INFLUENCE OF BIOFERTILIZER AND PHOSPHORUS LEVEL ON GROWTH, NODULATION AND YIELD OF SOYBEAN

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CERTIFICATE

*This is to certify that the thesis entitled **"INFLUENCE OF BIOFERTILIZER AND PHOSPHORUS LEVEL ON GROWTH, NODULATION AND YIELD OF SOYBEAN"** submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (MS)** in **AGRONOMY**, embodies the result of a piece of bona fide research work carried out by **MUSLIMA JAHAN RUNIA**, Registration No. **12-05057** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that any help or source of information, received during the course of this investigation has duly been acknowledged.

Dated:

Dhaka, Bangladesh

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Dedicated to

My

Beloved Parents

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INFLUENCE OF BIOFERTILIZER AND PHOSPHORUS LEVEL ON GROWTH, NODULATION AND YIELD OF SOYBEAN

ABSTRACT

A field experiment was conducted at the research farm of Sher-e-Bangla Agricultural University, Dhaka, during January to April, 2018 to study the influence of biofertilizer and phosphorus level on growth, nodulation and yield of soybean. The experiment consists of two factors- factor A: Biofertilizer level-2; i) Control (without biofertilzer) (B_0) and ii) Biofertilizer (B_1); factor B: P levels-5; i) Control (no phosphorus) (P_0), ii) 25% less TSP than recommended dose (P_1), iii) Recommended dose of TSP (P_2), iv) 25% higher TSP than recommended dose (P_3) and 50% higher TSP than recommended dose (P_4). Biofertilizer was used @ 25 g kg^{-1} seed. The experiment was laid out in split plot design with three replications. Growth, yield attributes and yield data like plant height, number of branches $plant^{-1}$, dry weight $plant^{-1}$, number of nodules $plant^{-1}$, pod length, number of pods $plant^{-1}$, 100 seed weight, shelling percentage, seed yield and stover yield were collected from this experiment. Data were statistically analyzed using MSTAT-C software program. The significance of difference among the treatments means was estimated by the Duncan's Multiple Range Test (DMRT)at 5% level of probability. The result revealed that biofertilizer applied treatment (B_1) was found best by producing higher yield as well as highest 100 seed weight, number of seeds pod^{-1}, pod length, nodules $plant^{-1}$, and other growth characters. On the other hand, P levels at 25% higher phosphorus than recommended dose (P_3) produced highest yield (3613.00 kg ha^{-1}), plant height, branches $plant^{-1}$, dry weight $plant^{-1}$, nodules $plant^{-1}$, pods $plant^{-1}$, 100 seed weight, stover yield and biological yield. In case of interaction, B_1P_3 was found superior by producing highest seed yield (3714.00kg ha^{-1}) and yield attributes like pods $plant^{-1}$ (55.40), seeds pod^{-1} (2.98). From the result of study, it was revealed that application of biofertilzer and 25% higher TSP than recommended dose had positive impact on soybean (BINA Soybean-1).

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ABBREVIATIONS AND ACRONYMS

%	=	Percentage
AEZ	=	Agro-Ecological Zone
ANNOVA		Analysis of variance
BBS	=	Bangladesh Bureau of Statistics
BCSRI	=	Bangladesh Council of Scientific Research Institute
Ca	=	Calcium
cm	=	Centimeter
CV %	=	Percent Coefficient of Variation
DAS	=	Days After Sowing
DMRT	=	Duncan's Multiple Range Test
e.g.	=	exempli gratia (L), for example
et al.,	=	And others
etc.	=	Etcetera
FAO	=	Food and Agricultural Organization
g	=	Gram (s)
GM	=	Geometric mean
i.e.	=	id est (L), that is
K	=	Potassium
Kg	=	Kilogram (s)
L	=	Litre
LSD	=	Least Significant Difference
M.S.	=	Master of Science
m^2	=	Meter squares
mg	=	miligram
ml	=	miliLitre
N	=	Nitrogen
NaOH	=	Sodium hydroxide
No.	=	Number
NST	=	National Science and Technology
^oC	=	Degree Celsius
P	=	Phosphorus
SAU	=	Sher-e-Bangla Agricultural University
USA	=	United States of America
var.	=	Variety
WHO	=	World Health Organization
µg	=	Microgram

CHAPTER 1

INTRODUCTION

Soybean *(Glycine max* L. Merr) is one of the most important recognized oil seed and protein rich crops in the world. In Bangladesh, about 5 thousand ha of land is under soybean cultivation and annual production is approximately 4 thousand tons with an average yield of 1.5-2.3 t ha^{-1} (BARI, 2016). Soy protein products can replace animal-based foods which also have complete proteins but tend to contain more fat, especially saturated fat without requiring major adjustments elsewhere in the diet. Because soybeans contain no starch, they are a good source of protein for diabetics (USFDA, 2000). Soybean is called “miracle bean” or protein hope of future in Bangladesh. Soybean contains 40-45% protein, 18-20% edible oil and 24-26% carbohydrate (Gowda and Kaul, 1982).

Excessive uses of chemical fertilizers are increasing environmental pollution every day. On the contrary, bio-fertilizer technology is inexpensive and environmentally sound. As a legume crop, soybean in association with *Bradyrhizobium* has the unique ability of fixing atmospheric nitrogen for their growth and enriching nitrogen fertility as well as organic matter content in soil (Saha, 2007).

Atmosphere contains 78.08% N_2, which is practically unavailable to plants. Some plants, basically leguminous plants can assimilate atmospheric N_2, with the help of bacteria such as *Rhizobium.* The cooperation of plants and bacteria in nodules to convert atmospheric N_2 to reduced N is called symbiotic N_2-fixation. Successful *Rhizobium*-legume symbiosis will definitely increase the incorporation of biological N_2- fixation into soil ecosystem (Vance, 2001, Khairalseed, 2016). On a global basis these symbiotic association between legume and *Rhizobium* may reduce about 70 million tons of atmospheric N_2 to ammonia per annum which amounts to about 40% of all biologically fixed nitrogen per year (Bums and Hardy, 2004). Legumes play a pivotal role in developing new strategic approaches to ensure sustainable increase in agricultural productivity, without harming the environment (Hardarson *et al.*, 1984 and Khairalseed, 2016). Leguminous crops like soybean could utilize atmospheric N_2 and then the volume of nitrogen fertilizers applied to fields could be reduced, without losing the maximum biomass of crops (Kannaiyan, 1999). The symbiotically fixed N_2 can meet up to 30-90% N_2 requirement of the plant (Vessey, 2004 and Javaid and Mahmood, 2010). This fixed N_2 also acts as a renewable source of nitrogen if the legume crop is rotated with a non-leguminous one.

Bradyrhizobium japonicum has the beneficial effect on the growth and yield of soybean through producing root nodules. Fortunately, the soybean nodulating bacteria *Bradyrhizobium japonicum* can fix sufficient atmospheric nitrogen (about 300 kg ha^{-1} yr^{-1}) in symbiosis with soybean (Keyser and Li, 1992). So, the use of *Bradyrhizobium* inoculant in soybean production can play a vital role in improving soil environment and agricultural sustainability. Increased nodulation, higher dry mater and grain yield production due to *Bradyrhizobium* inoculation have been documented by several workers (Hoque and Jahiruddin, 1988, Singh, 2005 and Venkatarao *et al.*, 2017). Again, effective nodulation and high N_2-fixation depend largely on the efficiency of the nodule bacteria. The efficiency of the symbionts depends on many factors, important of which are genetic variability of the symbiont host plant, soil and environmental factors (Danso *et al.*, 1987 and Somasegaran *et al.*, 1990).

After nitrogen, phosphorus (P) is another plant growth- limiting nutrient despite being abundant in soils in both inorganic and organic forms. However, many soils throughout the world are phosphorus deficient because the free phosphorus concentration (the form available to plants) even in fertile soils is generally not sufficient (Gyaneshwar *et al.,* 2002).

Since phosphorus is one of the essential major nutrient and is required in adequate amounts in the available form for the growth and reproduction of plants and is also associated with several vital functions and is responsible for many characteristics of plant growth. The high biomass implies increase in the rate of photosynthesis due to high leaf number and leaf area (Majengo *et al*., 2011). The photosynthates are transported via phloem and used in grain yield production. The results obtained in the investigation are in line with the findings of Bhatt *et al*., (2013), Pramanik *et al*., (2014), Vanita *et al*., (2014), Tiwari *et al*., (2015), Rathour *et al*., (2015), Chowdhary *et al*., (2015).

Root improvement, stalk and stem vigor, flower and seed formation, crop production, crop maturity and resistance to plant pests and diseases are the attributes associated with phosphorus availability. Phosphorus is needed in relatively large amounts by legumes for growth and has been reported to promote leaf area, biomass, yield, nodule number and nodule mass in different legumes (Tiwari *et al*., 2015 and Chowdhary *et al*., (2015).

Furthermore, phosphorus has important effects on photosynthesis, root development, fruiting and improvement of crop quality. Efficiency of P fertilizer throughout the world is around 10 - 25 % nutrition of available phosphorus in soil is very low reaching the level of 1.0 mg kg^{-1} soil (Sara *et al.*, 2013). In soybean production, phosphorus and inoculation with the appropriate *Rhizobium* strains have quite prominent effects on nodulation, growth and yield parameters (Shahid *et al*., 2009).

The absence of the required *Rhizobia* species and optimal phosphorus levels limit legume production in different parts of the world. Inoculation with compatible and suitable *Rhizobia* with optimum phosphorus levels may be essential where a low population of native rhizobial strains prevail and is one of the key components of which grain legume farmers can use to optimize yields. The use of fertilizers and bio-fertilizer in soybean production can play a significant role in terms of biomass production, yield, improving soil environment and agricultural sustainability. Research on the contribution of *Bradyrhizobium* and fertilizers especially phosphorus on the growth, yield and N_2- fixation of soybean is very limited in our country.

Therefore, the present investigation was carried out to evaluate the performance of bio-fertilizer on yield of soybean under different levels of phosphorus with the following objectives:

1. To evaluate the effect of biofertilizer on growth, nodulation and yield of soybean,
2. To select the optimum phosphorus dose for better growth, nodulation and yield of soybean and
3. To observe the interaction of biofertilizer and phosphorus level on growth, nodulation and yield of soybean.

CHAPTER II

REVIEW OF LITERATURE

An effort was made in this section to gather and study the relevant information on hand in the home and abroad regarding the influence of biofertilizer and phosphorus level on growth, nodulation and yield of soybean to gather knowledge helpful in conducting the present research work and subsequently writing up the result and discussion.

2.1. Effect of bio-fertilizer on growth, nodulation and yield

Biofertilizers are gaining importance as they are ecofriendly, non-hazardous and non-toxic. A substantial number of bacterial species, mostly those associated with the plant rhizosphere, may exert a beneficial effect upon plant growth. Biofertilizers include mainly encouraging the nitrogen fixing, phosphate solubilizing and plant growth promoting micro-organism. Inoculating pulse crops with *Rhizobia* to add nitrogen is routine for most growers. The presence of efficient and specific strains of *Rhizobium* in the rhizosphere is one of the most important requirements for proper establishment and growth of grain legume plant. Phosphate solubilizing bacteria partly solubilizes inorganic and insoluble phosphate and improves applied phosphorus use efficiency stimulating plant growth by providing hormone, vitamin and other growth promoting substances (Gyaneshwar *et al*., 2002).

Effective nodulation of soybean requires the presence of specific species of *Bradyrhizobium* in the soil. Population of such compatible *Bradyrhizobia* species are most of the time not available in soils, especially those with no soybean cropping history (Abaidoo *et al*., 2007). Soybean introduced in many tropical soils for the first time required inoculation with *Bradyrhizobium japonicum* strains to ensure adequate and effective nodulation in these soils that contained high cowpea *Bradyrhizobia* populations. Inoculation is a major constraint in the production of soybean genotypes which require specific *Bradyrhizobium* species. It was to overcome this problem of specificity in soybean that the soybean breeding programme at the International Institute for Tropical Agriculture (IITA) in Nigeria developed promiscuous soybean varieties which were designated TGx (Tropical Glycine cross). These varieties had reduced nodulation specificity and therefore could nodulate effectively with native *Bradyrhizobium* strain populations since the non promiscuous soybean did not do well under tropical climate (Abaidoo *et al*., 2007).

Several experiments have been conducted using promiscuous soybean genotypes in many countries in West (Sanginga *et al*., 1996), East and South Africa (Mpepereki *et al*., 2000) without N fertilizer and inoculation and the results have indicated that the indigenous strains did not always meet the N requirements of the plants; in spite of the fact that these soybean genotypes were nodulated by indigenous *Rhizobia*. Musiyima *et al*. (2005) obtained similar results using different promiscuous soybean varieties in Zimbabwe. The presence of nodules is not indicative of an effective nitrogen fixation that can enhance growth of the soybean plant significantly, since there is the possibility of ineffectiveness of indigenous *Bradyrhizobia* strains in root nodules of promiscuous soybean (Zengeni and Giller, 2007). These results have generated a huge discussion on whether it is necessary to inoculate promiscuous soybean genotypes. There is variability in the effectiveness and population of indigenous *Bradyrhizobia* in a given location (Fening and Danso, 2002). This has made it necessary for promiscuous soybean to be inoculated with foreign *Bradyrhizobia* strains depending on the indigenous *Bradyrhizobia* population and their effectiveness in the locality (Okereke *et al*., 2000) as well as the variety's degree of promiscuity (Sanginga *et al*., 1999).

The significant role of *Bradyrhizobium* inoculants application in enhancing nitrogen fixation in soybean on smallholder farms in Ghana was demonstrated by the N_2Africa project which was aimed at putting nitrogen fixation to work for smallholder farmers in Africa. An assessment of the project's impact on biological nitrogen fixation from both agronomy and delivery and dissemination (D and D) trials conducted in northern Ghana between 2008 and 2012 revealed that, nitrogen fixation in soybean increased from 89 kg N ha^{-1} in control treatments to 112 kg N ha^{-1} where inoculants were applied at a rate of 5 g of inoculants kg^{-1} of soybean seed (Ronner and Franke, 2012).

There have been varied responses of soybean to rhizobial inoculation in sub - Saharan Africa. In assessing the response of soybean to *Bradyrhizobia* and phosphorus application in Ghana, Kumaga and Ofori (2004) observed significant increases in nodulation after inoculation of both promiscuous and non promiscuous soybean varieties and the increase in nodulation was attributed to high competitive ability of the *Bradyrhizobia* inoculants used. Similar findings were also reported by Okereke *et al*. (2000) for promiscuous soybean in the moist Savanna of West Africa.

Kumaga and Etu-Bonde (2004) through pot studies showed that nodulation and N_2 fixation of promiscuous soybean may be increased when inoculated with effective *Bradyrhizobia*. In a similar study, Thuita *et al*. (2012) found out that application of commercial *Rhizobia* inoculants resulted in significant increase in growth and nitrogen fixation of promiscuous soybean in Kenyan soils.

In assessing the potential of commercial inoculants to improve cowpea yields in Kenya, Mathu *et al*. (2012) found out that rhizobial inoculation did not have a significant effect on nodulation, biomass yield and shoot N content in cowpea compared with controls. Cowpea, like many other promiscuous grain legumes, is not likely to respond positively to rhizobial inoculation unless inoculated with selected strains applied in high concentrations.

A study by Fening and Danso (2002), on the symbiotic effectiveness of 100 cowpea *Bradyrhizobia* isolates in soils indicates that, 26% of the isolates were effective in fixing nitrogen with cowpea, while 68% were moderately effective and 6% being ineffective. Incorporation of cowpea residues into soils was estimated to supply 60 kg N ha^{-1} soil nitrogen which was beneficial to subsequent crops.

Rajaa and Takankhar (2017) carried out a field experiment on "Effect of liquid biofertilizers (*Bradyrhizobium* and PSB) on growth characters of soybean". It was conducted in Kharif season and variety MAUS-81 was used as a test crop along with 16 treatment combination containing four levels of liquid *Bradyrhizobium* (0ml, 5ml, 10ml, and 15ml) and four levels of liquid PSB (0ml, 5ml, 10ml, and 15ml). The results of field research indicated that the growth parameters *viz*. plant height, number of functional leaves, root length, and dry matter yield were significantly increased due to dual inoculation with 10 ml of *Bradyrhizobium japonicum* kg^{-1} seed + 10 ml of PSB kg^{-1} seed (A_2B_2) treatment over rest of the treatments but they were at par with (A_3B_3). Number of branches of soybean was significantly increased with individual seed inoculation of 10 ml *Bradyrhizobium japonicum* kg^{-1} seed (A_2) as well as 10 ml of PSB kg^{-1} seed (B_2) over rest of the treatments but they were at par with A_3 (15 ml *Bradyrhizobium japonicum* kg^{-1} seed) and B_3 (15 ml of PSB kg^{-1} seed), respectively.

Diep *et al*. (2017) conducted a field experiment to study the effects of *Rhizobia* and phosphate-solubilizing bacteria (PSB) on soybean (cv. Cujut) cultivated on ferralsols. The experiment consisted of six treatments as follows: control (no fertilizer, no inoculant), 240 kg ha^{-1} NPK 15-15-15, rhizobial inoculant [with liquid cover seeds] + 20 kg N ha^{-1} applied at 10 days after sowing [DAS], PSB inoculant [with liquid cover seeds] + 20 kg N ha^{-1} at 10 DAS, rhizobial and PSB inoculant [with liquid cover seeds] + 400 kg fertilizer ha^{-1} + 20 kg N ha^{-1} at 10 DAS and endophytic bacteria inoculant [with liquid cover seeds] + 400 kg fertilizer ha^{-1} + 20 kg N ha^{-1} at 10 DAS from June to August, 2016. The results showed that application of rhizobial inoculant and/or PSB inoculant produced significantly higher yield component, grain yield than control and did not differ from 240 kg ha^{-1} NPK 15-15-15. Consequently, application of

Rhizobia and PSB improved soil fertility after harvesting however using mixture of *Rhizobia* and PSB inoculation plus 400 kg biofertilizer ha^{-1} +20 kg N ha^{-1} for soybean cultivation supported yield component, grain yield and oil, protein in seed than control and equivalent with treatment of chemical fertilizer (240 kg ha^{-1} NPK 15-15-15). This technique not only increased grain yield, incomes for farmers but also improved soil fertility.

The application of biofertilizers, micronutrients and RDF enhanced the plant height appreciably at harvest stages. Increase in plant height might be attributed to the fact that the better nourishment causes beneficial effects such as accelerated rate of photosynthesis, assimilation, cell division and vegetative growth. These results are in agreement with the findings of Singh *et al*., (2007).

Dhingra *et al*.(1988) results showed that the interactions between phosphorus and *Rhizobium* inoculation was significantly in 3 out of 5 years, indicating that the combination of *Rhizobium* and 20 kg P_2O_5 ha^{-1} gave yield equivalent to 40 kg P_2O_5 ha^{-1} without *Rhizobium*. Gupta and Sharma (1992) reported from the result of an experiment that yield of lentil 0.87 - 1.30 t ha^{-1} with 0 - 32 kg phosphorus and no inoculation, and 0.89 - 1.68 t ha^{-1} with 0 – 32 kg phosphorus and inoculation. Seeds protein content increased with application of phosphorus and inoculation.

Rajput and Kushwah (2005) studied that the application of bio-fertilizer on production of pea. On the basis of three years pooled data, the highest yield was recorded with the application or recommended doses of fertilizer followed by soil application of bio-fertilizer mixed 25 kg FYM along with 50% recommended dose of fertilizer and were at par statistically. So the use of bio-fertilizer saved 50% N, P (10 kg N, 25 kg P_2O_5). It also saved the financial resource as well as FYM.

Sharma and Sharma (2004) determined the effects of P (0, 20 and 40 kg ha^{-1}), potassium (0 or 20 kg ha^{-1}) and *Rhizobium* inoculation on the growth and yield of lentil cv. L-4147. The mean number of branches, nodules and pods per plant; 100-seed weight and seed yield were highest with the application of 40 kg P ha^{-1}, whereas mean plant height and plant stand row length were highest with the application of 20 kg P ha^{-1}. Application of K resulted in the increase in number of branches and pods per plant and seed yield, whereas inoculation with *Rhizobium* increased the mean plant height; number of branches, nodules and pods per plant, 100-seed weight and seed yield.

Hossain and Suman (2005) conducted an experiment to evaluate the effect of *Azotobacter*, *Rhizobium* and different levels of urea N on growth, yield and N-uptake of lentil. Among the treatments *Azotobacter* plus *Rhizobium* inoculation had significant effect on nodule formation, plant height, number of seeds, seed and stover yields, compared to uninoculated controls. The highest seed yield was recorded for the treatment *Azotobacter* + *Rhizobium* that was statistically similar to that of 100% N and *Rhizobium* with the corresponding yields of 1533 and 1458 kg ha^{-1}, respectively. The dual inoculation of *Azotobacter* and *Rhizobium* significantly influenced all the crop characters including N contents, N uptake by seed and shoot as well as protein content of seed. The highest N-uptake by seed (78.61 kg ha^{-1}) was recorded for the treatment *Azotobacter* + *Rhizobium* and N-uptake by shoot (53.87 kg ha^{-1}) was recorded for the treatment 100% N. The performances of *Azotobacter* or *Rhizobium* alone were not as good as *Azotobacter* + *Rhizobium* in most cases. Therefore, inoculation of both *Azotobacter* and *Rhizobium* together may be a good practice to achieve higher seed yield of lentil.

Kumar and Uppar (2007) carried out a field experiment to evaluate the effects of organic manures, biofertilizers, micronutrients and plant growth regulators on the seed yield and quality of mothbean. RDF + FYM @ 10 t ha^{-1} recorded the highest values for the different seed yield and quality attributes of moth bean.

Javaid and Mahmood (2010) conducted a field experiment to investigate the effect of a symbiotic nitrogen fixing bacterium *Bradyrhizobium japonicum* strain TAL-102 and a commercial biofertlizer EM (effective microorganisms) on growth, nodulation and yield of soybean [*Glycine max* (L.) Wilczek] in soils amended either with farmyard manure or *Trifolium alexandrinum* L. green manure @ 20 tons ha^{-1} each. In green manure amendment, *B. japonicum* inoculation significantly enhanced number and biomass of nodules resulting in a significant increase of 27, 65 and 55% in shoot biomass and number and biomass of pods, respectively. In farmyard manure amended soil, *B. japonicum* inoculation significantly enhanced fresh biomass of nodules. As a result a significant increase of 45 and 47% in shoot biomass and number of pods was recorded, respectively. Generally, the effect of sole EM application on various studied parameters was insignificant in both the soil amendment systems. Combined application of EM and *B. japonicum* in green manure amended soil reduced shoot growth and number of pods as compared to sole *B. japonicum* inoculation. Conversely, in farmyard manure amendment, plants co-inoculated with *B. japonicum* and EM exhibited highest and significantly greater shoot biomass, and number and biomass of pods as compared to all other treatments.

Ronner and Franke, (2012) found that nitrogen fixation in soybean increased from 89 kg N ha^{-1} in control treatments to 112 kg N ha^{-1} where inoculants were applied at a rate of 5 g of inoculants kg^{-1} of soybean seed. The significant role of *Bradyrhizobium* inoculants application in enhancing nitrogen fixation in soybean.

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Fening and Danso (2002) carried out an experiment on the symbiotic effectiveness of 100 cowpea *Bradyrhizobia* isolates in soils and indicates that, 26% of the isolates were effective in fixing nitrogen with cowpea, while 68% were moderately effective and 6% being ineffective. Incorporation of cowpea residues into soils was estimated to supply 60 kg N ha^{-1} soil nitrogen which was beneficial to subsequent crops (Dakora *et al*., 1987).

2.4. Effect of phosphorus on growth, nodulation and yield

Phosphorus plays a major role in many plant processes, including storing and transfer of energy; stimulation of root growth, flowering, fruiting and seed formation; nodule development and N_2 fixation (Ali *et al*., 1997). Phosphorus application on legumes can also increase leaf area, yield of tops, roots and grain; nitrogen concentration in tops and grain; number and weight of nodules on roots; and increased acetylene reduction rate of the nodules (Zeidan*et al*., 2006).

Research documents evident that the influence of P on nodule development and N_2 fixation by legumes. The N_2-fixation process in legumes is sensitive to phosphorus deficiency due to reduced nodule mass and decreased ureide production (Van-Kessel and Hartley, 2000). Nodules are a strong P sink and nodule P concentration normally exceeds that of roots and shoots. Therefore, nodule number, volume, and dry weight can be increased by treating P deficient soils with fertilizer P. However, Bremer *et al*. (1989) found that P application increased dry matter and grain yield but did not affect N_2 fixation indicating that the legume host was more responsive to P application than the *Rhizobia.*

Saskatchewan soils generally test low to medium in available phosphorus, a nutrient required in relatively large amounts by pulse crops. Total phosphorus in soils ranges from about 400 to 2200 kg ha^{-1} in the top 15 cm of soil, but only a very small amount of the total P is available to the crop during a growing season (Saskatchewan Ministry of Agriculture, 2006). Although crops can sometimes be grown for a few years without adding P fertilizer, yields sooner or later begin to decline. Phosphorous is relatively immobile (moves very little) in the soil. Most crops recover only 10 to 30% of the P in fertilizer the first year following application (Havlin *et al*., 2005). Recovery varies widely depending on soil type and conditions, the crop grown and application method. However, Saskatchewan research has shown 9 that the newly formed soil P reaction products are more plant available than the native soil P minerals and crops can continue to recover fertilizer P for several years after application (SAF, 2006).

Granular monoammonium phosphate (MAP) (12-51-0 or 11-55-0) is the most common P fertilizer used in Saskatchewan (SAF, 2006). Lentils are sensitive to higher rates of P fertilizer placed directly in the seed rows. Research conducted over a three year period indicated that increasing rates of seed-placed MAP (11-55-0) resulted in reduced stands of lentil but high yield per plant as compared to side-banded P application (McVicar *et al*., 2010). Lentil has a relatively high requirement for phosphorus to promote development of its extensive root systems and vigorous seedlings; and may benefit from improved frost, disease, and drought tolerance because of P application (McVicar *et al*., 2010). Bremer *et al*. (1989) reported that P response is more prevalent in the

Black soils, which had the most favorable growing conditions and lowest available soil P levels, than in Brown or Dark Brown soils of Saskatchewan.

Hussain *et al*. (2003) conducted an experiment to observed the effect of different phosphorus rates (0, 25, 50 and 75 kg ha^{-1}) on the chemico-qualitative parameters of lentil cultivars Masoor local, Masoor-85 and Masoor-93 were studied under field conditions in Faisalabad, Pakistan on a sandy-clay loam soil for two years. The seed protein concentration was significantly higher (25.36%) in Masur-93 than Masur-85 (23.24%) and Masur-local (23.07%) whereas the seed contents of P, K, Ca, Mg, and phytic acid and cooking quality were similar in all cultivars. By contrast, 50 kg P_2O_5 ha^{-1} significantly improved the cooking quality, seed P and phytic acid content compared to the control.

Devi (2012) conducted a field experiment to study the effect of different sources and levels of phosphorus on productivity of soybean [*Glycine max* (L.) Merrill]. The treatments consisted of four sources of phosphorus [Single super phosphate (SSP), Di-ammonium phosphate (DAP), Single super phosphate (SSP)+Phosphate solubilizing bacteria (PSB), Di-ammonium phosphate DAP)+Phosphate solubilizing bacteria (PSB)], four levels of phosphorus (20, 40, 60 and 80 kg P_2O_5 ha^{-1}) and one absolute control(without any fertilizer and PSB). Application of SSP+PSB produced significantly higher number of nodules per plant, dry weight of nodules per plant, number of pods per plant and 100-seed weight than the other treatments. Maximum grain yield and total phosphorus uptake were also recorded when using SSP + PSB. Yield attributing characters, grain and stover yield were increased with increasing levels of phosphorus. Regarding evaluation of various efficiency fractions of soybean, agronomic efficiency, physiological efficiency and phosphorus use efficiency had more pronounced effects on combined application of SSP + PSB. However, apparent recovery of phosphorus was higher in DAP + PSB due to higher stover yield and higher phosphorus uptake. Among the different levels the efficiency fractions increase up to 60 kg P_2O_5 ha^{-1} and declined at 80 kg P_2O_5 ha^{-1}.

Dhage *et al*. (2014) conducted a field experiments for two consecutive years during 2009-10 and 2010-11to study the effect of phosphorus and sulphur levels on soybean (*Glycine max* L.). The treatments consisted of four levels of sulphur (S0 , S20, S40 and S60 kg ha^{-1}) and four levels of phosphorus (P0, P30, P60 and P90 kg P_2O_5 ha^{-1}) applied through elemental sulphur and DAP, respectively. Results revealed that due to increase in the phosphorus and sulphur levels, there was effective improvement in nodulation, fresh weight of nodules $plant^{-1}$ and growth parameters *viz*., plant height, leaf area, root length, root dry weight $plant^{-1}$ and number of pods $plant^{-1}$ at various growth stages of soybean. The yield i.e. grain, straw and total biological yield of soybean increased significantly with increasing levels of both phosphorus and sulphur. Further, synergistic effect of phosphorus and sulphur interactions on straw and total biological yield was highest at 90 kg P_2O_5 + 60 kg S ha^{-1} followed by 90 kg P_2O_5 + 40 kg S ha^{-1}, 90 kg P_2O_5 + 20 kg S ha^{-1} and 60 kg P_2O_5 + 60 kg S ha^{-1} in straw yield and 90 kg P_2O_5 ha^{-1} with 60 or 40 kg S ha^{-1} produced significantly higher yield over S application with 30 and 0 kg P_2O_5 ha^{-1} in total biological yield.

2.3 Combined effect of biofertilizer and phosphorus

Tarekegn and Kibret (2017) conducted a field study to determine the influence of *Bradyrhizobium japonicum* inoculation and N and P fertilizers application on nodulation, yield and yield attributes of soybean. Three levels of N (0, 11.5 and 23 kg N ha^{-1}); three levels of P (0, 23 and 46 kg P_2O_5 ha^{-1}) with two levels of *Rhizobium* were arranged with three replications. Nodule number, nodule fresh and dry weights, plant height, number of pods and seeds per plant, 100 seeds weight and grain yield responded significantly to the interaction effects of *B. japonicum* inoculation and application of N and P fertilizers but nodule volume, seed and biomass yields, and harvest index were significantly affected by the main effects of any one or more of the factors and interaction of any two of the factors. The maximum numbers of nodules of 80.26, fresh and dry weights of 3.77 and 0.99 gm/plant respectively; were measured by combined effect of 11.5 kg N ha^{-1}, 46 kg P_2O_5 ha^{-1} and *B. japonicum*. Similarly the highest nodule volume of 3.53 and 3.27 ml/plant were measured after applications of 46 kg P_2O_5 ha^{-1} with *B. japonicum* and with 11.5 kg N ha^{-1} respectively. The highest plant heights of 79.26 cm followed by 76.94 cm were measured by application of 46 kg P_2O_5 ha^{-1} with *B. japonicum* and 46 kg P_2O_5 ha^{-1} itself respectively. Seed yield significantly increased to 11.91 gm/plant and 15.97 gm/plant following application of *B. japonicum* alone and 46 kg P_2O_5 ha^{-1} with *B. japonicum* respectively. Applied 23 kg ha^{-1} brought the highest plant biomass of 27.25 gm/plant. Inoculation with 46 kg P_2O_5 ha^{-1} and the combined effects of 11.5 kg N ha^{-1}, 46 kg P_2O_5 ha^{-1} and *B. japonicum* resulted 73.93 and 80.66 number of pods per plant respectively. The maximum 100.60 numbers of seeds per plant were counted during inoculation of *B. japonicum* with 46 kg P_2O_5 ha^{-1}. The maximum 100 seed weight of 16.96 gm and grain yield of 3151.88 kg ha^{-1} were produced by combined application of 11.5 kg N ha^{-1}, 46 kg P_2O_5 ha^{-1} and *B. japonicum.* Each nodule attributes were significantly and positively correlated each other and with each yield and yield attributes. The results showed that growth and yield potential of soybean and an increase N_2 fixing can be achieved by using *B. japonicum* and P fertilizer with reduced level of N as starter fertilizer.

Khairalseed (2016) conducted an experiment to examine the effect of composite strains of *Rhizobia* (TAL102, TAL379and TAL 377) carried on peat used for soybean (*Glaycine max*) inoculation. Nitrogen and phosphorus were used at different levels to determine the effect on the soybean number of nodules, shoot dry weight soybean yield, nitrogen percentages, and crude protein. The most probable number (MPN) was used to determine the number of the *Rhizobium* per gram on the peat. Treatments were factorially combined and laid out in a complete block design. Seed inoculation increased nodule dry matter and nitrogen fixation. Added 50Kg N ha^{-1} to inoculated soybean decreased nodule dry mass and doubling the dose further decreased the nodule dry mass. Adding 50KgP_2O_5 ha^{-1} to inoculated soybean significantly increased soybean shoot dry mass over mere inoculation. Inoculation alone significantly increased soybean seed yield over that the control and gave the same seed yield over that of inoculated with 100KgN ha^{-1}. Inoculation with 50Kg N ha^{-1} significantly increased seed yield over that of the inoculated soybean. Effect of different treatments on crude protein percentage (CP %) followed the same trend as for seed N%.

Venkatarao *et al*. (2017) conducted a field experiment was conducted during kharif season of 2015 on loamy sand soil at the Agronomy farm, S. K. N. College of Agriculture, Jobner (Rajasthan). The experiment consisted of four levels of phosphorus (Control, 20, 40 and 60 kg P_2O_5 ha^{-1}) and four treatments of biofertilizers (Control, PSB, *Aspergillus awamori* and PSB + *Aspergillus awamori*) thereby, making sixteen treatment combinations and replicated thrice. The results indicated that application of phosphorus upto 40 kg P_2O_5 ha^{-1} recorded the highest number of total and effective number of nodules per plant, plant height, leaf area index, total chlorophyll content, grain yield (1221 kg ha^{-1}) and straw yield (2988 kg ha^{-1}) which was at par with 60 kg P_2O_5 ha^{-1}. Results further indicated that seed inoculation with the PSB and *Aspergillus awamori* significantly increased highest number of total and effective number of nodules per plant, plant height, leaf area index, total chlorophyll content, grain yield (1260 kg ha^{-1}) and straw yield (3140 kg ha^{-1}) over the rest of the treatments. The seed inoculation with PSB and *Aspergillus awamori* individually remained at par.

Islam *et al*. (2017) conducted a field experiment was conducted at the Soil Science Field Laboratory of Bangladesh Agricultural University (BAU), Mymensingh during January to May 2015 to study the response of soybean to *Bradyrhizobium* biofertilizer under different levels of phosphorus on growth, yield, nutrient content and uptake by soybean. The experiment was laid out in a randomize complete block design with three replication of each treatment. The treatments were: To = Control, T_1 = (100% Nitrogen), T_2 = (*Bradyrhizobium*), T_3 = (*Bradyrhizobium* inoculation + 75% P), T_4 = (*Bradyrhizobium* inoculation+10 P), T_5 = *Bradyrhizobium* + 125% P), T_6 = (100% RFD + *Bradyrhizobium*). Potassium and Sulphur at recommended dose were applied as basal to all the treatments. Urea was applied in three spits. Phosphorus in the form of TSP was applied as per treatment during final land preparation. Soybean seeds were inoculated with *Bradyrhizobium* as per treatments. Intercultural operations were done as and when necessary. Data were collected on pods weight, grain and stover yields. The N and P contents in grain stover and total N and P uptake by soybean were determined. Inoculation of seeds with *Bradyrhizobium* and application of N and P fertilizer at recommended dose recorded the highest grain and straw yields of soybean. The results suggest that soybean cultivation can effectively be done in the Old Brahmaputra Floodplain soils by Inoculating with *Bradyrhizobium* biofertilizer in combination with recommended dose of N, P, K and fertilizer.

Tahir *et al*. (2009) conducted a research experiment to examine the effect of *Rhizobium* inoculation (RI) and P fertilization (P) on nodulation, growth and yield characteristics of soybean grown in the presence of starter N fertilizer. Treatments included: i) 02 levels of RI (RI_0, RI_1), ii) 02 levels of P (P0, P1 that is, P_2O_5 @ 90 kg ha^{-1}) iii) 03 levels of N (N_0, N_1 and N_2 that is, N at of 25 and 50 kg N ha^{-1}) iv) 03 replication. Results of the experiment revealed that total number of nodules increased from 73 in the un-inoculated control to 125 and 95 following the application of RI and P representing 70 and 30% increase over control. N supply did not affect the number of nodules; however, combination of RI and P with 25 kg N ha^{-1} ($RI_1P_1N_1$) produced the highest number of nodules (152). RI, P, N and their combinations increased shoot and root biomass. Seed yield in the control was 767 kg ha^{-1} that significantly increased to 1081, 907 and 940 kg ha^{-1} following the application of RI, P and N demonstrating 41, 18 and 23% increase over control. The highest seed yield of 1208 kg ha^{-1} was recorded in the combine treatment of $RI_1P_1N_1$ indicating 57% increase over control. Relative increase in dry matter yield due to RI, P and N was 63, 46 and 49%. Seed protein content in different treatments ranged between 33 - 40% while oil content ranged between 13 - 18%. Application of RI, P and their combinations increased protein content by 6 - 22% while increase in oil content was 12 - 35%. Concentrations of N and P in plants and their uptake was significantly increased and relative increase in N uptake due to RI, P and K was 77, 21 and 31%, respectively, while the corresponding increase in P uptake was 79, 92 and 56%. It was found that the efficiency of RI and P fertilization increased substantially with the application of 25 kg N ha^{-1} but the efficiency decreased when N supply increased from 25 kg N ha^{-1} to 50 kg N ha^{-1}. The results demonstrate the potential benefits of using *Rhizobium* inoculation and P fertilization with reduced level of N as starter fertilizer in order to achieve plant-growth promotion, increased nodulation and seed yield of soybean.

From the above presented review of literature on biofertilizer treatments, P treatments and also their combination on pulse production, it can be concluded that soybean yield can be significantly enhanced by the application of biofertilizer inoculation and/or P application. These applications also contribute to achieve higher growth and yield characters like plant height, branches, nodules, pods number, 100-seed weight and seed yield.

CHAPTER 3

MATERIALS AND METHODS

The experiment was carried out at the farm of Sher-e-Bangla Agricultural University, Dhaka-1207 during the period from January to April,2018. Detailed of the experimental materials and methods followed in the study are presented in this chapter. The experiment was conducted to study the influence of biofertilizer and phosphorus level on growth, nodulation and yield of soybean.

3.1 Experimental site

The experiment was carried out at Sher-e-Bangla Agricultural University Farm, Dhaka-1207, Bangladesh. It is located at 90°22′ E longitude and 23°4l′ N latitude at an altitude of 8.6 meters above the sea level. The land belongs to Agro-ecological zone of Modhupur Tract, AEZ-28 (Appendix I).

3.2 Climatic condition

The experimental area is under the sub-tropical climate that is characterized by less rainfall associated with moderately low temperature during rabi season, (October-March) and high temperature, high humidity and heavy rainfall with occasional gusty winds during kharif season (April-September). Details of weather data in respect of temperature (^{0}C), rainfall (mm) and relative humidity (%) for the study period was collected from Bangladesh Meteorological Department, Agargoan, Dhaka-1207 have been presented (Appendix II).

3.3 Soil condition

The soil of experimental area situated to the Modhupur Tract (UNDP, 1988) under the AEZ no. 28 and Tejgoan soil series (FAO, 1988). The soil was sandy loam in texture with pH 5.47 - 5.63. The physical and chemical characteristics of the soil have been presented in Appendix III.

3.4 Details of the experiment

3.4.1 Treatments

The experiment consisted of two (2) factors:

Factor A: Biofertilizer – Two levels

1. B_0 = Control (No biofertilizer)
2. B_1 = Inoculation with biofertilizer (*Bradyrhizobium*)

Factor B: Phosthetic fertilizer – Four levels with one control

1. P_0 = Control (No TSP)
2. P_1 = 25% less TSP than recommended dose
3. P_2 = Recommended dose of TSP (160 kg ha^{-1})
4. P_3 = 25% higher TSP than recommended dose
5. P_4 = 50% higher TSP than recommended dose

Treatment combinations: Ten treatment combinations

B_0P_0, B_0P_1, B_0P_2, B_0P_3, B_0P_4, B_1P_0, B_1P_1, B_1P_2, B_1P_3, B_1P_4.

The phosphorus (P) fertilizers were applied in the form of triple super phosphate (TSP).

3.4.2 Experimental design and layout

The experiment was laid out in Split Plot Design with three replications. There were 10 treatment combinations. Biofertilizer treatments were considered in main plot and phosphorus treatments were in sub-plot. The total numbers of unit plots were 30. The size of unit plot was 4.0×3.0 m^2. The distances between plot to plot and replication to replication were 0.50 m and 0.75 m, respectively.

3.5 Planting Material

The variety of soybean, BINA Soybean-1 was used as plant material.

3.6 Preparation of experimental land

A pre- sowing irrigation was given on 14 December 2017. After that the land was open with the help of a tractor drawn disc harrow and then ploughed with rotary plough twice followed by laddering to achieve a medium tilth required for the crop under consideration. All weeds and other plant residues of previous crop were removed from the field. Immediately after final land preparation, the field layout was made on 30 December, 2017 according to experimental specification. Individual plots were cleaned and finally prepared the plot.

3.7 Fertilizer application

Biofertilizer: Under the present study, biofertilizer was used as per treatment. Biofertilizer was used @ 25 g kg^{-1} seed.

Again, the recommended doses of different fertilizer used in the present study was as follows:

Name of fertilizer	Doses (ha^{-1})	Nutrients (ha^{-1})
Urea	50 kg	N = 23 kg
TSP	160 kg	P_2O_5 = 72 kg
MoP	110 kg	K_2O = 66 kg
Gypsum	100 kg	S =18 kg, Ca = 22 kg
Boric acid	10 kg	B = 1.7 kg

All the fertilizers according to the treatment were applied and mixed with soil thoroughly at the time of final land preparation after making plot. Biofertilizer was used instead of urea in some plot according to treatment.

3.8 Seed collection

Seeds of BINA Soybean-1 were collected from Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh, Bangladesh.

3.9 Seed sowing

The seeds of BINA Soybean-1 were shown by hand in 30 cm apart from lines with continuous spacing at about 3 cm depth at the rate of 40 g $plot^{-1}$ on 1 January, 2018.

3.10 Intercultural operations

3.10.1. Thinning

The plots were thinned out on 15 days after sowing (16 January, 2018) to maintain a uniform plant stand which facilitates proper aeration and light for optimum growth and development of the crops. Plant to plant distance was 5-6 cm.

3.10.2. Weeding

The crop was infested with some weeds during the early stage of crop establishment. Two hand weeding were done, first weeding was done at 15 days after sowing followed by second weeding at 15 days after first weeding.

3.10.3. Application of irrigation water

Irrigation water was added to each plot, first irrigation was done as pre-sowing and other two irrigation were given 20-25 days after sowing and before pod formation (after 50-55days).

3.10.4 Drainage

Drainage channel were properly prepared to easy and quick drained out of excess water.

3.10.5 Plant protection measures

The crop was infested by hairy caterpillar (*Diacrisia obliqua*) at early growth stage which was controlled by applying sumithion 50 EC @ 1.0 Lha^{-1} . Mites were effectively and timely controlled by applying Malathion 18 ml L^{-1} as protection measure. Marshall 20 EC was used on 15 March @ 3 ml L^{-1} to control painted lady. Diseased plants were uprooted.

3.11 Harvesting and post-harvest operation

Maturity of crop was determined when 80-90% of the pods become straw color. The harvesting of BINA Soybean-1was done on 26 April, 2018. Five pre-selected plants per plot were harvested from which different yield attributing data were collected and 1 m^2 area from middle portion of each plot was separately harvested and bundled, properly tagged and then brought to the threshing floor. The seeds were cleaned and sun dried to a moisture content of 8%. Stover was also sun dried properly to obtain stover yield. Finally grain yields plot^{-1} and stover yield plot^{-1} were determined and converted to kg ha^{-1}.

3.12 Recording of data

Emergence of plants was counted from starting to a constant number of plants m^{-2} area of each plot. Experimental data were determined from 20 days of growth duration and continued to harvest. The following data were recorded during the experimentation.

3.12.1 Growth parameters

1. Plant height (cm) (at 20, 40, 60 and 80 DAS and at harvest)
2. Number of branches plant^{-1}(at 60 and 80 DAS and at harvest)
3. Dry weight plant^{-1}(at 30, 60 and 80 DAS and at harvest)
4. Number of nodules plant^{-1}(at 55, 70 and 85 DAS)

3.12.2 Yield contributing parameters

1. Pod length (cm)
2. Number of pods plant^{-1}
3. Number of seeds pod^{-1}
4. 100 seed weight (g)
5. Shelling percentage

3.12.3 Yield parameters

1. Seed yield (kg ha^{-1})
2. Stover yield (kg ha^{-1})
3. Biological yield (kg ha^{-1})
4. Harvest index (%)

3.13 Detailed procedures of recording data

A brief outline of the data recording procedure followed during the study given below:

3.13.1 Growth parameters

Plant height

The height of 10 randomly selected plants from each treatments of all three replication was taken carefully at 20, 40, 60, 80 DAS and at harvest. Plant height was measured from the above ground portion to tip of the plants with a meter scale and expressed in centimeter (cm).

Number of branches plant^{-1}

Number of branches plant^{-1} was counted carefully from 10 randomly selected plant from each treatment of all three replications at 60 and 80 DAS and at harvest stage.

Dry weight plant^{-1}

Randomly selected 5 plants from each plot excluding the harvest area were uprooted and dried in an oven at 70°C for 72 hours and weighed. The average value was recorded in g plant^{-1}.

Number of nodules plant^{-1}

The nodule plant^{-1} was counted carefully from 5 randomly selected plant from each treatments of all three replications at 55, 70 and 85 DAS. Then it was averaged.

3.13.2 Yield contributing parameters and yield

Pod length (cm)

Pod length was measured from randomly selected 20 pods from each treatment of all three replications with a meter scale and then averaged. It was expressed in centimeter (cm).

Number of pods plant^{-1}

The pods of five preselected plants were collected from each replication at the time of harvest and then counted the total number and then averaged to get pods plant^{-1}.

Number of seeds pod^{-1}

The number of seeds pods^{-1} was recorded randomly from selected pods at the time of harvest. Data were recorded as the average of 20 pods from each plot.

Hundred seed weight (g)

Hundred seeds from each treatment of all three replications were collected and their weight was taken by digital electric balance and expressed in gram (g).

Shelling percentage (%)

Shelling percentage was measured from shell weight and seed weight by using the following formula

$$\text{Shelling percentage (\%)} = \frac{\text{Shell weight}}{\text{Seed weight + shell weight}} \times 100$$

3.13.3 Yield parameters

Grain yield (kg ha^{-1})

Total grains of 1 m^2 area in each plot was weighed and then converted into kg ha^{-1}. The grain weight was taken at 12% moisture content.

Stover yield (kg ha^{-1})

After separation of seeds from plant, the straw and shell of harvested area was sun dried and the weight was recorded and then converted into kg ha^{-1}.

Biological yield (kg ha^{-1})

The summation of seed yield and above ground stover yield was the biological yield i.e. Biological yield = Grain yield + Stover yield.

Harvest index (%)

Harvest index was calculated by dividing the economic (seed) yield from the net plot by the total biological yield (seed + stover) from the same area and multiplying by 100.

$$\text{Harvest index (\%)} = \frac{\text{Seed yield (kg ha}^{-1}\text{)}}{\text{Biological yield (kg ha}^{-1}\text{)}} \times 100$$

3.14 Statistical analysis

The data obtained for different parameters were analyzed to find out the effect of biofertilizer and phosphorus on soybean varieties. The mean values of all the characters were calculated and the analysis of variance (ANOVA) was performed by the 'F' (variance ratio) test using MSTAT-C software. The significance of the difference among the treatment means was estimated by the Duncan Multiple Range Test (DMRT) at 5% level of probability (Gomez and Gomez, 1984).

CHAPTER 4

RESULTS AND DISCUSSION

The experiment was conducted to find out influence of biofertilizer and phosphorus level on growth, nodulation and yield of soybean. The analyses of variance of data in respect of all the parameters have been shown in Appendix IV-VII. The results have been presented and discussed with the help of tables and graphs and possible interpretation has been given under the following headings.

4.1 Growth parameters

4.1.1 Plant height

Effect of biofertilizer

Plant height was significantly affected by biofertilizer at different growth stages of soybean (Fig. 1 and Appendix V). The result revealed that irrespective of biofertilizer treatments, plant height showed a gradual increase trend with the advances of growth stages and the highest increase was observed at 80 DAS, after that it reduced slightly. On the other hand, application of biofertilizer (B_1) showed highest plant height at all growth stage. However, the highest value 8.22, 20.41, 43.86, 58.26 and 52.18 cm at 20, 40, 60, 80 DAS and at harvest, respectively was found from the treatment B_1 (Inoculation with biofertilizer) where the lowest value 7.78, 18.22, 37.93, 49.76 and 45.56 cm at 20, 40, 60, 80 DAS and at harvest, respectively was found from the treatment B_0 (no biofertilizer). Singh *et al.*, (2007) and Sharma and Sharma (2004) also found similar result in respect of plant height which confirms the present findings.

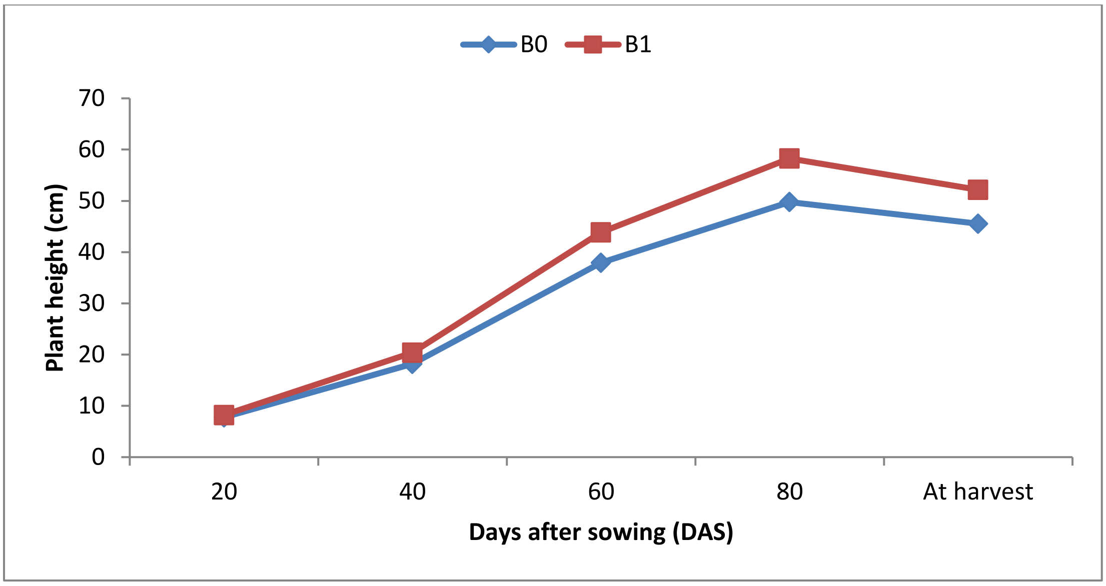

Fig. 1. Plant height of soybean as influenced by bio-fertilizer at different days after sowing (SE ± = 0.32, 0.27, 0.22, 0.310.32 at 20, 40, 60, 80 DAS and at harvest, respectively)

B_0 = Control (No biofertilizer), B_1 = Inoculation with biofertilizer

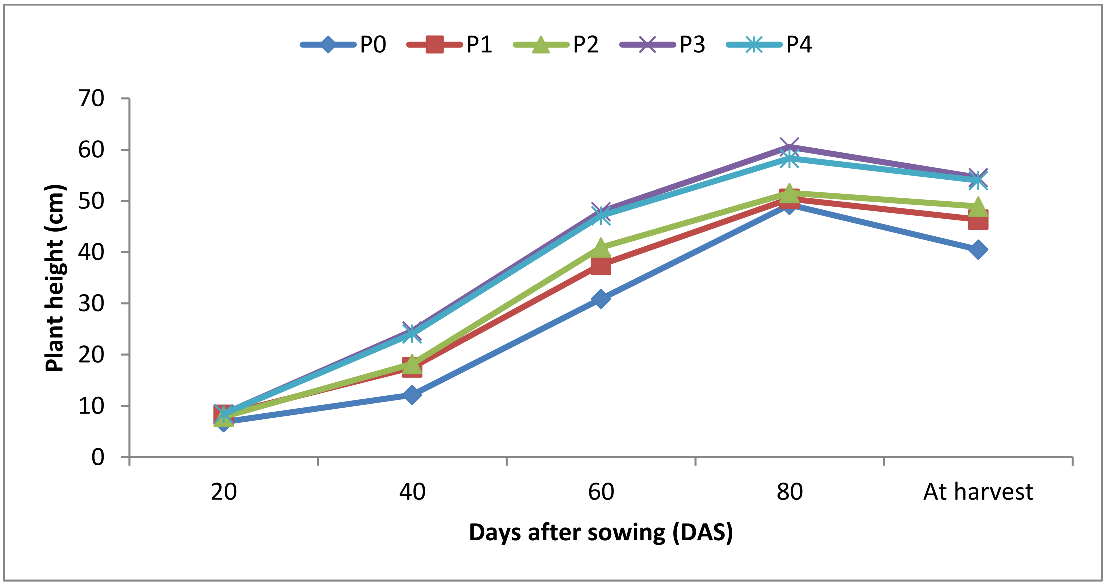

Fig. 2. Plant height of soybean as influenced by different phosphorus levels at different days after sowing (SE ± = 0.50, 0.42, 0.34, 0.48 and 0.51 at 20, 40, 60, 80 DAS and at harvest, respectively)

P_0 = Control (No phosphorus), P_1 = 25% less phosphorus than recommended dose, P_2 = Recommended dose of phosphorus (160 kg ha^{-1}), P_3 = 25% higher phosphorus than recommended dose, P_4 = 50% higher phosphorus than recommended dose

Effect of phosphorus level

Different phosphorus levels showed significant variation on plant height at different growth stages of soybean (Fig. 2 and Appendix V). It can be inferred from the figure that plant height showed an increasing trend with the increases of growth stages, irrespective of P levels. The highest increase of plant height was observed at 80 DAS after that the value of plant height reduced slightly. Phosphorus level P_3 showed the highest plant height for all growth stages (8.47, 24.63, 47.95, 60.53 and 54.55 cm at 20, 40, 60, 80 DAS and at harvest, respectively) which was followed by phosphorus level P_4 for all stages of growth. However, the lowest values of plant height was found with P_0 (without P) level (6.87, 12.14, 30.89, 49.24 and 40.49 cm at 20, 40, 60, 80 DAS and at harvest, respectively). Similar result was also observed by Dhage *et al*. (2014) and Tarekegn and Kibret (2017) which supported the present study.

Combined effect of biofertilizer and phosphorus level

There observed a significant variation on plant height of soybean due to combined effect of biofertilizer and phosphorus level at different growth stages (Table 1 and Appendix V). The highest plant height (8.91, 25.79, 50.47, 66.14, 57.99 cm at 20, 40, 60, 80 DAS and at harvest respectively) was obtained from the treatment combination of B_1P_3 which was statistically similar with B_1P_4 at 40, 60 DAS and at harvest. But at 20 DAS, plant height obtained from the interaction of B_0P_1, B_1P_0 and B_1P_4 showed statistically similar plant height with B_1P_3. The lowest plant height (6.45, 11.05, 28.23, 43.71 and 37.35 cm at 20, 40, 60, 80 DAS and at harvest, respectively) was observed from treatment combination of B_0P_0.

Table 1. Plant height of soybean as influenced by different combination of bio-fertilizer and phosphorus levels at different days after sowing

Treatment	Plant height (cm) at				
	20 DAS	**40 DAS**	**60 DAS**	**80 DAS**	**At harvest**
B_0P_0	6.45 e	11.05 e	28.23 g	43.71 f	37.35 g
B_0P_1	8.31 ab	16.27 d	32.91 f	47.46 e	43.72 f
B_0P_2	7.59 cd	17.25 cd	38.34 e	47.75 e	45.54 e
B_0P_3	8.03 bc	23.46 b	44.75 bc	54.95 cd	51.11 bc
B_0P_4	8.53 ab	23.07 b	45.43 b	54.93 cd	50.06 cd
B_1P_0	8.31 ab	13.23 e	33.54 f	54.77 cd	43.62 f
B_1P_1	7.29 d	18.79 c	42.29 d	53.36 d	49.08 d
B_1P_2	8.23 b	19.15 c	43.49 cd	55.39 c	52.38 b
B_1P_3	8.91 a	25.79 a	50.47 a	66.14 a	57.85 a
B_1P_4	8.38 ab	25.08 ab	49.50 a	61.66 b	57.99 a
SE(±)	**0.709**	**0.599**	**0.483**	**0.675**	**0.717**
CV(%)	**8.24**	**10.19**	**9.06**	**11.23**	**8.61**

B_0 = Control (No biofertilizer), B_1 = Inoculation with biofertilizer

P_0 = Control (No phosphorus), P_1 = 25% less phosphorus than recommended dose, P_2 = Recommended dose of phosphorus (160 kg ha^{-1}), P_3 = 25% higher phosphorus than recommended dose, P_4 = 50% higher phosphorus than recommended dose

4.1.2 Number of branches plant^{-1}

Effect of biofertilizer

Number of branches plant^{-1} was significantly influenced by different biofertilizer treatments (Fig. 3 and Appendix VI). It was observed that the highest number of branches plant^{-1} (1.13, 2.06, 3.79 at 60, 80 DAS and at harvest, respectively) was found from the treatment B_1 (Inoculation with biofertilizer) and the lowest number of branches plant^{-1} (0.93, 1.83 and 3.01 at 60, 80 DAS and at harvest, respectively) was found from the treatment B_0 (No biofertilizer). The result obtained from the present study was consistence with the findings of Sharma and Sharma (2004) in respect of branches plant^{-1}.

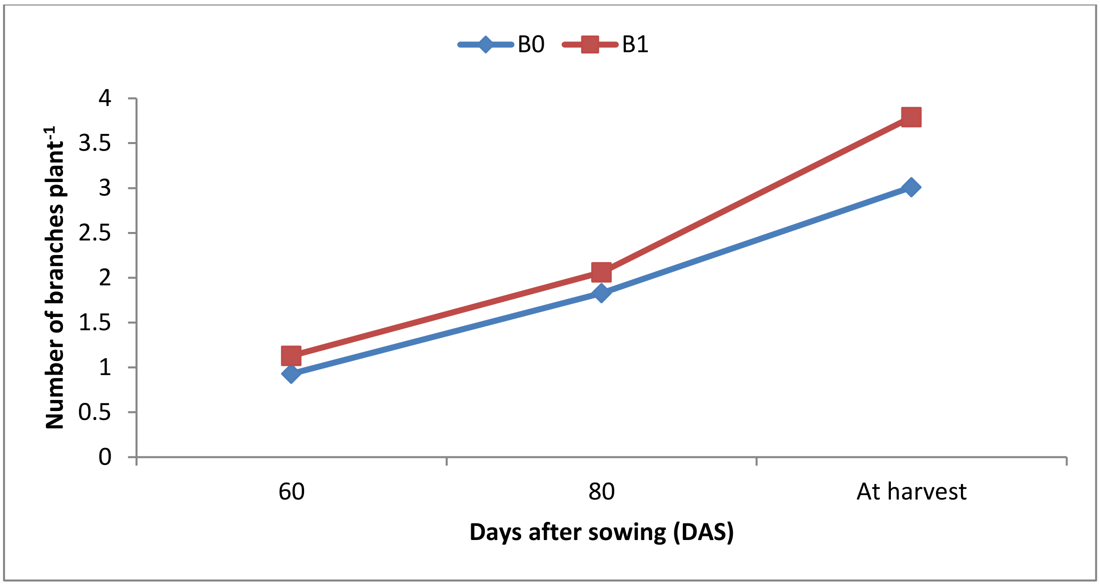

Fig. 3. Number of branches plant^{-1} of soybean as influenced by bio-fertilizer at different days after sowing (SE ± = 0.097, 0.082 and 0.147 at 60, 80 DAS and at harvest, respectively)

B_0 = Control (No biofertilizer), B_1 = Inoculation with biofertilizer

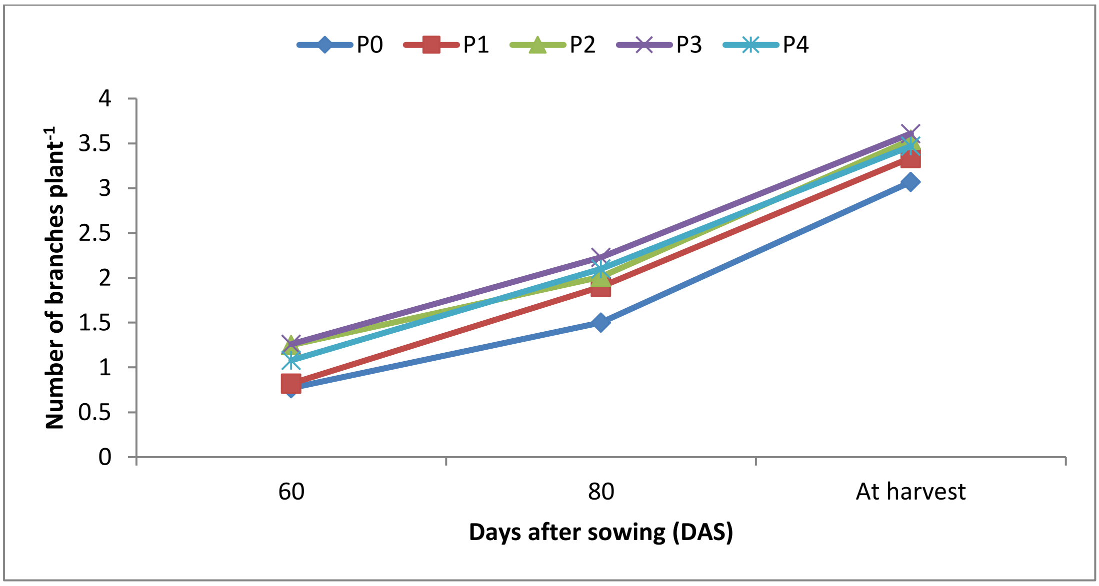

Fig. 4. Number of branches plant^{-1} of soybean as influenced by different phosphorus levels at different days after sowing (SE ± = 0.153, 0.129 and 0.232 at 60, 80 DAS and at harvest, respectively)

P_0 = Control (No phosphorus), P_1 = 25% less phosphorus than recommended dose, P_2 = Recommended dose of phosphorus (160 kg ha^{-1}), P_3 = 25% higher phosphorus than recommended dose, P_4 = 50% higher phosphorus than recommended dose

Effect of phosphorus level

Different phosphorus levels showed significant influence on number of branches plant^{-1} at all growth stages (Fig. 4 and Appendix VI). The figure indicates that irrespective P levels, number of branches plant^{-1} showed an increasing trend with the advantages of growth stages. The rate of increase was similar from 60 DAS to at harvest. However, the highest number of branches plant^{-1} (1.26, 2.23 and 3.61 at 60, 80 DAS and at harvest, respectively) was found from the treatment P_3 (25% higher phosphorus than recommended dose) which was significantly different from all other treatments where the lowest number of branches plant^{-1} (0.77, 1.50 and 3.07 at 60, 80 DAS and at harvest, respectively) was found from the control treatment P_0 (No phosphorus).

Combined effect of biofertilizer and phosphorus level

Combined effect of biofertilizer and phosphorus had significant influence on number of branches plant^{-1} at different growth stages of soybean (Table 2 and Appendix VI). The highest number of branches plant^{-1} (1.48, 2.29 and 4.01 at 60, 80 DAS and at harvest, respectively) was obtained from the treatment combination of B_1P_3 which was statistically similar with B_1P_2 and B_1P_4at harvest and with B_1P_4 at 80 DAS. The lowest number of branches plant^{-1} (0.72, 1.20 and 2.60 at 60, 80 DAS and at harvest, respectively) was observed from treatment combination B_0P_0 which was significantly different from all other treatments combinations at 80 DAS and at harvest but at 60 DAS it was statistically similar with the treatment combination of B_0P_1, B_1P_0 and B_1P_1.

Table 2. Number of branches plant^{-1} of soybean as influenced by different combination of bio-fertilizer and phosphorus levels at different days after sowing

Treatment	Number of branches plant^{-1}		
	60 DAS	**80 DAS**	**At harvest**
B_0P_0	0.72 f	1.20 g	2.60 e
B_0P_1	0.83 ef	1.87 ef	3.00 d
B_0P_2	1.03 d	1.99 cd	3.11 d
B_0P_3	1.17 c	2.17 b	3.21 cd
B_0P_4	0.92 de	1.93 de	3.15 d
B_1P_0	0.82 ef	1.80 f	3.53 bc
B_1P_1	0.81 ef	1.93 de	3.67 ab
B_1P_2	1.33 b	2.03 c	3.97 a
B_1P_3	1.48 a	2.29 a	4.01 a
B_1P_4	1.23 bc	2.27 a	3.78 ab
SE (±)	**0.216**	**0.183**	**0.328**
CV(%)	**8.17**	**6.46**	**7.30**

B_0 = Control (No biofertilizer), B_1 = Inoculation with biofertilizer

P_0 = Control (No phosphorus), P_1 = 25% less phosphorus than recommended dose, P_2 = Recommended dose of phosphorus (160 kg ha^{-1}), P_3 = 25% higher phosphorus than recommended dose, P_4 = 50% higher phosphorus than recommended dose

4.1.3 Dry weight plant^{-1}

Effect of biofertilizer

Dry weight plant^{-1} was significantly influenced by different biofertilizer treatments in soybean (Fig. 5 and Appendix VII). The figure shows that biofertilizer applied treatment (B_1) gave the highest values of dry weight plant^{-1} than B_0 (without biofertilizer) for all growth stages. The highest dry weight was observed at harvest growth stage. Numerically, the highest dry weight plant^{-1} (0.94, 3.39, 8.22 and 8.74 g at 30, 60, 80 DAS and at harvest, respectively) was found from the treatment B_1 (Inoculation with biofertilizer) and the lowest dry weight plant^{-1} (0.75, 2.84, 7.02 and 7.18 g at 30, 60, 80 DAS and at harvest, respectively) was found from the treatment B_0(No biofertilizer). Sharma and Sharma (2004) also found similar result which supported the present study.

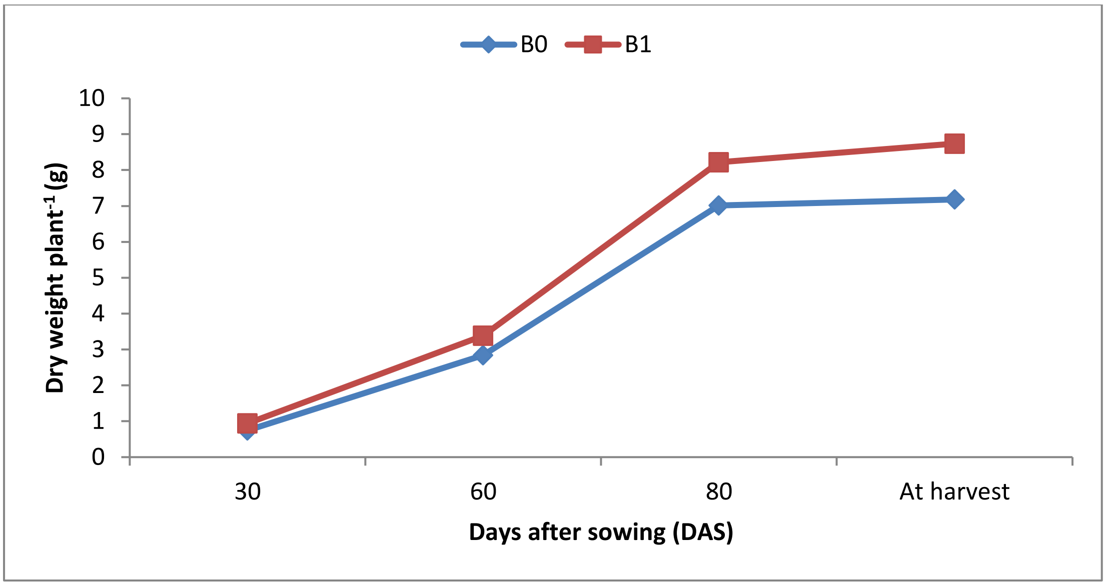

Fig. 5. Dry weight plant^{-1} as influenced by bio-fertilizer at different days after sowing (SE ± = 0.167, 0.149, 0.198 and 0.176 at 30, 60, 80 DAS and at harvest, respectively)

B_0 = Control (No biofertilizer), B_1 = Inoculation with biofertilizer

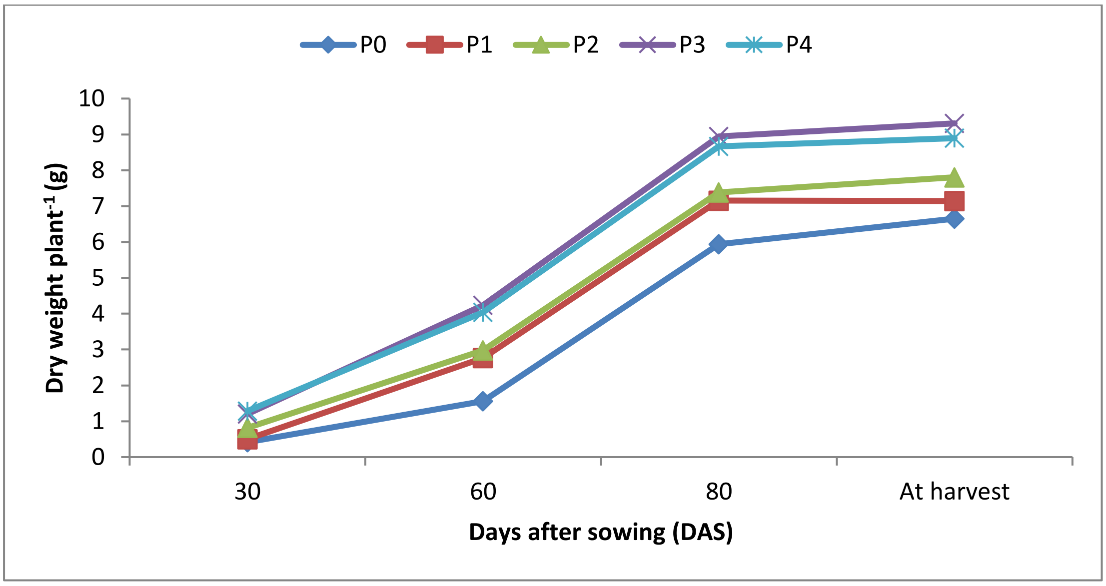

Fig. 6. Dry weight plant^{-1} as influenced by different phosphorus levels at different days after sowing (SE ± = 0.265, 0.235, 0.314 and 0.279 at 30, 60, 80 DAS and at harvest, respectively)

P_0 = Control (No phosphorus), P_1 = 25% less phosphorus than recommended dose, P_2 = Recommended dose of phosphorus (160 kg ha^{-1}), P_3 = 25% higher phosphorus than recommended dose, P_4 = 50% higher phosphorus than recommended dose

Effect of phosphorus level

Significant influence was recorded on dry weight plant^{-1} at different growth stages of soybean as affected by different phosphorus levels (Fig. 6 and Appendix VII). The result revealed that dry weight plant^{-1} of soybean exhibit an increasing trend with increases of growth stages irrespective of P levels up to last date of growth stages. But the rate of increase was much higher from 60 DAS to 80 DAS than earlier (30 DAS to 60 DAS) and later (80 DAS to at harvest) growth stages. On the other hand, P_3 (25% higher phosphorus than recommended dose) level showed the highest dry weight plant^{-1} and that of lowest was observed from P_0 (without P) treatments for all growth stages. Numerically, the highest dry weight plant^{-1} (1.20, 4.24, 8.95 and 9.31 g at 30, 60, 80 DAS and at harvest, respectively) was found from the treatment P_3 (25% higher phosphorus than recommended dose) which was statistically similar with P_4 (50% higher phosphorus than recommended dose) at all growth stages. The value of lowest dry weight plant^{-1} (0.42, 1.56, 5.94 and 6.65 g at 30, 60, 80 DAS and at harvest, respectively) was found from the control treatment P_0 (No phosphorus) treatment. The result was similar with the findings of Dhage *et al*. (2014) who reported that dry weight plant^{-1} increased with increased P levels.

Combined effect of biofertilizer and phosphorus level

There was a significant variation on dry weight plant^{-1} was found due to combined effect of biofertilizer and phosphorus level at different growth stages of soybean (Table 3 and Appendix VII). Results revealed that the highest dry weight plant^{-1} (1.73, 4.45, 9.43 and 9.83 g at 30, 60, 80 DAS and at harvest, respectively) was obtained from the treatment combination of B_1P_3 at all growth stages which was statistically similar with the treatment combination of B_1P_4 at 60 and 80 DAS and at harvest. The lowest dry weight plant^{-1} (0.34, 1.49, 5.43 and 5.71 g at 30, 60, 80 DAS and at harvest, respectively) was observed from treatment combination of B_0P_0.

Table 3. Dry weight plant^{-1} of soybean as influenced by different combination of bio-fertilizer and phosphorus levels at different days after sowing

Treatment	**Dry weight plant^{-1}at**			
	30 DAS	**60 DAS**	**80 DAS**	**At harvest**
B_0P_0	0.34 f	1.49 f	5.43 e	5.71 f
B_0P_1	0.46 ef	2.35 e	6.45 d	6.10 f
B_0P_2	0.78 d	2.63 e	6.59 d	7.00 e
B_0P_3	1.39 b	4.02 bc	8.46 b	8.79 b
B_0P_4	1.01 c	3.72 c	8.14 bc	8.31 bc
B_1P_0	0.49 ef	1.63 f	6.45 d	7.59 d
B_1P_1	0.54 e	3.17 d	7.86 c	8.18 c
B_1P_2	0.85 d	3.32 d	8.17 bc	8.61 bc
B_1P_3	1.73 a	4.45 a	9.43 a	9.83 a
B_1P_4	0.84 d	4.36 ab	9.19 a	9.48 a
SE(±)	**0.374**	**0.332**	**0.444**	**0.394**
CV(%)	**8.32**	**9.04**	**10.39**	**8.98**

B_0 = Control (No biofertilizer), B_1 = Inoculation with biofertilizer

P_0 = Control (No phosphorus), P_1 = 25% less phosphorus than recommended dose, P_2 = Recommended dose of phosphorus (160 kg ha^{-1}), P_3 = 25% higher phosphorus than recommended dose, P_4 = 50% higher phosphorus than recommended dose

4.1.4 Number of nodules plant^{-1}

Effect of biofertilizer

Number of nodules plant^{-1} was significantly affected due to different biofertilizer treatments (Fig. 7 and Appendix VIII). Biofertilizer treatment (B_1) showed the highest number of nodulesplant^{-1} for all sampling dates than B_0 treatment and the highest number of nodules plant^{-1} was found at 70 DAS. After 70 DAS, nodule production markedly reduced. However, that the highest number of nodules plant^{-1} (22.21, 48.13 and 32.20 at 55, 70 and 85 DAS, respectively) was found from the treatment B_1 (inoculation with biofertilizer) where the lowest number of nodules plant^{-1} (16.50, 39.51 and 25.59 at 55, 70 and 85 DAS, respectively) was found from the treatment B_0 (No biofertilizer). Similar result was also observed by Sharma and Sharma (2004), Hossain and Suman (2005) and Javaid and Mahmood (2010) which supported the present study.

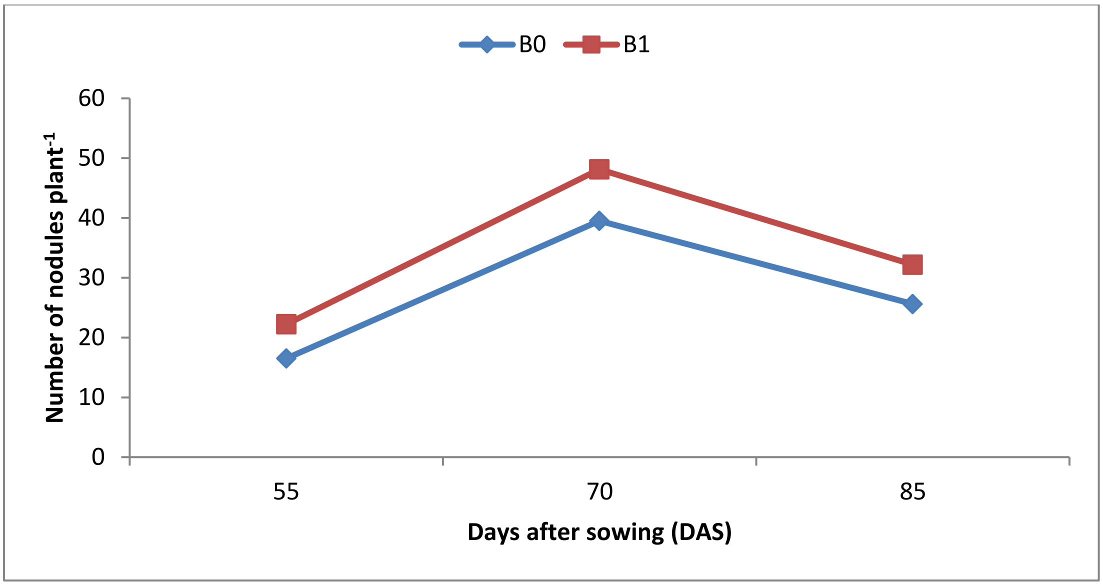

Fig. 7. Number of nodules plant^{-1}of soybean as influenced by bio-fertilizer at different days after sowing(SE ± = 0.239, 0.785 and 0.260 at 55, 70 and 85 DAS, respectively)

B_0 = Control (No biofertilizer), B_1 = Inoculation with biofertilizer

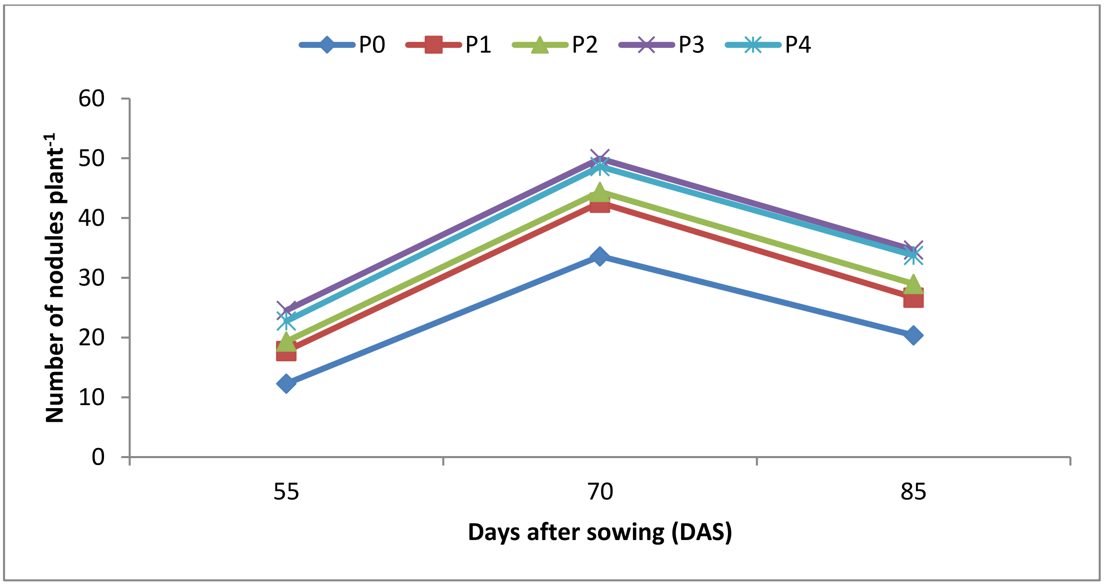

Fig. 8. Number of nodules plant^{-1}as influenced by different phosphorus levels at different days after sowing (SE ± = 0.377, 1.241 and 0.411 at 55, 70 and 85 DAS, respectively)

P_0 = Control (No phosphorus), P_1 = 25% less phosphorus than recommended dose, P_2 = Recommended dose of phosphorus (160 kg ha^{-1}), P_3 = 25% higher phosphorus than recommended dose, P_4 = 50% higher phosphorus than recommended dose

Effect of phosphorus level

Different phosphorus treatments showed significant variation on number of nodules plant^{-1} (Fig. 8 and Appendix VIII). The figure indicates that nodules plant^{-1} was highest at 70 DAS for all P treatments. It can also be inferred that nodule production was increased from 55 DAS to 75 DAS after that it reduced sharply. However, P treatment comprised with P_3 (25% higher phosphorus than recommended dose) showed the highest nodules plant^{-1} (24.56, 49.94 and 34.67 at 55, 70 and 85 DAS, respectively) for all sampling dates and the second highest was observed in P_4 treatment for the same sampling dates. However, the lowest values of nodule number plant^{-1} (12.30, 33.61 and 20.39 at 55, 70 and 85 DAS, respectively) from P_0 treatment for all the sampling dates. The result obtained from the present study was similar with the findings of Zeidan, *et al*. (2006), Van-Kessel and Hartley, 2000 and Dhage *et al*. (2014) which support the present results.

Combined effect of biofertilizer and phosphorus level

Number of nodules plant^{-1} at different growth stages was significantly varied due to combined effect of biofertilizer and phosphorus levels in soybean (Table 4 and Appendix VIII). The result showed that the highest number of nodules plant^{-1} (27.44, 54.78 and 38.78 at 55, 70 and 85 DAS, respectively) at all growth stages was obtained from the treatment combination of B_1P_3 which was statistically identical with the treatment combination of B_1P_4 at 70 and 85 DAS. The lowest number of nodules plant^{-1} (9.56, 29.78 and 18.11 at 55, 70 and 85 DAS, respectively) was observed from treatment combination B_0P_0 which was significantly different from all other treatments combinations.

Table 4. Number of nodules plant^{-1} of soybean as influenced by different combination of bio-fertilizer and phosphorus levels at different stages of growth

Treatment	Number of nodules plant^{-1}at		
	55 DAS	70 DAS	85 DAS
B_0P_0	9.560 g	29.78 g	18.11 f
B_0P_1	14.67 f	38.22 f	24.22 de
B_0P_2	16.50 e	40.67 e	25.41 d
B_0P_3	21.67 cd	45.11 cd	30.55 bc
B_0P_4	20.11 d	43.78 d	29.67 c
B_1P_0	15.03 ef	37.44 f	22.67 e
B_1P_1	20.89 cd	46.89 bc	29.15 c
B_1P_2	22.23 c	48.11 b	32.56 b
B_1P_3	27.44 a	54.78 a	38.78 a
B_1P_4	25.44 b	53.45 a	37.86 a
SE(±)	**0.533**	**1.755**	**0.582**
CV(%)	**6.87**	**6.99**	**8.96**

B_0 = Control (No biofertilizer), B_1 = Inoculation with biofertilizer

P_0 = Control (No phosphorus), P_1 = 25% less phosphorus than recommended dose, P_2 = Recommended dose of phosphorus (160 kg ha^{-1}), P_3 = 25% higher phosphorus than recommended dose, P_4 = 50% higher phosphorus than recommended dose

4.2 Yield contributing parameters

4.2.1 Pod length

Effect of biofertilizer

Significant variation was found on pod length as affected by biofertilizer treatments (Table 5 and Appendix IX). The highest pod length (3.85 cm) was found from the treatment B_1 (Inoculation with biofertilizer) and the lowest pod length (3.57 cm) was found from the treatment B_0 (No biofertilizer) which indicates that biofertilizer enhance the length of pod in soybean over control (0.26 cm).

Effect of phosphorus level

Significant influence was recorded on pod length as affected by different phosphorus levels (Table 5 and Appendix IX). Results indicated that the highest pod length (3.96 cm) was found from the treatment P_3 (25% higher phosphorus than recommended dose) which was statistically similar with P_2 (Recommended dose of phosphorus) and P_4 (50% higher phosphorus than recommended dose). The lowest pod length (3.28 cm) was found from the control treatment P_0 (No phosphorus) followed by P_1 (25% less phosphorus than recommended dose).

Combined effect of biofertilizer and phosphorus level

Significant variation was observed on pod length influenced by combined effect of biofertilizer and phosphorus level (Table 5 and Appendix IX). Results revealed that the highest pod length (4.16 cm) was obtained from the treatment combination of B_1P_3 which was statistically similar with the treatment combination of B_1P_2 and B_1P_4. The lowest pod length (3.37 cm) was observed from treatment combination B_0P_0 which was statistically similar with the treatment combination of B_0P_1 and B_0P_2.

4.2.2 Number of pods plant^{-1}

Effect of biofertilizer

Significant variation was found on number of pods plant^{-1} as affected by biofertilizer treatments (Table 5 and Appendix IX). The highest number of pods plant^{-1} (47.78) was found from the treatment B_1 (Inoculation with biofertilizer) and the lowest number of pods plant^{-1} (38.30) was found from the treatment B_0 (No biofertilizer). The result obtained from the present study was similar with the findings of Sharma and Sharma (2004) and Javaid and Mahmood (2010) which supports the result.

Effect of phosphorus level

Number of pods plant^{-1} affected significantly due to different phosphorus levels in soybean (Table 5 and Appendix IX). Results showed that the highest number of pods plant^{-1} (49.27) was found from the treatment P_3 (25% higher phosphorus than recommended dose) which was significantly different from all other treatments but followed by P_4 (50% higher phosphorus than recommended dose). The lowest number of pods plant^{-1} (32.60) was found from the control treatment P_0 (No phosphorus). The findings of Dhage *et al*. (2014) and Tarekegn and Kibret (2017) fairly agree with the present study.

Combined effect of biofertilizer and phosphorus level

Number of pods plant^{-1} was significantly varied due to the combined effect of biofertilizer and phosphorus (Table 5 and Appendix IX). The highest number of pods plant^{-1} (55.40) was obtained from the treatment combination of B_1P_3 which was significantly different from all other treatments combinations followed by the treatment combination of B_1P_2 and B_1P_4. The lowest number of pods plant^{-1} (29.00) was observed from treatment combination B_0P_0 which was significantly different from all other treatments combinations.

4.2.3 Number of seeds pod^{-1}

Effect of biofertilizer

Significant variation was found on number of seeds pod^{-1} affected by biofertilizer treatments (Table 5 and Appendix IX). The result revealed that biofertilizer increased the seeds pod^{-1} over control (without biofertilizer) by 15.52%. The highest number of seeds pod^{-1} (2.63) was found from the treatment B_1 (Inoculation with biofertilizer) and the lowest number of seeds pod^{-1} (2.28) was found from the treatment B_0 (No biofertilizer). Sharma and Sharma (2004) also found similar result which supported the present study.

Effect of phosphorus level

Different phosphorus levels showed significant influence on number of seeds pod^{-1} (Table 5 and Appendix IX). Data present in table indicates that the highest number of seeds pod^{-1} (2.80) was found from the treatment P_3 (25% higher phosphorus than recommended dose) which was statistically similar with P_4 (50% higher phosphorus than recommended dose). The lowest number of seeds pod^{-1} (1.99) was found from the control treatment P_0 (No phosphorus) which was significantly lowest that all other P levels.

Combined effect of biofertilizer and phosphorus level

There observed a significant variation on number of seeds pod^{-1} as influenced by combined effect of biofertilizer and phosphorus level (Table 5 and Appendix IX). The highest number of seeds pod^{-1} (2.98) was obtained from the treatment combination of B_1P_3 which was statistically similar with the treatment combination of B_1P_4. The lowest number of seeds pod^{-1} (1.83) was observed from treatment combination B_0P_0 which was also significantly different from all other treatments combinations.

4.2.4 Weight of 100 seeds (g)

Effect of biofertilizer

Significant influence was found on100 seed weight affected by biofertilizer treatments (Table 5 and Appendix IX). The highest 100 seed weight (7.68 g) was found from the treatment B_1 (Inoculation with biofertilizer) and the lowest 100 seed weight (6.81 g) was found from the treatment B_0 (No biofertilizer) which mean that biofertilizer treatment produced 12.65% heavier seed than control (no biofertilizer) treatment. The result corroborates with findings of Sharma and Sharma (2004) who reported that biofertilizer in soybean produce heavier seed than control (no biofertilizer).

Effect of phosphorus level

Different phosphorus levels showed significant of soybean as influence on 100 seed weight of soybean (Table 5 and Appendix IX). The highest 100 seed weight (8.03 g) was found from the treatment P_2 (Recommended dose of phosphorus) followed by P_3 (25% higher phosphorus than recommended dose) and P_4 (50% higher phosphorus than recommended dose). The lowest 100 seed weight (6.18 g) was found from the control treatment P_0 (No phosphorus). Similar result was also observed by Tarekegn and Kibret (2017) that higher P level increase the seed weight of soybean.

Combined effect of biofertilizer and phosphorus level

Weight of 100 seeds was significantly influenced by combined effect of biofertilizer and phosphorus level (Table 5 and Appendix IX). The highest 100 seed weight (8.33 g) was obtained from the treatment combination of B_1P_2 which was significantly different from all other treatments combinations second highest was B_1P_3 and B_1P_4. The lowest 100 seed weight (5.69 g) was observed from treatment combination B_0P_0 which was also significantly different from all other treatments combinations.

4.2.5 Shelling percentage (%)

Effect of biofertilizer

Significant influence was found on shelling percentage affected by biofertilizer treatments (Table 5 and Appendix IX). The highest shelling percentage (33.39%) was found from the treatment B_1 (Inoculation with biofertilizer) and the lowest shelling percentage (25.73) was found from the treatment B_0 (No biofertilizer) which mean that biofertilizer treatment produced 8.09% higher shelling percent than control (no biofertilizer) treatment.

Table 5. Yield contributing parameters of soybean as influenced by different bio-fertilizer and phosphorus levels and their combinations in soybean

Treatment	Pod length (cm)	Number of pods plant^{-1}	Number of seeds pod^{-1}	100 seed weight (g)	Shelling percentage (%)
Effect of biofertilizer					
B_0	3.57 b	38.30 b	2.28 b	6.81 b	25.73 b
B_1	3.85 a	47.78 a	2.63 a	7.68 a	33.39 a
SE(±)	**0.1548**	**0.2733**	**0.1079**	**0.1230**	**0.362**
CV(%)	**5.34**	**8.17**	**4.71**	**5.78**	**6.28**
Effect of phosphorus level					
P_0	3.28 c	32.60 e	1.99 c	6.18 d	23.13 d
P_1	3.61 b	41.86 d	2.30 b	7.02 c	26.58 c
P_2	3.79 a	44.30 c	2.45 b	8.03 a	33.32 a
P_3	3.96 a	49.27 a	2.80 a	7.54 b	33.94 a
P_4	3.93 a	47.15 b	2.72 a	7.47 b	30.84 b
SE(±)	**0.2448**	**0.4322**	**0.1705**	**0.1944**	**0.514**
CV(%)	**6.97**	**7.43**	**6.65**	**6.32**	**8.74**
Combined effect of biofertilizer and phosphorus level					
B_0P_0	3.37 d	29.00 g	1.83 e	5.69 g	18.90g
B_0P_1	3.43 d	36.39 f	2.12 d	6.58 f	21.38f
B_0P_2	3.51 d	38.93 e	2.25 d	7.73 bc	31.42c
B_0P_3	3.86 b	44.03 d	2.62 bc	7.12 d	30.52cd
B_0P_4	3.70 c	43.13 d	2.55 bc	6.95 de	26.44e
B_1P_0	3.30 e	36.21 f	2.15 d	6.66 ef	27.36e
B_1P_1	3.79 bc	47.33 c	2.47 c	7.45 c	31.78c
B_1P_2	4.07 a	49.67 b	2.65 b	8.33 a	36.12 a
B_1P_3	4.16 a	55.40 a	2.98 a	7.96 b	36.46 a
B_1P_4	4.05 a	50.27 b	2.89 a	7.98 b	35.24ab
SE(±)	**0.3462**	**0.6112**	**0.2412**	**0.2749**	**0.311**
CV(%)	**6.97**	**7.43**	**6.65**	**6.32**	**8.74**

B_0 = Control (No biofertilizer), B_1 = Inoculation with biofertilizer

P_0 = Control (No phosphorus), P_1 = 25% less phosphorus than recommended dose, P_2 = Recommended dose of phosphorus (160 kg ha^{-1}), P_3 = 25% higher phosphorus than recommended dose, P_4 = 50% higher phosphorus than recommended dose

Effect of phosphorus level

Different phosphorus levels showed significant of soybean as influence on shelling percentage of soybean (Table 5 and Appendix IX). The highest shelling percentage (33.94%) was found from the treatment P_3 (25% higher phosphorus than recommended dose) which was statistically similar with P_2 (Recommended dose of phosphorus). The lowest shelling percentage (23.13%) was found from the control treatment P_0 (No phosphorus).

Combined effect of biofertilizer and phosphorus level

Shelling percentage was significantly influenced by combined effect of biofertilizer and phosphorus level (Table 5 and Appendix IX). The highest shelling percentage (36.46%) was obtained from the treatment combination of B_1P_3which was significantly same with B_1P_2 and significantly similar with B_1P_4.The lowest shelling percentage (18.90%) was observed from treatment combination B_0P_0 which was significantly different from all other treatments combinations.

4.3 Yield parameters

4.3.1 Seed yield (kg ha^{-1})

Effect of biofertilizer

Significant variation was found on seed yield influenced by biofertilizer treatments (Table 6 and Appendix X). However, the result revealed that biofertilizer applied treatment showed its superiority by producing 7.42% higher yield than no biofertilizer applied treatment. The highest seed yield (3140 kg ha^{-1}) was found from the treatment B_1 (Inoculation with biofertilizer). The lowest seed yield (2923 kg ha^{-1}) was found from the treatment B_0 (Control/No biofertilizer). The result obtained from the present study was similar with the findings of Venkatarao *et al*. (2017) who reported that biofertilizer increased seed yield of soybean.

Effect of phosphorus level

The recorded data on seed yield was significantly varied due to the application of different phosphorus levels (Table 6 and Appendix X). The highest seed yield (3613 kg ha^{-1}) was found from the treatment P_3 (25% higher phosphorus than recommended dose) followed by P_4 (50% higher phosphorus than recommended dose) where the lowest seed yield (1962 kg ha^{-1}) was found from the control treatment P_0 (No phosphorus). The result obtained from the present study was similar with the findings of McVicar *et al*. (2010) and Ali *et al*. (1997) in that higher P level increased seed yield of soybean.

Combined effect of biofertilizer and phosphorus level

Significant variation was observed on seed yield of soybean as influenced by combined effect of biofertilizer and phosphorus level (Table 6 and Appendix X). The highest seed yield (3714 kg ha^{-1}) was obtained from the treatment combination of B_1P_3 which was significantly different from all other treatments combinations where the second highest seed yield was found from the treatment combination of B_1P_4. The lowest seed yield (1837 kg ha^{-1}) was observed from treatment combination B_0P_0 which was also significantly different from all other treatments combinations followed by B_1P_0. Similar result was also observed by Venkatarao *et al*. (2017) and Islam *et al*. (2017).

4.3.2 Stover yield (kg ha^{-1})

Effect of biofertilizer

Stover yield was significantly varied due to biofertilizer (Table 6 and Appendix X). It was found that the highest stover yield (3642 kg ha^{-1}) was found from the treatment B_1 (Inoculation with biofertilizer) where the lowest stover yield (3591 kg ha^{-1}) was found from the treatment B_0 (No biofertilizer).

Effect of phosphorus level

Significant influence was observed on stover yield as affected by different phosphorus levels (Table 6 and Appendix X). The highest stover yield (4073 kg ha^{-1}) was found from the treatment P_3 (25% higher phosphorus than recommended dose) which was significantly different from all other treatments where the lowest stover yield (2624 kg ha^{-1}) was found from the control treatment P_0 (No phosphorus).

Combined effect of biofertilizer and phosphorus level

Stover yield was significantly varied due to combined effect of biofertilizer and phosphorus level (Table 6 and Appendix X). The highest stover yield (4101 kg ha^{-1}) was obtained from the treatment combination of $B_1P_3$and the second highest yield was found with the treatment combination of B_0P_4. The lowest stover yield (2525 kg ha^{-1}) was observed from treatment combination B_0P_0.

4.3.3 Harvest index (%)

Effect of biofertilizer

Significant variation was observed on harvest index of soybean as influenced by biofertilizer treatments (Table 6 and Appendix X). The highest harvest index (46.00%) was found from the treatment B_1 (Inoculation with biofertilizer) and the lowest harvest index (44.00%) was found from the treatment B_0 (No biofertilizer)

Effect of phosphorus level

The recorded data on harvest index was significantly influenced by application of different phosphorus levels (Table 6 and Appendix X). The highest harvest index (47.06%) was found from the treatment P_4 (50% higher phosphorus than recommended dose) which was significantly different from all other treatments where the lowest harvest index (41.76%) was found from the control treatment P_0 (No phosphorus).

Table 6. Yield parameters of soybean as influenced by different bio-fertilizer and phosphorus levels and their combinations

Treatment	Seed yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Harvest index (%)
Effect of biofertilizer			
B_0	2923.00 b	3591.00 b	44.00 b
B_1	3140.00 a	3642.00 a	46.00 a
SE(±)	**19.0950**	**10.7446**	**0.4568**
CV(%)	**8.29**	**7.25**	**6.14**
Effect of phosphorus level			
P_0	1962.00 e	2624.00 e	41.76 c
P_1	2880.00 d	3590.00 d	44.49 b
P_2	3125.00 c	3774.00 c	45.29 b
P_3	3613.00 a	4073.00 a	45.76 b
P_4	3577.00 b	4021.00 b	47.06 a
SE(±)	**30.1919**	**16.9886**	**0.7222**
CV(%)	**12.46**	**10.17**	**8.99**
Combined effect of biofertilizer and phosphorus level			
B_0P_0	1837.00 i	2525.00 j	40.16 g
B_0P_1	2718.00 g	3479.00 h	43.86 f
B_0P_2	3048.00 f	3779.00 e	44.65 e
B_0P_3	3512.00 c	4101.00 a	46.13 b
B_0P_4	3498.00 d	4070.00 b	46.22 b
B_1P_0	2086.00 h	2723.00 i	43.37 f
B_1P_1	3043.00 f	3701.00 g	45.12 de
B_1P_2	3202.00 e	3769.00 f	45.93 bc
B_1P_3	3714.00 a	4044.00 c	45.39 cd
B_1P_4	3657.00 b	3973.00 d	47.90 a
SE(±)	**42.6978**	**24.0256**	**1.0214**
CV(%)	**12.46**	**10.17**	**8.99**

B_0 = Control (No biofertilizer), B_1 = Inoculation with biofertilizer

P_0 = Control (No phosphorus), P_1 = 25% less phosphorus than recommended dose, P_2 = Recommended dose of phosphorus (160 kg ha^{-1}), P_3 = 25% higher phosphorus than recommended dose, P_4 = 50% higher phosphorus than recommended dose

Combined effect of biofertilizer and phosphorus level

There observed a significant variation on harvest index of soybean as influenced by combined effect of biofertilizer and phosphorus level (Table 6 and Appendix X). The highest harvest index (47.90%) was obtained from the treatment combination of B_1P_4 which was significantly different from all other treatment combinations. The lowest harvest index (40.16%) was observed from treatment combination B_0P_0 which was significantly different from all other treatment combinations. Tarekegn and Kibret (2017) and Venkatarao *et al*. (2017) also found similar result with the present study.

CHAPTER V

SUMMARY AND CONCLUSION

A field experiment was conducted at the research farm of Sher-e-Bangla Agricultural University, Dhaka, during January – April, 2018 to study the influence of biofertilizer and phosphorus level on growth, nodulation and yield of soybean. The experiment consisted of two factor *viz*. factor A: Biofertilizer – two levels; (1) B_0 = Control (No biofertilizer) and (ii) B_1 = Inoculation with biofertilizer and factor B: Phosthetic fertilizer – five levels; (i) P_0 = Control (No phosphorus), (ii) P_1 = 25% less TSP than recommended dose, (iii) P_2 = Recommended dose of TSP (160 kg ha^{-1}), (iv) P_3 = 25% higher TSP than recommended dose and (iv) P_4 = 50% higher TSP than recommended dose. The experiment was laid out in a Split Plot Design with three replications.

Biofertilizer had significant effect on growth and yield parameters. The maximum plant height (8.22, 20.41, 43.86, 58.26 and 52.18 cm at 20, 40, 60, 80 DAS and at harvest, respectively), number of branches $plant^{-1}$ (1.13, 2.06, 3.79 at 60, 80 DAS and at harvest, respectively), dry weight $plant^{-1}$ (0.941, 3.386, 8.219 and 8.738 g at 30, 60, 80 DAS and at harvest, respectively) and number of nodules $plant^{-1}$ (22.207, 48.134 and 32.204 at 55, 70 and 85 DAS, respectively) were found from the treatment B_1 (Inoculation with biofertilizer). The lowest plant height (7.78, 18.22, 37.93, 49.76 and 45.56 cm at 20, 40, 60, 80 DAS and at harvest, respectively), number of branches $plant^{-1}$ (0.93, 1.83 and 3.01 at 60, 80 DAS and at harvest, respectively), dry weight $plant^{-1}$ (0.746, 2.842, 7.015 and 7.181 g at 30, 60, 80 DAS and at harvest, respectively) and number of nodules $plant^{-1}$ (16.502, 39.512 and 25.592 at 55, 70 and 85 DAS, respectively) were found from the treatment B_0 (No biofertilizer). Again, the highest pod length (3.835 cm), number of pods $plant^{-1}$ (47.776), number of seeds pod^{-1} (2.628), 100 seed weight (7.676 g), shelling percentage (33.39 %), seed yield (3140 kg ha^{-1}), stover yield (3642 kg ha^{-1}) and harvest index (46.00%) was also found from the treatment B_1 (inoculation with biofertilizer) where the lowest pod length (3.574 cm), number of pods plant^{-1} (38.296), number of seeds pod^{-1} (2.275), 100 seed weight (6.814 g), shelling percentage (25.73 %), seed yield (2923 kg ha^{-1}), stover yield (3591 kg ha^{-1}) and harvest index (44.00%) was found from the control treatment B_0 (No biofertilizer).

Again, P level had also significant effect on growth and yield parameters. The highest plant height (8.47, 24.63, 47.95, 60.53 and 54.55 cm at 20, 40, 60, 80 DAS and at harvest, respectively), number of branches plant^{-1} (1.26, 2.23 and 3.61 at 60, 80 DAS and at harvest, respectively), dry weight plant^{-1} (1.202, 4.235, 8.945 and 9.308 g at 30, 60, 80 DAS and at , respectively) and number of nodules plant^{-1} (24.56, 49.94 and 34.67 at 55, 70 and 85 DAS, respectively) was found from the treatment P_3 (25% higher phosphorus than recommended dose) whereas the lowest plant height (6.87, 12.14, 30.89, 49.24 and 40.49 cm at 20, 40, 60, 80 DAS and at harvest, respectively), number of branches plant^{-1} (0.77, 1.50 and 3.07 at 60, 80 DAS and at harvest, respectively), dry weight plant^{-1} (0.417, 1.560, 5.94 and 6.65 g at 30, 60, 80 DAS and at harvest, respectively) and number of nodules plant^{-1} (12.30, 33.61 and 20.39 at 55, 70 and 85 DAS, respectively) was found from the control treatment P_0 (No phosphorus). Similarly, the highest pod length (3.955 cm), number of pods plant^{-1} (49.27), number of seeds pod^{-1} (2.80), shelling percentage (33.94%), seed yield (3613 kg ha^{-1}) and stover yield (4073 kg ha^{-1}) was found from the treatment P_3 (25% higher TSP than recommended dose). But the highest 100 seed weight (8.028 g) was found from the treatment P_2 (Recommended dose of TSP) and highest harvest index (47.06%) was found from the treatment P_4 (50% higher TSP than recommended dose). The lowest pod length (3.283 cm), number of pods plant^{-1} (32.60), number of seeds pod^{-1} (1.99), 100 seed weight (6.175 g), shelling percentage (23.13%), seed yield (1962 kg ha^{-1}), stover yield (2624 kg ha^{-1}) and harvest index (41.76%) were also found from the control treatment P_0 (No TSP).

Considering combined effect of biofertilizer and P level had also significant effect on growth and yield parameters. The maximum plant height (8.91, 25.79, 50.47, 66.14, 57.85 cm at 20, 40, 60, 80 DAS and at harvest, respectively), number of branches plant^{-1} (1.48, 2.29 and 4.01 at 60, 80 DAS and at harvest, respectively), dry weight plant^{-1} (1.73, 4.45, 9.427 and 9.83 g at 30, 60, 80 DAS and at harvest, respectively) and number of nodules plant^{-1} (27.44, 54.78 and 38.78 at 55, 70 and 85 DAS, respectively) were obtained from the treatment combination of B_1P_3 whereas the lowest plant height (6.45, 11.05, 28.23, 43.71 and 37.35 cm at 20, 40, 60, 80 DAS and at harvest, respectively), number of branches plant^{-1} (0.72, 1.20 and 2.60 at 60, 80 DAS and at harvest, respectively), dry weight plant^{-1} (0.343, 1.49, 5.43 and 5.71 g at 30, 60, 80 DAS and at harvest, respectively) and number of nodules plant^{-1} (9.56, 29.78 and 18.11 at 55, 70 and 85 DAS, respectively) were observed from treatment combination B_0P_0. Again, the highest pod length (4.16 cm), number of pods plant^{-1} (55.40), number of seeds pod^{-1} (2.98), shelling percentage (36.46%) and seed yield (3714 kg ha^{-1}) were obtained from the treatment combination of B_1P_3 but the highest 100 seed weight (8.327 g), stover yield (4101 kg ha^{-1}) and harvest index (47.90%) was achieved from the treatment combination of B_1P_2, B_0P_3 and B_1P_4 ,respectively. The lowest pod length (3.37 cm), number of pods plant^{-1} (29.00), number of seeds pod^{-1} (1.83), 100 seed weight (5.69 g), Shelling percentage (18.90%), seed yield (1837 kg ha^{-1}), stover yield (2525 kg ha^{-1}) and harvest index (40.16%) were observed from treatment combination B_0P_0.

Conclusion

1. Biofertilizer (B_1) improves the growth and yield of soybean,
2. Phosphorus treatment comprised with 25% higher than recommended doses (P_3) performed best in producing higher yield as well as growth and yield attributes of soybean, and
3. Interaction of biofertilizer (B_1) with 25% higher TSP than recommended dose (P_3) gave higher yield along with higher growth and yield attributes parameters of BINA Soybean-1.

Recommendation

Such study need to be performed in different agro-ecological zones (AEZ) of Bangladesh for regional adaptability and other performance. More combinations of nitrogen and phosphorus with different management practices may be included for further study.

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APPENDICES

Appendix I. Agro-Ecological Zone of Bangladesh showing the experimental location

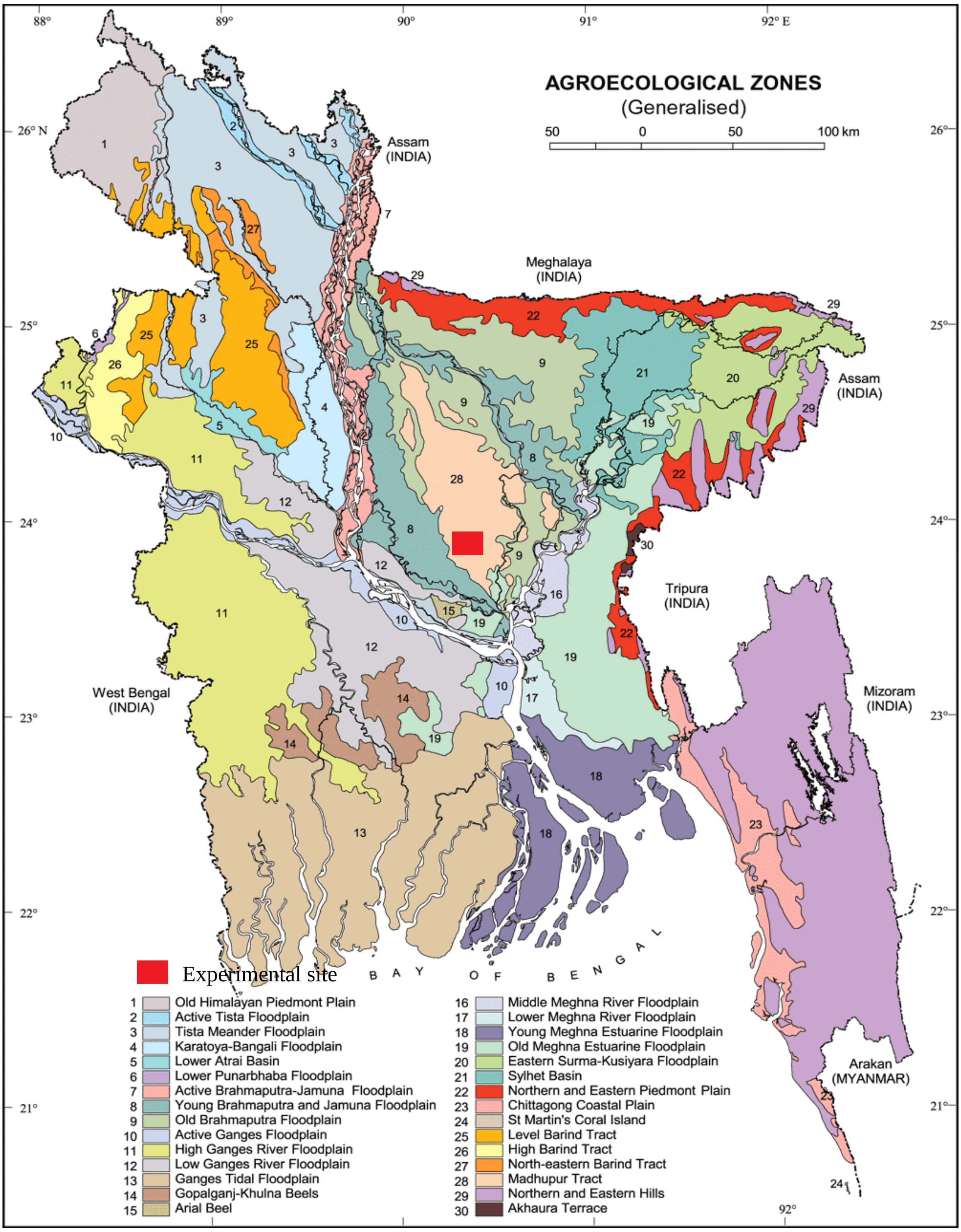

Fig. 9. Experimental site

Appendix II. Monthly records of air temperature, relative humidity and rainfall during the period from January to April 2018.

Year	Month	Air temperature (°C)			Relative humidity (%)	Rainfall (mm)
		Max	*Min*	*Mean*		
2018	January	23.80	11.70	17.75	46.20	0.0
2018	February	22.75	14.26	18.51	37.90	0.0
2018	March	35.20	21.00	28.10	52.44	20.4
2018	April	34.70	24.60	29.65	65.40	165.0
2018	January	23.80	11.70	17.75	46.20	0.0
2018	February	22.75	14.26	18.51	37.90	0.0

Source: Bangladesh Meteorological Department (Climate division), Agargaon, Dhaka-1212.

Appendix III. Characteristics of experimental soil analyzed at Soil Resources Development Institute (SRDI), Farmgate, Dhaka.

A. Morphological characteristics of the experimental field

Morphological features	**Characteristics**
Location	Agronomy Farm, SAU, Dhaka
AEZ	Modhupur Tract (28)
General Soil Type	Shallow red brown terrace soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained
Cropping pattern	Not Applicable

Source: Soil Resource Development Institute (SRDI)

B. Physical and chemical properties of the initial soil

Characteristics	**Value**
Partical size analysis % Sand	27
%Silt	43
% Clay	30
Textural class	Silty Clay Loam (ISSS)
pH	5.6
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total N (%)	0.03
Available P (ppm)	20
Exchangeable K (me/100 g soil)	0.1
Available S (ppm)	45

Source: Soil Resource Development Institute (SRDI)

Appendix IV. Layout of the experiment field

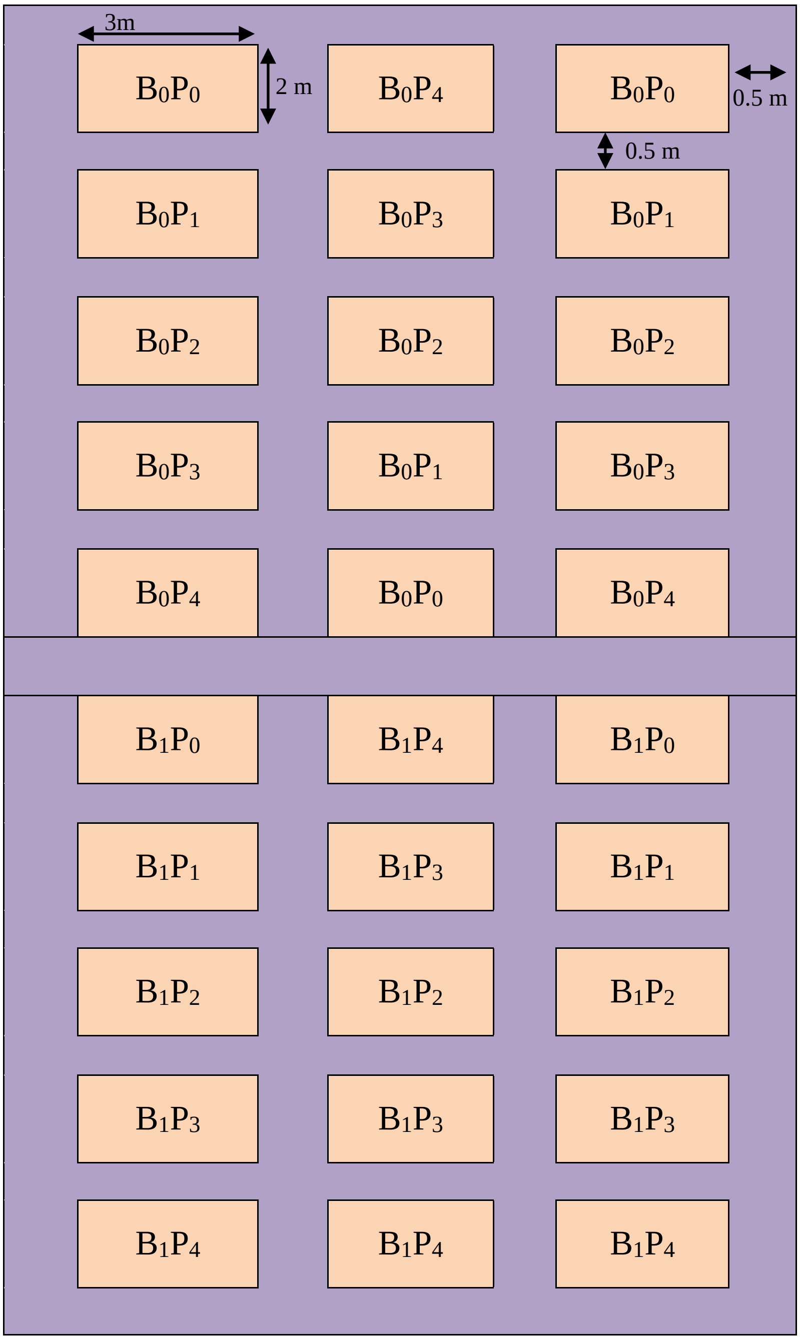

Fig. 10. Layout of the experimental plot

Appendix V. Plant height of soybean as influenced by different bio-fertilizer and phosphorus levels and their combinations

Sources of variation	Degrees of freedom	Plant height (cm) at				
		20 DAS	40 DAS	60 DAS	80 DAS	At harvest
Replication	2	0.150	14.12	11.79	9.990	7.830
Factor A	1	1.456*	35.88*	263.4*	542.3*	329.4*
Error	2	0.352	1.076	0.299	2.514	6.388
Factor B	4	2.718*	160.1*	299.4*	154.0*	201.8*
AB	4	0.350**	0.093*	5.653*	9.225*	1.198*
Error	8	1.509	1.078	0.700	1.365	1.542

NS = Non-significant * = Significant at 5% level ** = Significant at 1% level

Appendix VI. Number of branches plant^{-1} of soybean as influenced by different bio-fertilizer and phosphorus levels and their combinations

Sources of variation	Degrees of freedom	Number of branches plant^{-1} at		
		60 DAS	80 DAS	At harvest
Replication	2	0.768	1.082	1.000
Factor A	1	0.302*	0.404*	4.547*
Error	2	0.014	0.024	0.012
Factor B	4	0.320*	0.464*	0.275*
AB	4	0.051**	0.085*	0.024*
Error	8	0.140	0.100	0.322

NS = Non-significant * = Significant at 5% level ** = Significant at 1% level

Appendix VII. Dry weight plant^{-1} of soybean as influenced by different bio-fertilizer and phosphorus levels and their combinations

Sources of variation	Degrees of freedom	Dry weight plant^{-1}at			
		30 DAS	60 DAS	80 DAS	At harvest
Replication	2	1.155	0.166	1.931	2.166
Factor A	1	0.286*	2.220*	10.88*	18.17*
Error	2	0.004	0.636	1.259	2.137
Factor B	4	0.936**	7.011*	8.916*	7.657*
AB	4	0.293**	0.106*	0.112*	0.298**
Error	8	0.420	0.331	0.590	0.466

NS = Non-significant * = Significant at 5% level ** = Significant at 1% level

Appendix VIII. Number of nodules plant^{-1} of soybean as influenced by different bio-fertilizer and phosphorus levels and their combinations

Sources of variation	Degrees of freedom	Number of nodules plant^{-1}at		
		55 DAS	70 DAS	85 DAS
Replication	2	4.063	18.425	10.35
Factor A	1	244.0*	557.5*	327.8*
Error	2	1.389	2.346	1.527
Factor B	4	136.6*	250.0*	201.3*
AB	4	0.175**	1.696*	4.664*
Error	8	2.853	9.239	1.015

NS = Non-significant * = Significant at 5% level ** = Significant at 1% level

Appendix IX. Yield contributing parameters of soybean as influenced by different bio-fertilizer and phosphorus levels and their combinations

Sources of variation	Degrees of freedom	Pod length (cm)	Number of pods plant^{-1}	Number of seeds pod^{-1}	100 seed weight (g)
Replication	2	2.598	5.406	2.797	1.711
Factor A	1	0.582*	674.0*	0.936*	5.573*
Error	2	0.012	1.073	0.004	0.003
Factor B	4	0.460**	251.2*	0.647*	2.921*
AB	4	0.123*	10.18*	0.001**	0.042*
Error	8	0.360	1.121	0.174	0.227

NS = Non-significant * = Significant at 5% level ** = Significant at 1% level

Appendix X. Yield parameters of soybean as influenced by different bio-fertilizer and phosphorus levels and their combinations

Sources of variation	Degrees of freedom	Seed yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Harvest index (%)
Replication	2	35.665	50.294	0.648
Factor A	1	5047.0*	8839.3*	13.49*
Error	2	32.524	48.529	4.288
Factor B	4	8515.7*	9549.4*	23.30*
AB	4	78.066*	83.116*	2.990*
Error	8	69.305	71.684	3.130

NS = Non-significant * = Significant at 5% level ** = Significant at 1% level

PLATES

Plate 1a : Field view at early vegetative growth stage

Plate 1b : Field view at vegetative growth stage

Plate 2 : Field view of pod formation stage

Plate 3 : Field view of pod ripening stage