of its phosphate solubilization ability RPB3 recorded significantly highest seed yield (34.44 q ha<sup>-1</sup>) over control (27.80 q ha<sup>-1</sup>).

Singh *et al.* (2011) studied the influence of phosphate solubilizing bacteria for enhancement of plant growth and seed yield in lentil. The comparative evaluation of different PSB strain revealed that the treatment including RPB3 significantly increased the yield parameters such as pods plant<sup>-1</sup> (77.07), seeds pod<sup>-1</sup> (1.58), seeds plant<sup>-1</sup> (122.45), 1000-seed weight (24.39 g), seed yield (14.23 q ha<sup>-1</sup>) compared to RMV1, RMV4 and control.

Ramana *et al.* (2010) worked on effect of biofertilizers on growth, yield attributes and yield of French bean. The results of their study revealed that the application of 75 per cent RDF + VAM + PSB significantly increased number of pods per plant (11.65), number of pods per cluster (2.26), number of seeds per pod (7.20), 100 seed weight (34.77 g), pod length (16.17 cm), pod yield per plant (81.86 g) and pod yield per hectare (7.28 t ha<sup>-1</sup>) in Arka suvidha variety as compared other treatments.

Singh and Sharma (2011) studied the effect of P enriched organic manure in combination of *Rhizobium* and phosphate solubilizing microorganism on seed yield of chickpea. The reported

that the maximum grain yield (2639 kg ha<sup>-1</sup>) and stover yield (2978 kg ha<sup>-1</sup>) of chickpea was recorded with addition of recommended dose of phosphorus through P enriched vermicompost along with *Rhizobium* and phosphate solubilizing microorganism over control.

Waghmare *et al.* (2011) conducted an experiment to appraise the influence of bio-inoculants and farmyard manure under rainfed condition. Their results showed that application 75% RDF+ FYM (5 t ha<sup>-1</sup>) + *Rhizobium* + PSB recorded the higher yield attributes such as pod yield plant<sup>-1</sup> (20.25 g), grain yield plant<sup>-1</sup> (16.12 g) and test weight (121.67 g). The same combination treatment also produced significantly higher grain yield (1742 kg ha<sup>-1</sup>), straw yield (2762 kg ha<sup>-1</sup>), and biological yield (4504 kg ha<sup>-1</sup>), protein yield (967 kg ha<sup>-1</sup>) and oil yield (366 kg ha<sup>-1</sup>) over rest of treatment and at par with 100 % RDF.

Zarei *et al.* (2012) studied the effect of bio-fertilizer and different fertilizer levels on grain yield and protein content of two soybean cultivars. Their results showed that the treatment receiving 100 % N + *Bacillus* + *Pseudomonas* + 50% P recorded highest number of seed per plant (117.25) and seed yield (2711 kg ha<sup>-1</sup>) when compared to other combination treatments. They further, emphasized that the bio-fertilizer can be considered as a replacement for part of chemical fertilizers in soybean production.

Argaw (2012) evaluated co-inoculation of *Bradyrhizobium japonicum* and phosphate solubilizing (*Pseudomonas spp.*) for their effect on soybean yield and yield attributing characters. They reported that co-inoculation with *Bradyrhizobium japonicum* and *Pseudomonas spp* with N and P chemical fertilizer significantly increased number of pod per plant (61.83) over control (27.57) which accounted to be 112.7% over control. Similarly, the un-inoculated also exhibited increased seed yield per hectare by 36.3% over control, 34.7% over N fertilized and 9.8% over un-inoculated P fertilized.

Devi (2012) made an attempt to study the response of soybean to different sources of P fertilizer in combination with phosphate solubilizing bacteria. The results of this study indicated that among the different combinations of P fertilizer and PSB, the combination treatment of SSP + PSB recorded significant and maximum grain yield (1529 kg ha<sup>-1</sup>) followed by DAP + PSB (1447 kg ha<sup>-1</sup>). Similarly, the treatment of SSP+PSB also recorded significant and higher oil content (18.53%) and protein content (35.35%).

Tytova *et al.* (2013) studied the effect of complex microbial inoculants on the number and diversity of rhizospheric microorganisms and the yield of soybean. The results of their study showed that *Ecovital* application (inoculation with *Bradyrhizobium* and *Bacillus strains*) significantly improved soybean yield (2600 kg ha<sup>-1</sup>) as compare to un-inoculated plots of *Romantica* (1380 kg ha<sup>-1</sup>). Maximum grain yield was achieved by the co-inoculated of rhizobia and phosphate solubilizing bacteria.

Munda *et al.* (2013) verified the response of soybean to phosphorus fertilizers in conjunction to bio-fertilizers *viz.* Phosphate solubilizing bacteria (*Pseudomonas straita*) and vesicular arbuscular mycorrhizae. They tested two sources of phosphorus *viz.* rock phosphate and di-ammonium phosphate in different combination with bio-fertilizer. Their results revealed that the application as rock phosphate along with biofertilizer such as PSB and VAM had positive impact on yield attributes and recorded highest number of pods (30.63 plant<sup>-1</sup>), number of seed per pod (2.57) and seed index (13.62). The same combination treatment of RP + PSB + VAM also registered maximum seed yield (1.56 t ha<sup>-1</sup>) and biological yield of (4.56 t ha<sup>-1</sup>) and maximum protein content (38.89 %). They further, argued that qualitative improvement is possible with conjunct use of fertilizers and bio-fertilizers.

Uddin *et al.* (2013) investigated N and P bio-fertilizers in combination with reducing rate of inorganic phosphorus application. Subsequently, they reported that when compared to 60 kg P ha<sup>-1</sup> with and without bio-fertilizers, the combination of 30 kg P ha<sup>-1</sup>+ biological nitrogen fertilizer (*Rhizobium cicero*) + biological phosphorus fertilizer (*pseudomonas striata*) resulted in greater seed yield (21.1 %), content of seed protein (2.9 %) and carbohydrates (5.6 %) over control. They opined that the use of bio-fertilizer could save costly P fertilizer to achieve greater yield and enhanced quality in soybean.

Meena and Ghasolia (2013) studied the effect of phosphate solubilizer and FYM on microbial population and seed yield of soybean. They reported that bio-fertilizer along with FYM resulted in higher microbial population as well as yield attributes and seed yield of soybean

Suryantini (2014) studied the soybean response to mycorrhiza, *Rhizobium*, P-solubilizing bacteria and lime application in Ultisol soil. Their study aimed to assess the effect of lime and synergistic effect between bio-fertilizers, mycorrhiza, rhizobium, and P-solubilizing bacteria on soybean grown in Ultisol soil. The result divulged that the treatments consisting of VAM + PSB + *Rhizobium* resulted in highest number of pod 45.4 in not limed and 50.5 plant<sup>-1</sup> in limed soil whereas, highest grain yield 9.0 g plant<sup>-1</sup> and 11.7 g plant<sup>-1</sup> was recorded in not limed and limed soil respectively

Diep *et al.* (2017) studied the conjunct use bio-inoculant and chemical fertilizer in soybean. The emphasized that conjunct use of *Rhizobial*, PSB and chemical fertilizers produced significantly higher value of yield component, such as grain yield, oil and protein content in seed than control and equivalent to chemical fertilizer alone. The results revealed that treatment of *Rhizobium* + 20 kg N ha<sup>-1</sup> recorded highest number of pod per plant (24.55) while the treatment *Rhizobium* + PSB + 400 kg bio-fertilizer + 20 Kg N ha<sup>-1</sup> recorded highest protein yield (72.96 kg ha<sup>-1</sup>). The seed yield of soybean was found to be statistically at par in both the treatments.

## 2.4 Effect of PSB on uptake of nutrients by crops

Tanwar and Shaktawat (2003) investigated the influence of phosphorus sources levels and solubilizers on nutrient uptake of soybean-wheat cropping system. The findings of their study revealed application of optimum phosphorus to soybean crop ( $38.7 \text{ kg ha}^{-1}$ ) enhanced the N uptake and P uptake to the tune of 18.7 and 30.5 % respectively by soybean crop over rest of the phosphorus levels. Furthermore, they reported that organic manures with and without phosphorus solubilizing bacteria enhanced N uptake (17.8 and 13.2) while, P uptake by (17.5 to 13.4 %) respectively in soybean.

Rudresh *et al.* (2005) studied the tricalcium phosphate solubilizing abilities of *Trichoderma* spp. in relation to P uptake of chickpea (*Cicerarietinum* L.). They reported that PSB + *Trichoderma* spp along with rock phosphate significantly improved the P uptake of shoots. The significant highest value of P uptake was found to be recorded by PSB + TH + RP treatment ( $6.02 \text{ mg plant}^{-1}$ ) superior over all individual treatments of either rock phosphate or microorganism alone treatments. Phosphorus uptake in PSB + RP ( $5.55 \text{ mg plant}^{-1}$ ) was greater than all individual treatments. They pointed out that the fertilized control treatment showed significantly less P uptake ( $1.46 \text{ mg plant}^{-1}$ ) compared to the un-inoculation treatment.

Tran *et al.* (2006) studied the effect *Bradyrhizobia* (*Bradyrhizobium japonicum*) and phosphate solubilizing bacteria (*Pseudomonas* spp.) on soybean crop at three different locations. In this study the researchers evaluated the treatment effect different combination levels of inorganic nitrogen fertilizer and bio-fertilizer as compared to conventional farmers' fertilizer levels. Their results revealed that application of *Bradyrhizobia* and phosphate solubilizing bacteria enhanced the nutrient uptake by soybean. At location, *An Giang* experimental result showed that N and P uptake by soybean grain increased from 13.64 % to 37.27 % and 17.77 to 41.12 %, respectively. At location, *Can Tho*, N and P uptake by soybean grain increased from 3.25 to 21.14 % and from 0.96 to 27.88 %, respectively. In *Dong Thap*, nitrogen uptake increased from 13.64 to 30.00 % and Phosphorus increased from 17.17 to 41.12 % due to application of 40 N + *Bradyrhizobium* + PSB + 30 K<sub>2</sub>O and 20 N + *Bradyrhizobium* + PSB + 30 K<sub>2</sub>O as compared to farmers' fertilizer level (un-inoculation)

Dadhich and Somani (2007) studied and elaborated the effect of integrated nutrient management on yield and micronutrient uptake in soybean-wheat cropping sequence. They verified four levels of phosphorus and two levels of FYM with and without inoculation of PSB and VAM. They found that increased level of P and FYM along with PSB and VAM inoculation to be significantly highest in Cu ( $175.16 \text{ mg ha}^{-1}$ ), Fe ( $464.74 \text{ mg ha}^{-1}$ ), Zn ( $114.04 \text{ mg ha}^{-1}$ ) and Mn ( $223.07 \text{ mg ha}^{-1}$ ) uptake by soybean and subsequent wheat crop.

Athul *et al.* (2008) evaluated the influence of phosphate solubilizing bacteria in combination with different P sources and P sources alone on yield and nutrient uptake by soybean in a pot culture experiment for 60 day after sowing. They indicated that N and P uptake both in straw and seeds of soybean was substantially increased due to microbial inoculation combined with reluctantly soluble P sources as comparable to readily soluble P fertilizers. Furthermore, they went on reporting highest N uptake ( $1241.78 \text{ mg pot}^{-1}$ ) in treatment receiving super phosphate after 60 DAS (SP<sub>60</sub>) which was followed by (RP<sub>60</sub>) *A. niger* + rock phosphate after 60 DAS ( $1234.56 \text{ mg pot}^{-1}$ ). Similarly, the highest P uptake ( $116.98 \text{ mg pot}^{-1}$ ) was recorded by super phosphate after 60 DAS (SP<sub>60</sub>) which was followed by P (RP<sub>60</sub>). *Vermiculosum* + rock phosphate ( $113.9 \text{ mg pot}^{-1}$ ).

Dhage and Kachhave (2008) studied the effect of dual inoculation of rhizobium and PSB on nutrient uptake of soybean. Their results revealed that the significantly highest nutrient content at flowering, in soybean grain N (6.23 %), P (2.29 %) K (2.29 %) and in straw N (1.73 %), P (1.11 %) K (0.47 %) was recorded due to interaction of *rhizobium* + PSB with 100% RDF over rest of the treatments. The same treatment was also reported to be significantly higher in grain and straw yield.

Aftab *et al.* (2008) carried out both pot and field experiments and studied the effect of inoculation of *Bradyrhizobium* and *Pseudomonas*, or both, in presence and absence of phosphate fertilizer on soybean yield. Their results showed that the co-inoculation of *Bradyrhizobium* and *Pseudomonas* strain along with the P<sub>2</sub>O<sub>5</sub> resulted in increased seed N content (6.1%), seed P content (0.87%). The inoculated treatment was also 38% and 12 % higher grain yield in pot and field experiment as compared to P<sub>2</sub>O<sub>5</sub> treatment alone.

Ahemad and Khan (2010) evaluated the effect of three concentrations of quizalafop-p-ethyl on chlorophyll, leghehemoglobin, N content, P content and seed protein in greengram plant grown in soil inoculated with *P. aeruginosa* strain PS1 and without bioinoculant. The treatment with inoculation of PSB was found to significantly higher over uninoculated compared inoculated treatment indicated increased total shoot N ( $50 \text{ mg g}^{-1}$ ), root N ( $35 \text{ mg g}^{-1}$ ), shoot P ( $43 \text{ mg g}^{-1}$ ), root P ( $76 \text{ mg g}^{-1}$ ) (RP<sub>60</sub> -g), shoot P ( $43 \text{ mg g}^{-1}$ ) and in green gram plant respectively.

Singh and Sharma (2011) studied the effect of sources of phosphorus and microbial inoculation on productivity, nutrient availability in soil and uptake of nutrient by chickpea grown on sandy loam soil. Their result revealed that the uptake N and P after harvest of chickpea crop was significantly higher in treatments relieving *rhizobium* and PSB incubation only or in combination with organic manure and P fertilizers over control. Application of recommended dose of P through P-enriched compost + vermicompost + *Rhizobium* inoculation + PSB

inoculation recorded the maximum uptake value of N (92.89 kg ha<sup>-1</sup>), P (12.03 kg ha<sup>-1</sup>), K (7.36 kg ha<sup>-1</sup>) and S (7.39 kg ha<sup>-1</sup>) in grain.

Argaw (2012) evaluated co-inoculation of *Bradyrhizobium japonicum* and phosphate solubilizing (*Pseudomonas spp.*) for their effect on soybean yield and nutrient uptake. They reported that co-inoculation of *Bradyrhizobium japonicum* and *Pseudomonas spp.* with N and P chemical fertilizer significantly increased total N and P content in soybean seeds besides increasing the yield.

Munda *et al.* (2013) verified the response of soybean to phosphorus fertilizers in conjunction with bio-fertilizers *viz.*, phosphorus solubilizing bacteria (*Pseudomonas straita*) and vesicular arbuscular mycorrhizae. They tested two sources of phosphorus *viz.* rock phosphate and Di-ammonium phosphate in different combination with bio-fertilizer. Their results revealed that the application of bio-fertilizer with 100% P as RP + PSB + VAM had positive impact on P uptake (14.73 kg ha<sup>-1</sup>), K uptake (39.19 kg ha<sup>-1</sup>) and N uptake (186.1 kg/ha<sup>-1</sup>). They concluded that combined application had positive effect on yield and uptake.

Uddin *et al.* (2013) investigation the use of N and P bio-fertilizers to reduce inorganic phosphorus application and to increases nutrient uptake and yield of chickpea. They evidently proved that the interaction between P levels and bio fertilizer treatments was most profitable for N uptake and P uptake. The treatment application of P<sub>30</sub> + BNF + BPF resulted in greater N uptake (128.72 mg plant<sup>-1</sup>), P uptake (6.09 mg plant<sup>-1</sup>) and yield. The P<sub>30</sub> + BNF + BPF was found to be statistically significant over P<sub>60</sub> without inoculation, thus indicated saving 30 kg P ha<sup>-1</sup> of the costly inorganic P fertilizers.

Rotaru (2016) studied the effect of two phosphate solubilizing rhizobacteria combined with insoluble phosphate in soybean. The results of their study revealed that all the inoculated treatment showed better nutrient uptake. The result revealed that insoluble Ca-P inoculated with *Rhizobium* and *Pseudomonas sp.* recorded higher P uptake (1.39 ± 0.08 mg plant<sup>-1</sup>) when compared to un-inoculated control.

Raj and Mallick (2017) studied the integrated approach of nutrient management in yellow sarson for its effect on yield and nutrient uptake. They found that the N, P and K uptake by sarson differed significantly due to different treatments. The combination of *Azotobacter* and phosphate solubilizing bacteria inoculation along with recommended dose of fertilizer (up to 50 %) resulted in general, higher uptake of N, P and K.

Savaliya *et al.* (2018) investigated the role of PSB and KSB in enhancing the phosphorus and potassium use efficiency. They reported that 45 kg P<sub>2</sub>O<sub>5</sub> + seed inoculation of PSB recorded highest phosphorus and potassium use efficiency (14.97 and 9.13 kg kg<sup>-1</sup> respectively) while similar was observed in case of KSB + seed inoculation.

## 2.5 Effect of PSB on nodulation of soybean crops

Tran *et al.* (2006) studied the effect *Bradyrhizobia* (*Bradyrhizobium japonicum*) and phosphate solubilizing bacteria (*Pseudomonas* spp.) application in soybean-rice-rice cropping system. In this study the researchers evaluated the effect of different combinations of inorganic nitrogen fertilizer levels and bio-fertilizer as compared to conventional farmers' fertilizer levels at three different locations. Their results revealed that application of 40N and 60N + *Bradyrhizobia inoculant* + phosphate solubilizing bacteria enhanced the number of nodules such as number of nodules plant<sup>-1</sup> ranged from 26.9 to 40.8, 17.2 to 45.8 and 27.8 to 34.60 at *An Giang, Can Tho and Thap* province, respectively. Same trend was reported in dry weight of nodules.

Yadav *et al.* (2007) studied the response of bio-fertilizer, poultry manure and different levels of phosphorus on nodulation of greengram. The results revealed that the significantly highest number of nodules per plant (35.62) was recorded due to interaction of *Rhizobium* + PSB + P<sub>2</sub>O<sub>5</sub> @ 75 kg/ha + PM 5 t ha<sup>-1</sup> over rest of the treatments.

Athul *et al.* (2008) conducted a pot culture experiment to study the influence of phosphate solubilizing bacteria on the yield of soybean. The combination treatments of phosphate solubilizing microorganism and rock phosphate were compared with treatment receiving super phosphate alone. The results of their study highlighted that the PSB inoculation along with rock phosphate significantly increased the number and dry weight of nodules as compared to phosphate alone and rock phosphate in combination with other organisms. The highest number (135.5) and dry weight (482.5mg) of nodules were recorded in the treatment of *P. vermiculosum* with RP<sub>60</sub> followed by *A. niger* with RP<sub>60</sub> which recorded 124.5 number of nodules per plant and 427.5 mg nodule dry weight.

Elkoca *et al.* (2008) studied the effect of single, dual and triple combination of nitrogen fixing and phosphorus solubilizing bacteria on nodulation, plant growth and yield of chickpea crop. Their results revealed that bacterial inoculation significantly influenced the nodules dry weight. Dual inoculation of *Rhizobium* and *Bacillus subtilis* (OSU-142) revealed highest nodules dry weight (104.0 mg plant<sup>-1</sup>) followed by *Rhizobium* + *Bacillus megaterium* (97.7 mg plant<sup>-1</sup>).

Vikram and Hamzehzarghani (2008) appraised the effect of phosphate solubilizing bacteria on nodulation and growth parameters of green gram in a pot culture experiments. They tested 16 PSB strains for their effect on nodulation, growth parameter and P uptake by green gram. They reported that inoculation of green gram seeds with PSBV-14 (*Serratia* sp) recorded the highest nodule number, nodule dry weight, shoot dry matter in green gram plants 45 days after sowing.

Akhtar and Siddiqui (2009) examined effects of phosphate solubilizing microorganisms and *Rhizobium* sp. on the nodulation in chickpea under field condition. Their result indicated that the number of nodules ( $21.48 \pm 0.18 \text{ g plant}^{-1}$ ) was significantly higher in plants inoculated with *Rhizobium* sp. compared to plants without *Rhizobium* sp.

Singh *et al.* (2010) studied comparative evaluation of three phosphate solubilizing bacteria viz., RMV1, MRV4 and RPB3 for the P solubilizing capacity. Their results revealed that among the different PSB strains, RPB3 recorded significantly highest number nodules ( $82.33 \text{ plant}^{-1}$ ) and dry weight ( $152.83 \text{ mg plant}^{-1}$ ).

Ahemad and Khan (2010) investigated the phytotoxicity of herbicides viz., quizalafop-*p*-ethyl on growth, nodulation, grain yield and nutrient uptake by green gram. They exhibited that inoculated treatment with *Pseudomonas aeruginosa* strain (PS1) recorded increased number of nodules per plant (209 and 180) and nodule dry weight ( $220$  and  $245 \text{ mg plant}^{-1}$ ) at 50 DAS and 80 DAS respectively.

Argaw (2012) evaluated co-inoculation of *Bradyrhizobium japonicum* and phosphate solubilizing (*Pseudomonas spp.*) for their effect on soybean yield and yield attributing characters. They reported that co-inoculation with *Bradyrhizobium japonicum* and *Pseudomonas spp.* with N and P chemical fertilizer significantly increased number of nodules per plant (74.67) and fresh weight of nodules ( $6.99 \text{ mg plant}^{-1}$ ).

Devi *et al.* (2012) worked on response of soybean to sources and levels of phosphorus. They demonstrated that sources of phosphorus had influenced number of nodules per plant after 60 days of sowing. Further, they reported that combine application of SSP+PSB produced significantly higher number of nodules per plant, dry weight of nodules per plant (32.23) over all the treatments and lowest was recorded by control (21.00).

Qin *et al.* (2012) studied the affinity of phosphate transporter gene GmPT5 phosphate transport to nodules and nodulation in soybean. They opined that in an agro ecosystem nodules in soybean apart from biological nitrogen fixation also process requiring a considerable amount of phosphorus. They further found that effective rhizobium strains enhances soybean  $\text{N}_2$  fixation and phosphorus nutrition in the field. In their study they identified and characterized the nodules high affinity phosphate transporter gene GmPT5.

Tagore *et al.* (2013) studied effect of *Rhizobium* and phosphate solubilizing bacterial inoculants on symbiotic traits, nodule leghemoglobin, and yield of chickpea genotypes. Their results revealed that the application of *Rhizobium* + PSB had positive impact on nodulation. They reported that inoculation with *Rhizobium* + PSB increased the number of nodules per plant at different day such as 35 days (20.7), 55 days (27.7) and 75 days (26.7), nodules fresh weight 35 days ( $86.8 \text{ mg plant}^{-1}$ ), 55 days ( $144.9 \text{ mg plant}^{-1}$ ) and 75 days ( $120.4 \text{ mg plant}^{-1}$ ),

nodules dry weight 35 days (46.6 mg plant<sup>-1</sup>), 55 days (74.3 mg plant<sup>-1</sup>) and 75 days (70.5 mg plant<sup>-1</sup>) compared with other treatment.

Diep *et al.* (2017) studied the conjunct use bio-inoculant and chemical fertilizer in soybean. They emphasized that conjunct use of *Rhizobial*/PSB and chemical fertilizers produced significantly higher number of nodules per plant than control and equivalent to chemical fertilizer alone. The results revealed that treatment of PSB inoculation + 20 kg N ha<sup>-1</sup> recorded highest number nodules (18.33 plant<sup>-1</sup>) and dry weight of nodules per plant (91.81 mg plant<sup>-1</sup>). However, the treatment *Rhizobium* + PSB + 400 kg bio-fertilizer + 20 kg N ha<sup>-1</sup> also recorded highest number of nodules (18.25 plant<sup>-1</sup>) and dry weight of nodules (64.42 mg plant<sup>-1</sup>). The number of nodules in soybean was found to be at par in both the treatments.

Kuntyastuti and Sutrisno (2017) studied the effect of phosphate solubilizing bacteria and chemical fertilizer application on growth and nodulation of soybean crop. They reported significant increase number of nodules (1.67 per plant) with application of 1500 kg ha<sup>-1</sup> manure + PSB + 150 kg ha<sup>-1</sup> NPK fertilizer over all other treatment.

## 2.6 Effect of PSB on soil properties

Tran *et al.* (2006) studied the effect *Bradyrhizobia* (*Bradyrhizobium japonicum*) and phosphate solubilizing bacteria (*Pseudomonas* spp.) application in soybean-rice-rice cropping system. In this study the researchers evaluated the effect different combination levels of inorganic nitrogen fertilizer and bio-fertilizer as compared to conventional farmers' fertilizer levels. Their results revealed that application of 40N and 60N + *Bradyrhizobia* inoculant + phosphate solubilizing bacteria did not influence the soil properties *viz.*, soil pH, organic carbon. However, the soil available N increased from 3.17 % to 28.35 %, 12.36 % to 26.76 % and 2.93 to 24.77 % and soil available phosphorus from 14.58 to 59.72 %, 5.15 % to 32.16 % and 4.42 % to 36.18 % in all the three locations *viz.*, *An Giang*, *Can Tho* and *Thap* province of Vietnam, respectively due to combine application of *Bradyrhizobia* inoculant + phosphate solubilizing bacteria and varied N levels.

Tagore *et al.* (2013) studied the effect of rhizobium and phosphate solubilizing bacteria inoculants on symbiotic traits of chickpea and soil properties. They found that soil characteristics such a pH and EC remained unaffected due to microbial inoculants. However, the soil nutrient status improved due to *Rhizobium* + PSB with significant highest value of available N (220.3 kg ha<sup>-1</sup>), available P (14 kg ha<sup>-1</sup>) and available K (556.9 kg ha<sup>-1</sup>) over non inoculated treatments.

Parewa *et al.* (2014) studied the effect of fertilizer levels, FYM and bioinoculants on soil properties in Inceptisol. 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<sup>-1</sup>) 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. They found that fertilizer levels, FYM and bioinoculants had no significant effect on pH and EC however, soil pH was either maintained or slightly decreased to the initial value. They reported that the organic carbon value was significantly highest in these treatments when compared to control. Further, they indicated that the available N, P and K status decreased from its initial value whereas, the availability of these nutrients increased from its initial values in inoculation treatments. The highest available N (227.48 and 228.76 kg ha<sup>-1</sup>), P (18.25 to 18.31 kg ha<sup>-1</sup>) and K (233.40 to 235.78 kg ha<sup>-1</sup>) were obtained due to combination of 100 % NPK fertilizer + FYM and bioinoculants (PGPR + VAM).

Kumar *et al.* (2017) verified enhancement of nutrient availability in soil using microbial cultures in soybean grown on Vertisol. The results emerged out indicated that in the nutrient availability in soil after harvest of crop was more in the plots treated with RDF along with inoculation *Rhizobium* + *Trichoderma viride*. Their results indicated that that change in soil pH and EC after harvest of soybean showed non significant differences but slight decrease in soil pH with bio-inoculant treatments was observed. They reported that treatment with *Rhizobium* + *Trichoderma viride* recorded significantly higher organic carbon content over control and remained at par with all other treatments. Similar results were also projected in case of available nutrient status. The significant highest available N (216 kg ha<sup>-1</sup>) and available K (639.3 kg ha<sup>-1</sup>) was recorded in treatment with RDF + *Rhizobium* + *Trichoderma viride* that found to be at par with other inoculation treatments and superior over non-inoculated treatments

Diep *et al.* (2017) studied the conjunct use bio-inoculant and chemical fertilizer in soybean. They emphasized that conjunct use of *Rhizobia*/PSB and chemical fertilizers significantly influenced the soil properties than control and equivalent to chemical fertilizer alone. Their results revealed that treatments of PSB inoculation + 20 kg N ha<sup>-1</sup> and PSB + *rhizobium* + 20 N recorded significantly increased soil organic matter 2.83% and 2.62%, available P (36.40 and 40.19 mg P<sub>2</sub>O<sub>5</sub> soil kg<sup>-1</sup>) respectively.

Gulnaz *et al.* (2017) examined the effect of PGPR II (*Pseudomonas fluorescens* + *Bacillus megaterium* + *Azospirillum brasilense*) on soil chemical properties and nutrient status changes after harvest of irrigated maize under varying levels of phosphorus. Their result indicated that higher level of phosphorus i.e 100% and 125% P<sub>2</sub>O<sub>5</sub> with PGPR recorded significantly higher values of available N 181 kg ha<sup>-1</sup> and 180.23 kg ha<sup>-1</sup>, available P 51.08 kg ha<sup>-1</sup> and 52.70 kg ha<sup>-1</sup> and K 177.11 kg ha<sup>-1</sup> and 172.43 kg ha<sup>-1</sup> respectively. However, these values were found to be at par with 75 % P<sub>2</sub>O<sub>5</sub> which recorded 179.33 kg ha<sup>-1</sup>, 51.80 kg ha<sup>-1</sup> and 167.83 kg ha<sup>-1</sup> N, P and K respectively and superior over other treatments.

Jangir *et al.* (2017) studied the effect of fertility levels and biofertilizers on physical and chemical properties of soil under blackgram (*Vignamungo* L.). Their results revealed that the pH and EC were not affected by various treatments of inoculation and different fertilizer levels (50% RDF, 75% RDF, and 100% RDF). However the available nutrient status was reported to be significantly affected with different levels and inoculation treatments as well. For instance, the increase in available nitrogen in soil with individual treatments such as control, PSB, *Rhizobium*, and *Rhizobium* + PSB was to the extent of 259.25, 286.16, 287.40 and 300.22 kg ha<sup>-1</sup> respectively. The increase in available phosphorus in soil with treatments consisting of PSB, *Rhizobium* and *Rhizobium* + PSB inoculation was to the extent of 21.10, 21.26 and 22.30 kg ha<sup>-1</sup> respectively while control was 18.38 kg ha<sup>-1</sup>.

### **2.7 Effect of P solubilizers on release of phosphorus**

Fernandez *et al.* (2007) studied the efficiency of different phosphate-solubilizing bacteria species by evaluating soil phosphorus availability and growth of soybean under greenhouse conditions. These inoculants were also studied for their effect on phosphate availability during different incubation period. They measured the availability of soil P in the soil plate assay after 15 days, 30 days, 60 days and 90 days of incubation. At 15 days of incubation, they reported maximum available P of 60 mg kg<sup>-1</sup> soil was recorded in the soil with soluble phosphate. The inoculation with isolates *Burkholderia* and *Enterobacter sp.* increased available P in the soil (ranging from 8.25 to 9 mg kg<sup>-1</sup> soil) where as, in un-inoculated control 6.4 mg kg<sup>-1</sup> soil however, it was found to be statistically non-significant. They further reported that after 30 days incubation treatments showed significantly and higher values of phosphate solubilization (10 mg kg<sup>-1</sup> soil) over controls and the rest of the studied strains. While, after 60 days, most of the strains solubilized phosphorus ranging from 11.6 to 15.4 mg P kg<sup>-1</sup> soil, these value were statistically superior than controls. They concluded that soil soluble P continuously increased during the 60-day incubation period due to inoculation of PSB strains. After 90 days, solubilization of soil P by all the studied strains was statistically higher than the value recorded by control treatment.

Park *et al.* (2010) studied the enhancement in solubility of insoluble phosphorus compounds by phosphate solubilizing bacteria. The results of their investigation revealed that phosphate solubilizing bacterial inoculation increased the concentration of citric acid-soluble P by 70 - 100 times compared to the control treatment. Furthermore, they reported that citric acid-soluble P increased with incubation period and PSB inoculation achieved 0.93 % (w/w) citric acid-soluble P (9.3 % of total P) compared to un-inoculated treatment (0.13 % of total P) at 28 days after incubation.

Sreenivasulu *et al.* (2014) evaluated the abilities of three indigenous bacteria isolated from muscovite mine for their phosphate solubilization capacity. The outcome of their study suggested that the P release from mica by all the three strain at 14 days ranged from 44.8 - 66.50 mg kg<sup>-1</sup> and 28 days 74 - 96.10 mg kg<sup>-1</sup>.

Abbasi *et al.* (2015) studied the mineralization of soluble P fertilizers and insoluble rock phosphate in response to phosphate-solubilizing bacteria and poultry manure and their effect on the growth and P utilization efficiency of chilli. The results of their incubation experiment indicated that chemical P fertilizers used in the study, i.e., SSP and DAP, released the highest P at the start of the experiment, but this mineral P significantly decreased with subsequent incubation periods. They further added that at the end of the experiment (on day 60), about 80 % of P initially present had disappeared from the system, showing that the P recovery in the soil mineral pool was 20% of the total P applied from P fertilizers. Rock phosphate (RP) alone or RP + PSB released a maximum of 12 mg P kg<sup>-1</sup>, demonstrating that the application of RP directly to soil with a slightly alkaline pH did not show any positive effect on overall P mineralization or P availability. However, the use of PSB and PM with RP in the combined treatment (1/2 RP+1/2 PM+PSB) released a substantial amount of P (25 mg kg<sup>-1</sup>) that remained at high levels (without any loss) until the end of incubation (day 60). They finally concluded that the combination of PSB and PM with RP may be a feasible option for releasing P from insoluble RP for a longer period.

Sharma *et al.* (2016) evaluated the effect of PSB and organic manure on release pattern of phosphorus applied through rock phosphate as P-fertilizer in Vertisol soil. They observed that the rock phosphate inoculated with PSB and organic manure to be most beneficial for P release among all the treatments. The data of their study revealed that Jambua Rock Phosphate @ 120 kg P ha<sup>-1</sup> + PSB @ 150 g ha<sup>-1</sup>+FYM @ 5 t ha<sup>-1</sup> recorded significant maximum release of available-P at 15 days (34.17 kg ha<sup>-1</sup>), 30 days (37.28 kg ha<sup>-1</sup>), 45 days (41.56 kg ha<sup>-1</sup>), 60 days (46.18 kg ha<sup>-1</sup>), 75 days (51.51 kg ha<sup>-1</sup>), 90 days (55.24 kg ha<sup>-1</sup>) which was followed application of 60 kg DAP ha<sup>-1</sup> alone.

Adnan *et al.*, (2017) suggested that phosphate-solubilizing bacteria reduce the negative effects of soil calcification on soil phosphorus nutrition. In this incubation study, they explored the ability of PSB (control and inoculated) to release P from different P sources [single super phosphate (SSP), rock phosphate (RP), poultry manure (PM) and farm yard manure (FYM)] with various soil lime contents (4.78, 10, 15 and 20%) in alkaline soil. They reported that PSB inoculation progressively enriched Olsen's extractable P from all sources compared to the control over the course of 56 days; however, this increase was greater from organic sources (PM and FYM) than from mineral P sources (SSP and RP). Furthermore, they found that lime

addition to the soil decreased bioavailable P, but this effect was largely neutralized by PSB inoculation. They added that PSB were the most viable in soil inoculated with PSB and amended with organic sources, while lime addition decreased PSB survival. Their findings imply that PSB inoculation can counteract the antagonistic effect of soil calcification on bioavailable P when it is applied using both mineral and organic sources, although organic sources support this process more efficiently than the mineral P sources. Finally they concluded that PSB inoculation combined with organic manure application is one of the best options for improving soil P nutrition.

## 2.8 Effect of P solubilizers on soil enzymatic activity

Abdel-Fattah *et al.* (2014) studied the influence of arbuscular mycorrhiza and phosphorus fertilization on acid and alkaline phosphatase activity in soybean plants. In all treatments, soluble acid phosphatase activity was much higher than alkaline phosphatase, and these activities were elevated, in most cases, by the mycorrhizal inoculation. Addition of soluble phosphate to soil decreased the activities of acid and alkaline phosphatase in mycorrhizal and non-mycorrhizal soybean root extracts. Regarding P concentration, soluble acid (810 and 750  $\text{mU ml}^{-1}$ ) and alkaline phosphatase activities (260 and 200  $\text{mU ml}^{-1}$ ) in root extracts were significantly higher in mycorrhizal than in non-mycorrhizal inoculation respectively.

Dotaniya *et al.* (2014) investigated the rhizosphere effect of *kharif* crops on phosphatases and dehydrogenase activities in a typic Haplustert. Through their experimentation they focused on effect of major *kharif* crops on phosphatases and dehydrogenase activities in soil at different crop growth periods (30, 50, 75, 90 days after sowing and at crop harvest). The maximum acid phosphatase and dehydrogenases activities were observed at 75 days in rice. They concluded that the enzyme activity is associated with maximum availability and uptake of nutrients, particularly phosphorus in plant.

Rani *et al.* (2014) studied the integrated effect of organic manure and inorganic fertilizers on soil phosphatase activity in maize-spinach cropping system. They exhibited that application of different levels of manures in conjunction with inorganic fertilizer recorded significantly highest acid and alkaline phosphatase activity. They found that 100% vermicompost showed significantly highest enzyme activities at all the plant growth stages for instance 37.93 and 68.43  $\text{PNP g}^{-1} \text{ soil h}^{-1}$  of acid and alkaline phosphatase activities at vegetative stage respectively.

Xuan Yu *et al.* (2014) studied the effect of inoculated soil with PSB on growth and soil quality in walnut. They reported that inoculation with *P. aurantiaca* or *P. fluorescens* significantly improved the activities of dehydrogenase, neutral phosphatase, and urease activities in the rhizosphere compared with the control. Furthermore, mixed inoculation with the three PSB strains led to the maximum activities of dehydrogenase, neutral phosphatase, and urease than

when these organisms were used individually. Even the addition of RP alone into the soil slightly increased the activities of the three enzymes compared with the control. Nevertheless, the combine effect of RP and *P. aurantiaca*, *P. fluorescens*, or the mixture of the three PSB strains on the activities of the three soil enzymes was significant. The most pronounced beneficial effects on soil enzyme activities were observed when the three PSB strains were coinoculated with RP.

Raghuveer *et al.* (2017) investigated the effect of phosphorus levels and PSB strains on soil enzyme activity in acid soil under rice cultivation. They found that the highest phosphatase activity was recorded with the inoculation of *Pseudomonas sp.* ( $35.14 \mu\text{g pNP g}^{-1} \text{h}^{-1}$ ) and was superior over control, *Enterobacter sp.*, and *Arthrobacter sp.*, but was at par with *Bacillus polymixia*. They further, indicated that the interaction effect of P levels and PSB strains was significant on PHA and maximum PHA ( $40.98 \mu\text{g pNP g}^{-1} \text{h}^{-1}$ ) was found by P control when was inoculated with *Pseudomonas sp.* Their results revealed that, the highest ( $5.61 \mu\text{g TPF g}^{-1} \text{h}^{-1}$ ) dehydrogenase activity was observed with the application of  $60 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$  over rest of the  $\text{P}_2\text{O}_5$  levels. The inoculation of *Pseudomonas sp.* recorded highest dehydrogenase activity ( $5.03 \mu\text{g TPF g}^{-1} \text{h}^{-1}$ ) was superior over PSB control and *Enterobacter sp.*, but was at par with *Arthrobacter sp.* and *Bacillus polymixia*.

Namli *et al.* (2017) studied the effect of phosphate solubilizing bacteria on some soil properties, yield and nutrient contents in wheat crop. They reported that alkaline phosphate activities were highest in the PGPR treatment (20.1 to  $22.76 \mu\text{g PNP}$ ) than other treatments.

Pradhan *et al.* (2017) studied the effect of P- solubilizing bacteria on phosphatase activity in groundnut. They examined the potency of five bacterial strains (2 strains of *Bacillus* and 3 strains of *Burkholderia*) on soil phosphatase activities. They reported significantly enhanced soil phosphatase activities at 40, 75 days and at harvest. Their result indicated higher acid phosphate activity  $0.148$ ,  $0.148$  and  $0.158 \mu\text{m PNP g}^{-1} \text{soil h}^{-1}$  and alkaline phosphatase at 40, 75 and at harvest  $0.026$ ,  $0.038$  and  $0.042 \mu\text{m PNP g}^{-1} \text{soil h}^{-1}$  respectively with combined application of SSP and PSB strains.

Saikia *et al.* (2018) studied the influence of microbial consortium inoculation on soil health. The results of their study explicitly validated that the use of enriched compost along with consortium improved the soil microbial enzyme activity. They found increased microbial population in treatment with enriched compost along with consortium (*Rhizobium* + *Azotobacter* + *Azospirillum* + PSB) and recorded highest dehydrogenase activity ( $711.50 \mu\text{g TPF g}^{-1} \text{h}^{-1}$ ) and phosphomonoesterase activity ( $442.43 \mu\text{g p-nitrophenol g}^{-1} \text{h}^{-1}$ ) over consortium and enriched compost alone.

### 3. MATERIAL AND METHODS

The present investigation pertaining to the, “Effect of consortium phosphate solubilizing bacteria on phosphorus availability, nutrient content and yield of soybean (*Glycine max.L*)” was conducted during *Kharif* 2018 at PG Research Farm, Agronomy Section, Rajarshee Chhatrapati Shahu Maharaj, College of Agriculture, Kolhapur. The analytical work partly was carried out in the research laboratory of Soil Science and Agricultural Chemistry, Rajarshee Chhatrapati Shahu Maharaj, College of Agriculture, Kolhapur and partly at Soil Science and Agriculture Chemistry laboratory, Zonal Agricultural Research Station, Sub-montane zone, Kolhapur. The details regarding materials used and methods followed during the course of investigation are presented in this chapter.

#### 3.1 Experimental Material

##### 3.1.1 Experimental Site

The field experiment was conducted at PG Research Farm, Agronomy Section, Rajarshee Chhatrapati Shahu Maharaj, College of Agriculture, Kolhapur during *Kharif* 2018 under rainfed condition. The experiment was laid out on well drained soil for cultivation of soybean.

##### 3.1.2 Soil

The experiment was conducted on medium deep soil (Inceptisol). The topography of experimental field was fairly uniform and levelled. In order to know the chemical compositions of experimental soil, samples were collected from 5 randomly selected spots from experimental area and composite sample was prepared and analyzed. The chemical composition indicated that the soil was very low in available nitrogen ( $191 \text{ kg ha}^{-1}$ ), high in available phosphorus ( $30 \text{ kg ha}^{-1}$ ) and high in available potassium ( $319 \text{ kg ha}^{-1}$ ). The soil was alkaline in reaction (pH-8.22), having electrical conductivity  $0.174 \text{ dS m}^{-1}$  and organic carbon content was medium (0.56%).

### 3.1.3 Chemical Properties of the Initial Soil

**Table: 3.1. Chemical properties of the initial soil of experimental plot**

Sr. No.	Parameters	Values
1	pH (1:2.5 Soil: Water ratio)	8.22
2	EC (dS m <sup>-1</sup> )	0.17
3	Organic carbon (%)	0.56
4	Available nitrogen (kg ha <sup>-1</sup> )	191
5	Available phosphorus (kg ha <sup>-1</sup> )	30
6	Available potassium (kg ha <sup>-1</sup> )	319
7	Fe (mg kg <sup>-1</sup> )	4.3
8	Mn (mg kg <sup>-1</sup> )	5.69
9	Cu (mg kg <sup>-1</sup> )	2.28
11	Zn (mg kg <sup>-1</sup> )	0.52

### 3.1.4 Climatic Conditions and Location

#### 3.1.4.1 General

Kolhapur is situated on an elevation of 548 meters above the mean sea level on 16° 42' North latitude and 74° 14' East longitudes and comes under the Sub-mountain zone of Maharashtra. The average annual rainfall is 1057 mm, with 84 rainy days, which are received mostly from South-West monsoon. Out of the total annual precipitation about 80 percent is received from June to September (South-West monsoon), while the remaining precipitation is received from North-East monsoon in the months of October and November. The annual mean maximum temperature ranges between 34°C and 40°C while, the annual mean minimum temperature varies from 6°C to 10°C. The mean humidity percentage during summer season ranges between 78 to 95 per cent.

**Table 3.2: Weather data recorded during experimental period (June-18 to November-18)**

Month and year	Date	Met. Week	Mean Temp (°C)		Relative humidity (%)		Rainfall (mm)	Rainy days	Evaporation (mm)
			Max.	Min.	Morn.	Even.			
June-2018	04-10	23	31.1	20.8	84	74	5.3	1	3.6
	11-17	24	30.2	20.9	86	76	8.4	3	2.1
	18-24	25	29.3	19.3	86	77	9.1	6	1.5
	25-01 July	26	28.5	18.2	91	89	8.7	5	1.7
July-2018	02-08	27	26.8	17.7	92	86	20.7	6	0.6
	09-15	28	25.3	16.5	94	91	32.2	7	1.2
	16-22	29	25.2	17.0	93	92	3.9	6	1.1
	23-29	30	26.4	17.8	93	90	3.5	5	1.8
	30-05 Aug	31	27.0	18.4	91	89	3.8	5	1.9
Aug-2018	06-12	32	26.2	18.4	91	89	9.5	7	1.1
	13-19	33	24.9	17.8	91	88	6.2	4	1.3
	20-26	34	26.2	17.2	90	87	7.5	4	2.1
	27-02 Sept	35	26.1	17.4	90	88	2.6	4	2.6
Sept-2018	03-09	36	27.3	19.3	88	85	0.0	0	4.6
	10-16	37	30.2	18.8	81	69	7.5	2	4.3
	17-23	38	31.1	19.6	79	63	7.2	4	3.8
	24-30	39	31.0	20.0	86	67	0.3	0	4.5
Oct- 2018	01-07	40	33.0	15.2	82	53	0.7	1	5.1
	08-14	41	33.1	13.8	84	49	3.6	2	4.6
	15-21	42	31.5	13.4	83	56	0.0	0	4.1
	22-28	43	32.3	13.1	80	53	2.0	3	3.4

### 3.1.5 Cropping History of the Experimental Plot

The cropping history of the experimental plot for previous three years is presented in Table 3.3.

**Table 3.3: Cropping history of experimental plot**

Year	<i>Kharif</i>	<i>Rabi</i>	Summer
2016-2017	Soybean	Wheat	Groundnut
2017-2018	Soybean	Wheat	Groundnut
2018-2019	Soybean (experiment)	-	-

### 3.1.6 Experimental Details

The field experiment was laid out in a randomized block design (RBD) comprising seven treatments with three replications. The details are as under:

- 1) Crop : Soybean
- 2) Variety : Phule Sangam
- 3) Design : Randomized Block Design
- 4) No. of Replications : 3
- 5) No. of Treatments : 8
- 6) Season : *Kharif*, 2018
- 7) Seed rate : 80 kg ha<sup>-1</sup>
- 8) Spacing : 45 x 10 cm<sup>2</sup>
- 9) Plot size (m) : Gross plot : 5.4 x 3.6 m<sup>2</sup>  
Net plot : 3.6x 3.4 m<sup>2</sup>
- 10) Location : PG Research Farm, Agronomy Section,  
Rajarshee Chhatrapati Shahu Maharaj,  
College of Agriculture, Kolhapur.

### 3.1.7 Treatment details

**Table 3.4 Treatment details**

<b>T<sub>1</sub></b>	:	Absolute control
<b>T<sub>2</sub></b>	:	50 % P <sub>2</sub> O <sub>5</sub> + 100 % N and K <sub>2</sub> O
<b>T<sub>3</sub></b>	:	75 % P <sub>2</sub> O <sub>5</sub> + 100 % N and K <sub>2</sub> O
<b>T<sub>4</sub></b>	:	100 % General recommended dose of fertilizer (50 kg N: 75 kg P <sub>2</sub> O <sub>5</sub> :45 kg K <sub>2</sub> O ha <sup>-1</sup> )
<b>T<sub>5</sub></b>	:	Consortium of PSB only
<b>T<sub>6</sub></b>	:	Consortium of PSB + 50 % P <sub>2</sub> O <sub>5</sub> + 100 % N and K <sub>2</sub> O
<b>T<sub>7</sub></b>	:	Consortium of PSB + 75 % P <sub>2</sub> O <sub>5</sub> + 100 % N and K <sub>2</sub> O
<b>T<sub>8</sub></b>	:	Consortium of PSB + 100 % GRDF

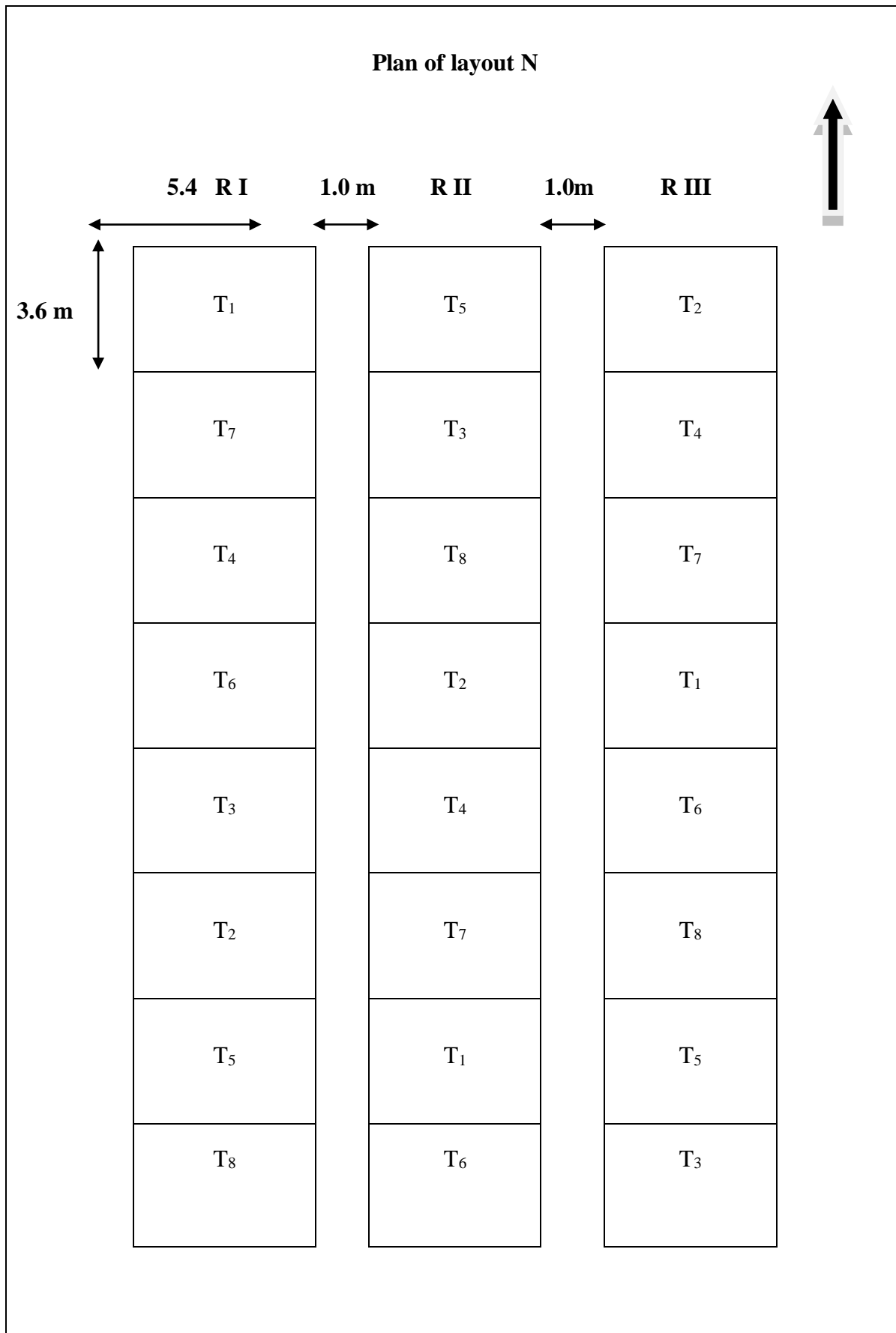
**Note:**

1. Consortium of PSB consisting of *Bacillus subtilis*, *Pseudomonas fluorescens* and *Bacillus megaterium* talc based was used.
2. Seed treatment with consortium of PSB was followed @ 10 g consortium kg<sup>-1</sup> seed
3. FYM @ 10 t ha<sup>-1</sup> was applied common to all treatments except control.

### 3.1.8 Experimental layout

The field experiment was laid out in a randomized block design (RBD) comprising seven treatments with three replications. The details are as under.

**Fig. 3.1: Plan of layout and treatment details of experimental plot**



### 3.1.9 Details of field operations

**Table 3.5: Schedule of field operations carried out on the experimental plot during kharif 2018**

Sr. No.	Name of operations	Frequencies	Date of operation
1	Ploughing	1	27.05.2018
2	Harrowing	2	02.06.2018 04.06.2018
3	Preparation of field layout	1	06.06.2018
4	Application of FYM	1	15.06.2018
5	Pre sowing irrigation	1	24.06.2018
6	Seed treatment with Consortium of PSB consisting of <i>Bacillus subtilis</i> , <i>Pseudomonas fluorescens</i> and <i>Bacillus megaterium</i>	1	2 <sup>nd</sup> July, 2018
7	Sowing, covering the seed and application of basal dose 50:75:45 (N:P <sub>2</sub> O <sub>5</sub> :K <sub>2</sub> O kg ha <sup>-1</sup> )	1	2 <sup>nd</sup> July, 2018
8	Application of fertilizers (Treatment wise)	1	2 <sup>nd</sup> July, 2018
9	Gap filling	1	11.07.018
10	Hand weeding	1	27.7.2018
11	Harvesting	1	25.10.2018

#### 3.1.9.1 Preparatory tillage

The experimental site was ploughed with the help of tractor and tractor drawn cultivator. The clod crushing was done by tractor drawn rotavator. The field was leveled with the help of wooden plank and was made ready for layout.

#### 3.1.9.2 Fertilizer application

The soybean crop was fertilized with 50 kg N, 75 kg P<sub>2</sub>O<sub>5</sub> and 45 kg K<sub>2</sub>O per hectare. At the time of sowing of soybean, full dose of nitrogen, Phosphorus and Potassium was applied as per treatment basal dose respectively.

### 3.1.9.3 Seeds and selection of variety

The variety Phule Sangam was used for sowing. The variety had maturity of 115-120 days.

### 3.1.9.4 Seed treatment

The seeds of soybean variety Phule Sangam were treated with consortium of PSB consisting of phosphate solubilising bacteria phosphate viz, *Bacillus subtilis*, *Pseudomonas fluorescens* and *Bacillus megaterium* @ 250 g per 10 kg of seeds and then used for sowing.

### 3.1.9.5 Sowing

Sowing was done by opening very small furrow at distance of 45 cm with the help of marker and soybean seed was dibbled at a distance of 10 cm to a depth of 2 to 3 cm by manual labours and it was covered with soil.

### 3.1.9.6 Gap filling

The gap filling was done at 10 days after sowing to maintain uniform plant population.

### 3.1.9.7 Irrigations

The crop was irrigated as per requirements considering the rainfall and crop growth stages.

### 3.1.9.8. Intercultural operation

Two hand weedings and one hoeing with the help of cycle hoe were done as per the weed

density to keep the plot free from weeds.

### 3.1.9.9. Plant protection measures

Two sprayings of insecticide was done by cypermethrin 25% @ 4 mL per 10 lit<sup>-1</sup> of water and Chlorofenapyr @ 4 mL 15 lit<sup>-1</sup> of water with Wetron-80 @ 20 ml in 15 lit of spray solution.

### 3.1.9.10 Harvesting

The soybean crop was harvested when grains were fully matured. The border lines of plants were removed first to eliminate border effect. The crop from net plot was cut close to the ground and kept in respective plots for sun drying.

### 3.1.9.11 Threshing

The threshing of soybean was done treatments wise. The grains were separated from plant by tractor drawn thresher. The straw yields and soybean grain yield were recorded by weighing as per the treatment.

## 3.2 Observations

### 3.2.1 Biometric observations

The details of different observations recorded during the course of investigation are presented in Table 3.6.

**Table 3.6: Details of observations**

Sr. No.	Particulars	Period of observations
	<b>Plant observation</b>	
<b>A</b>	<b>Growth studies</b>	
1	Plant height	At harvest
2	Number of nodules plant <sup>-1</sup>	50 % flowering
4	Number of pods plant <sup>-1</sup> i.e. filled and unfilled	At harvest
<b>B</b>	<b>Post harvest studies</b>	
1	100 seed weight	At harvest
2	Grain yield (kg ha <sup>-1</sup> )	At harvest
3	Straw yield (kg ha <sup>-1</sup> )	At harvest
<b>C</b>	<b>Quality parameters</b>	
1	Protein content (%) in grain	At harvest
2	Oil content (%) in grain	At harvest
	<b>Soil observations</b>	
<b>A</b>	<b>Soil analysis</b>	
	pH, EC, OC and available N, P, K, and Micronutrients Fe, Mn, Zn, Cu, acid and alkaline Phosphatase and dehydrogenase activities.	Initial and at harvest
<b>B</b>	<b>Plant analysis</b>	
	Total uptake of N, P, K, and micronutrients: Fe, Mn, Zn, Cu.	After harvest

### **3.2.2 Post harvest studies**

#### **3.2.2.1 Plant height (cm)**

Plant height was recorded from selected five plants at 60 DAS. The height was recorded from the soil surface to the top at harvest.

#### **3.2.2.2 Number of nodules plant<sup>-1</sup>**

The total number of nodules plant<sup>-1</sup> were counted from five randomly selected plants from each plot after 60 DAS.

#### **3.2.2.3 Number of pods plant<sup>-1</sup>**

The filled and unfilled pods plant<sup>-1</sup> were determined from five randomly selected plants at harvest and average values were recorded.

#### **3.2.2.4 100 seed weight**

After harvest of crop the pods were dried and 100 seed weight was recorded.

#### **3.2.2.5 Grain yield kg ha<sup>-1</sup>**

The treatment wise pods were harvested and pod yield were recorded. Care was taken to remove soil from the pods. The pods were later dried and then weights were recorded.

### 3.2.3 Soil and plant analysis

The analytical work was partly completed in the research laboratory at Division of Soil Science and Agricultural Chemistry, College of Agriculture, Kolhapur and SSAC, ZARS, sub montane, Kolhapur during the academic year 2018-2019. The analytical methods employed are presented in the Table 3.6 and 3.7.

#### 3.2.3.1 Soil analysis

Representative soil samples initial and after harvest were collected from 0-15 cm depth, processed and analyzed by following standard procedures.

**Table 3.7: Methods used for soil analysis**

Sr. No.	Parameters	Methods	References
1	pH (1:2.5; Soil : Water)	Potentiometry	Jackson (1973)
2	EC (1:2.5; Soil : Water) dS m <sup>-1</sup>	Conductometry	Jackson (1973)
3	Organic Carbon	Wet oxidation	Nelson and Sommers (1982)
4	Available Nitrogen	Alkaline permanganate	Subbiah and Asija (1956)
5	Available Phosphorus	Olsen (0.5 M sodium bicarbonate) (pH-8.5)	Olsen and Dean (1954)
6	Available Potassium	Flame photometry, 1 N neutral ammonium acetate (pH-7.0)	Knudsen <i>et al.</i> (1982)
7	Phosphatase activity	Disodium p-nitrophenyl phosphate	Tabatabai and Bremner (1969)
8	Dehydrogenase activity	Triphenyltetrazolium chloride (TTC)	Lenhard (1956)
9	DTPA extractable micronutrients (Fe, Mn, Zn and Cu)	Atomic absorption spectrophotometry	Lindsay and Norvell (1978)

### 3.2.3.1.1 Soil reaction (pH)

The pH of soil was measured with pH meter having glass electrode and calomel electrode having 1:2.5 soil: water ratio as described by Jackson (1973).

### 3.2.3.1.2 Electrical conductivity ( $\text{dS m}^{-1}$ )

It was determined in 1:2.5 soil: water suspension with conductivity meter as described by Jackson (1973).

### 3.2.3.1.3 Organic carbon (%)

Organic carbon in soil (0.5 mm sieved) was determined by wet oxidation method as described by Nelson and Sommer (1982).

### 3.2.3.1.4 Available nitrogen ( $\text{kg ha}^{-1}$ )

Available nitrogen was estimated by alkaline potassium permanganate (0.32%  $\text{KMnO}_4$ ) method as described by Subbiah and Asija (1956).

### 3.2.3.1.5 Available phosphorus ( $\text{kg ha}^{-1}$ )

It was estimated by adopting Olsen's method using 0.5 M  $\text{NaHCO}_3$  extractant at pH 8.5. The soil: extractant ratio was 1:20 and the shaking time was 30 minutes. The phosphorus in the extract was determined calorimetrically at 880 nm wavelength by using UV-VIS spectrophotometer (Olsen and Dean 1954).

### 3.2.3.1.6 Available potassium ( $\text{kg ha}^{-1}$ )

The available potassium content in soil was extracted with neutral normal ammonium acetate (pH= 7.0). The potassium in the extract was determined by flame photometer as described by Knudsen *et al.* (1982).

### 3.2.3.1.7 Phosphomonoesterases (Acid and Alkaline Phosphatase) ( $\text{mg kg}^{-1}$ )

Phosphatase activity was measured by the method of Tabatabai and Bremner (1969). 1 g of air-dried soil was taken in to a 50 ml conical flask, add 0.2 ml of toluene, 4 ml of modified universal buffer (pH 6.5 for assay of acid phosphatase and pH 11 for assay of alkaline phosphatase), 1 ml *p*-nitrophenyl phosphate (PNP) solution made in the same buffer. The flask was swirled for few seconds and then incubated at 37° C for one hour in an incubator. After incubation 1 ml of 0.5 M calcium chloride and 4 ml of 0.5 M sodium hydroxide was added to the mixture. The soil suspension was filtered through Whatman filter paper No. I. The optical density of the filtrate was measured at 420 nm on Lab India UV 3000 UV-VIS spectrophotometer. Blank was maintained similarly without soil. The phosphatase activity in terms of concentration of *p*-141 nitrophenyl in each sample was calculated by a standard curve of *p*-nitrophenol in water and was expressed as mole of *p*-nitrophenol released per gram dry soil per hour.

### 3.2.3.1.8 Dehydrogenase activity ( $\text{mg kg}^{-1}$ )

The dehydrogenase activity in soil was estimated by following the method given by Lehnard (1956). This method involves colorimetric determination of 2,3,5-triphenyl formazan (TPF) produced by the reduction of 2,3,5-triphenyltetrazolium chloride (TTC). In order to estimate dehydrogenase, 1 gram air dried soil was taken in air tight screw capped test tube (15 ml cap.) , 0.2 ml of 3 % TTC, which followed with addition of 0.5 ml of 1% glucose. The test tube were sealed and incubated for  $28 \pm 0.5$  °C for 24 hours. After incubation 10 ml of methanol was added and allowed to stand for 6 hours. The intensity of pink coloured supernatant liquid was determined using Lab India UV 3000 UV-VIS spectrophotometer. Triphenyl formazane formed was extrapolated against standard curve drawn in the range of 10 to 90  $\text{mg TPF L}^{-1}$

### 3.2.3.1.9 Available micronutrients ( $\text{mg kg}^{-1}$ )

Micronutrients from soil samples were determined by Atomic Absorption Spectrophotometer using DTPA extract as described by Lindsay and Norvell (1978).

### 3.2.3.2 Plant analysis

The pod and straw samples collected at harvest were washed thoroughly and dried in hot air oven at  $65^{\circ}\text{C} \pm 5^{\circ}\text{C}$ . Further, these samples were milled to in a willey mill and stored in plastic containers for further analysis

**Table 3.8: Methods for plant analysis**

Sr. No.	Parameters	Methods	References
1	Total N	Microkjeldhal (Diacid digestion)	Parkinson and Allen (1975)
2	Total P	Vandomolybdateyellow colour in nitric acid system	Jackson (1973)
3	Total K	Flame photometry (Triacid digestion)	Chapman and Pratt (1961)
4	Micronutrients (Fe, Mn, Zn and Cu)	Atomic absorption spectrophotometry	Zososki and Burau (1977)
5	Oil content	Soxhlet ether extract	A.O.A.C. (2016)
6	Crude protein	Per cent N x 6.25	A.O.A.C. (2016)

### 3.2.3.2.1 Total nitrogen ( $\text{kg ha}^{-1}$ )

The 0.5 g plant sample was digested with concentrated  $\text{H}_2\text{SO}_4$  (5 mL) and digestion mixture ( $\text{CuSO}_4 + \text{K}_2\text{SO}_4 + \text{selenium powder}$ ). The volume was made to 100 mL with distilled water after digestion. The nitrogen of aliquot was determined by Micro Kjeldahl method (Parkinson and Allen 1975).

### 3.2.3.2.2 Total phosphorus ( $\text{kg ha}^{-1}$ )

The plant samples (0.5 g each) were digested with nitric acid, sulphuric acid, and perchloric acid in ratio 9:4:1 and the volume was made to 100 mL with distilled water. The phosphorus content in aliquot was estimated by vanado-molybdate phosphoric yellow colour method in nitric acid medium and the colour intensity was measured at 880 nm wave length as described by Jackson (1973).

### 3.2.3.2.3 Total potassium ( $\text{kg ha}^{-1}$ )

The total potassium was determined of digested extract by flame photometer (Chapman and Pratt 1961).

### 3.2.3.2.4 Total micronutrients ( $\text{mg kg}^{-1}$ )

The plant samples (0.5 g each) were wet digested with nitric acid and perchloric acid in ratio 9:4 and the volume was made to 100 mL with double distilled water after digestion. The micronutrients from plant samples were determined by Atomic Absorption Spectrophotometer as described by Zososki and Bureau (1977).

### 3.2.3.2.5 Uptake of nutrients by the Crop

The uptake of nitrogen, phosphorus, potassium and micronutrients iron, manganese, zinc, copper was determined by multiplying the percentage of these nutrients with the corresponding yield of respective constituent.

## 3.3 Phosphorus incubation studies:

The incubation studies were carried out at 0, 15, 30, 45, 60 and 90 days intervals. Soil samples were collected from the field. These samples were air dried and sieved through 2 mm sieve. Replicated 100 g sample representing each treatment was taken in plastic container, covered with perforated wax paper or polythene sheet. These samples were inoculated with of PSB consortium and calculated amount of N, P and K fertilizers. The samples were maintained at field capacity at room temperature for desired intervals. After the incubation period, the soils were air dried and available phosphorus was estimated as per Olsen's method (0.5 M sodium bicarbonate).

### 3.4 Preparation of talc-based consortium of phosphate solubilizing bacteria

A loopful culture of *Bacillus subtilis* was inoculated separately in nutrient broth medium, *Pseudomonas fluorescens* was inoculated separately into King's B broth medium and *Bacillus megaterium* was inoculated separately in Pikovaskaya broth medium. The inoculated broth culture media was incubated on a rotary shaker at 150 rpm for 72 h at room temperature (28<sub>±</sub>2°C). After 72 h of incubation, the broth culture media containing  $9 \times 10^8$  cfu mL<sup>-1</sup> of each organism were used for the preparation of talc-based consortium of phosphate solubilizing bacteria. To 3 kg of talc powder (sodium ammonium silicate) 400 ml bacteria suspension of all the three organisms were mixed. To the mixture, calcium carbonate 15 g (to adjust the pH to neutral) and carboxy methyl cellulose (CMC) 10 g (as an adhesive) were mixed under sterile conditions (Vidhyasekaran and Muthamila, 1995). The product was shade dried to reduce the moisture content to 20% and then packed in polypropylene bags and sealed.

### 3.5 Statistical analysis

The experimental data were analyzed statistically by applying the techniques of "Analysis of variance" and significance was tested by variance ratio i.e. F value at 5 percent level of significance as described by Panse and Sukhatme (1989). Standard error of mean (S.Em.) and critical difference (CD) was worked out to evaluate differences between treatment means.

## 4. RESULTS AND DISCUSSION

An experiment entitled, “Effect of consortium of phosphate solubilizing bacteria on phosphorus availability, nutrient content and yield of soybean (*Glycine max.* L.) was conducted at PG farm, Rajarshee Chatrapati Shahu Maharaj, College of Agriculture during 2018. The results of the said investigation are presented below under appropriate subheadings.

4.1 Effect of PSB consortium on growth and yield attributes of soybean

4.2 Effect of PSB consortium on nodulation characteristics of soybean

4.3 Effect of PSB consortium on grain and straw yield of soybean

4.4 Effect of PSB consortium on protein content and protein yield of soybean

4.5 Effect of PSB consortium on oil content and oil yield of soybean

4.6 Effect of PSB consortium on major nutrient uptake

4.7 Effect of PSB consortium on micronutrient uptake

4.8 Effect of PSB consortium on soil properties and available nutrient status

4.9 Effect of PSB on phosphorus release at different days of incubation

4.10 Effect of PSB consortium on dehydrogenase and phosphatase activity

4.11 Effect of PSB consortium on nutrient use efficiency

### 4.1: Effect of PSB consortium on growth and yield attributes of soybean

The rhizospheric bacteria such as phosphate solubilizing bacteria form an important and integral component of soil ecosystems and affect the soil fertility through different mechanisms. However, the possible explanations could be production of phytohormones, growth regulators and most importantly dissolution of insoluble phosphorus whose availability in soil is affected due to change in soil reaction (pH) and thereby making phosphorus available for uptake by plant.

The results of the present study exhibited beneficial influence of consortium of phosphate solubilizing bacteria on growth and yield attributes of soybean crop. The data pertaining to growth and yield attributes is presented in table 4.1 and graphically depicted through figure 4.1.

#### 4.1.1: 100 Seed weight (g)

The seed weight, which is generally expressed as 100 seed weight, is one of the most important yield components in soybean. Through numerous studies it has been evidently proved that 100 seed weight is positively associated with seed yield of the crop. It has also been reported that 100 seed weight is closely correlated with seed germination and vigor (Ramana *et al.*, 2010)

The data presented in table 4.1 and depicted in figure 4.1 revealed that 100 seed weight per plant ranged from 18.32 to 19.52 g within the different treatments. In general, treatments receiving inoculation of consortium of phosphate solubilizing bacteria recorded higher 100 seed weight per plant as compared to un-inoculated treatments. The treatment, consortium of PSB +

75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (T<sub>7</sub>) recorded higher 100 seed weight of 19.52 g plant<sup>-1</sup> followed by consortium of PSB + 100% GRDF (19.51 g plant<sup>-1</sup>) among the inoculated treatments. However, among un-inoculated treatments, 100% GRDF i.e. (50 kg N: 75 kg P<sub>2</sub>O<sub>5</sub>:45 kg K<sub>2</sub>O ha<sup>-1</sup>) recorded higher 100 seed weight to the tune of 18.94 g plant<sup>-1</sup> followed by 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (18.91 g plant<sup>-1</sup>). The lowest value of 100 seed weight was observed in control treatment (18.32 g plant<sup>-1</sup>).

Despite, the observed variation in 100 seed weigh per plant, statistical analysis of the data revealed non-significant relationship between the treatments.

The numeric increment in seed weight in inoculated treatments could be attributed to the ability of PSB to release phytohormones, antibiotics or siderophores, increased availability of phosphorus due to dissolution of organic and bound phosphorus besides increase in nodulation.

The results of the present investigation are in close agreement with those of several researchers. Uddin *et al.* (2014) found increased 100 seed weight due to application of rhizobium and phosphate solubilizing bacteria (*Pseudomonas straita*) over control. Similarly, Ramana *et al.*, (2010) also reported that the treatment receiving 75% of RDF + VAM + PSB induced an increase in 100 seed weight among treatments of nutrient management in conjunction with phosphate solubilizing microorganism. The results are even in close agreement with those of Shahid *et al.*, (2009) and Afzal *et al.*, (2010) who reported higher seed weight per plant due to conjunct use of PSB and inorganic P fertilizers. Thus, these results explicitly validates that inorganic phosphorus fertilizer along with inoculation of PSB consortium exhibited better performance in regards of seed weight per plant in soybean as compared to un-inoculated treatments.

#### **4.1.2: Plant height (cm)**

Plant height is an important measure of plant vigor and health. Generally, plant height is hypothetically correlated with higher grain yield. However, in soybean, more plant height might result in lodging of the crop. But, it has also being argued that more vegetative growth is associated with higher grain yield.

The data pertaining to plant height of soybean crop is presented in table 4.1 and graphically depicted in figure 4.1. The results of the present investigation indicated that the plant height in soybean did not differ much within the treatments with and without inoculation of consortium of PSB. However, significant higher plant height was recorded by treatment consortium of PSB + 100% GRDF (T<sub>8</sub>) to the tune of 48.9 cm over absolute control (43.5 cm). Whereas, it was statistically at par with 100% GRDF (47.7 cm), consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (47.6 cm), consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (47.2 cm),

75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O without consortium of PSB (47.1 cm) and 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O without consortium of PSB (46.5 cm).

The result of present investigation regarding plant height explicitly substantiated the findings of many researchers. (Jayashree and Jagadeesh 2017) reported that the consortium of beneficial microorganisms is an innovative approach for plant growth and synergistic effect of the formulated microbes on crop production. Singh *et al.* (2010). Indicated that the treatments of seed inoculation with PSB significantly enhanced the seed germination, plant height, and number of branches per plant and ultimately seed yield. Kuntiyastuti and Sutrisno (2017) reported that the treatment receiving organic manure + PSB + 150 kg N, P and K fertilizer recorded highest plant height as compared to treatment receiving organic manure + 150 kg N, P and K fertilizer only. Similarly, Ramana *et al.*, (2010) reported that the treatment receiving RDF + VAM + PSB significantly increased the plant height number of branches, leaf area and dry weight and were closely related with seed germination and vigor.

#### 4.1.3 Number of Pod

The number of pod per plant is an important growth component which directly contributes to the final grain yield in soybean. It has been observed by many researchers that the number of pod per plant is directly correlated to the grain yield of soybean. Generally, higher the number of pod per plant higher is the grain yield.

The data in context to the number of pod per plant of soybean is presented in table 4.1 and graphically depicted in figure 4.1. The findings about number of pod per plant of soybean explicitly substantiate that the number of pod per plant are largely affected by the inoculation of consortium of PSB along with inorganic fertilizers as compared to un-inoculated treatments. The treatment of consortium of PSB + 100% GRDF recorded highest number of pod per plant of soybean (89.3 plant<sup>-1</sup>) However, it was statistically significant and superior over T<sub>6</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub> + 100 % N and K<sub>2</sub>O consortium of PSB (83.0 plant<sup>-1</sup>), T<sub>5</sub> i.e. Consortium of PSB only (76.7 plant<sup>-1</sup>), T<sub>3</sub> i.e. 75 % P<sub>2</sub>O<sub>5</sub>+ 100% N and K<sub>2</sub>O (82.7), T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub>+ 100% N and K<sub>2</sub>O (76.5) and over control (66.3 plant<sup>-1</sup>). However, it was found to be statistically at par with T<sub>7</sub> treatment consisting Consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100 % N and K<sub>2</sub>O (87.7 plant<sup>-1</sup>) and treatment T<sub>4</sub> which consisted 100 % GRDF without inoculation with PSB consortium (84.1 plant<sup>-1</sup>).

The findings unambiguously revealed that treatment receiving P through chemical source along with consortium of phosphate solubilizing bacteria had substantial positive effect on number of pod per plant when compared to treatments receiving P through chemical sources only. Improved values of growth attribute due to integration of phosphate solubilizing bacteria and chemical fertilizer might be due to improved supply of phosphorus and other nutrients by bio-fertilizers during latter stage of growth. Generally nutrient supply of legume plant gets

reduced towards maturity and steady and consistent supply of nutrients towards the important stage of soybean growth may result in higher number of pod per plant (Munda *et al.* 2013)

These findings are overtly validated by the findings of some researchers. Munda *et al.* (2013) found that application of 100% P through rock phosphate along with dual inoculation of PSB and VAM recorded significant highest number of pod per plant. Kuntastyuti and Sutrisno (2017) reported that the treatment receiving organic manure + PSB + 150 kg N, P and K fertilizer recorded highest number of soybean pod per plant as compared to treatment receiving organic manure + 150 kg N, P and K fertilizer only. Similarly, Yadav *et al.* (2007) found that combine application of *rhizobium* + PSB + 75 kg P<sub>2</sub>O<sub>5</sub> + poultry manure registered highest number of pods per plant in soybean among the various combination treatments. Afzal *et al.* (2010) showed that conjunct use of *Bradyrhizobium* and PSB along with recommended dose of phosphorus only recorded significant highest number of pod per soybean plant.

**Table 4.1: Growth and yield attributes of soybean as influenced by different treatments**

Treatments	100 seed weight (g)	Plant height (cm)	Number of Pods plant <sup>-1</sup>
T <sub>1</sub> -Absolute control	18.32	43.5	66.3
T <sub>2</sub> -50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	18.73	46.5	76.5
T <sub>3</sub> -75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	18.91	47.1	82.7
T <sub>4</sub> -100% GRDF (50 kg N: 75 kg P <sub>2</sub> O <sub>5</sub> :45 kg K <sub>2</sub> O ha <sup>-1</sup> )	18.94	47.7	84.1
T <sub>5</sub> -Consortium of PSB only	18.92	46.0	76.7
T <sub>6</sub> -Consortium of PSB + 50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	19.45	47.2	83.0
T <sub>7</sub> -Consortium of PSB + 75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	19.52	47.6	87.7
T <sub>8</sub> -Consortium of PSB + 100% GRDF	19.51	48.9	89.3
S.E. ±	0.406	0.97	1.86
CD at 5%	NS	2.94	5.63

#### 4.2 Effect of PSB Consortium on Nodulation Characteristics of Soybean

Legumes interact with specific soil rhizobia to develop symbiotic relationships that lead to the formation of root nodules. These nodules fix atmospheric nitrogen and allow the legume plant to grow at initial stages without or with limited nitrogen supply. The developments of these nodules are governed by certain molecular mechanism (Yuan *et al.* 2017). It is believed that beside biological nitrogen fixation, these root nodule also process requiring considerable amount of phosphorus (Qin *et al.* 2012)

The data pertaining to nodulation characteristics such as active nodule, non-active nodules, total number nodules per plant and nodule dry weight is presented in table 4.2 and graphically depicted through figure 4.2, 4.3 and 4.4.

#### 4.2.1 Active nodules:

From the Table 4.2 and figure 4.2 it has been revealed that the treatment receiving consortium of PSB recorded highest number of active nodules when compared to the un-inoculated treatments. However, seed application of *rhizobium* was common to all the treatment except control. This indicated that *rhizobial* bacteria along with phosphate solublizing bacteria enhanced the nodulation in soybean. Significantly highest number of active root nodule was recorded by PSB inoculated treatment T<sub>8</sub> consisting consortium of PSB + 100% GRDF (89.40 plant<sup>-1</sup>) which was statistically at par with treatment T<sub>7</sub> i.e. Consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (88.30 plant<sup>-1</sup>), T<sub>6</sub> i.e. Consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (79.90 plant<sup>-1</sup>) and T<sub>5</sub> which consisted only consortium of PSB (71.57 plant<sup>-1</sup>) and significantly superior over un-inoculated treatment. The percent contribution of active nodule to total number of nodule in all the above inoculated treatments was found to be 68.9%, 68.6%, 65.7% and 62.8% respectively. The highest number of active nodules amongst the non-inoculated treatments was recorded by T<sub>4</sub> i.e. 100% GRDF (60.33 plant<sup>-1</sup>) followed by 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (54.40 plant<sup>-1</sup>), 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (52.27 plant<sup>-1</sup>) and control (36.47 plant<sup>-1</sup>) which contributed 60.1%, 56.2%, 56.3% and 53.2% of total number of nodules respectively.

#### 4.2.2 Non active nodules:

From the data presented in table 4.2 and figure 4.2 it was observed that in case of non-active nodules no definite trend was observed when only numbers of non-active nodules are taken into consideration. However, percentage of non-active nodules to total number of nodules was found to be decreasing in inoculated treatments when compared un-inoculated treatment. The least per cent of non-active nodules to total number of nodules amongst the inoculated treatment was observed in treatment PSB + 100% GRDF (31.1%) which went on gradually increasing in treatment, consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (31.4%), consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (34.3%) and only consortium (37.2%). However, among the un-inoculated treatment lowest percentage of non-active nodules was recorded in 100% GRDF (39.9%) and went on increasing to tune of 46.8% in absolute control.

#### 4.3.3 Total number of nodules:

The total number of nodules per plant followed almost similar trend to that of active nodules per plant of soybean. The findings exhibited that the treatment T<sub>8</sub> having consortium of PSB + 100% GRDF recorded significant and highest number of nodules (129.8 plant<sup>-1</sup>) which was statistically at par with treatment T<sub>7</sub> i.e. consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O

(128.6 plant<sup>-1</sup>), T<sub>6</sub> i.e. consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (121.5 plant<sup>-1</sup>) and T<sub>5</sub> which consisted only consortium of PSB (114.0 plant<sup>-1</sup>) and significantly superior over all the un-inoculated treatment. When the per cent increase of total number of nodules over control was calculated, it revealed that all the above treatments recorded 47.1%, 46.7%, 43.6% and 39.8% increase over control respectively. Amongst the un-inoculated treatment T<sub>4</sub> i.e. 100% GRDF recorded highest number of nodules (100.4 plant<sup>-1</sup>) followed by 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (96.8 plant<sup>-1</sup>), 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (92.9 plant<sup>-1</sup>) and control (68.6 plant<sup>-1</sup>). The per cent increase in number of nodule among these un-inoculated treatments was found to be 31.7%, 29.1%, 26.1% over control respectively. These findings publicized that inoculation with consortium of PSB was found to be beneficial in enhancing the number of nodules per plant as compared to un-inoculated treatment.

#### 4.2.4 Nodule dry weight

The results pertaining to nodule dry weight per plant are illustrated in table 4.2 and figure 4.4. The data showed that nodule dry weight closely followed the trend to that of number of nodules per plant. Higher the number of nodules higher was the nodule dry weight per plant. The treatment T<sub>8</sub> having Consortium of PSB + 100% GRDF recorded significantly highest value of nodule dry weight (0.321 g plant<sup>-1</sup>) however, it was statistically at par with inoculated treatments T<sub>7</sub> i.e. Consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (0.316 g plant<sup>-1</sup>), T<sub>6</sub> i.e. Consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (0.302 g plant<sup>-1</sup>) and T<sub>5</sub> which consisted only consortium of PSB (0.299 g plant<sup>-1</sup>) and significantly superior over un-inoculated treatment T<sub>4</sub> i.e. 100% GRDF recorded highest value of nodule dry weight (0.292 g plant<sup>-1</sup>), 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (0.278 g plant<sup>-1</sup>), 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (0.276 g plant<sup>-1</sup>) and control (0.226 g plant<sup>-1</sup>). The findings evidently validated that inoculation with consortium of PSB played vital role in increasing the nodule dry weight as compared to un-inoculated treatments.

The improvement in total number of nodules and nodule dry weight per plant could be attributed to the role consortium of PSB in solubilizing inorganic and organic phosphate by production of organic acids. These organic acids dissolve phosphatic minerals or chelate cationic partners of phosphate ions i.e. PO<sub>4</sub> into the soil (Khan *et al.* 2009). The organic acids either dissolve the phosphorus directly by lowering the soil pH which in turn helps in ion exchange of PO<sub>4</sub><sup>2-</sup> and also chelate heavy metals like Ca, Al, Fe and release the associated phosphorus (Rashmi *et al.* 2011). The role of phosphorus in several energy transformation processes and biochemical reactions including nitrogen fixation is very well known. The enhanced phosphorus release due to activity of PSB might have resulted in improved root development, stalk and stem strength, and nitrogen fixation in soybean. As it is also known that phosphorus is needed in relatively large amounts by legumes like soybean, the increase supply of P to the soybean plant

might have resulted in multiplication of rhizobia and essentially the movement of phosphorus in the soil system which in turn resulted in improved nodulation viz., number of nodules and nodules dry weight etc.

The results on nodulation are in close agreement with that of Agraw (2012) who reported that dual inoculation of *Bradyrhizobium* and PSB along with inorganic fertilizer scored significant increase in number of nodules and nodule weight over un-inoculated treatments. Devi *et al.* (2012) studied effect of different of phosphorus on growth and nodulation in soybean and they reported significant increase in number of nodules per plant and nodule dry weight with increase in levels of phosphorus. Singh *et al.* (2010) validated that inoculation treatments with different strains of PSB showed significantly greater number of nodules and dry weight on nodules per plant over un-inoculated control treatments. They reported that the extent of inoculated treatments increase in nodulation over control ranged from 56.95 to 74.68% in terms of nodulation while, per cent increase in context to dry weight of nodule ranged from 61.32 to 86.08% over control. The findings of present investigation also confirmed the finding of Vikram and Hamzehzarghani (2008) who reported that inoculation of green gram seeds with PSBV-14 (*Serratia* sp) recorded the highest nodule number, nodule dry weight, shoot dry matter in green gram plants 45 days after sowing.

**Table 4.2: Nodulation characteristics of soybean as influenced by different combination treatments**

Treatments	Number of nodules plant <sup>-1</sup>			Nodule dry weight (g)
	Active	Non active	Total	
T <sub>1</sub> -Absolute control	36.47 (53.2) <sup>a</sup>	32.13 (46.8) <sup>a</sup>	68.6	0.226
T <sub>2</sub> -50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	52.27 (56.3) <sup>a</sup>	40.60 (43.7) <sup>a</sup>	92.9 (26.1) <sup>b</sup>	0.276
T <sub>3</sub> -75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	54.40 (56.2) <sup>a</sup>	42.37 (43.8) <sup>a</sup>	96.8 (29.1) <sup>b</sup>	0.278
T <sub>4</sub> -100% GRDF (50 kg N: 75 kg P <sub>2</sub> O <sub>5</sub> :45 kg K <sub>2</sub> O ha <sup>-1</sup> )	60.33 (60.1) <sup>a</sup>	40.07 (39.9) <sup>a</sup>	100.4 (31.7) <sup>b</sup>	0.292
T <sub>5</sub> -Consortium of PSB only	71.57 (62.8) <sup>a</sup>	42.43 (37.2) <sup>a</sup>	114.0 (39.8) <sup>b</sup>	0.299
T <sub>6</sub> -Consortium of PSB + 50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	79.90 (65.7) <sup>a</sup>	41.63 (34.3) <sup>a</sup>	121.5 (43.6) <sup>b</sup>	0.302
T <sub>7</sub> -Consortium of PSB + 75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	88.30 (68.6) <sup>a</sup>	40.33 (31.4) <sup>a</sup>	128.6 (46.7) <sup>b</sup>	0.316
T <sub>8</sub> -Consortium of PSB + 100% GRDF	89.40 (68.9) <sup>a</sup>	40.40 (31.1) <sup>a</sup>	129.8 (47.1) <sup>b</sup>	0.321
S.E. ±	5.989	3.157	8.42	0.0092
CD at 5%	18.165	NS	25.54	0.0279

Values given in parentheses (<sup>a</sup>) indicate per cent contribution to total number of nodule and (<sup>b</sup>) indicate per cent increase over control.

### 4.3 Effect of PSB Consortium on Grain and straw yield of Soybean

#### 4.3.1 Grain yield

The data regarding grain yield of soybean is presented in table 4.3 and graphically illustrated in figure 4.5. The results of the present investigation indicated that fertilizer P played an imperative role in enhancing the grain yield of soybean. However, the integrated effect of consortium of phosphate solubilizing bacteria along with optimum dose of fertilizer P was found to be comparatively more beneficial in terms of grain yield of soybean. The highest grain yield was recorded by treatment T<sub>8</sub> consisting of inoculation with consortium of PSB + 100% GRDF to the tune of 36.9 q ha<sup>-1</sup> which was statistically at par with T<sub>7</sub> treatment consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (36.2 q ha<sup>-1</sup>) and significantly superior over inoculated treatments such as, T<sub>6</sub> i.e. consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (29.3 q ha<sup>-1</sup>), T<sub>5</sub> i.e. only consortium without inorganic fertilizer (27.6 q ha<sup>-1</sup>) and un-inoculated treatments viz., T<sub>4</sub> receiving 100% GRDF (31.7 q ha<sup>-1</sup>), T<sub>3</sub> i.e. 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (29.4 q ha<sup>-1</sup>), T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (24.3 q ha<sup>-1</sup>) and control treatment (18.6 q ha<sup>-1</sup>). The treatment with inoculation of PSB consortium along with 100% GRDF accounted for 14.3% increment in grain yield over 100% GRDF without inoculation while, PSB consortium with 75% P<sub>2</sub>O<sub>5</sub> recorded 18.7% increase in grain yield over 75% P<sub>2</sub>O<sub>5</sub> without inoculation.

#### 4.3.2 Straw yield

The data regarding straw yield of soybean is presented in table 4.3 and graphically illustrated in figure 4.5. From the results, it was observed that the straw yield of soybean followed the similar pattern to that of grain yield of soybean. The highest straw yield was recorded by treatment T<sub>8</sub> consisting of inoculation with consortium of PSB + 100% GRDF to the tune of 55.9 q ha<sup>-1</sup> which was statistically at par with T<sub>7</sub> treatment consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (53.1 q ha<sup>-1</sup>) and significantly superior over inoculated treatments such as, T<sub>6</sub> i.e. consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (40.3 q ha<sup>-1</sup>), T<sub>5</sub> i.e. only consortium without inorganic fertilizer (39.5 q ha<sup>-1</sup>) and un-inoculated treatments viz., T<sub>4</sub> receiving 100% GRDF (43.6 q ha<sup>-1</sup>), T<sub>3</sub> i.e. 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (40.9 q ha<sup>-1</sup>), T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (35.1 q ha<sup>-1</sup>) and control treatment (25.9 q ha<sup>-1</sup>). The treatment with inoculation of PSB consortium along with 100% GRDF accounted for 22.0% increment in straw yield over 100% GRDF without inoculation while, PSB consortium with 75% P<sub>2</sub>O<sub>5</sub> recorded 23.0% increase in straw yield over 75% P<sub>2</sub>O<sub>5</sub> without inoculation.

It seems that due to increase in yield components such as number of pod per plant, plant height, 100 seed weight, number of nodules per plant and nodule dry weight correspondingly contributed towards increase in grain and straw yield. It is also believed that for high yield, plant should have proper balance between the vegetative and reproductive growth and developmental

stages of seeds. This status can be achieved when we have balanced the necessary element for vegetative growth i.e. nitrogen and the necessary element for reproductive growth which is phosphorus. Inoculation with consortium of PSB might have accelerated the availability of soil phosphorus as a result of its tendency to solubilize of insoluble organic and fixed inorganic P and also stabilized nitrogen. Phosphate solubilizing bacteria led to increased adsorption of other elements such micronutrient through chelation by virtue of its property to release organic acids besides production of stimulant material, development of root system and anti-pathogenic effect (Zarei *et al.* 2012). These factual collectively might have resulted in increasing grain and straw yield in treatments receiving PSB inoculation.

The result of present investigation regarding grain and straw yield explicitly substantiated the findings of many researchers. Singh and Sharma (2011) found that inoculation treatment consisting *rhizobium* and PSB along with recommended dose of P through enriched vermicompost recorded maximum grain and strover yield in chickpea crop when compared to un-inoculated control. Shahid *et al.* (2009) reported that inoculated treatment with higher level of phosphorus resulted in higher seed yield of soybean over un-inoculated treatments. Yadav *et al.* (2007) found that combine application of *rhizobium* + PSB + 75 kg P<sub>2</sub>O<sub>5</sub> + poultry manure recorded highest grain and straw yield of soybean among the various combination treatments. Singh *et al.* (2011) studied effect of different PSB strain on grain yield of soybean and they validated that inoculation treatment with PSB has an ability to enhance grain yield and went on reporting significant higher grain yield in inoculated treatment over un-inoculated control. Waghmare *et al.* (2011) compared different treatments of nutrient management with and without biofertilizer for their influence on growth and yield of soybean. They found that combination treatment of 75% NPK + Rhizobium + PSB + organic manure emerged as the most beneficial treatment in terms of grain yield and straw yield when compared to other combination treatments. The result of present investigation also in agreement with the finding of Uddin *et al.* (2014) who investigated the combine effect of *Pseudomonas straita* and *Rhizobium ciceri* along with different level of phosphatic fertilizer on growth attributes, grain and straw yield of soybean. They found that 75% P<sub>2</sub>O<sub>5</sub> along with PSB and rhizobium to be optimum level of P fertilizer in recording significantly higher grain and straw yield.

**Table 3: Grain and straw yield of soybean as influenced by different treatments**

Treatments	Grain yield	Straw yield
	-----( $\text{q ha}^{-1}$ )-----	
T <sub>1</sub> -Absolute control	18.6	24.9
T <sub>2</sub> -50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	24.3	35.1
T <sub>3</sub> -75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	29.4	40.9
T <sub>4</sub> -100% GRDF (50 kg N: 75 kg P <sub>2</sub> O <sub>5</sub> :45 kg K <sub>2</sub> O ha <sup>-1</sup> )	31.7	43.6
T <sub>5</sub> -Consortium of PSB only	27.6	39.5
T <sub>6</sub> -Consortium of PSB + 50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	29.3	40.3
T <sub>7</sub> -Consortium of PSB + 75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	36.2	53.1
T <sub>8</sub> -Consortium of PSB + 100% GRDF	36.9	55.9
S.E. $\pm$	1.47	2.52
CD at 5%	4.46	7.64

#### 4.4 Effect of PSB Consortium on Protein Content and Protein Yield of Soybean

##### 4.4.1 Protein content

One of the reasons behind soybean gaining more attention over most of the other oil seed crop is the richness of soybean in terms of protein content. Soybean contains high quality protein due to which it is also known as poor man's 'meat'.

The data pertaining to protein content is presented in table 4.4 and depicted in figure 4.6. From the table 4.4, it was observed that interactive effect of inoculation with consortium of PSB with varied level of P fertilizer recorded numerical higher values of protein content. The protein content in soybean seed within the different treatments ranged from 39.5 to 42.4 per cent. Despite, this variation in protein content, all the treatments revealed statistically non-significant relationship in terms of protein content. Among the various treatments receiving inoculation with consortium of PSB, the treatment T<sub>7</sub> which consisted consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O recorded numerical highest values protein content of 42.4% which was followed by treatment T<sub>8</sub> i.e. consortium of PSB + 100% GRDF (42.3%), T<sub>6</sub> consisting consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (41.6%) and T<sub>5</sub> i.e. consortium only (41.2%). Among the un-inoculated treatments the lowest protein content was recorded by absolute control (39.5%). The highest protein content within the un-inoculated treatment was obtained in T<sub>4</sub> treatment receiving 100% GRDF (41.1%)

These findings confirmed the findings of some researchers who studied and validated influence of phosphate solubilizing bacteria along with inorganic P fertilizer on protein content

of soybean. The findings of this study in context of protein content confirmed the finding of Shahid *et al.* (2009) who reported that 100 kg P<sub>2</sub>O<sub>5</sub> along with biofertilizer recorded significant highest value of protein content (41.4%) in soybean seed. Waghmare *et al.* (2011) compared different treatments of nutrient management with and without biofertilizer for their influence on yield and quality of soybean. They found that combination treatment of 75% NPK + Rhizobium + PSB + organic manure emerged as the most beneficial treatment in terms of protein content. Similar results were also reported by Munda *et al.* who reported significant increase in protein content due to conjunct use of PSB and VAM along with 100% P irrespective of P sources. Afzal *et al.* (2010) reported that inoculation with *Bradyrhizobium* + *Pseudomonas* along with P<sub>2</sub>O<sub>5</sub> registered higher value of protein content.

#### 4.4.2 Protein yield

Data on protein yield is presented in Table 4.4 and graphically illustrated through figure 4.7. The data revealed that protein yield being the product of protein content and grain yield corresponded to the grain yield of soybean. The highest protein yield was recorded by treatment T<sub>8</sub> consisting of inoculation with consortium of PSB + 100% GRDF to the tune of 1560 kg ha<sup>-1</sup> which was statistically at par with T<sub>7</sub> treatment consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O ( 1533 kg ha<sup>-1</sup>) and significantly superior over inoculated treatments such as, T<sub>6</sub> i.e. consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (1214 kg ha<sup>-1</sup>), T<sub>5</sub> i.e. only consortium without inorganic fertilizer (1134 kg ha<sup>-1</sup>) and un-inoculated treatments viz., T<sub>4</sub> receiving 100% GRDF (1301 kg ha<sup>-1</sup>), T<sub>3</sub> i.e. 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (1193 q ha<sup>-1</sup>), T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (973 kg ha<sup>-1</sup>) and control treatment (735 kg ha<sup>-1</sup>). The finding pointed out that protein yield was affected similarly due to inoculation with consortium of PSB as in the case of yield attributes, nodulation and grain yield.

The findings of this study in context of protein yield confirmed the findings of Shahid *et al.* (2009) who reported that 100 kg P<sub>2</sub>O<sub>5</sub> along with biofertilizer recorded significant highest protein yield. Waghmare *et al.* (2011) compared different treatments of nutrient management with and without biofertilizer for their influence on yield and quality of soybean. They found that combination treatment of 75% NPK + Rhizobium + PSB + organic manure significantly increased the protein yield. Similar results were also reported by Munda *et al.* who reported significant increase in protein yield due to conjunct use of PSB and VAM along with 100% P irrespective of P sources. Afzal *et al.* (2010) reported that inoculation with *Bradyrhizobium* + *Pseudomonas* along with P<sub>2</sub>O<sub>5</sub> registered higher value of protein yield.

**Table 4: Protein content and protein yield of Soybean as influenced by different treatments**

Treatments	Protein content (%)	Protein yield (kg ha <sup>-1</sup> )
T <sub>1</sub> -Absolute control	39.5	735
T <sub>2</sub> -50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	40.2	973
T <sub>3</sub> -75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	40.7	1193
T <sub>4</sub> -100% GRDF (50 kg N: 75 kg P <sub>2</sub> O <sub>5</sub> :45 kg K <sub>2</sub> O ha <sup>-1</sup> )	41.1	1301
T <sub>5</sub> -Consortium of PSB only	41.2	1134
T <sub>6</sub> -Consortium of PSB + 50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	41.6	1214
T <sub>7</sub> -Consortium of PSB + 75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	42.4	1533
T <sub>8</sub> -Consortium of PSB + 100% GRDF	42.3	1560
S.E. ±	0.99	45.6
CD at 5%	NS	138.2

#### 4.5 Effect of PSB consortium on oil content and oil yield of soybean

##### 4.5.1 Oil Content:

Apart from protein content, oil content is one of the most decisive parameter in regards to quality of soybean crop. Soybean though basically a pulse crop, is known as an oil seed crop as it contains substantial amount of oil.

The data pertaining to oil content is presented in table 4.5 and depicted in figure 4.6. From the table 4.5, it was observed that interactive effect of inoculation with consortium of PSB with varied level of P fertilizer recorded numerical higher values of oil content. The oil content in soybean seed within the different treatments ranged from 19.8 to 21.2. The different treatments consisting consortium of PSB and without consortium of PSB revealed statistically non-significant relationship in terms of oil content. Among the various treatments receiving inoculation with consortium of PSB, the treatment T<sub>8</sub> i.e. consortium of PSB + 100% GRDF and T<sub>7</sub> which consisted consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O and recorded numerical highest values of oil content (21.2%) which was followed by T<sub>6</sub> consisting consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (20.9%) and T<sub>5</sub> i.e. consortium only (20.3%). Among the un-inoculated treatments the lowest oil content was recorded by absolute control (19.8%). The highest oil content within the un-inoculated treatment was obtained in T<sub>4</sub> treatment receiving 100% GRDF (20.6%)

The role of PSB in increasing the oil content of soybean seed has been argued by many researchers. Some researchers reported positive effect of PSB on oil content while few reported non-significant effect of PSB on oil content.

The findings of this study in context of oil content confirmed the finding of Shahid *et al.* (2009) who reported that 100 kg P<sub>2</sub>O<sub>5</sub> along with biofertilizer recorded significant highest value of oil content (19.35%) in soybean seed. Waghmare *et al.* (2011) found that combination treatment of 75% NPK + Rhizobium + PSB + organic manure recorded higher significantly superior value of oil content over rest of the treatments in soybean crop. Similarl, results were also manifested by that of Munda *et al.* (2013) who reported significant increase in oil content due to conjunct use of PSB and VAM along with 100% P irrespective of P sources. Tanwar and Shaktawat (2002) reported non significant but higher soybean seed oil content due to conjunct use of FYM and PSB.

#### 4.5.2 Oil yield

Data on oil yield is presented in Table 4.5 and graphically illustrated through figure 4.7. The data revealed that oil yield being the product of oil content and grain yield corresponded to the grain yield of soybean. The highest oil yield was recorded by treatment T<sub>8</sub> consisting of inoculation with consortium of PSB + 100% GRDF to the tune of 784 kg ha<sup>-1</sup> which was statistically at par with T<sub>7</sub> treatment consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (767 kg ha<sup>-1</sup>) and significantly superior over inoculated treatments such as, T<sub>6</sub> i.e. consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (613 kg ha<sup>-1</sup>), T<sub>5</sub> i.e. only consortium without inorganic fertilizer (564 kg ha<sup>-1</sup>) and un-inoculated treatments viz., T<sub>4</sub> receiving 100% GRDF (652 kg ha<sup>-1</sup>), T<sub>3</sub> i.e. 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (596 q ha<sup>-1</sup>), T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (486 kg ha<sup>-1</sup>) and control treatment (369 kg ha<sup>-1</sup>). The finding pointed out that oil yield was affected similarly due to inoculation with consortium of PSB as in the case of yield attributes, nodulation and grain yield.

The findings of this study in context of oil yield confirmed the finding of Shahid *et al.* (2009) who reported that 100 kg P<sub>2</sub>O<sub>5</sub> along with biofertilizer recorded significant highest oil yield. Waghmare *et al.* (2011) reported that combination treatment of 75% NPK + Rhizobium + PSB + organic manure significantly increased the oil yield. Similar results were also reported by Munda *et al.* who reported significant increase in oil yield due to conjunct use of PSB and VAM along with 100% P irrespective of P sources. Afzal *et al.* (2010) reported that inoculation with *Bradyrhizobium* + *Pseudomonas* along with P<sub>2</sub>O<sub>5</sub> registered higher value of oil yield.

**Table 4: Oil content and oil yield of soybean as influenced by different treatments**

Treatments	Oil content (%)	Oil yield (kg ha <sup>-1</sup> )
T <sub>1</sub> -Absolute control	19.8	369
T <sub>2</sub> -50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	20.1	486
T <sub>3</sub> -75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	20.3	596
T <sub>4</sub> -100% GRDF (50 kg N: 75 kg P <sub>2</sub> O <sub>5</sub> :45 kg K <sub>2</sub> O ha <sup>-1</sup> )	20.6	652
T <sub>5</sub> -Consortium of PSB only	20.3	564
T <sub>6</sub> -Consortium of PSB + 50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	20.9	613
T <sub>7</sub> -Consortium of PSB + 75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	21.2	767
T <sub>8</sub> -Consortium of PSB + 100% GRDF	21.2	784
S.E. ±	0.63	34.3
CD at 5%	NS	103.9

#### 4.6 Effect of PSB consortium on major nutrient uptake

It has been widely accepted that microbes are critically involve in dissolution of unavailable nutrients into available form. *Rhizospheric* bacteria, such as phosphate solubilizing bacteria releases soil nutrients by virtue of its action of solubilizing organic and inorganic phosphate. Phosphate solubilizing bacteria accelerates the availability of soil phosphorus as a result of its tendency to solubilize of insoluble organic and fixed inorganic P and also stabilized nitrogen. They also led to increased adsorption of other elements such micronutrient through chelation by as they release organic acids besides production of stimulant material, development of root system and anti-pathogenic effect (Zarei et al. 2012). Developed root system ensures better biomass and thus facilitate enhanced nutrient uptake.

##### 4.6.1 Nitrogen uptake

The data pertaining to nitrogen content and uptake is presented in table 4.5 and graphically represented in figure 4.8. The results of the present investigation indicated that fertilizer P in general, played a very vital role in nutrient uptake by soybean. However, the integrated effect of consortium of phosphate solubilizing bacteria along with optimum dose of fertilizer P was found to be comparatively more beneficial in terms of nitrogen content and uptake by soybean. The nitrogen content in soybean grain and straw did not differ due to various treatment however, the treatment T<sub>7</sub> consisting consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O was observed to be highest in N content in soybean grain (6.78%) and straw (1.33%) and the lowest was recorded by control treatment (6.32% and 1.23%) respectively. In regards of N uptake significant difference was noticed, the treatment T<sub>8</sub> consisting of inoculation

with consortium of PSB + 100% GRDF recorded significant maximum nitrogen uptake by soybean grain (250 kg ha<sup>-1</sup>) and straw (73 kg ha<sup>-1</sup>) which was statistically at par with T<sub>7</sub> i.e. consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (245 and 71 kg ha<sup>-1</sup>) respectively and significantly superior over all the other treatments. The total uptake of nitrogen by soybean crop revealed similar trend to that grain and straw N uptake and the maximum total nitrogen uptake was recorded in treatment T<sub>8</sub> i.e. inoculation with consortium of PSB + 100% GRDF to the tune of 323 kg ha<sup>-1</sup> which was statistically at par with treatment T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (316 kg ha<sup>-1</sup>) and significantly superior over inoculated treatments such as, T<sub>6</sub> i.e. consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (247 kg ha<sup>-1</sup>), T<sub>5</sub> i.e. only consortium without inorganic fertilizer (231 kg ha<sup>-1</sup>) and un-inoculated treatments viz., T<sub>4</sub> receiving 100% GRDF (267 kg ha<sup>-1</sup>), T<sub>3</sub> i.e. 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (243 kg ha<sup>-1</sup>), T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (200 kg ha<sup>-1</sup>) and control treatment (146 kg ha<sup>-1</sup>).

**Table 4.5: Nitrogen content and uptake by soybean crop at harvest as influenced by different treatments**

Treatments	N content (%)		Nitrogen uptake		
			Grain	Straw	Total
	Grain	Straw	------(kg ha <sup>-1</sup> )-----		
T <sub>1</sub> -Absolute control	6.32	1.23	118	29	146
T <sub>2</sub> -50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	6.43	1.24	156	44	200
T <sub>3</sub> -75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	6.51	1.27	191	52	243
T <sub>4</sub> -100% GRDF (50 kg N: 75 kg P <sub>2</sub> O <sub>5</sub> :45 kg K <sub>2</sub> O ha <sup>-1</sup> )	6.58	1.36	208	59	267
T <sub>5</sub> -Consortium of PSB only	6.59	1.27	181	50	231
T <sub>6</sub> -Consortium of PSB + 50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	6.66	1.32	194	53	247
T <sub>7</sub> -Consortium of PSB + 75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	6.78	1.33	245	71	316
T <sub>8</sub> -Consortium of PSB + 100% GRDF	6.76	1.32	250	73	323
S.E. ±	0.158	0.040	7.3	3.7	8.9
CD at 5%	NS	NS	22.1	11.1	27.1

#### 4.6.2 Phosphorus uptake

The data pertaining to phosphorus content and uptake is presented in table 4.6 and graphically illustrated in figure 4.8. The phosphorus content in soybean grain and straw exhibited statistically non-significant relationship however, the treatment T<sub>8</sub> consisting consortium of PSB + 100% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O was observed be highest in P content in soybean grain (0.62% ) and straw (0.37%) and the lowest was recorded by control treatment (0.53% and 0.31%) respectively. Phosphorus uptake in general exhibited close relation with applied P. The treatment receiving higher amount P reflected higher P uptake values. However, inoculation with consortium of phosphate solubilizing bacteria along with optimum dose of fertilizer P was found to be comparatively more beneficial in terms of phosphorus uptake by soybean. The phosphorus uptake by soybean grain and straw was found to be significantly highest in treatment T<sub>8</sub> consisting of inoculation with consortium of PSB + 100% GRDF to the tune of 22.9 and 20.5 kg ha<sup>-1</sup> respectively which was statistically at par with T<sub>7</sub> i.e. consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O which recorded 21.6 and 18.9 kg ha<sup>-1</sup> P uptake by soybean grain and straw respectively and significantly superior over all the other treatments. In regards of total P uptake by soybean crop, the treatment T<sub>8</sub> consisting of inoculation with consortium of PSB + 100% GRDF recorded maximum phosphorus uptake by soybean crop to an extent of 43.4 kg ha<sup>-1</sup> which was statistically at par with treatment T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (40.5 kg ha<sup>-1</sup>) and significantly superior over inoculated treatments such as, T<sub>6</sub> i.e. consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (30.4 kg ha<sup>-1</sup>), T<sub>5</sub> i.e. only consortium without inorganic fertilizer (28.4 kg ha<sup>-1</sup>) and un-inoculated treatments viz., T<sub>4</sub> receiving 100% GRDF (32.1 kg ha<sup>-1</sup>), T<sub>3</sub> i.e. 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (30.3 kg ha<sup>-1</sup>), T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub>+ 100% N and K<sub>2</sub>O (24.7 kg ha<sup>-1</sup>) and control treatment (17.5 kg ha<sup>-1</sup> ).

**Table 4.6: Phosphorus content and uptake by soybean crop at harvest as influenced by different treatments**

Treatments	P content (%)		Phosphorus uptake		
	Grain	Straw	Grain	Straw	Total
			-----( $\text{kg ha}^{-1}$ )-----		
T <sub>1</sub> -Absolute control	0.53	0.31	9.9	7.6	17.5
T <sub>2</sub> -50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	0.56	0.32	13.7	11.1	24.7
T <sub>3</sub> -75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	0.56	0.33	16.5	13.8	30.3
T <sub>4</sub> -100% GRDF (50 kg N: 75 kg P <sub>2</sub> O <sub>5</sub> :45 kg K <sub>2</sub> O ha <sup>-1</sup> )	0.56	0.33	17.9	14.2	32.1
T <sub>5</sub> -Consortium of PSB only	0.54	0.33	15.1	13.3	28.4
T <sub>6</sub> -Consortium of PSB + 50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	0.57	0.34	16.7	13.7	30.4
T <sub>7</sub> -Consortium of PSB + 75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	0.60	0.36	21.6	18.9	40.5
T <sub>8</sub> -Consortium of PSB + 100% GRDF	0.62	0.37	22.9	20.5	43.4
S.E. $\pm$	0.033	0.024	1.47	1.42	2.17
CD at 5%	NS	NS	4.44	4.30	6.58

#### 4.6.3 Potassium uptake

In general, potassium uptake is much more than phosphorus uptake. Soybean grain and straw remove significant amount of potassium from the soil (Gaspar *et al.*, 2017). The data pertaining to potassium content and uptake is presented in table 4.7 and graphically depicted in figure 4.8. The potassium content in soybean grain and straw was found to be statistically non-significant however, the treatment T<sub>8</sub> consisting consortium of PSB + 100% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O was observed be highest in K content 1.01% and 1.52% in soybean grain and straw respectively. The lowest K content in soybean grain (0.97%) and straw (1.49%) was recorded by control treatment. The potassium uptake by grain and straw of soybean was found to be significantly highest in treatment i.e consortium of PSB + 100% GRDF to the tune of 56.3 and 56.3 kg ha<sup>-1</sup> respectively and it was statistically at par with T<sub>7</sub> i.e. consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O which recorded 53.4 and 55.1 kg ha<sup>-1</sup> K uptake by soybean grain and straw respectively. Nevertheless, treatment T<sub>8</sub> was found to be significantly superior over rest of the other treatments. In context of total potassium uptake by soybean crop, the treatment T<sub>8</sub> consisting of inoculation with consortium of PSB + 100% GRDF recorded maximum potassium uptake by soybean crop to the tune of 112.5 kg ha<sup>-1</sup> which was statistically at par with treatment

T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (108.4 kg ha<sup>-1</sup>) and significantly superior over inoculated treatments such as, T<sub>6</sub> i.e. consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (84.6 kg ha<sup>-1</sup>), T<sub>5</sub> i.e. only consortium without inorganic fertilizer (80.9 kg ha<sup>-1</sup>) and un-inoculated treatments viz., T<sub>4</sub> receiving 100% GRDF (91.8 kg ha<sup>-1</sup>), T<sub>3</sub> i.e. 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (85.2 kg ha<sup>-1</sup>), T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (70.7 kg ha<sup>-1</sup>) and control treatment (51.8 kg ha<sup>-1</sup>).

The Nitrogen, Phosphorus and potassium uptake by soybean crop differed significantly within different treatment. The findings indicated that higher N, P and K uptake corresponded directly to higher grain and biomass yield of soybean. This might be attributed to release of phosphorous from insoluble phosphate by PSB and fixation of atmospheric nitrogen by *rhizobium* in soils.

Microorganisms with higher phosphate solubilizing potential increase the availability of soluble phosphate and enhance the plant growth and yield due to better root growth and increases uptake of nutrients (Raj and Mallick, 2017). These microorganisms release humic acid, growth hormones etc. which had greater influence in stimulating roots and regulating metabolism, speeding up the developmental process of plant which, in turn, resulted in better N, P and K content. Roots also interact extensively with soil microorganism, which further impact plant nutrition either directly by influencing nutrient availability and uptake or indirectly through plant (root) growth promotion.

The findings regarding uptake of nitrogen, phosphorus and potassium by soybean crop were found to be in agreement with those of Singh and Sharma (2011) who investigated the effect of *Rhizobium* and PSM on yield and uptake of nutrient by chickpea. They reported that application of recommended dose of P through enriched vermicompost with *Rhizobium* and PSM inoculation recorded higher value of N, P and K uptake. Tanwar and Shaktawat (2002) found that conjunct use of FYM and PSB influenced the total uptake of N and P by soybean. Similarly, Raj and Mallick, (2017) investigated integrated approach of nutrient management in yellow sarson for its effect on yield and nutrient uptake. It was being found that the N, P and K uptake by sarson differed significantly due to different treatments. The combination of Azotobacter and phosphate solubilizing bacteria inoculation along with recommended dose of fertilizer (up to 50%) resulted in general higher uptake of N, P and K.

**Table 4.7: Potassium content and uptake by soybean crop at harvest as influenced by different treatments**

Treatments	K content (%)		Potassium uptake		
	Grain	Straw	Grain	Straw	Total
			-----( $\text{kg ha}^{-1}$ )-----		
T <sub>1</sub> -Absolute control	0.97	1.49	24.2	27.6	51.8
T <sub>2</sub> -50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	0.98	1.50	34.3	36.4	70.7
T <sub>3</sub> -75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	1.00	1.51	40.7	44.5	85.2
T <sub>4</sub> -100% GRDF (50 kg N: 75 kg P <sub>2</sub> O <sub>5</sub> :45 kg K <sub>2</sub> O ha <sup>-1</sup> )	1.00	1.52	43.7	48.0	91.8
T <sub>5</sub> -Consortium of PSB only	0.99	1.51	39.3	41.6	80.9
T <sub>6</sub> -Consortium of PSB + 50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	1.00	1.51	40.5	44.1	84.6
T <sub>7</sub> -Consortium of PSB + 75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	1.01	1.52	53.4	55.1	108.4
T <sub>8</sub> -Consortium of PSB + 100% GRDF	1.01	1.52	56.3	56.3	112.5
S.E. $\pm$	0.027	0.024	3.07	2.06	4.54
CD at 5%	NS	NS	9.30	6.26	13.78

#### 4.7 Effect of PSB consortium on micronutrient uptake

The micronutrient uptake by soybean crop differed significantly within the treatments. In general, the inoculation treatments along the application with conventional fertilizer proved to be superior in micronutrient uptake by soybean crop.

##### 4.7.1 Iron uptake

The data pertaining to iron content and uptake is presented in table 4.8 and graphically depicted in figure 4.9. The iron content in soybean grain and straw revealed statistically non-significant relationship however, the treatment T<sub>8</sub> consisting consortium of PSB + 100% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O was observed to be highest in Fe content in soybean grain (427.52 mg kg<sup>-1</sup>) and straw and (26.99 mg kg<sup>-1</sup>) and the lowest was recorded by control treatment (413 and 26 mg kg<sup>-1</sup>) respectively. The iron uptake by soybean grain and straw was found to be positively affected due to inoculation treatments. Significantly highest iron uptake by soybean grain (1578 g ha<sup>-1</sup>) and straw (151 g ha<sup>-1</sup>) was recorded in treatment T<sub>8</sub> i.e. consortium of PSB + 100% GRDF which was at par with T<sub>7</sub> i.e. consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (1549 and 143 g ha<sup>-1</sup>) respectively.

The positive impact of inoculation with consortium of PSB was also noticed in total iron uptake by soybean crop. The treatment T<sub>8</sub> consisting of inoculation with consortium of PSB + 100% GRDF recorded maximum iron uptake by soybean crop to the tune of 1729 g ha<sup>-1</sup> which was statistically at par with treatment T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (1691g ha<sup>-1</sup>) and significantly superior over other inoculated treatments such as, T<sub>6</sub> i.e. consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (1354 g ha<sup>-1</sup>), T<sub>5</sub> i.e. only consortium without inorganic fertilizer (1276 g ha<sup>-1</sup>) and also over un-inoculated treatments viz., T<sub>4</sub> receiving 100% GRDF (1469 g ha<sup>-1</sup>), T<sub>3</sub> i.e. 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (1360 g ha<sup>-1</sup>), T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub>+ 100% N and K<sub>2</sub>O (1123 g ha<sup>-1</sup>) and control treatment (827 g ha<sup>-1</sup>).

**Table 4.8: Iron content and uptake by soybean crop at harvest as influenced by different treatments**

Treatments	Fe content (mg kg <sup>-1</sup> )		Iron uptake		
	Grain	Straw	Grain	Straw	Total
			----- (g ha <sup>-1</sup> ) -----		
T <sub>1</sub> -Absolute control	413	26	770	64	834
T <sub>2</sub> -50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	424	26	1030	92	1123
T <sub>3</sub> -75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	425	26	1252	108	1360
T <sub>4</sub> -100% GRDF (50 kg N: 75 kg P <sub>2</sub> O <sub>5</sub> :45 kg K <sub>2</sub> O ha <sup>-1</sup> )	427	27	1352	117	1469
T <sub>5</sub> -Consortium of PSB only	424	26	1172	104	1276
T <sub>6</sub> -Consortium of PSB + 50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	426	27	1246	107	1354
T <sub>7</sub> -Consortium of PSB + 75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	427	27	1549	143	1691
T <sub>8</sub> -Consortium of PSB + 100% GRDF	428	27	1578	151	1729
S.E. ±	5.0	0.91	67.0	7.4	71.0
CD at 5%	NS	NS	203.3	22.4	215.3

#### 4.7.2 Manganese uptake

The data on manganese content and uptake is presented in table 4.9 and graphically represented in figure 4.9. The results of the present investigation indicated that the phosphate solubilizing bacteria in conjunction with inorganic fertilizer recorded higher Mn content and uptake by soybean. The manganese content in soybean grain and straw did not differ among the

treatments and found to be statistically non-significant however, the treatment T<sub>8</sub> consisting consortium of PSB + 100% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O was observed be highest in Mn content in soybean grain (34.7 mg kg<sup>-1</sup>) and straw (19.4 mg kg<sup>-1</sup>) and the lowest was recorded by control treatment (30.7 and 18.1 mg kg<sup>-1</sup>) respectively. The soybean grain and straw Mn uptake was found to be significantly highest in T<sub>8</sub> i.e. consortium of PSB + 100% GRDF with 128 g ha<sup>-1</sup> and 109 g ha<sup>-1</sup> Mn uptake in soybean grain and straw respectively and was found to be at par with T<sub>7</sub> i.e. consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O which recorded 123 g ha<sup>-1</sup> and 103 g ha<sup>-1</sup> soybean grain and straw Mn uptake respectively. However, the treatment T<sub>8</sub> was significantly superior over rest of the treatments.

In the context of total Mn uptake, the treatment T<sub>8</sub> consisting of inoculation with consortium of PSB + 100% GRDF recorded maximum manganese uptake by soybean crop to the tune of 237 g ha<sup>-1</sup> which was statistically at par with treatment T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (226 g ha<sup>-1</sup>) and significantly superior over inoculated treatments such as, T<sub>6</sub> i.e. consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (171g ha<sup>-1</sup>), T<sub>5</sub> i.e. only consortium without inorganic fertilizer (163 g ha<sup>-1</sup>) and un-inoculated treatments viz., T<sub>4</sub> receiving 100% GRDF (188 g ha<sup>-1</sup>), T<sub>3</sub> i.e. 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (174 g ha<sup>-1</sup>), T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (145 g ha<sup>-1</sup>) and control treatment (102 g ha<sup>-1</sup>).

**Table 4.9: Manganese content and uptake by soybean crop at harvest as influenced by different treatments**

Treatments	Mn content		Manganese uptake		
	(mg kg <sup>-1</sup> )		Grain	Straw	Total
	Grain	Straw	----- (g ha <sup>-1</sup> ) -----		
T <sub>1</sub> -Absolute control	30.7	18.1	57	45	102
T <sub>2</sub> -50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	32.8	18.5	80	65	145
T <sub>3</sub> -75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	33.0	18.7	97	77	174
T <sub>4</sub> -100% GRDF (50 kg N: 75 kg P <sub>2</sub> O <sub>5</sub> :45 kg K <sub>2</sub> O ha <sup>-1</sup> )	33.2	19.2	105	83	188
T <sub>5</sub> -Consortium of PSB only	32.8	18.5	90	72	163
T <sub>6</sub> -Consortium of PSB + 50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	32.8	18.9	96	76	171
T <sub>7</sub> -Consortium of PSB + 75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	33.9	19.4	123	103	226
T <sub>8</sub> -Consortium of PSB + 100% GRDF	34.7	19.4	128	109	237
S.E. ±	2.51	0.88	8.9	5.6	13.1
CD at 5%	NS	NS	27.0	17.1	39.8

### 4.7.3 Zinc uptake

The data pertaining to zinc content and uptake is presented in table 4.10 and graphically illustrated in figure 4.9. The zinc content in soybean grain and straw was also exhibited statistically non-significant relationship however, the treatment T<sub>8</sub> consisting consortium of PSB + 100% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O was observed be highest in Zn content in soybean grain (37.3 mg kg<sup>-1</sup>) and straw (17.7 mg kg<sup>-1</sup>) and the lowest was recorded by control treatment (33.6 and 15.3 mg kg<sup>-1</sup>) respectively. The Zn uptake by soybean grain and straw was found to be significantly superior in treatment T<sub>8</sub> consisting of inoculation with consortium of PSB + 100% GRDF which recorded significantly highest value of Zn uptake by soybean grain (137 g ha<sup>-1</sup>) and straw (99 g ha<sup>-1</sup>) which was statistically at par with T<sub>7</sub> i.e. consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O which recorded 228 g ha<sup>-1</sup> and 93 g ha<sup>-1</sup> soybean grain and straw uptake respectively. However, the treatment T<sub>8</sub> was superior over rest of the treatments. The total Zn uptake by soybean crop corresponded to yield as in the case of other nutrient uptake. The treatment T<sub>8</sub> consisting of inoculation with consortium of PSB + 100% GRDF recorded maximum total zinc uptake by soybean crop to the tune of 236 g ha<sup>-1</sup> which was statistically at par with treatment T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (228 g ha<sup>-1</sup>) and significantly superior over inoculated treatments such as, T<sub>6</sub> i.e. consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (174 g ha<sup>-1</sup>), T<sub>5</sub> i.e. only consortium without inorganic fertilizer (160 g ha<sup>-1</sup>) and also on un-inoculated treatments viz., T<sub>4</sub> receiving 100% GRDF (187 g ha<sup>-1</sup>), T<sub>3</sub> i.e. 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (170 g ha<sup>-1</sup>), T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (141 g ha<sup>-1</sup>) and control treatment (101 g ha<sup>-1</sup>).

**Table 4.10: Zinc content and uptake by soybean crop at harvest as influenced by different treatments**

Treatments	Zn content (mg kg <sup>-1</sup> )		Zinc uptake		
	Grain	Straw	Grain	Straw	Total
			(g ha <sup>-1</sup> )		
T <sub>1</sub> -Absolute control	33.6	15.3	63	38	101
T <sub>2</sub> -50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	34.4	16.2	84	57	141
T <sub>3</sub> -75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	34.6	16.7	102	68	170
T <sub>4</sub> -100% GRDF (50 kg N: 75 kg P <sub>2</sub> O <sub>5</sub> :45 kg K <sub>2</sub> O ha <sup>-1</sup> )	35.7	17.1	113	74	187
T <sub>5</sub> -Consortium of PSB only	34.5	16.5	95	66	160
T <sub>6</sub> -Consortium of PSB + 50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	35.2	17.4	103	70	174
T <sub>7</sub> -Consortium of PSB + 75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	37.4	17.5	135	93	228
T <sub>8</sub> -Consortium of PSB + 100% GRDF	37.3	17.7	137	99	236
S.E. ±	1.95	0.92	6.8	5.8	9.1
CD at 5%	NS	NS	20.7	17.6	27.5

#### 4.7.4 Copper uptake

The data pertaining to copper content and uptake is presented in table 4.11 and graphically represented in figure 4.9. The results of the present investigation indicated that the integrated effect of consortium of phosphate solubilizing bacteria along with optimum dose of fertilizer P was found to be comparatively more beneficial in terms of copper content and uptake by soybean. The copper content in soybean grain and straw was found to revealed statistically non-significant relationship however, to the treatment T<sub>8</sub> consisting consortium of PSB + 100% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O was observed be highest in Cu content in soybean grain (1.90 mg kg<sup>-1</sup>) and straw (0.59 mg kg<sup>-1</sup>) and the lowest was recorded by control treatment (24.4 and 15.6 mg kg<sup>-1</sup>) respectively. The soybean grain and straw Cu uptake was found to be significantly highest in T<sub>8</sub> i.e. consortium of PSB + 100% GRDF with 100 g ha<sup>-1</sup> and 96 g ha<sup>-1</sup> Cu uptake in soybean grain and straw respectively and was found to be at par with T<sub>7</sub> i.e. consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O which recorded 93 g ha<sup>-1</sup> and 91 g ha<sup>-1</sup> soybean grain and straw Cu uptake respectively. The total copper uptake by soybean crop varied substantially, the T<sub>8</sub> consisting of inoculation with consortium of PSB + 100% GRDF recorded maximum total

copper uptake by soybean crop to the tune of 196 g ha<sup>-1</sup> which was statistically at par with treatment T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (183 g ha<sup>-1</sup>) and significantly superior over inoculated treatments such as, T<sub>6</sub> i.e. consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (145 g ha<sup>-1</sup>), T<sub>5</sub> i.e. only consortium without inorganic fertilizer (138 g ha<sup>-1</sup>) and un-inoculated treatments viz., T<sub>4</sub> receiving 100% GRDF (154 g ha<sup>-1</sup>), T<sub>3</sub> i.e. 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (144 g ha<sup>-1</sup>), T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (118 g ha<sup>-1</sup>) and control treatment (83 g ha<sup>-1</sup>).

This enhanced micronutrient uptake in PSB inoculated treatments could be attributed to higher yield and yield attributes because of phosphate solubilizing bacteria ability to release organic acids which dissolve phosphatic minerals or chelate cationic partners of phosphate ions i.e. PO<sub>4</sub> into the soil (Khan *et al.* 2009). This led to increased adsorption of other elements such micronutrient through chelation, production of stimulant material, development of root system and anti-pathogenic effect (Zarei *et al.* 2012). Developed root system obviously led to development of root hairs and the lateral root tip development that ensures better biomass and thus facilitate enhanced micronutrient uptake.

The results of the present investigation confirmed the findings of Dadhich and Somani (2007) who studied and elaborated the effect of integrated nutrient management on yield and micronutrient uptake in soybean-wheat cropping sequence. They verified four levels of phosphorus, two levels of FYM with and without inoculation of PSB and VAM. They found that increased level of P and FYM along with PSB and VAM inoculation to be significantly highest in Fe, Mn, Zn and Cu uptake by soybean and subsequent wheat crop.

**Table 4.11: Copper content and uptake by soybean crop at harvest as influenced by different treatments**

Treatments	Cu content (mg kg <sup>-1</sup> )		Grain uptake	Straw uptake	Total Cu uptake
	Grain	Straw			
T <sub>1</sub> -Absolute control	24.4	14.9	45	37	83
T <sub>2</sub> -50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	25.0	16.8	61	59	120
T <sub>3</sub> -75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	25.5	16.8	75	69	144
T <sub>4</sub> -100% GRDF (50 kg N: 75 kg P <sub>2</sub> O <sub>5</sub> :45 kg K <sub>2</sub> O ha <sup>-1</sup> )	25.2	16.8	80	74	154
T <sub>5</sub> -Consortium of PSB only	26.1	16.9	72	66	138
T <sub>6</sub> -Consortium of PSB + 50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	26.3	16.9	77	68	145
T <sub>7</sub> -Consortium of PSB + 75% P <sub>2</sub> O <sub>5</sub> + 100 % N and K <sub>2</sub> O	25.5	17.1	93	91	183
T <sub>8</sub> -Consortium of PSB + 100% GRDF	26.9	17.2	100	96	196
S.E. ±	0.84	0.96	4.7	6.1	8.3
CD at 5%	NS	NS	14.2	18.5	25.1

#### 4.8 Effect of PSB on soil properties and available nutrient status after harvest

The soil properties and available nutrient status after harvest of soybean varied substantially within the different treatments. The effect of PSB consortium was observed to be more pronounced in case of available nutrient status

##### 4.8.1 Soil properties:

The data presented in table 4.12 and depicted in figure 4.10 revealed that the soil properties viz., pH, electrical conductivity and organic carbon did not differ significantly due to various treatments. However, slight decrease in pH was being observed in treatments receiving conjunct use of consortium of PSB and inorganic fertilizer. The soil pH ranged from 8.09 to 8.21 within the different treatments. The lowest value of soil pH was observed in treatment T<sub>8</sub> and T<sub>7</sub> i.e. inoculation of consortium of PSB with 100% and 75% of recommended phosphorus (8.09) while, the highest pH was recorded in absolute control treatment (8.21). Similarly, the electrical conductivity remained uninfluenced due to various treatments and ranged from 0.167 to 0.172 dS m<sup>-1</sup>. The lowest values of EC were recorded by treatments having consortium of PSB along with

100% and 75% of recommended P fertilizer ( $0.167 \text{ dS m}^{-1}$ ). However, the highest EC was observed in control treatment ( $0.172 \text{ dS m}^{-1}$ ).

A decrease in pH might be due to release of organic acid to solubilize the insoluble phosphorus fixed in the soil by the applied consortium of PSB (Perewa et al. 2014). Namli *et al.* (2017) reported similar changes in pH and EC due to application of phosphate solubilizing bacteria. Tagore *et al.* (2013) reported that pH and EC remained unaffected under chickpea due to microbial inoculation. Similarly, Saikai *et al.* (2018) reported unaffected pH due to application of enriched compost and consortium of PSB.

The organic carbon content among the various treatments did not vary to major extent. However, the treatment, PSB + 100%  $\text{P}_2\text{O}_5$  + 100% N and  $\text{K}_2\text{O}$  recorded highest value of organic carbon (0.62%) which was at par with all other treatments and significantly superior over control (0.54%)

The change in organic carbon is primarily depends on carbon input, mineralization and period of experimentation i.e. time (Pete 2004). The meagre difference in organic carbon content between the fertilizer treatments *vis-à-vis* control treatment might be due to common application of FYM to all the treatments except control. Perhaps, the PSB consortium treatments may need to study furthermore to confirm the increase in soil organic carbon.

The results are conformity with that of Tagore *et al.* (2013) who reported increase in organic carbon over un-inoculated control. Parewa *et al.* (2014) reported increase in organic carbon due application of PGPR and VAM over control.

#### 4.8.2 Available major nutrients

The major nutrient viz. available nitrogen, phosphorus and potassium varied significantly due to the various treatments. The data pertaining to available nutrient status is presented in table 4.12 and graphically illustrated in figure 4.10.

##### Available Nitrogen:

The results of the present investigation indicated that the integrated effect of consortium of phosphate solubilizing bacteria along with optimum dose of fertilizer P revealed enhancement in major available nutrient status. The treatment  $T_8$  consisting of inoculation with consortium of PSB + 100% GRDF recorded significantly highest available nitrogen ( $252 \text{ kg ha}^{-1}$ ) which was statistically at par with treatment  $T_7$  consisting consortium of PSB + 75%  $\text{P}_2\text{O}_5$  + 100% N and  $\text{K}_2\text{O}$  ( $248 \text{ kg ha}^{-1}$ ),  $T_6$  i.e. consortium of PSB + 50%  $\text{P}_2\text{O}_5$  + 100% N and  $\text{K}_2\text{O}$  ( $248 \text{ kg ha}^{-1}$ ), and  $T_4$  i.e. un-inoculated 100% GRDF ( $246 \text{ kg ha}^{-1}$ ). Whereas, it was found to be significantly superior over  $T_5$  i.e. only consortium ( $226 \text{ kg ha}^{-1}$ ),  $T_3$  i.e. 75%  $\text{P}_2\text{O}_5$  + 100% N and  $\text{K}_2\text{O}$  ( $214 \text{ kg ha}^{-1}$ ),  $T_2$  i.e. 50%  $\text{P}_2\text{O}_5$  + 100% N and  $\text{K}_2\text{O}$  ( $203 \text{ kg ha}^{-1}$ ), and control treatment ( $184 \text{ kg ha}^{-1}$ ).

### Available Phosphorus:

In case of available phosphorus the treatment, T<sub>8</sub> consisting of inoculation with consortium of PSB + 100% GRDF recorded significantly highest available P (37.8 kg ha<sup>-1</sup>) which was statistically at par with treatment T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (35.8 kg ha<sup>-1</sup>), T<sub>6</sub> i.e. consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (33.8 kg ha<sup>-1</sup>), and T<sub>4</sub> i.e. un-inoculated 100% GRDF (34.9 kg ha<sup>-1</sup>). Whereas, it was found to be significantly superior over T<sub>5</sub> i.e. only consortium (30.8 kg ha<sup>-1</sup>), T<sub>3</sub> i.e. 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (31.1 kg ha<sup>-1</sup>), T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (30.1 kg ha<sup>-1</sup>), and control treatment (28.8 kg ha<sup>-1</sup>).

### Available Potassium:

The available potassium revealed slightly indifferent trend to that of available N and P. The highest significant value of available K was observed in treatment T<sub>8</sub> consisting of inoculation with consortium of PSB + 100% GRDF recorded significantly highest available K (379 kg ha<sup>-1</sup>) which was at par with all the other treatment viz., T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (375 kg ha<sup>-1</sup>), T<sub>6</sub> i.e. consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (362 kg ha<sup>-1</sup>), T<sub>5</sub> i.e. only consortium (357 kg ha<sup>-1</sup>), T<sub>4</sub> i.e. un-inoculated 100% GRDF (347 kg ha<sup>-1</sup>), T<sub>3</sub> i.e. 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (342 kg ha<sup>-1</sup>) however, it significant superior over T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub> + 100% N (314 kg ha<sup>-1</sup>) and except control (304 kg ha<sup>-1</sup>).

The increase in available nitrogen could be attributed to greater multiplication of soil microbes which converts organically bound N to inorganic form (Kumar et al. 2017). Also, PSB with inorganic fertilizer improves the nodulation in soybean which directly influences the available nitrogen status in soil (Agraw 2012). The increase in available phosphorus may be attributed to the role consortium of PSB in solubilizing inorganic and organic phosphate by production of organic acids. These organic acids dissolve phosphatic minerals or chelate cationic partners of phosphate ions i.e. PO<sub>4</sub> into the soil (Khan *et al.* 2009). The enhanced available K status may be attributed to the beneficial effect of organic acid affecting clay-organo interaction.

The findings of the present investigation are in close agreement with that of Tagore *et al.* (2013) who pointed out that the inoculation treatments with Rhizobium and PSB recorded highest value of available N, P and K over non-inoculation treatments. Similar results were also reported by Parewa *et al.* (2014) who found that fertilizer levels, FYM and bioinoculants had no significant on pH and EC however, soil pH was either maintained or slightly decreased to the initial value. They reported that the organic carbon value was significantly highest in these treatments when compared to control. Further, they indicated that the available N, P and K status decreased from its initial whereas, the availability of these nutrients increased from its initial values. The highest available N (227.48 and 228.76 kg ha<sup>-1</sup>), P (18.25 to 18.31 kg ha<sup>-1</sup>) and K

(233.40 to 235.78 kg ha<sup>-1</sup>) were obtained due to combination of 100% NPK fertilizer + FYM and bioinoculants (PGPR + VAM). Tran et al. (2006) reported 4.42% to 59.72% increase in available phosphorus due to dual inoculation of *Bradyrhizobium* and PSB over un-inoculated treatments. Kumar et al. (2017) indicated that change in soil pH and EC after harvest of soybean showed non-significant differences but revealed slight decrease in soil pH with bio-inoculant treatments. They found *Rhizobium* + *Trichoderma viride* recorded significantly higher organic carbon content over control and remained at par with all other treatments. Significant highest available N and K were recorded in treatment with RDF + *Rhizobium* + *Trichoderma viride* that found to at par with other inoculation treatments and superior over non-inoculated treatments. Diep et al. (2017) found PSB inoculation + 20 Kg N ha<sup>-1</sup> and PSB + *Rhizobium* + 20 N recorded significantly highest and at par values of soil organic matter and available P in soil. Higher availability of available nutrients with treatment receiving PGPR and varied levels of phosphorus was also reported by Gulnaz et al. (2017)

**Table 4.12: Soil chemical properties and available soil major nutrient status after harvest of crop as influenced by different treatments**

Treatments	pH (1:2.5)	EC dS m <sup>-1</sup>	Org. Carbon (%)	Available soil nutrients (kg ha <sup>-1</sup> )		
				N	P	K
T <sub>1</sub> -Absolute control	8.21	0.172	0.54	184	28.8	304
T <sub>2</sub> -50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	8.13	0.170	0.58	203	30.1	314
T <sub>3</sub> -75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	8.11	0.170	0.59	214	31.1	342
T <sub>4</sub> -100% GRDF (50 kg N: 75 kg P <sub>2</sub> O <sub>5</sub> :45 kg K <sub>2</sub> O ha <sup>-1</sup> )	8.13	0.168	0.60	246	34.9	347
T <sub>5</sub> -Consortium of PSB only	8.11	0.171	0.60	226	30.8	357
T <sub>6</sub> -Consortium of PSB + 50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	8.11	0.165	0.61	241	33.8	362
T <sub>7</sub> -Consortium of PSB + 75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	8.09	0.167	0.61	248	35.8	375
T <sub>8</sub> -Consortium of PSB + 100% GRDF	8.09	0.167	0.62	252	37.8	379
S.E. ±	0.057	0.008	0.012	5.3	1.37	15.9
CD at 5%	NS	NS	0.036	16.2	4.15	48.3
Initial	8.22	0.17	0.56	191	30	319

### 4.8.3 Available micronutrients (DTPA Extractable)

The DTPA extractable available micronutrient content in soil was found to be significantly varying within various treatments. In general, the treatment receiving consortium of PSB along with inorganic fertilizers recorded higher values of DTPA extractable micronutrients as compared to un-inoculated treatments. The data pertaining to available micronutrient status is presented in table 4.13 and graphically illustrated in figure 4.11.

#### Available Iron

The inoculation treatments with consortium of PSB along with inorganic fertilizer were found to be beneficial in available iron content. The treatment T<sub>8</sub> consisting of inoculation with consortium of PSB + 100% GRDF recorded significantly highest DTPA extractable available Fe (6.02 mg kg<sup>-1</sup>) which was statistically at par with treatment T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (5.93 mg kg<sup>-1</sup>), T<sub>6</sub> i.e. consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (5.88 mg kg<sup>-1</sup>), and T<sub>5</sub> i.e. only consortium (4.76 mg kg<sup>-1</sup>). Whereas, it was found to be significantly superior over T<sub>4</sub> i.e. un-inoculated 100% GRDF (4.65 mg kg<sup>-1</sup>), T<sub>3</sub> i.e. 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (4.48 mg kg<sup>-1</sup>), T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (4.35 mg kg<sup>-1</sup>), and control treatment (4.19 mg kg<sup>-1</sup>).

#### Available Manganese

The amount of available manganese content in the soil after harvest of the crop also revealed enhanced values due to the inoculation treatments with consortium of PSB along with inorganic fertilizer. The treatment T<sub>8</sub> consisting of inoculation with consortium of PSB + 100% GRDF recorded significantly highest DTPA extractable available Mn (7.82 mg kg<sup>-1</sup>) which was statistically at par with treatment T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (7.18 mg kg<sup>-1</sup>), T<sub>6</sub> i.e. consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (6.61 mg kg<sup>-1</sup>), and T<sub>5</sub> i.e. only consortium (6.38 mg kg<sup>-1</sup>). Whereas, it was found to be significantly superior over T<sub>4</sub> i.e. un-inoculated 100% GRDF (5.96 mg kg<sup>-1</sup>), T<sub>3</sub> i.e. 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (5.74 mg kg<sup>-1</sup>), T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (5.79 mg kg<sup>-1</sup>), and control treatment (5.67 mg kg<sup>-1</sup>).

#### Available Zinc

Identical trend of zinc availability was notice due to the inoculation treatments with consortium of PSB along with inorganic fertilizer. The treatment T<sub>8</sub> consisting of inoculation with consortium of PSB + 100% GRDF recorded significantly highest DTPA extractable available Zn (0.97 mg kg<sup>-1</sup>) which was statistically at par with treatment T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (0.87 mg kg<sup>-1</sup>), T<sub>6</sub> i.e. consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (0.85 mg kg<sup>-1</sup>), and T<sub>5</sub> i.e. only consortium (0.85 mg kg<sup>-1</sup>). Whereas, it was found to be significantly superior over T<sub>4</sub> i.e. un-inoculated 100% GRDF (0.77

mg kg<sup>-1</sup>), T<sub>3</sub> i.e. 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (0.65 mg kg<sup>-1</sup>), T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub>+ 100% N and K<sub>2</sub>O (0.63 mg kg<sup>-1</sup>), and control treatment (0.58 mg kg<sup>-1</sup>).

### Available Copper

The available copper content in soil was affected due to different treatments. The inoculated treatments in general, recorded higher values of Cu as compared to un-inoculated treatments. The treatment T<sub>8</sub> consisting of inoculation with consortium of PSB + 100% GRDF recorded significantly highest DTPA extractable available Cu (2.97 mg kg<sup>-1</sup>) which was statistically at par with treatment T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (2.85 mg kg<sup>-1</sup>), T<sub>6</sub> i.e. consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (2.72 mg kg<sup>-1</sup>), and T<sub>5</sub> i.e. only consortium (2.57 mg kg<sup>-1</sup>). Whereas, it was found to be significantly superior over T<sub>4</sub> i.e. un-inoculated 100% GRDF (2.35 mg kg<sup>-1</sup>), T<sub>3</sub> i.e. 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (2.34 mg kg<sup>-1</sup>), T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub>+ 100% N and K<sub>2</sub>O (2.32 mg kg<sup>-1</sup>), and control treatment (2.31 mg kg<sup>-1</sup>)

The increase in micronutrient concentration in the treatments receiving inoculation of PSB consortium along with inorganic fertilizer coupled with FYM could be attributed to the tendency of microorganisms to solubilize micronutrient through various mechanisms which include secretion of organic acid and the release of organic acid i.e. 2-Ketogluconic and 5 Ketogluconic acid and change in the micro environment near the root system which increase the H<sup>+</sup> ion concentration or protein extrusion or production of chelating agents (Altomare *et al.* 1999).

The findings of present investigation explicitly validate the results reported by Kumar *et al.* (2017) who found that significant increase in available Zn, Fe, Cu and Mn concentration due to application of RDF along with biofertilizers.

**Table 4.13: Soil micronutrient status after harvest of crop as influenced by different treatments**

Treatments	DTPA extractable soil micronutrient (mg kg <sup>-1</sup> )			
	Fe	Mn	Zn	Cu
T <sub>1</sub> -Absolute control	4.19	5.67	0.58	2.31
T <sub>2</sub> -50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	4.35	5.79	0.63	2.32
T <sub>3</sub> -75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	4.48	5.74	0.65	2.34
T <sub>4</sub> -100% GRDF (50 kg N: 75 kg P <sub>2</sub> O <sub>5</sub> :45 kg K <sub>2</sub> O ha <sup>-1</sup> )	4.65	5.96	0.77	2.35
T <sub>5</sub> -Consortium of PSB only	4.76	6.38	0.85	2.57
T <sub>6</sub> -Consortium of PSB + 50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	5.88	6.61	0.85	2.72
T <sub>7</sub> -Consortium of PSB + 75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	5.93	7.18	0.87	2.85
T <sub>8</sub> -Consortium of PSB + 100% GRDF	6.03	7.82	0.97	2.97
S.E. ±	0.444	0.595	0.057	0.141
CD at 5%	1.348	1.806	0.173	0.426
Initial	4.3	5.69	0.52	2.28

#### 4.9 Effect of PSB on Phosphorus release at different days of Incubation

Phosphate solubilizing bacteria are known for augmenting phosphorus release in soil. In this investigation attempt was made to study the phosphorus release pattern at different days after incubation.

The persuasion of data presented in table 4.14 and graphically illustrated in figure 4.12 and 4.13 revealed that the available phosphorus at 0 and 15 days after incubation did not vary significantly amongst the different treatments. However, at 30, 45, 60 and 90 days after incubation the available P release were found to be significantly varying between the treatments.

##### 4.9.1 (30 DAI):

At 30 day after incubation, the data revealed that the treatment with consortium of PSB and inorganic fertilizer release significant amount of available P with significant and highest concentration recorded by treatment T<sub>8</sub> i.e. inoculation with consortium of PSB + 100% GRDF (27.63 mg kg<sup>-1</sup>) which was statistically at par with treatment T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (26.90 mg kg<sup>-1</sup>), T<sub>6</sub> i.e. consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (24.87 mg kg<sup>-1</sup>). Whereas, it was found to be significantly superior over and T<sub>5</sub> i.e. only consortium (20.87 mg kg<sup>-1</sup>), T<sub>4</sub> i.e. un-inoculated 100% GRDF (21.63 mg kg<sup>-1</sup>), T<sub>3</sub> i.e. 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (19.73 mg kg<sup>-1</sup>), T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (18.93 mg kg<sup>-1</sup>), and control treatment (14.50 mg kg<sup>-1</sup>).

##### 4.9.2 (45 DAI):

At 45 DAI, the data revealed that the treatment T<sub>8</sub> consisting inoculation with consortium of PSB + 100% GRDF recorded significant highest concentration of Available P (35.27 mg kg<sup>-1</sup>) which was statistically at par with treatment T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (34.33 mg kg<sup>-1</sup>), T<sub>6</sub> i.e. consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (31.80 mg kg<sup>-1</sup>). Whereas, it was found to be significantly superior over and T<sub>5</sub> i.e. only consortium (25.73 mg kg<sup>-1</sup>), T<sub>4</sub> i.e. un-inoculated 100% GRDF (25.40 mg kg<sup>-1</sup>), T<sub>3</sub> i.e. 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (23.17 mg kg<sup>-1</sup>), T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (21.10 mg kg<sup>-1</sup>), and control treatment (17.30 mg kg<sup>-1</sup>).

##### 4.9.3 (60 DAI):

Similar trend was observed at 60 DAI with treatment T<sub>8</sub> consisting inoculation with consortium of PSB + 100% GRDF recording significant highest concentration of Olsen's P (39.50 mg kg<sup>-1</sup>) which was statistically at par with treatment T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (38.60 mg kg<sup>-1</sup>), T<sub>6</sub> i.e. consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (35.27 mg kg<sup>-1</sup>). Whereas, it was found to be significantly superior over and T<sub>5</sub> i.e. only consortium (28.57 mg kg<sup>-1</sup>), T<sub>4</sub> i.e. un-inoculated 100% GRDF (28.30 mg kg<sup>-1</sup>), T<sub>3</sub> i.e. 75% P<sub>2</sub>O<sub>5</sub>

+ 100% N and K<sub>2</sub>O (26.07 mg kg<sup>-1</sup>), T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (24.80 mg kg<sup>-1</sup>), and control treatment (18.20 mg kg<sup>-1</sup>).

#### 4.9.4 (90 DAI):

At 90 DAI, the variation in available P was found to be maximum than other DAI under study. The treatment T<sub>8</sub> consisting inoculation with consortium of PSB + 100% GRDF recorded significant highest concentration of available P (41.70 mg kg<sup>-1</sup>) which was statistically at par with treatment T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (40.57 mg kg<sup>-1</sup>), T<sub>6</sub> i.e. consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (38.33 mg kg<sup>-1</sup>). Whereas, it was found to be significantly superior over and T<sub>5</sub> i.e. only consortium (30.60 mg kg<sup>-1</sup>), T<sub>4</sub> i.e. uninoculated 100% GRDF (30.43 mg kg<sup>-1</sup>), T<sub>3</sub> i.e. 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (29.20 mg kg<sup>-1</sup>), T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (26.37 mg kg<sup>-1</sup>), and control treatment (19.67 mg kg<sup>-1</sup>).

From the data on phosphorus release it was evident that optimum quantity of applied phosphorus along with consortium of PSB played imperative role in enhancing the P availability at 30, 45, 60 and 90 DAI. The difference in phosphorus release depicted in figure 14.3 showed that the maximum peak of available phosphorus was obtained at 30 DAI and 45 DAI in treatment T<sub>8</sub> followed by treatment T<sub>7</sub>. The enhanced P availability with time could be due to enhanced activity of solubilizing bacteria which would have solubilized insoluble phosphorus during course of time.

The findings regarding solubilization of phosphorus during incubation period are in conformity with findings of Fernandez *et al.* (2007) who reported enhanced P release at 30, 60 and 90 days after incubation due combine application of phosphorus and PSB strains. Sharma *et al.* (2016) who studied the effect of PSB and FYM in releasing phosphorus when rock phosphate was used as source of P. They studied the available P release at 15, 30, 45, 60, 75 and 90 DAI and reported that the combination treatment of rock phosphate + PSB + FYM resulted in significant highest concentration of available P at all the DAI under investigation.

**Table 4.14: Available soil phosphorus as influenced by different treatment during incubation period**

Treatments	Available phosphorus (mg kg <sup>-1</sup> ) days after Incubation					
	0 (DAI)	15 (DAI)	30 (DAI)	45 (DAI)	60 (DAI)	90 (DAI)
T1-Absolute control	12.83	12.97	14.50	17.30	18.20	19.67
T2-50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	13.00	14.13	18.93	21.10	24.87	26.37
T3-75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	13.10	14.73	19.73	23.17	26.07	29.20
T4-100% GRDF (50 kg N: 75 kg P <sub>2</sub> O <sub>5</sub> :45 kg K <sub>2</sub> O ha <sup>-1</sup> )	13.17	15.50	21.63	25.40	28.30	30.43
T5-Consortium of PSB only	13.00	14.37	20.87	25.73	28.57	30.60
T6-Consortium of PSB + 50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	13.23	15.17	24.87	31.80	35.27	38.33
T7-Consortium of PSB + 75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	13.07	15.67	26.90	34.33	38.60	40.57
T8-Consortium of PSB + 100% GRDF	13.17	15.83	27.63	35.27	39.50	41.70
S.E. ±	1.13	1.536	1.664	2.910	2.218	2.074
CD at 5%	NS	NS	5.047	8.825	6.727	6.291

#### 4.10 Effect of PSB Consortium on Dehydrogenase and Phosphatase Activity

In the present investigation an attempt was also made to study the enzyme activities viz. dehydrogenase and phosphomonoesterases i.e. acid and alkaline phosphatases. dehydrogenases can utilize both O<sub>2</sub> and other compounds as terminal electron acceptors, although anaerobic microorganisms produce most dehydrogenases. Therefore, DHA reflects metabolic ability of the soil and its activity is considered to be proportional to the biomass of the microorganisms in soil (Brzezińska *et al.* 2001). The phosphomonoesterases plays vital role in phosphorus availability as it is involved in mineralization of organically bound phosphorus to inorganic P compound (Usha Rani *et al.* 2014)

##### 4.10.1 Dehydrogenase activity:

The data on DHA enzyme activity is presented in table 4.15 and graphically illustrated in figure 4.14. The findings of the present investigation explicitly substantiate that dehydrogenase activity was largely affected by the inoculation of consortium of PSB along with inorganic fertilizers as compared to un-inoculated treatments. The significant and highest DHA activity was reflected in treatment T<sub>8</sub> having inoculation with consortium of PSB + 100% GRDF (4.21 µg TPF g Soil<sup>-1</sup> hr<sup>-1</sup>) which was statistically at par with treatment T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O ( 3.98 µg TPF g Soil<sup>-1</sup> hr<sup>-1</sup>), T<sub>6</sub> i.e. consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (3.77 µg TPF g Soil<sup>-1</sup> hr<sup>-1</sup>) and T<sub>5</sub> i.e. only consortium (3. 44 µg TPF g Soil<sup>-1</sup> hr<sup>-1</sup>). Whereas, it was found to be significantly superior over and T<sub>4</sub> i.e. un-inoculated 100% GRDF (3.19 µg TPF g Soil<sup>-1</sup> hr<sup>-1</sup>), T<sub>3</sub> i.e. 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (3.04 µg TPF g Soil<sup>-1</sup> hr<sup>-1</sup>), T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (2.94 µg TPF g Soil<sup>-1</sup> hr<sup>-1</sup>), and control treatment (2.80 µg TPF g Soil<sup>-1</sup> hr<sup>-1</sup>).

The increased activity of DHA could be attributed to increase in microbial population at the rhizospheric zone due to inoculation of PSB and addition of FYM. Added number of microbes through PSB inoculation and organic matter application might have increased the soil microbial biomass and enzyme activity (Siakia *et al.* 2018)

The results in regards of DHA explicitly validated those of Parewa *et al.* (2014) who indicated higher activity of DHA due to application PGPR and VAM. Similar results were observed by Xuan Yu *et al.* (2014) who reported that addition of rock phosphate along with PSB strains were found to be more pronounced and beneficial in enhancing dehydrogenase activity. Raghuveer *et al.* (2017) reported pronounced dehydrogenase activity with the application of 60 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> and inoculation of *Pseudomonas sp.*

#### 4.10.2 Phosphomonoesterases: (Acid and Alkaline Phosphatase)

The data on phosphomonoesterases i.e. acid and alkaline phosphatases enzyme activities is presented in table 4.15 and graphically illustrated in figure 4.15. The findings of the present investigation explicitly substantiate that phosphatases activity was largely affected by the inoculation of consortium of PSB along with inorganic fertilizers as compared to un-inoculated treatments. The significant and highest acid phosphate activity was reflected in treatment T<sub>8</sub> having inoculation with consortium of PSB + 100% GRDF (150.6  $\mu\text{g PNP g Soil}^{-1} \text{ hr}^{-1}$ ) which was statistically at par with treatment T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (146.2  $\mu\text{g PNP g Soil}^{-1} \text{ hr}^{-1}$ ), T<sub>6</sub> i.e. consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (138.0  $\mu\text{g PNP g Soil}^{-1} \text{ hr}^{-1}$ ). Whereas, it was found to be significantly superior over and T<sub>5</sub> i.e. only consortium (129.5  $\mu\text{g PNP g Soil}^{-1} \text{ hr}^{-1}$ ), T<sub>4</sub> i.e. un-inoculated 100% GRDF (128.0  $\mu\text{g PNP g Soil}^{-1} \text{ hr}^{-1}$ ), T<sub>3</sub> i.e. 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (121.9  $\mu\text{g PNP g Soil}^{-1} \text{ hr}^{-1}$ ), T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (110.8  $\mu\text{g PNP g Soil}^{-1} \text{ hr}^{-1}$ ), and control treatment (95.5  $\mu\text{g PNP g Soil}^{-1} \text{ hr}^{-1}$ ). The alkaline phosphate activity also varied with the different treatments, the highest activity was recorded by T<sub>8</sub> i.e. consortium of PSB + 100% GRDF (253.9  $\mu\text{g PNP g Soil}^{-1} \text{ hr}^{-1}$ ) which was statistically at par with treatment T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (248.1  $\mu\text{g PNP g Soil}^{-1} \text{ hr}^{-1}$ ). Whereas, it was found to be significantly superior over, T<sub>6</sub> i.e. consortium of PSB + 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (218.1  $\mu\text{g PNP g Soil}^{-1} \text{ hr}^{-1}$ ), T<sub>5</sub> i.e. only consortium (195.1  $\mu\text{g PNP g Soil}^{-1} \text{ hr}^{-1}$ ), T<sub>4</sub> i.e. un-inoculated 100% GRDF (196.7  $\mu\text{g PNP g Soil}^{-1} \text{ hr}^{-1}$ ), T<sub>3</sub> i.e. 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (194.8  $\mu\text{g PNP g Soil}^{-1} \text{ hr}^{-1}$ ), T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (179.9  $\mu\text{g PNP g Soil}^{-1} \text{ hr}^{-1}$ ), and control treatment (155.2  $\mu\text{g PNP g Soil}^{-1} \text{ hr}^{-1}$ ).

The increase in phosphomonoesterases activity may be attributed to availability of phosphorus due to solubilisation of organically bound P by PSB through various mechanisms of releasing organic acid besides production of stimulant material, development of root system.

The results are conformity to that of Xuan Yu *et al.* (2014) studied the effect of inoculated soil with PSB on growth and soil quality in walnut. They reported that addition of rock phosphate along with PSB strains were found to be more pronounced and beneficial in enhancing phosphatase and urease activity. Xiao Kai Shi *et al.* (2017) indicated PSB along with tri-calcium phosphate increased the phosphatase activity in soil. Similarly, Namli *et al.* (2017) reported enhanced alkaline phosphatase activity due combine application of nitrogenous fertilizer and PSB/PGPR. Dotaniya *et al.* (2014) concluded that the enzyme activity is associated with maximum availability and uptake of nutrients particularly phosphorus in plant. Raghuvveer *et al.* (2017) reported enhanced phosphatase activity with the application of 60 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> and inoculation of *Pseudomonas sp.*

**Table 4.15: Effect of different treatment of Dehydrogenase and phosphomonoesterases**

Treatments	DHA	Acid Phosphatase	Alkaline Phosphatase
	$\mu\text{g TPF g Soil}^{-1} \text{ hr}^{-1}$	----- $\mu\text{g PNP g Soil}^{-1} \text{ hr}^{-1}$ -----	
T1-Absolute control	2.80	95.5	155.2
T2-50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	2.94	110.8	179.9
T3-75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	3.04	121.9	194.8
T4-100% GRDF (50 kg N: 75 kg P <sub>2</sub> O <sub>5</sub> :45 kg K <sub>2</sub> O ha-1)	3.19	128.0	196.7
T5-Consortium of PSB only	3.44	129.5	195.1
T6-Consortium of PSB + 50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	3.77	138.0	218.1
T7-Consortium of PSB + 75% 50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	3.89	146.2	248.1
T8-Consortium of PSB + 100% GRDF	4.21	150.6	253.9
S.E. $\pm$	0.254	5.66	10.37
CD at 5%	0.769	17.17	31.46

#### 4.10. Effect of PSB consortium on nutrient use efficiency

There has been increasing awareness about nutrient use efficiency among the farmers due to increase prices of fertilizer and stagnant crop production. The nutrient use efficiency has been defined in several ways. In the present investigation, focus has been given on partial factor productivity (PFP) i.e. kg crop yield per kg nutrient applied.

##### 4.10.1 Nitrogen use efficiency (NUE):

Inoculation with consortium of PSB in conjunction with applied inorganic nutrient exhibited enhanced nitrogen use efficiency. The treatment with 100% GRDF and consortium of PSB i.e. T<sub>8</sub> was found to be more nitrogen efficient with 36.64 kg grain kg<sup>-1</sup> N applied which was T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (35.24 kg grain kg<sup>-1</sup> N). When compared to un-inoculated treatment T<sub>4</sub> i.e. un-inoculated 100% GRDF recorded maximum NUE (26.10 kg grain kg<sup>-1</sup> N) and lowest NUE was observed in T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub> + 100% N (11.30 kg grain kg<sup>-1</sup> N)

##### 4.10.2 Phosphorus use efficiency (PUE)

PUE was the major area of concern under this investigation. PUE followed the identical trend to that of NUE. The effect of consortium of PSB was prominent as in other case. The inoculated treatments revealed enhanced P use efficiency when compared to un-inoculated treatments. Inoculated treatment T<sub>8</sub> i.e. consortium of PSB + 100% GRDF recorded highest PUE (24.43 kg grain kg<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>) which was followed by T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (23.49 kg grain kg<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>). Among the un-inoculated treatment T<sub>4</sub> i.e. un-inoculated 100% GRDF recorded maximum PUE (17.40 kg grain kg<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>) and lowest PUE was observed in T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub> + 100% N (7.53 kg grain kg<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>)

##### 4.10.3 Potassium use efficiency (KUE)

Inoculated treatment T<sub>8</sub> i.e. consortium of PSB + 100% GRDF recorded highest KUE (40.71 kg grain kg<sup>-1</sup> K<sub>2</sub>O) which was followed by T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (39.16 kg grain kg<sup>-1</sup> K<sub>2</sub>O). Among the un-inoculated treatment T<sub>4</sub> i.e. un-inoculated 100% GRDF recorded maximum KUE (29.00 kg grain kg<sup>-1</sup> K<sub>2</sub>O) and lowest KUE was observed in T<sub>2</sub> i.e. 50% P<sub>2</sub>O<sub>5</sub> + 100% N (12.56 kg grain kg<sup>-1</sup> K<sub>2</sub>O)

Soil P solubilizing bacteria have been reported to mobilize poorly available phosphorus via solubilization and mineralization. As discussed earlier, PSB also enhance the nodulation beside dissolution of other minerals. This might be the reason for enhanced nitrogen, phosphorus and potassium use efficiency in inoculated treatments when compared to un-inoculated treatment.

These results are in conformity with those reported by Savaliya *et al.* (2018) who investigated the role of PSB and KSB in enhancing the phosphorus and potassium use efficiency.

They reported that 45 kg P<sub>2</sub>O<sub>5</sub> + seed inoculation of PSB recorded highest phosphorus and potassium use efficiency (14.97 and 9.13 kg kg<sup>-1</sup> respectively) while similar was observed in case of KSB + seed inoculation.

**Table 4.16: Effect of different treatments on nutrient use efficiency**

Treatments	Nutrient Use Efficiency (kg grain kg <sup>-1</sup> nutrient)		
	NUE	PUE	KUE
T1-Absolute control	--	--	--
T2-50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	11.30	15.07	12.56
T3-75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	21.68	19.27	24.09
T4-100% GRDF (50 kg N: 75 kg P <sub>2</sub> O <sub>5</sub> :45 kg K <sub>2</sub> O ha <sup>-1</sup> )	26.10	17.40	29.00
T5-Consortium of PSB only	--	--	--
T6-Consortium of PSB + 50% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	21.30	28.40	23.66
T7-Consortium of PSB + 75% P <sub>2</sub> O <sub>5</sub> + 100% N and K <sub>2</sub> O	35.24	31.32	39.16
T8-Consortium of PSB + 100% GRDF	36.64	24.43	40.71

NUE = Nitrogen use efficiency

PUE = Phosphorus use efficiency

KUE =Potassium use efficiency

## 5. SUMMARY AND CONCLUSIONS

A field experiment was conducted to study the, “Effect of consortium of phosphate solubilizing bacteria on phosphorus availability, nutrient content and yield of soybean (*Glycine max. L.*)” during *khariif* 2018 at PG Research Farm, Agronomy Section, RSCM College of Agriculture, Kolhapur. The experiment was laid out in randomized block design which consisted of eight treatments and three replications.

The soybean cv. Phule Sangam was sown by adopting recommended package of practices. The treatments were superimposed to respective plots. The growth and yield attributes, yield, nutrient uptake, quality parameter, nodulation characteristics of soybean, phosphorus release during incubation period, soil enzymes and fertilizer use efficiency were recorded to study the effect of different treatments on crop. Soil and plant samples were collected and analyzed by adopting standard procedures and methods. The results of experiment are summarized below.

### 5.1 Summary

#### 5.1.1 Effect of PSB Consortium on Growth and Yield Attributes of soybean

In general, treatments receiving inoculation of consortium of phosphate solubilizing bacteria recorded higher 100 seed weight per plant as compared un-inoculated treatments. The treatment, T<sub>7</sub> i.e. consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O and T<sub>8</sub> i.e. consortium of PSB + 100% GRDF recorded higher 100 seed weight of 19.52 and 19.51 g plant<sup>-1</sup> respectively. However, the lowest was recorded by control treatment (18.32 g plant<sup>-1</sup>).

The morphological character; plant height in soybean did not differ much within the treatments with and without inoculation of consortium of PSB. However, significant higher plant height was recorded by treatment Consortium of PSB + 100% GRDF (T<sub>8</sub>) to the tune of 48.9 cm over absolute control (43.5 cm). Whereas, it was statistically at par with all the other treatments

The treatment T<sub>8</sub>- consortium of PSB + 100% GRDF recorded highest number of pod per plant of soybean (89.3 plant<sup>-1</sup>) which was statistically at par with T<sub>7</sub> treatment consisting Consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (87.7 plant<sup>-1</sup>) and treatment T<sub>4</sub> which consisted 100% P<sub>2</sub>O<sub>5</sub> + 100 % N and K<sub>2</sub>O without inoculation with PSB consortium (84.1 plant<sup>-1</sup>) and significantly superior over rest of the treatments.

#### 5.1.2 Effect of PSB Consortium on Nodulation Characteristics of Soybean

In the present investigation the nodule characteristics viz., active, non-active total number of nodule and nodule dry weight were studied to generate supporting background for other parameters under study. The inoculated treatments revealed statistical at par relation in terms of active nodules while, significantly highest number of active root nodule was recorded by PSB inoculated treatment T<sub>8</sub> consisting consortium of PSB + 100% GRDF (89.40 plant<sup>-1</sup>) over un-inoculated treatments which was 68.9% of total number of nodules while, the control treatment

contributed the lowest of 53.2%. The least per cent of non-active nodules amongst the inoculated treatment was observed in treatment PSB + 100% GRDF (31.1%) while the highest of 46.8% was observed in absolute control. The total number of nodules followed identical trend to that of active nodule with significant highest number in inoculated treatment T<sub>8</sub> (129.8 plant<sup>-1</sup>) over all the un-inoculated treatments which registered a 47.1% increase over control. Inoculation treatment with consortium also recorded highest nodule dry weight. The maximum significant nodule dry weight was observed in T<sub>8</sub> i.e. Consortium of PSB + 100% GRDF (0.292 g plant<sup>-1</sup>)

### **5.1.3 Effect of PSB Consortium on Grain and Straw Yield of soybean**

Fertilizer P along with PSB played an imperative role in enhancing the grain and straw yield of soybean. The highest grain yield and straw yield was recorded by treatment T<sub>8</sub> consisting of inoculation with consortium of PSB + 100% GRDF (36.9 q ha<sup>-1</sup> and 55.9 q ha<sup>-1</sup> respectively) which was statistically at par with T<sub>7</sub> i.e. PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (36.2 q ha<sup>-1</sup> 53.1 q ha<sup>-1</sup> respectively) and the lowest was observed in control treatment (18.6 q ha<sup>-1</sup> and 25.9 q ha<sup>-1</sup> respectively).

### **5.1.4 Effect of PSB Consortium on Protein Content and Protein Yield of Soybean**

The protein content in soybean seed within the different treatments ranged from 39.5 to 42.4 per cent. Which highest value being recorded in T<sub>7</sub> which consisted consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (42.4%) which was followed by treatment T<sub>8</sub>. The protein yield corresponded to the grain yield of soybean. The highest protein yield was recorded by treatment T<sub>8</sub> consisting of inoculation with consortium of PSB + 100% GRDF to the tune of 1560 kg ha<sup>-1</sup> which was statistically at par with T<sub>7</sub> treatment consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (1533 kg ha<sup>-1</sup>)

### **5.1.5 Effect of PSB Consortium on Oil Content and Oil Yield of Soybean**

The oil content in soybean seed within the different treatments ranged from 19.8 to 21.2 per cent however, it did not differ much within the treatments. The oil yield also corresponded to the grain yield of soybean. The significant highest oil yield was recorded by PSB inoculated treatment T<sub>8</sub> to the tune of 784 kg ha<sup>-1</sup> which was statistically at par with T<sub>7</sub> i.e. consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O (767 kg ha<sup>-1</sup>)

### **5.1.6.6 Effect of PSB Consortium on Major Nutrient Uptake**

Integrated effect of consortium of phosphate solubilizing bacteria along with optimum dose of fertilizer P was found to be comparatively more beneficial in terms of major uptake by soybean. The significantly highest uptake of total nitrogen, phosphorus and potash was recorded with treatment T<sub>8</sub> consisting of inoculation with consortium of PSB + 100% GRDF (323 kg ha<sup>-1</sup>, 43.9 kg ha<sup>-1</sup> and 112.5 kg ha<sup>-1</sup> respectively) it was followed by T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O.

### 5.1.7 Effect of PSB Consortium on Micronutrient Uptake

The significantly highest uptake of copper, iron, zinc and manganese was recorded with treatment T<sub>8</sub> consisting of inoculation with consortium of PSB + 100% GRDF (189 g ha<sup>-1</sup>, 1729 g ha<sup>-1</sup>, 236 g ha<sup>-1</sup> and 237 g ha<sup>-1</sup> respectively) it was followed by T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O

### 5.1.8 Effect of PSB Consortium on Soil Properties and Available Nutrient Status

The soil properties viz., pH, electrical conductivity and organic carbon did not differ significantly due to various treatments. However, the treatment, PSB + 100% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O recorded significantly highest value of organic carbon (0.62%) over control (0.54%). The available major and micronutrient varied significantly within the various treatments. The inoculation treatments in general revealed better soil fertility after harvest of crop. Significant highest value of available N, P, K, Cu, Fe, Zn and Mn was recorded by treatment T<sub>8</sub> i.e. consortium of PSB + 100% GRDF (252 kg ha<sup>-1</sup>, 37.8 kg ha<sup>-1</sup>, 379 kg ha<sup>-1</sup>, 2.97 mg kg<sup>-1</sup>, 6.03 mg kg<sup>-1</sup>, 0.97 mg kg<sup>-1</sup> and 7.82 mg kg<sup>-1</sup>) which was statistically at par with treatment T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O

### 5.1.9 Effect of PSB on Phosphorus release at different days of Incubation

The available phosphorus at 0 and 15 days after incubation did not vary significantly amongst the different treatments. However, at 30, 45, 60 and 90 days after incubation the available P release were found to be significantly varying between the treatments. At 90 DAI, treatment PSB + 100% GRDF recorded significant highest concentration of available P (41.70 mg kg<sup>-1</sup>) which was statistically at par with treatment T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O

### 5.1.10 Effect of PSB Consortium on Dehydrogenase and Phosphatase Activity

The significant and highest DHA activity was reflected in treatment T<sub>8</sub> having inoculation with consortium of PSB + 100% GRDF (4.21 µg TPF g Soil<sup>-1</sup> hr<sup>-1</sup>) which was statistically at par with treatment T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O. Similar, results were obtained in regards of acid and alkaline phosphatases activities with significant highest activities were recorded by T<sub>8</sub> having inoculation with consortium of PSB + 100% GRDF (150.6 and 253.9 µg PNP g Soil<sup>-1</sup> hr<sup>-1</sup>) which was statistically at par with treatment T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O

### 5.1.11 Effect of PSB Consortium on Nutrient Use Efficiency

Inoculation with consortium of PSB in conjunction with applied inorganic nutrient exhibited enhanced nutrient use efficiency. The treatment with 100% GRDF and consortium of PSB i.e. T<sub>8</sub> recorded highest nitrogen, phosphorus and potassium use efficiency (36.64, 24.43 and 40.71 kg grain kg<sup>-1</sup> NUE, PUE and KUE respectively) which was followed T<sub>7</sub> consisting consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N and K<sub>2</sub>O

## 5.2 Conclusions

- i) The treatment consortium of PSB + 100% GRDF evidently proved maximum availability of soil phosphorus up to 90 DAI and significantly highest acid and alkaline phosphatase activity which was at par with consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N + K<sub>2</sub>O.
- ii) The treatment with consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N + K<sub>2</sub>O recorded at par grain and straw yield with treatment comprising consortium of PSB + 100% GRDF which recorded significantly highest grain and straw yield thereby ensuring 25% saving of phosphatic fertilizers.
- iii) The treatment consortium of PSB + 100% GRDF recorded maximum macronutrient and micronutrients content and significantly highest nutrient uptake by soybean which was at par with consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> and 100% N and K<sub>2</sub>O whereas, the quality of soybean seed remained unaffected due to different treatments.
- iv) The treatment consortium of PSB + 75% P<sub>2</sub>O<sub>5</sub> + 100% N + K<sub>2</sub>O revealed statistical at par relation with treatment consortium of PSB + 100% GRDF. It is therefore, concluded that 75% recommended dose of phosphorus along with consortium of PSB could prove beneficial for better growth and yield of soybean

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## 7. VITAE

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**IN**  
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