EFFECT OF PHOSPHORUS, MOLYBDENUM AND *BRADYRHIZOBIUM* INOCULANTS ON NODULATION, GROWTH AND YIELD OF SOYBEAN (*Glycine max* L. Merrill)

A THESIS

By

MOHAMMAD MOSHARRAF HOSSAIN

Examination Roll No. 02AgSSJJ-21M
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Approved as to style and content by:

Prof. Dr. M. Musharraf Hossain Mian
Research supervisor

Prof. Dr. M. Rafiqul Islam
Research co-supervisor

Prof. Dr. Md. Abdul Matin
Chairman
Examination committee
and
Head, Department of Soil Science
Bangladesh Agricultural University
Mymensingh

NOVEMBER 2003

Dedicated
To My
Beloved Parents
And To My Heavenly
Uncle

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ABSTRACT

An experiment was conducted at the experimental field of the Department of Soil Science, Bangladesh Agricultural University, Mymensingh during January to May 2003 to study the effect of added P, Mo and *Bradyrhizobium* inoculant on nodulation, yield and yield contributing characters of two soybean cultivars, Pb-1 and G-2. The treatments were: Control, Inoculum, P+Inoculum, Mo+Inoculum, P+Mo+Inoculum. The rates of P, Mo and *Bradyrhizobium* inoculant were 40 kg P ha^{-1}, 1 kg Mo ha^{-1} and 15 g inoculant kg^{-1} seed, respectively. TSP was used as a source of P and sodium molybdate as that of Mo. Basal application of 40 kg K ha^{-1}, 15kg S ha^{-1} and 2 kg Zn ha^{-1} was made to all plots for crop raising. The variety was placed in the main plots and the fertilizer and *Bradyrhizobium* inoculant were placed in the sub-plots. At 75 DAS, 10 plants were uprooted from each plot for recording data on nodulation and growth characteristics. The crop was harvested at maturity after 120 DAS. Between varieties, the G-2 showed higher nodulation, number of pods and seeds $plant^{-1}$ compared to Pb-1 variety. On the other hand, variety Pb-1 gave significantly higher 100-seed weight, seed and stover yields compared to the G-2. *Bradyrhizobium* inoculation significantly increased nodulation, number of pods and seeds $plant^{-1}$ and finally seed and stover yields of soybean. The combined application of P and Mo with *Bradyrhizobium* inoculation further increased the nodulation and yield of soybean varieties. *Bradyrhizobium* inoculation was found essential for soybean cultivation at BAU Farm and an application of P and Mo further increased the yield.

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Introduction

INTRODUCTION

Soybean (*Glycine max* L. Merrill) is an important and well-recognized oil and protein-containing crop of the world. Soybean grows well in different regions of the world, particularly in the tropics to the mid temperate zones. About 73,444 thousand hectares of land in the world is under cultivation of soybean and annual production is approximately 1,61,993 million tons (FAO, 2000). As a grain legume it is gaining an important position in the agriculture of tropical countries including India, Srilanka, Thailand and Bangladesh.

Soybean contains higher amounts of both oil and protein than any other legume crops. Soybean seeds contain about 40-45% protein and provides around 60% of the world's supply of vegetable protein and 30% of the oil (Fehr, 1989). Soybean is a good source of protein, unsaturated fatty acids, minerals like Ca and P including vitamin A, B, C and D (Rahman, 1982). Furthermore, soybean oil is cholesterol free and is an easily acceptable diet. On an average, about 8-10% of the protein intake in Bangladesh diet originates from animal sources (Begum, 1989) and the rest can be met from plant sources especially from the pulse crops like soybean.

Soybean is used for preparing many food dishes, confectioneries, baby foods and soybean milk. In industry, soybean is used in the manufacture of margarine, vegetable ghee, milk, pastries as well as in the manufacture of paints, varnishes, adhesives etc. Now a days, a variety of soya-products as feed such as soya-dal, soya-chatni, soya-khichuri, soya-milk, soya-card, soya-flour and roasted soybean snacks becoming familiar to the people of Bangladesh. Being a versatile crop with innumerable possibilities, soybean can support many agro-based industries.

Soybean improves the soil by fixing atmospheric nitrogen through *Rhizobium* that lives in the root nodules. Keser *et al* (1992) reported that *Bradyrhizobium japonicum* can fix atmospheric nitrogen (about 300 kg ha^{-1} $year^{-1}$), by a symbiotic process.

Due to the cultivation of modern varieties of different crops with unbalanced and heavy use of nitrogenous fertilizers, soil toxicity is arising and soils of Bangladesh are loosing their fertility and productivity. Soybean in association with rhizobia has the unique ability of fixing atmospheric nitrogen through *Rhizobium* which helps for their growth and enriching fertility of soil. Franco (1978) reported that *Rhizobium* associated with host plant are able to fix 20% of the atmospheric nitrogen throughout the world annually. So the use of rhizobial inoculants in soybean production can play a vital role in improving soil environment and agricultural sustainability.

Phosphorus has beneficial effects on both nodulation and nitrogen fixation capacity of soybean (Gates, 1975). Among the many factors phosphorus is one of them which influences the nitrogen fixation in soil. Rhizobial activities and nitrogen fixation can be depressed without proper application of phosphorus. The most obvious effect of phosphorus is on the plant root system. It promotes early root formation and thus formation of lateral fibrous and healthy roots, which is very important for nodule formation and fix atmospheric nitrogen. So, phosphorus application significantly increases dry matter production as well as yield and yield contributing characters of soybean (Idri *et al.*, 1989).

Molybdenum is an essential component of nitrogenase and nitrate reductase enzymes. Molybdenum application can play a vital role in increasing soybean yield through its effect on the plant itself and also on the nitrogen fixation process by *Rhizobium*. On the contrary deficiency of molybdenum resulted in decreased growth, yield and quality of soybean as well as nitrogen fixation process through *Rhizobium*. Grewal *et al.* (1967) reported that Mo had a significant response to fix atmospheric nitrogen and yield of legume crops. Chhonker and Chandel (1991) also reported that Mo increased the nitrogenase activity and nitrogen fixation in soybean.

Soybean has been introduced in Bangladesh in around 1942 but its cultivation did not expand satisfactorily. In recent years, MCC, CDP, BARC, BARI, BAU, BCSIR and others some NGO's (GKF, RDRS etc.) have been trying to expand its cultivation. Some of the varieties have already been found more suitable than the exotic varieties like Shohag (Pb-1) and BS-4 (G-2). These varieties have already been approved by the Bangladesh National Seed Board (BNSB) and are cultivated all over the country.

The efficiency of legume-*Rhizobium* symbiosis depends on many factors. This research work is aimed at testing the effect of phosphorus, molybdenum and *Bradyrhizobium* inoculants on nodulation, growth and yield of two soybean cultivars viz. Shohag (Pb-1) and BS-4 (G-2).

Chapter 2

Review of Literature

REVIEW OF LITERATURE

In this chapter, an attempt has been made to review some of the available published works mostly on the effect of phosphorus, molybdenum and *Bradyrhizobium* inoculant on nodulation, growth and yield of soybean cultivars, which have relevance to the present study.

2.1 Effect of *Rhizobium/Bradyrhizobium* inoculation on nodulation

Okereke *et al.* (2000) conducted two field experiments at Akwa, Nigeria, to assess the competitiveness of foreign bradyrhizobial inoculants in infecting the promiscuous soybean cultivars TGX (536-020). Seeds were inoculated with antibiotic mutants of the bradyrhizobia strains before sowing. Nodule number increased significantly and showed great variability at 84 days after sowing, probably due to difference in the ability of inoculants bradyrhizobia to form nodules with the soybean cultivars TGX (536-020).

Narjes *et al.* (2000) conducted an experiment in green house with soybean cv. Maple Glen Soils were inoculated with the plant growth promoting rhizobacteria (PGPR) *Serralia proleamaculans* 1-102 or *S. liquefaciens* 2-68 together *Rhizobium japonica* USDA 110 with or without inoculation. PGPR strains and genistein in combination increased the number of nodules than uninoculated control.

Taiwo *et al.* (1999) conducted a field experiment in Ibadan, Nigeria with soybean cv. TGX 1740-2F and TGX 1448-2E. Seeds were inoculated with *Bradyrhizobium* strains Irj284A or kept uninoculated are given 0 or 40 kg P ha^{-1}. Inoculation and P fertilizer led to increase in nodulation in both the cultivars.

Sobaran *et al.* (1999) conducted a field experiment in Uttar Pradesh, India, with one soybean variety and two levels of N (0 and 15 kg ha^{-1}), three levels of P (0, 30 and 90 kg P_20_5 ha^{-1}), two levels of K (0 and 30 kg K_20 ha^{-1}) and uniform inoculation with *Bradyrhizobium japonicum* multistrain culture (USDA-110 + TAL-377). The results showed that application of 30 kg P_2O_5 significantly increased the number of nodules at 60 days (flowering stage) of plant growth.

Islam *et al.* (1999) conducted an experiment to study the performance of some bradyrhzobial inoculants on soybean at BINA experimental farm, Mymensingh. They found that total nodule number was significantly higher in inoculant treatments.

Bhuiyan *et al.* (1998) conducted a field experiment at Regional Agricultural Research Station, Pabna to evaluate the effect of seed inoculation with 4 *Bradyrhizobium* strains on nodulation in soybean. They found that *Bradyrhizobium* inoculation significantly increased nodule number than the uninoculated control.

Uslu *et al.* (1997) reported that *Bradyrhizobium japonicum* inoculation in soybean increased number of nodules $plant^{-1}$ than uninoculated control.

Dubey (1997) revealed that seed inoculation with different strains of *Bradyrhizobium japonicum* enhanced symbiotic traits and yield attributes compared with uninoculated control. Soybean cultivars significantly increased nodulation due to by inoculation *Bradyrhizobium* strains.

Hoque and Hashem (1994) conducted six field experiments to study the effectiveness of several peat-based inoculants of *Bradyrhizobium japonicum* on soybean (var. Sohag) and groundnut. They observed the highest nodulation due to inoculation in soybean and groundnut.

Daramola *et al.* (1994) reported that the seed inoculation with effective *Bradyrhizobium* inoculum had significant effects on nodulation and nodule distribution along soybean roots.

Olufajo and Adu (1991) conducted a field experiment on soybean (cv. Sansory) inoculated with *Bradyrhizobium japonicum* and Mo application @ 270 g Mo ha^{-1}. They reported that the highest nodulation due to with *Bradyrhizobium japonicum* and Mo.

Yanni (1990) conducted an experiment on soybean inoculated with three strains of *Bradyrhizobium japonicum*. He observed that peat based inoculation tested under 2 or 4 ppm Mo significantly increased nodule number and weight, N- content of straw, number of pods per plant, seed yield and seed-N content.

2.2 Effect of *Rhizobium/Bradyrhizobium* inoculation on yield and yield contributing characters of soybean

Podder *et al.* (1999) carried out a field experiment at Brahmaputra floodplain soil to evaluate the effect of seed inoculation with 8 bradyrhizobial strains on shoot length of soybean. They reported significantly higher shoot length in the inoculated treatments than the uninoculated control.

Islam *et al.* (1999) conducted a field experiment to study the performance of some bradyrhizobial inoculants on soybean. There were 8 treatments viz. uninoculated, urea @ 50 kg N ha^{-1}, TSP @ 60 kg P_2O_5 ha^{-1}, inoculants RCT 3407, inoculants THA 5, inoculants TAL 102, mixed inoculants and in combination with TSP. All the *Bradyrhizobium* inoculants performed better in yield of soybean. Grain yield was found highest in mixed + inoculant TSP and lowest in uninoculated treatments.

Dubey (1999) carried out a field experiment with soybean using *Rhizobium* inoculants. Soil inoculation, broadcasting or drilling inoculum near the root zone at 10 or 13 days after germination. All inoculation methods increased seed yield and seed inoculation gave the highest yield.

Krishnamohan and Rao (1998) conducted a field experiment in Andra Pradesh, India, 4 soybean cultivars were seed inoculated with *Bradyrhizobium japonicum* strains ASB-10, ASB-13 and ASB-15 or not inoculated and found that inoculation with bradyrhizobial strains significantly increased dry matter production over uninoculated control.

Barakha and Heggo (1998) observed that seed inoculation with *Bradyrhizobium* sown in steam sterilized soil that had been amended with superphosphate (0.5 g ha^{-1} soil) increased soybean shoot and root dry weight compared with uninoculated control.

Bhuiyan *et al.* (1998) observed a field experiment at Regional Agricultural Research Station, Ishurdi, Pabna to evaluate the effect of seed inoculation with 4 bradyrhizobial strains viz. RGM-907, RGM-910, RGM-922 and RGM- 928 on plant height in soybean. Plant height of soybean was significantly influenced by the *Bradyrhizobium* inoculation. The RGM-922 produced the highest plant height. They were also observed that bradyrhizobial inoculation significantly increased nodule dry weight; shoot dry weight and straw yield over uninoculated control.

Uslu *et al.* (1997) conducted a field trial on soybean with or without *Bradyrhizobium japonicum* inoculation. They found that plant height was increased by inoculation.

Dubey (1997) conducted a field experiment on soybean and found that seed inoculation with different strains of *Bradyrhizobium japonicum* significantly increased plant height over uninoculated control.

Kulhere *et al.* (1996) reported that application of *Rhizobium* alone or in combination with mycorrhizas and PSB (Phosphorus solubilizing bacteria) with no fertilizer application slightly increased number of pods plant^{-1}, pod weight plant^{-1} and seed weight plant^{-1}, although results were not significant.

Thakare *et al.* (1996) inoculated soybean cultivar MACS-13 with 19 *Rhizobium* strains and found that strains SSR-4 produced the highest shoot and root dry weight. An average increase in seed and dry matter yield due to inoculation was 12.3 and 18.8%, respectively.

Vara *et al.* (1994) inoculated Gujrat soybean-1 seeds with *Rhizobium* and obtained the yield of 1293 kg ha^{-1} against the lower yield of 1197 kg ha^{-1} from with inoculation.

Vasilas and Furmann (1993) showed that nodulation of soybean plant by superior strains of *Bradyrhizobium japonicum* increased total shoot weight by 29% over uninoculated control.

Hoque and Hashem (1993) reported that the use of *Bradyrhizobium* inoculants as biofertilizer remarkably beneficial on grain yield of both soybean and groundnut. The strain BAU 107, TAL 102 and the mixed culture gave 60% to 86% increase in seed yield of Shohag (Pb-1) soybean.

Hoque and Hashem (1992) observed that inoculation of soybean seeds with *Bradyrhizobium* inoculum gave highest shoot dry weight and stover yield.

Bhuiyan and Obaidullah (1992) reported in a field experiment that *Rhizobium* inoculation increased shoot weight and pod yield significantly.

Hoque and Jahiruddin (1990) conducted two field experiments with soybean at BAU farm aimed at screening and selecting the most effective *Rhizobium japonicum* strains for inoculum production and found that inoculation produced marked effect on growth and yield of soybean.

Lee and Yun (1989) carried out an experiment to study the effect of nitrogen concentration of cultural solution, *Rhizobium* inoculation and plant density on the growth and yield of soybean cultivars and observed that *Rhizobium* inoculation increased the stem length of soybean.

Bhuiyan (1989) observed that *Rhizobium* inoculation either alone or in presence of PK fertilizers increased nodule weight, dry shoot weight, stover yield and 1000-seed weight of soybean significantly.

Joshi *et al.* (1989) stated that inoculation of soybean seed with *Rhizobium* increased pods plant^{-1}, 100-seed weight and gave the seed yield of 0.97 t ha^{-1} compared with 0.88 t ha^{-1} without seed inoculation.

Rahman (1989) observed significantly number of pods plant^{-1}, 1000-seed weight and grain yield due to inoculation over control in soybean.

Rahman (1988) conducted a field experiment to study the response of soybean to *Rhizobium* inoculation either alone or in presence of PK fertilizer increased 1000-seed weight and grain yield of the crop significantly.

Essa and Al-Dulaimi (1985) conducted an experiment on soybean inoculating with *Bradyrhizobium* inoculum and found that inoculated plants were taller than the uninoculated plants.

Shahidullah *et al.* (1985) inoculated soybean cultivar Davis seeds with 7 locally isolated strains of *Rhizobium japonicum* (GII-1, GII-5, GII-6, GII-7, GI-13, 3-9 and 0-4). Nodule dry weight was highest with GII-7, which also produced highest number of pods.

Rivero *et al.* (1984) carried out three greenhouse trials on soybean with different *Rhizobium japonicum* strains in Spain and observed that inoculation produced significantly more pods plant^{-1} and gave higher seed yield over application of 50-ppm N as NH_4N0_3.

Bishnoi and Dutta (1983) found that higher dry matter production, seed yield and 1000-seed weight of soybean were obtained with 120 kg N ha^{-1} by inoculating the seeds with *Rhizobium japonicum* compared with soil inoculation.

2.3 Effect of *Rhizobium/Bradyrhizobium* inoculation on nitrogen content

Okereke *et al.* (2000) reported from Akwa, Nigeria that soybean seeds inoculated with antibiotic mutants of the bradyrhizobia strains before sowing increased % N and total N of plant were results of increased nodulation by the effective *Bradyrhizobium* strains.

Narjes *et al.* (2000) conducted an experiment in greenhouse, soybeans cv. Maple Glen Soils were inoculated with the plant growth promoting rhizobacteria (PGPR) *Serralia proteamaculans* 1-102 or *S. Liquefacience* 2-68 together *Rhizobium japonicum* USDA 110 with or without inoculation PGPR strains and genistein in combination increased the amount of N fixed.

Taiwo *et al.* (1999) conducted in a field experiment in Ibadan, Nigeria, with soybean cv. TGX 1740 and TGX 1448-2E. Seeds were inoculated with *Bradyrhizobium* strains IRJ 284 A or not. Inoculated treatments led to increases in N in plant tissues when compared with the control.

Dashti *et al.* (1998) carried out a field experiment to evaluate the effect of seed inoculation with 2-plant growth promoting rhizobacteria (PGPR) strains (*Serralia liquefaciens* 2-68 or *Serralia proteamaculans* 1-102) on nodulation, nitrogen fixation and total nitrogen yield soybean. They observed that total plant N, and protein yield were also increased by PGPR inoculation.

Hoque *et al.* (1982) revealed that there was significant increase in N content and N uptake by plant tops of Davis soybean due to inoculation with *Rhizobium* inoculants recorded at 49 days of crop growth.

Hoque *et al.* (1981) conducted an experiment on soybean with five *Rhizobium* inoculants in Bangladesh and observed that the local peat based inoculants GII-7 showed the highest value for N content and N uptake by plant recorded both at 40 and 60 days after sowing.

2.4 Effect of phosphorus application on soybean

Singh and Bajpai (1990) reported that the grain yield of soybean increased significantly with increasing phosphorus levels up to 60 kg P_2O_5 ha^{-1}. The response in respect of per kg of applied phosphorus to grain yield (8.2 kg grain /kg P_2O_5 ha^{-1}) was highest up to 60 kg P_2O_5 ha^{-1}, with a further addition of 40 kg P_2O_5 ha^{-1} the grain yield per kg of phosphorus (3.5 kg grain / kg P_2O_5) declined.

Upadhyay *et al.* (1988) revealed that leaf area index of soybean increased with P level up to 69 kg P_2O_5 ha^{-1} from 40 days after sowing to reproductive stage. Total dry matter at harvest was maximum with 69 kg P_2O_5 ha^{-1} although was equal with that of 46 kg P_2O_5 ha^{-1}. The grain and straw yields increased significantly with increasing levels of phosphorus up to 40 and 69 kg P_2O_5 ha^{-1}, respectively. The increase in yield is attributed to the higher dry matter per plant and leaf area index with phosphorus application.

Gosh and Gosh (1988) showed that the statistically significant positive correlation obtained between fertilizer P and supply parameters (SP) values suggests that SP may be a suitable index for predicting fertilizer P uptake by plants.

Khandaker *et al.* (1985) reported that the dry matter yield of above ground parts during 30 to 60 days of growth and the number of nodules $plant^{-1}$ at 40 days of growth were significantly increased in black gram (*Vigna mungo*) by P application. The percentage of increase by application of phosphate at @ 30 kg P_2O_5 ha^{-1} over control was 51 and 45 for the grain and straw yields, respectively.

Kumar and Singh (1980) investigated that the application of P increased the P concentration. The concentration of P in 45 and 110 days gave significant positive correlation with P uptake and grain yield of soybean.

2.5 Interaction effects of *Rhizobium/ Bradyrhizobium* inoculation and phosphorus fertilizer on soybean

Ezedeen-Osman *et al.* (2002) conducted a greenhouse experiment to determine the effect of *Rhizobium* inoculation and addition of phosphorus to soil on the productivity. Shoot dry matter yield, root weight and shoot N and P concentration increased with increasing P application levels up to 80 kg P ha^{-1}. *Rhizobium* strain D522-1/2 was an effective inoculant for soybean when applied in combination with P fertilizer.

Stefanescu and Palanciuc (2000) conducted an experiment to evaluate the effect of three strains of *Rhizobium sp.* (SO-26, SO-110 and SO-122) and varying rates of N and P fertilizers on the yield of two soybean genotypes. The most efficient treatment combination was Diamant+SO-122+20 kg N ha^{-1}. The highest yield increase of 21% (409 kg ha^{-1}) was obtained with bacterial inoculation and application of 20 kg N ha^{-1}. Application of 70-80 kg N ha^{-1} and 80 kg ha^{-1} P_2O_5 gave an average grain yield of 289 kg ha^{-1} and protein yield of > 93 kg ha^{-1}.

Sharma and Namdeo (1999) conducted a field experiment with soybean cv. MACS 13 following biofertilizer singly or in all possible combinations. Seed inoculation with *Rhizobium* or phosphorus solubilizing bacteria (*Pseudomonas striata, PSB*) or application of 10 t ha^{-1} farmyard manure (FYM) plants were also given 0, 25 or 75 kg P ha^{-1}. Root nodulation, pods $plant^{-1}$, seeds pod^{-1}, seed $plant^{-1}$, 1000-seed weight and seed yield were greatest with 75 kg P ha^{-1} and *Rhizobium* + FYM + PSB.

Solankey *et al.* (1998) conducted a field experiment during kharif 1993/94 in swell-shrink (black) soil at Indore, Madhya Pradesh, India, soybeans cv. JS 71-05 were seed inoculated or top dressed with *Rhizobium japonicum* [*Bradyrhizobium japonicum*], with or without top dressing with phosphate-solubilizing microorganisms (PSM), and with the recommended rate of NPK, half this rate or no fertilizer. Application of *R. japonicum* by either method + PSM + half of the recommended rate of NPK significant increased yield compared with the recommended practice though increased values of yield attributes.

Rooge *et al.* (1998) carried out a field experiment during kharif season of 1994 at Dharwad, Karnataka, India. Soybeans cv. JS 335 were given 50 kg P ha^{-1} as single super phosphate (SSP) or Mussoorie rock phosphate (MRP), or 50:50 or 75:25 mixtures of SSP, with or without seed inoculation with *Bacillus polymyxa* or Biophos. Seed yield, yield components and P uptake were greatest with SSP + *B. polymyxa*, followed by equal proportions of SSP and MRP with *B. polymyxa* and Biophos.

Vara *et al.* (1994) carried out a field experiment during the rainy season of 1989 at Junagadh, Gujarat. Soybeans cv. Gujarat soybean–1 given 0, 20 or 40 kg N ha^{-1} gave seed yields of 1156,1276 and 1304 kg ha^{-1}, respectively. Application of 40, 60 or 80 kg P_2O_5 ha^{-1} gave seed yields of 1199,1255 and 1282 kg ha^{-1}, respectively. Seed inoculation with *Rhizobium* increased seed yield compared with no inoculation (1293 vs.1197 kg).

Tiwari *et al.* (1989) carried out a field trial at Rewa during the kharif (monsoon) season of 1994 soybean cv. JS-72-44 was given 0-60 kg N ha^{-1} and 0-50 kg P_2O_5 ha^{-1} with and without *Rhizobium* inoculation. Among the treatments 30 kg N + 50 kg P_2O_5 + inoculation gave the highest seed yields of 3.99 t ha^{-1}.

Rahman (1989) observed that *Rhizobium* inoculation either alone or in presence of PK increased nodule number and weight, root and shoot dry weight and grain of soybean significantly.

Fakir *et al.* (1988) revealed that biomass production of biological yield was highest with application of inoculum and phosphorus and all the effects were statistically significant over the control. They also observed that inoculation with phosphorus caused longest plant height in soybean.

2.6 Effect of molybdenum on yield and yield contributing characters of soybean

Bukhoriev (1997) noted that application of B+ Mo in soybean increased number and weight of nodules plant^{-1} by 24 and 29% respectively, active symbiotic potential by 63%, maximum leaf area by 23% and photosynthetic potential by 19%. Applying either B or Mo gave smaller increases. Seed yields were 2.6 t ha^{-1} in the control, 2.72 t ha^{-1} with Mo and 2.95 t ha^{-1} with B + Mo. Seed protein content and yield were highest with B + Mo.

Dabarajan and Palaniappan (1995) carried out field trials to determine the effect of zinc and molybdenum on yield and nutrition of soybean with soil application of 2.5 or 5.0 kg Zn as $ZnSO_4$, 5.0 kg Zn + 0.5% $ZnSO_4$ foliar spray after sowing, 0.5 or 1.0 kg Mo as Na_2MoO_4, 10 t FYM, dust equal to that in 2.5 and 5.0 kg $ZnSO_4$, 2.5 kg Zn + 0.5 kg Mo + 10 t ha FYM or 20 kg N +80 kg P_2O_5 + 40 kg K_2O ha^{-1} alone; all trace element treatments also received basal NPK. In both years a combination of Zn + Mo + FYM gave the highest seed yields.

Ibupoto and Kotecki (1994) observed that applying Mo or Mo + B to soybean increased the number of seeds plant^{-1}, dry weight and seed yield.

Amadi (1994) conducted a field experiment in Baghdad to investigate the influence of five levels of molybdenum (0, 0.16, 0.36, 0.48 and 0.64 kg ha^{-1}) as ammonium molybdate on the growth of soybean at the condition of alkali soil of Iraq. He showed that a significant increase in weight of seeds $plant^{-1}$ and total crop yield mean while, the height of plant, protein and oil percentage insignificant increased. A high positive correlation was found, between the accumulation of Mo, N, P, and K in the seed, followed by leaves and stems of the plant and the level of molybdenum application.

Aghatise and Tayo (1994) reported that application of Mo to soybean increased leaf number and area, plant height, number of branches per plant, number of nodules per plant compared with the control. At final harvest 0.2 and 0.4 kg Mo pot^{-1} increased seed dry weight by 29 and 10%, respectively.

Ali *et al.* (1993) observed that soybean cv. Clark was supplied with the equivalent of 0, 30 or 60 kg P $feddan^{-1}$ plus 0, 5 or 10 ppm Mo. The highest dry matter yield pot^{-1}, number of nodules and N and Mo uptake pot^{-1} came from the rates of 10 ppm Mo + 60 kg P $feddan^{-1}$ [1 feddan = 0.42 ha].

Yanni (1992) applied 3 ppm Mo and 1 ppm B in pulse crop and found that the effect of trace elements on nodulation and seed yield varied with species. Seed yield was generally highest in pulse given Mo.

Gupta and Narayanan (1992) reported that pod number, seed number and root and shoot dry weight showed significantly, higher values on exposure to 2 mg Mo kg ha^{-1} soil.

Olufajo and Adu (1991) conducted a field experiment on soybean (cv. Samsoy) inoculated with *Bradyrhizobium japonicum* and Mo application @ 270 g Mo ha^{-1} and reported that increased nodulation on soybean.

Chhonkar and Chandel (1991) conducted a field experiment on calcareous and showed that the separate basal application of 4.0 ppm Fe and 0.5 ppm Mo increased the nitrogenase activity and nitrogen fixation of soybean (*Glycine max* L.). They also showed that combined application of 4.0 ppm Fe with 0.5 ppm Mo resulted in the maximum nitrogen uptake by soybean.

Yanni (1990) studied soybean nodulation, induced indigenously by three strains of *Rhizobium japonicum* under soil application of 2 to 4 ppm Mo. He observed that inoculation with peat-based inoculum significantly increased nodule number and weight, N content, number of pods and seeds $plant^{-1}$, seed yield, seed N- content percentage and increasing the application of Mo led to further increases. A complex response of nodulation, vegetative growth and yield to the application of Mo was observed.

Dwivedi *et al.* (1990) conducted a field experiment on an acid soil in soybean and wheat crop sequence. They observed that Mo alone or in mixture of micronutrients increased significantly the yield of grain and straw of soybean and wheat.

Vargas and Rahmirez (1989) conducted a field experiment with 0 or 80 kg N+100kg P_2O_5 and reported that plant dry weight ranged from 129.0 g/10 plant without fertilizer or inoculation to 350.5 g with 30 kg

N+inoculation. They also observed that nodule dry weight was greatest with and without inoculation. They also observed that soybean pod dry weight yield at harvest ranged from 332 g /10 plants without fertilizer or inoculation to 658.7 g with 30 kg N + P_2O_5+Mo with inoculation. Pod yield ranged from 1.44 t ha^{-1} with fertilizer or inoculation to 6.58 t with 30 kg N + P_2O_5 + Mo with inoculation. They concluded that seed inoculation with low N rates and adequate P and Mo are necessary to increase soybean yields.

Nayak *et al.* (1989) reported that seed treatment with molybdenum exerted a significant influence on growth, yield and yield attributes. It also improved the protein content of seeds significantly.

Chandel *et al.* (1989) conducted a field experiment with soybean and observed that Mo @ 0.5 kg ha^{-1} gave the maximum pods/plant of soybean. 1 kg Mo ha^{-1} increased the seed yield significantly over the control. They also reported that Mo @ 0.5 and 1.0 kg ha^{-1} significantly increased the protein content in grain, grain yield and quality of soybean.

Freitas *et al.* (1988) in a field trial with soybean reported that yields without fertilizer were 70 kg ha^{-1} and were increased by application of various combinations of N, P, K, S, Mo and lime, with the highest yield of 1.3 t ha^{-1} being given by application of all these fertilizers.

Hurduc and Parjol-savulescu (1982) studied the effect of bacteria-urea-molybdenum relationship on soybean cv. Flora grown in quartz sand. They observed that the treatment resulted in increased pigment concentration of the foliage, increased photosynthetic productivity and pod and grain production.

2.7 Effect of molybdenum on the nutrient content and uptake by soybean

Tenywa (1997) conducted a glasshouse experiment with an oxisol to examine the relationship between soil trace elements and N-fixation in legumes. He reported that Mo did not affect nodulation or plant N content in soybean.

Saxena and Chandel (1997) conducted an experiment with treatments viz. Zinc @ 5.0 kg and 10.0 kg ha^{-1}, boron @ 0.4 kg ha^{-1} and 1.0 kg ha^{-1}, molybdenum @ 0.5 kg and 1.0 kg ha^{-1}, FYM @ 10 ton ha^{-1} and 2 control. Grain yield, total biomass, symbiotic nitrogen fixation and organic carbon in soil after the harvest increased significantly with micronutrients application over control.

Razmjoo and Henderlong (1997) conducted a field experiment and revealed that plant K, Mg and Ca contents and yields were not significantly affected by Mo application. Combinations of K, S, B and Mo fertilizer had variable effects and the effects were dependent on the combination of fertilizer sources and levels.

Dwivedi *et al.* (1996) carried out a field experiment to study the influence of phosphorus and molybdenum application on nutrient status in various plant parts of soybean. They reported that 1.0 kg Mo ha^{-1} enhances the absorption of all the nutrients and their accumulation by various plant parts including seed.

Li and Gupta (1995) conducted an open top field chamber experiment to evaluate the impact of molybdenum addition to soil on the physiological changes in soybean. They observed that addition of molybdenum increased leaf N shoot, root and nodule dry weight.

Chhonkar and Chandel (1991) conducted a field experiment on calcareous mollisol and showed that the separate basal application of 4.0 ppm Fe and 0.5 ppm Mo increased the nitrogenase activity and nitrogen fixation by soybean. They also showed that combined application of 4.0 ppm Fe with 0.5 ppm Mo resulted in the maximum nitrogen fixation by soybean.

Singh *et al.* (1986) conducted a pot experiment with pea and soybean. They observed that application of molybdenum in the feeding medium generally stimulate the Ca and K content but significantly increase the P- content and reduced the Mg-content.

Chapter 3

Materials and Methods

MATERIALS AND METHODS

This chapter describes the materials used and methods of the experiment steered in the field and in the laboratory to study the effect of phosphorus, molybdenum and *Bradyrhizobium* inoculant on nodulation, growth and yield of two different varieties of soybean. The field experiment was carried out at the Soil Science Farm of Bangladesh Agricultural University, Mymensingh, and the physico-chemical analysis of soils and chemical analysis of plants (seed and plant) were carried out in the laboratory of the Department of Soil Science.

3.1 Materials and operations undertaken

3.1.1 Experimental site

The field experiment was conducted at the Bangladesh Agricultural University (BAU) Farm, Mymensingh during the period from January to May 2003. The place where the study was conducted is located at 24°75′ N latitude and 90°50′E longitude. The land selected for the experiment was a medium high land.

3.1.2 Soil

The soil of the experimental area belongs to the Sonatala Soil Series of the Old Brahmaputra Floodplain, Agro Ecological Zone (AEZ 9). The soil samples were collected from 0-15 cm depth of the experimental field before opening the field. The morphological, physical, and chemical characteristics of the initial soil samples have been presented the Table 3.1.

Table 3.1 Morphological, physical and chemical characteristics of initial soil sample

A. Morphological characteristics

Locality	:	Soil Science Field Laboratory, Bangladesh Agricultural University, Mymensingh.
AEZ	:	Old Brahmaputra Floodplain (AEZ 9)
General soil type	:	Non-Calcareous Dark Grey Floodplain Soil
Parent material	:	Old Brahmaputra river borne deposits
Soil series	:	Sonatala
Drainage	:	Adequate
Flood level	:	Above flood level
Topography	:	Medium high land, fairly levelled

B. Physical characteristics

Constituents	Percent
Sand (2.00-0.05 mm dia)	11.6
Silt (0.05-0.002 mm dia)	70.4
Clay (below 0.002 mm dia)	18.0
Textural class	Silt loam

C. Chemical composition of the soil

PH	6.7
EC (μscm^{-1})	400.32
Organic matter (%)	1.37
Total N (%)	0.08
Available P (ppm)	16.5
Available S (ppm)	13.75
Exchangeable K (me/100g soil)	0.093
Exchangeable Ca (me/100g soil)	5.68
Exchangeable Mg (me/100g soil)	2.20
C: N ratio	8.5:1

3.1.3 Climate

The climate of the experimental area is characterized by high temperature and heavy rainfall during Kharif season (March-September) and low rainfall and moderately low temperature during Rabi season (October- February). The climatic factors recorded during the experiment have been presented in Appendix I.

3.1.4 Crop

The crop used in this study was soybean (*Glycine max* L. Merrill). The varieties of the crop were Shohag (Pb-1) and Bangladesh soybean-4 (G-2). These varieties have been recommended by the National Seed Board (NSB) of Bangladesh for cultivation in our country. The seeds were collected from the stock of the Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur. The seeds were healthy, vigorous, well matured and free from mixture of other crop seeds, weed seeds and extraneous materials.

3.1.5 Experimental treatments

There was ten treatments in the experiment resulting from two variety of soybean (Factor A) and five levels of inoculum/fertilizers (Factor B).

Factor A:

V_1: Bangladesh Soybean-4 (G-2)

V_2: Shohag (Pb-1)

Factor B:

T_0 = Control (no inoculum)

T_1 = Inoculum

T_2 = P + Inoculum

T_3 = Mo + Inoculum

T_4 = P + Mo + Inoculum

3.1.6 Land preparation

The land was first opened on 20 December, 2002 with the help of a disc plough then well prepared by ploughing and cross ploughing by country plough followed by laddering uniformly to achieve a medium tilth. Big clods were broken by a hand mallet. The weeds and stubbles were removed from the field and finally the land was evenly levelled. Plots were made by raising ails.

3.1.7 Experimental design

The experiment was laid out in Randomized Complete Block Design (RCBD) with two factors. The two variety of soybean was placed in the main plot and the inoculum /fertilizers were placed in the subplot. There were ten unit plots in a block. There were three replications of the treatments. The total number of individual plot was thirty. The size of the unit plot was 4m x 3.6m. Spacing between plots, blocks and border were 0.5 m and 1m each. One meter 1m-guard plot around the experimental plots was kept to protect the experiment. The layout plan of the experimental field has been shown in the Appendix II.

3.1.8 Collection of initial soil samples

Soil samples were collected from the experimental field before land preparation from 10 different random spots from a depth of 0-15 cm. The soil samples were mixed thoroughly to make a composite sample. Weeds, stubbles etc. were removed from soil. Soil samples were air-dried, ground and sieved through a 2 mm (10 mesh) sieve. The sample was stored in a clean plastic bag for physical and chemical analysis

3.1.9 Fertilizer application

Basal dose of potash fertilizer @ 40 kg K ha^{-1} as muriate of potash, sulphur fertilizer @ 15 kg S ha^{-1} as Gypsum and Zinc fertilizer @ 2 kg Zn ha-1 as zinc oxide were applied at the time of final land preparation. No nitrogenous fertilizer was used. Phosphorus and molybdenum were applied as triple super phosphate @ 40 kg P ha^{-1} and ammonium molybdate @ 1 kg Mo ha^{-1}. The fertilizers were mixed well with the soil by spading and were then leveled.

3.1.10 Inoculum preparation

The bradyrhizobial inoculant was prepared in the Professor Shamsul Haque Laboratory, Dept. of Soil Science, Bangladesh Agricultural University, Mymensingh following the methods of Vincent (1970). The *Bradyrhizobium* strain was obtained from the stock culture of the said laboratory. Yeast Mannitol Broth was prepared in 500 ml conical flask containing (g/litre basis) 10g Mannitol, 0.5 g K_2HPO_4, 0.2 g $MgSO_4.7H_2O$, 0.1 g NaCl, 1.0 g yeast extract and 1 litre distilled water. The broth was sterilized in an autoclave at 121°C temperature and 15 PSI for 20 minutes.

A loopful of the respective culture was inoculated in 400 ml of the Yeast Mannitol Broth. The inoculated flask was allowed to grow for 6-7 days on a rotary shaker. The mixed culture was prepared by mixing equal quantity of fully-grown individual broth culture in a sterile conical flask. From the ready broth, 25 ml were taken out by sterile syringe and were injected into the polythene packet having sterile 80 g of peat in each packet.

3.1.11 Inoculation of seed

The amount of seeds to be sown in each plot was weighed (65g/plot) on the basis of the recommended rate of 65 $kgha^{-1}$. The seeds for each plot were then taken in a plastic bag. *Bradyrhizobium* inoculant was added to the bag @ 15 g kg^{-1} seed and mixed well with seeds by shaking the bag thoroughly. The inoculum-coated seeds were placed in a cool dry place for a while and then sown in the field on 29 December 2002 in the afternoon.

3.1.12 Sowing of seeds

The inoculated seeds were sown at a depth of 4 cm on the furrow, which was covered by soil immediately. Seeding was done on the same day of inoculation in the afternoon. The line-to-line and seed to seed distance were maintained 30 cm and 5 cm, respectively. The inoculated seeds were sown on the 29 December 2002.

3.1.13 Germination of seeds

Germination of seeds started from 3 DAS and up to 10 DAS. The percentage of germination was more than 80% and on the 10^{th} day nearly all plants came out of the soil.

3.1.14 Intercultural operations

a) Weeding and thinning

First weeding and thinning were done on 15 DAS (13.01.03) of sowing when the plants attained a height of 8-10 cm and plant to plant distance maintained was 10 cm. Second weeding and thinning were done on 25 DAS (23.01.03) when the plants attained about 22-25 cm height.

b) General observation

The field was frequently observed to notice any change in plant character and pest and disease attack on the crop, if any. The crops were almost free from any disease and pest. Only few weeks before harvest, some hairy caterpillar attacked the crops. Those were controlled successfully by the application of Melathion 57 EC @ 1.0 lit ha^{-1}.

3.1.15 Plant sampling

Plant samples were collected from the field after 75 days of sowing. Ten randomly selected plants were carefully uprooted from each plot with the help of a spade so that no nodule was left in the soil. The roots were washed and the nodules from the main and branch roots of each plant were collected separately on a white paper and counted. The shoot and nodule materials were dried in sun. Data on plant height, plant dry weight, total no. of nodules $plant^{-1}$, dry weight of total nodules $plant^{-1}$, shoot weight and root weight were recorded at 75 DAS and their mean values were recorded.

3.1.16 Harvesting

The experimental crop was harvested on 28.04.03 after 120 days after sowing (DAS) when the crop attained the full maturity. From each plot 10 randomly selected plants were collected and then plants of 2 sq. m. were harvested and tied with rope separately and tagged and brought to threshing floor.

3.1.17 Threshing and Processing

The harvested plant materials of 2 sq. m. were allowed to dry in the sun for 3 days. After drying, threshing and processing were done plot wise carefully. The processed seed and stover were again dried in the sun for 3 days. Seed and stover yields were recorded plot wise, which were then converted into yield in Kg per hectare.

3.1.18 Analytical methods

3.1.18.1 Soil analysis

3.1.18.1.1 Mechanical analysis

Mechanical analysis of the soil sample was carried out by hydrometer method (Black, 1965) and the textural class was determined by using Marshall's Triangular Diagram.

3.1.18.1.2 Soil pH

Soil pH was determined using a glass electrode pH meter, soil: water ratio being 1:2.5 as described by Jackson (1962).

3.1.18.1.3 Organic carbon

Soil organic carbon was determined by wet oxidation method as outlined by Jackson (1962). Organic matter content was calculated by multiplying the percent organic carbon with the conventional van Bemmelen factor of 1.723 (Piper, 1950).

3.1.18.1.4 Total nitrogen

Total nitrogen in soil was determined by the micro kjeldahl method by digesting with H_2O_2 and concentrated H_2SO_4 and catalyst mixture (K_2SO_4:$CuSO_4$:$5H_2O$:Se=10:1:0.01) and distilling with 40% NaOH followed by titration of the distillate trapped in H_3BO_3 with 0.01N H_2SO_4 (Page *et al.*, 1989).

3.1.18.1.5 Available phosphorus

Available phosphorus was extracted from the soil with 0.5 M $NaHCO_3$ at pH 8.5. The phosphorus in extract was then determined by developing the blue colour by $SnCl_2$ reduction of phosphomolybdate complex and measuring the colour colorimetrically at 600 nm (Olsen *et al.*,1954).

3.1.18.1.6 Exchangeable potassium

Exchangeable potassium of the soil was determined by flame photometer after extraction with 1N NH_4OAc, pH 7.0 as described by Page *et al.* (1989).

3.1.18.1.7 Cation exchange capacity (CEC)

Cation exchange capacity of soil was determined by sodium saturation method as outlined by Page *et al.* (1989). The soil samples were saturated with 1N NaOAc solution followed by replacing the Na^+ from the saturated sample by 1N NH_4OAc at pH 7.0. The amount of Na^+ in the extract was then determined by flame photometer. The results were expressed as me/100g soil.

3.1.19 Plant analysis

The oven dry plant materials were ground in a grinding mill USIA to pass through a 20-mesh sieve. The total nitrogen content in plant was determined by semi-microkjeldahl method. An amount of 0.1 g of ground material, 4 ml conc. H_2SO_4, 3ml H_2O_2 and two kjeltab were taken in a 75 ml ticator flask. Digestion was carried out in ticator digestion unit at 200°C for 30 minutes. After completion of the digestion, sample was cooled for 1½ hr. The digested sample was made the volume with distilled water up to 75 ml of ticator flask; 10 ml of stock solution was distilled with 40% NaOH using Buchi distillation unit. The distillate was collected in 10 ml of 2% boric acid containing 2 drops of red and methylene blue mixed indicator. The distillate was titrated against 0.01 N H_2SO_4.

3.1.20 Statistical analysis

All the data recorded data on growth parameter, yield and N, P uptake were analyzed statistically. Statistically analysis was done following RCBD Design of the MSTAT soft ware packages (Freed, 1992). The mean for all treatments were calculated and analysis of variance of all characters were performed. When the ANOVA was significant ($P<0.05$) Duncan's Multiple Range Test (Gomez and Gomez, 1984) was used to indicate treatment differences.

Chapter 4

Results and Discussion

RESULTS AND DISCUSSION

An experiment was conducted at Soil Science Field Laboratory of Bangladesh Agricultural University Farm during the Rabi season of 2003 to evaluate the performance of phosphorus, molybdenum and *Bradyrhizobium* inoculants on nodulation, growth and yield of two soybean varieties viz. Pb-1 and G-2. The results are presented and discussed in this chapter:

4.1 Growth characters

4.1.1 Plant height

There was significant variation in plant height of two varieties of soybean recorded at 75 DAS (Table 4.1). Variety G-2 showed significantly higher (49.0 cm $plant^{-1}$) plant height compared to that found in variety Pb-1 (42.9 cm $plant^{-1}$).

The different chemical fertilizers (P and Mo) and *Bradyrhizobium* inoculant showed significant variation in plant height recorded at 75 DAS (Table 4.1). The application of *Bradyrhizobium* inoculant significantly increased the plant height compared to that found in control. The tallest plants were found when Mo+ *Bradyrhizobium* was used and the effect was statistically identical to those found in P+*Bradyrhizobium* or P+Mo+*Bradyrhizobium* or use of *Bradyrhizobium* inoculum only. These findings are in agreement with the results of Podder *et al.*(1999) and Bhuiyan *et al.*(1998). Fakir *et al.* (1988) reported that the use of *Bradyrhizobium* with phosphorus increased plant height. Amadi (1994) reported that molybdenum and phosphorus also increased plant height of soybean.

Results presented in Table 4.2 showed that there was no significant interaction effect due to varieties, chemical fertilizers and *Bradyrhizobium* inoculant on plant height of soybean. In variety G-2, plant height ranged from 36.8 cm in control to 54.0 cm when Mo+*Bradyrhizobium* inoculant was used while in variety Pb-1, it ranged from 32.8 cm in control to 48.2 cm when Mo+ *Bradyrhizobium* inoculant was used.

4.1.2 Number of nodules plant^{-1}

The number of nodules plant^{-1} was significantly different in two varieties of soybean recorded at 75 DAS (Table 4.1). Variety G-2 showed significantly higher (56.0 nodules plant^{-1}) number of nodules plant^{-1} compared to that found in variety Pb-1 (38.0 nodules plant^{-1}).

The different chemical fertilizers (P and Mo) and *Bradyrhizobium* inoculant showed significant variation in the formation of nodules plant^{-1} recorded at 75 DAS (Table 4.1). The application of *Bradyrhizobium* inoculant showed significantly higher number of nodules plant^{-1} compared to that obtained in control. The use of P or Mo in presence of *Bradyrhizobium* inoculant slightly increased the number of nodules plant^{-1} compared to that found with *Bradyrhizobium* inoculum only. However, the use of P+Mo+*Bradyrhizobium* significantly increased the nodule number compared to those found with *Bradyrhizobium* inoculant or in combined with P or Mo. Similar results were obtained by Narjes *et al*.(2000), Sobaran *et al*.(1999)and Bhuiyan *et al*.(1998). Ali *et al*.(1993) also reported that application of Mo and phosphorus significantly increased the number of nodules of soybean.

Results presented in Table 4.2 showed that there was significant interaction between the varieties and chemical fertilizers and *Bradyrhizobium* inoculant to produce number of nodules plant^{-1} recorded at 75 DAS. The total number of nodules plant^{-1} in variety Pb-1 ranged from 20.5 in control to 45.4 when P+Mo+ *Bradyrhizobium* inoculant was used while in variety G-2, it ranged from 25.6 in control to 72.4 when P+Mo+*Bradyrhizobium* inoculant was used.

4.1.3 Nodule dry weight

Weight of nodules varied significantly between two varieties of soybean recorded at 75 DAS (Table 4.1). Variety G-2 produced significantly higher (136.9 mg plant^{-1}) nodule dry weight compared to that of variety Pb-1 (96.3 mg plant^{-1}).

Application of different chemical fertilizers (P and Mo) and *Bradyrhizobium* inoculant also showed significant variation in the production of nodule dry weight recorded at 75 DAS (Table 4.1). Application of *Bradyrhizobium* inoculant produced significantly higher nodule dry weight compared to that of control. The application of P or Mo in presence of *Bradyrhizobium* inoculant produced slightly higher nodule weight plant^{-1} compared to that found with *Bradyrhizobium* inoculant but such increase was not statistically significant. Singh and Bajpai (1990) reported that phosphorus also increased nodule dry weight plant^{-1}. Yanni (1990) also found *Rhizobium japonicum* application with Mo increased nodule dry weigh of soybean.

It is seen in Table 4.2 that nodule dry weight varied significantly due to the interaction effect of varieties, chemical fertilizers and *Bradyrhizobium* inoculant recorded at 75 DAS (Table 4.2). The production of nodule dry weight plant^{-1} in variety G-2 ranged from 69.5 mg plant^{-1} in control to 156.4 mg plant^{-1} when P+Mo+ *Bradyrhizobium* inoculant was used while in variety Pb-1 it ranged from 51.8 mg plant^{-1} in control to 114.3 mg plant^{-1} when P+Mo+ *Bradyrhizobium* inoculant was used.

4.1.4 Shoot weight

There was significant variation in the shoot weight of two varieties of soybean recorded at 75 DAS (Table 4.1). Variety G-2 showed significantly higher (17.7 g plant^{-1}) shoot dry weight compared to that found in variety Pb-1 (15.5 g plant^{-1}).

The application of P and Mo fertilizers and *Bradyrhizobium* inoculant showed significant variation in the shoot weight of soybean (Table 4.1). Shoot weight ranged from 10.6g plant^{-1} in control to 19.1g plant^{-1} when Mo+*Bradyrhizobium* inoculant was used. Application of only *Bradyrhizobium* inoculant significantly increased shoot weight plant^{-1} compared to that found in control. The use of Mo or P+Mo in the presence of *Bradyrhizobium* inoculant produced significantly higher shoot weight compared to that found in control. The highest shoot dry weight observed by the application of Mo+ *Bradyrhizobium* inoculant and was statistically identical to these found P+Mo+*Bradyrhizobium* inoculant, and *Bradyrhizobium* inoculant. Okereke *et al*.(2000) and Begum (1989) found the similar results.

Results presented in Table 4.2 showed that there was significant interaction effect due to varieties and P, Mo and *Bradyrhizobium* inoculant on shoot weight of soybean. In variety G-2, the shoot weight ranged from 10.8 g plant^{-1} in control to 21.0 g plant^{-1} when Mo+ *Bradyrhizobium* inoculant was used while in variety Pb-1, it ranged from 10.4 g plant^{-1} in control to 17.6 g plant^{-1} when P+ *Bradyrhizobium* inoculant was used.

4.1.5 Root weight

There was significant variation in root weight of two soybean varieties (Table 4.1). Variety G-2 showed significantly higher (1.58 g plant^{-1}) root weight compared to that found in variety Pb-1(1.42 g plant^{-1}).

The application of P, Mo and *Bradyrhizobium* inoculant showed significant variation in root weight of soybean recorded at 75 DAS (Table 4.1). Root weight ranged from 1.23 g plant^{-1} in control to 1.65 g plant^{-1} due to application of Mo+*Bradyrhizobium* inoculant. The use of *Bradyrhizobium* inoculant significantly increase the root weight of soybean compared to that found in control. The use of P or Mo or their combination with *Bradyrhizobium* inoculant did not affect the root weight of soybean. Thakare *et al.* (1996) and Li and Gupta (1995) found the similar results.

Results presented in the Table 4.2 showed that interaction effect of varieties, P, Mo and *Bradyrhizobium* inoculant showed significant variation on root weight. In variety G-2, root weight ranged from 1.12 g plant^{-1} in control to 1.82 g plant^{-1} when Mo+ *Bradyrhizobium* inoculant was used while in variety Pb-1, it ranged from 1.34 g plant^{-1} in control to 1.52 g plant^{-1} when P+ *Bradyrhizobium* inoculant was used.

Table 4.1 Effect of variety and fertilizers on plant height, number of nodules, nodule dry weight, Shoot weight and Root weight of soybean at 75 DAS

Factor	Plant height (cm)	Number of nodules plant^{-1}	Nodule dry weight plant^{-1} (mg)	Shoot weight (g plant^{-1})	Root weight (g plant^{-1})
Variety					
G-2	49.0 b	56.0 a	136.9 a	17.7 a	1.58 a
Pb-1	42.9 a	37.0 b	96.3 b	15.5 b	1.42 b
$S\bar{x}$	0.780	1.473	2.186	0.391	0.034
Fertilizer					
Control	35.0 c	23.1 c	60.6 b	10.6 c	1.23 b
Inoculum	46.6 b	50.0 b	125.7 a	17.7 ab	1.60 a
P + Inoculum	48.1 ab	51.2 b	130.4 a	17.0 b	1.47 a
Mo + Inoculum	51.1 a	51.9 b	131.1 a	19.1 a	1.65 a
P + Mo + Inoculum	49.1 ab	58.9 a	135.4 a	18.5 ab	1.58 a
$S\bar{x}$	1.235	2.328	3.457	0.618	0.054
CV (%)	6.57	12.13	7.26	9.12	8.85

In a column figures having same letter(s) do not differ significantly by DMRT at 5% level of probability

Table 4.2. Interaction effect of variety and fertilizers on plant height, number of nodules, nodule dry weight, shoot and root weight of soybean at 75 DAS

Variety × Fertilizer		Plant height (cm)	Number of nodules $plant^{-1}$	Nodule dry weight $plant^{-1}$ (mg)	Shoot weight (g $plant^{-1}$)	Root weight (g $plant^{-1}$)
G-2	Control	36.8	25.6d	69.5c	10.8 d	1.12 c
	Inoculum	50.0	60.5 b	151.4 a	19.3 ab	1.77 a
	P+Inoculum	51.4	60.1 b	153.2 a	16.3 c	1.43 b
	Mo+Inoculum	54.0	61.3 b	154.0 a	21.0 a	1.82 a
	P+Mo+Inoculum	53.0	72.4 a	156.4 a	20.9 a	1.80 a
Pb-1	Control	32.8	20.5 d	51.8 c	10.4 d	1.34 bc
	Inoculum	43.2	39.5 c	99.9 b	16.1 c	1.43 b
	P+Inoculum	44.9	42.3 c	107.6 b	17.6 bc	1.52 b
	Mo+Inoculum	48.2	42.6 c	108.2 b	17.2 bc	1.48 b
	P+Mo+Inoculum	45.2	45.4 c	114.3 b	16.2 c	1.37 b
$S\overline{x}$		NS	3.293	4.889	0.077	0.077
CV (%)		6.57	12.13	7.26	8.85	8.85

In a column figures having same letter(s) do not differ significantly by DMRT at 5% level of probability.

NS = Non significant

4.2 Yield characters

4.2.1 Number of pods plant^{-1}

Data presented in Table 4.3 indicated that the number of pods plant^{-1} was significantly different between the two varieties of soybean. Variety G-2 showed significantly higher number of pods plant^{-1} compared to that found in variety Pb-1.

Application of P, Mo and *Bradyrhizobium* inoculant significantly affected the number of pods plant^{-1} (Table 4.3). The pods plant^{-1} ranged from 26.3 in control to 36.9 with the combined application of P+Mo+*Bradyrhizobium* inoculant. The application of *Bradyrhizobium* inoculant significantly increased the number of pods plant^{-1} compared to that found in control (Table 4.3). The use of P in presence of important recorded higher number of pods plant^{-1} but such increase was not statistically significant. The application of Mo or P+Mo in presence of *Bradyrhizobium* inoculant significantly increased the number of pods plant^{-1} over *Bradyrhizobium* inoculant only. Similar results were found by Sharma and Namdeo (1999) and Yanni (1990).

The interaction effect of varieties, P, MO fertilizers and *Bradyrhizobium* inoculant did not show any significant variation in respect of pod plant^{-1} (Table 4.4). The pod plant^{-1} in variety G-2, it ranged from 27.0 pod plant^{-1} in control to 39.4 pod plant^{-1} when P+Mo+*Bradyrhizobium* inoculant was used while in variety Pb-1, it ranged from 25.6 pod plant^{-1} in control to 34.4 pod plant^{-1} when P+Mo+*Bradyrhizobium* inoculant was used.

4.2.2 Seeds plant^{-1}

The results presented in Table 4.3 showed that there was no significant variation in producing seeds plant^{-1} of two varieties of soybean .Variety G-2 showed slightly higher (59.8 plant^{-1}) seeds plant^{-1} compared to that found in variety Pb-1 (57.3 plant^{-1}).

Application of P, Mo and *Bradyrhizobium* inoculant significantly affected the formation of the number of seeds plant^{-1} (Table 4.3). The number seeds plant^{-1} of soybean ranged from 43.7 in control to 67.8 due to application of P+Mo+*Bradyrhizobium* inoculant. The use of *Bradyrhizobium* inoculant significantly increased the number of seeds plant^{-1} compared to that found in control. The application of P or Mo in presence of *Bradyrhizobium* inoculant increased the number of seeds plant^{-1} compared to that found with *Bradyrhizobium* inoculant but such increase was not statistically significant. However, the combined use of P an Mo in presence of *Bradyrhizobium* inoculant significantly increased the number of seeds plant^{-1} compared to that found with *Bradyrhizobium* inoculant. Similar results were found by Sharma and Namdeo (1999) and Ibupoto and Kotecki (1994).

Results presented in Table 4.4 showed that there was no significant interaction of varieties, P, Mo fertilizers and *Bradyrhizobium* inoculant the number of seeds plant^{-1} recorded at harvest. In variety G-2, the seeds plant^{-1} ranged from 45.4 seed plant^{-1} in control to 70.3 seed plant^{-1} when P+Mo+*Bradyrhizobium* inoculant was used while in variety Pb-1, it ranged from 42.0 seeds plant^{-1} in control to 65.3 seeds plant^{-1} when P+Mo+*Bradyrhizobium* inoculant was used.

4.2.3 100-seed weight

Varieties of soybean showed significant variation in case of 100-seed weight (Table 4.3). Variety Pb-1 showed significantly higher 100-seed weight compared to that found in variety G-2.

Application of P, Mo and *Bradyrhizobium* inoculant showed significant variation on 100-seed weight recorded at harvest (Table 4.3). The 100-seed weight of soybean ranged from 10.6 g in control to 11.6 g when combined application of P+Mo+*Bradyrhizobium* inoculant was used. The use of Mo or P in presence of *Bradyrhizobium* inoculant insignificantly increased 100-seed weight of soybean compared to that found in control. However, application of P+Mo+*Bradyrhizobium* inoculant significantly increased 100-seed weight of soybean compared to that found in control. Similar results were found by Rahman (1988), Begum (1989) and Nayak *et al.* (1989).

Interaction between of varieties, Mo and *Bradyrhizobium* inoculant did not show any significant variation of 100-seed weight (Table 4.4). In case of variety G-2,100-seed weight ranged from 8.20 g in *Bradyrhizobium* inoculant application to 8.94g when P+Mo +*Bradyrhizobium* inoculant was used. On the other hand in variety Pb-1, 100-seed weight ranged from 12.8 g in control to 14.3 g when P+Mo+*Bradyrhizobium* inoculant was used.

4.2.4 Seed yield

Results presented in Table 4.3 showed that there was significant variation in seed yield of two soybean varieties. Variety Pb-1 showed higher seed (1635 kg ha^{-1}) yield compared to that found in variety G-2 (1474 kg ha^{-1}).

Seed yield of soybean varied significantly due to different chemical fertilizers (P and Mo) and *Bradyrhizobium* inoculant (Table 4.3). Seed yield of soybean ranged from 1325 kg ha^{-1} in control to 1775 kg ha^{-1} due to combined application of P+Mo+*Bradyrhizobium*. The application of *Bradyrhizobium* inoculant significantly increased the seed yield of soybean compared to that found in control. The application of P or Mo in presence of *Bradyrhizobium* inoculant slightly increased the seed yield of soybean compared to these found with *Bradyrhizobium* inoculant only but such increase in yield was not statistically significant. Combined use of P+Mo+*Bradyrhizobium* significantly increased the seed yield of soybean compared to these found with either *Bradyrhizobium* inoculant or in presence of P or Mo. Result presented in Fig. 4.1 showed that the application of *Bradyrhizobium* inoculant recorded an increased of 14.2% yield over control. The use of P or Mo in presence of *Bradyrhizobium* inoculant increased the seed yield by 16.6% and 21.7% respectively. The use of P+Mo+*Bradyrhizobium* recorded 33.96% yield increased over control. Vargas and Rahmirez (1989) found that the use of *Bradyrhizobium* inoculant with P_2O_5 and Mo significantly increased seed yield of soybean.

Results presented in Table 4.4 showed that there was no significant due to interaction effect of varieties, P, Mo and *Bradyrhizobium* inoculant on seed yield. Seed yield in variety G-2 ranged from 1300 kg ha^{-1} in control to 1725 kg ha^{-1} when P+Mo+*Bradyrhizobium* inoculant was used while in variety Pb-1, it ranged from 1350 kg ha^{-1} in control to 1825 kg ha^{-1} when P+Mo+*Bradyrhizobium* inoculant was used.

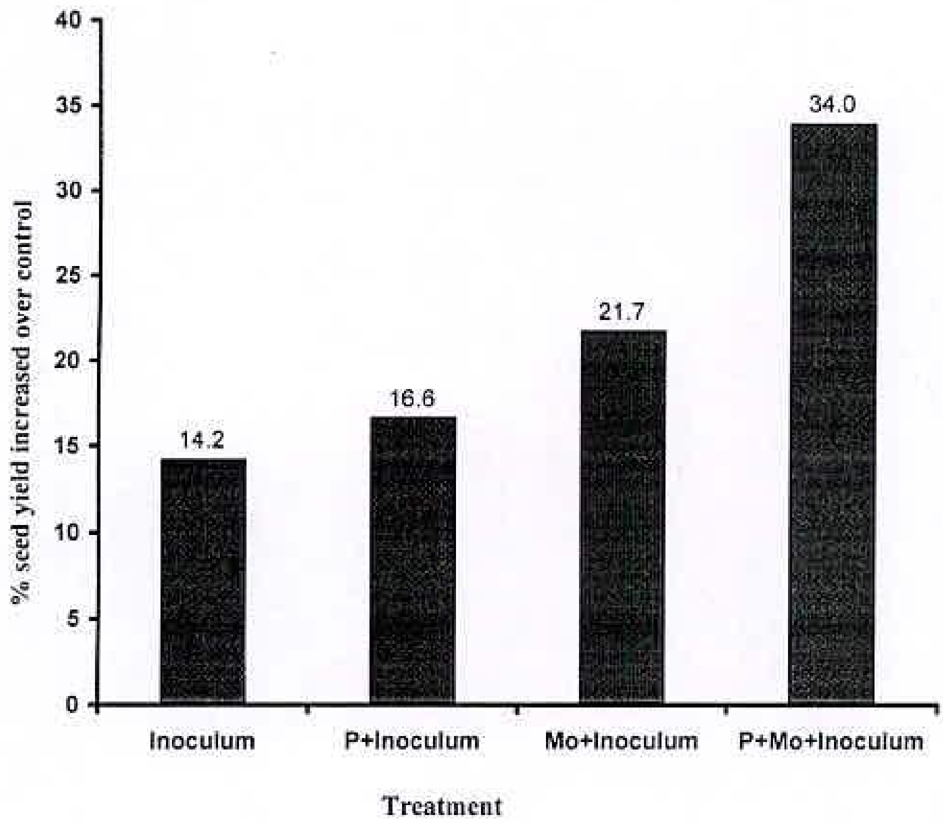

Fig. 4.1 Yield benefit due to different chemical fertilizers and *Bradyrhizobium* inoculant.

4.2.5 Stover yield

There was significant variation in the production of stover yield of two soybean varieties (Table 4.3). Variety Pb-1 produced significantly higher (2620 kg ha^{-1}) stover yield compared to that found in variety G-2 (2363 kg ha^{-1}).

The stover yield of soybean was also affected significantly by P, Mo and *Bradyrhizobium* inoculant (Table 4.3). Stover yield of soybean ranged from 2125 kg ha^{-1} in control to 2851 kg ha^{-1} when P+Mo+*Bradyrhizobium* was used. The application of *Bradyrhizobium* inoculant significantly increased the stover yield of soybean (Table 4.3). The use of P or Mo with *Bradyrhizobium* inoculant could not significant increased in stover yield of soybean. However, the application of P+Mo+*Bradyrhizobium* inoculant significantly increased in stover yield of soybean compared to that obtained with *Bradyrhizobium* inoculant or *Bradyrhizobium* inoculant with P or Mo application. Dwivedi *et al.* (1990) reported that application of Mo significantly increased the stover yield of soybean. Freitas *et al.* (1988) reported that combined application of phosphorus and molybdenum enriched the stover yield of soybean.

Results presented in Table 4.4 showed that there was no significant effect due to varieties, P, Mo and *Bradyrhizobium* inoculant . In variety G-2, stover yield ranged from 2075 kg ha^{-1} in control to 2777 kg ha^{-1} when P+Mo+*Bradyrhizobium* inoculant was used while in variety Pb-1, it ranged from 2175 kg ha^{-1} in control to 2925 kg ha^{-1} when P+Mo+*Bradyrhizobium* inoculant was used.

Table 4.3 Effect of variety and fertilizers on pods plant^{-1}, seeds plant^{-1}, 100-seed weight, seed yield and stover yield of soybean

Factor	Pods plant^{-1} (no.)	Seeds plant^{-1} (no.)	100-seed weight (g)	Seed yield (kg ha^{-1})	Stover yield (kg ha^{-1})
Variety					
G-2	35.4 a	59.8	8.54 b	1474 b	2363 b
Pb-1	30.2 b	57.3	13.5 a	1635 a	2620 a
$S\bar{x}$	0.820	NS	0.137	30.07	50.54
Fertilizer					
Control	26.3 c	43.7 c	10.6 b	1325 c	2125 c
Inoculum	31.3 b	57.6 b	10.6 b	1513 b	2400 b
P + Inoculum	33.6 ab	60.8 b	10.9 ab	1546 b	2494 b
Mo + Inoculum	35.9 a	63.1 ab	11.2 ab	1613 b	2588 b
P + Mo + Inoculum	36.9 a	67.8 a	11.6 a	1775 a	2851 a
$S\bar{x}$	1.297	1.947	0.216	47.55	79.90
CV (%)	9.67	8.13	4.82	7.49	7.86

In a column figures having same letter(s) do not differ significantly by DMRT at 5% level of probability, NS = Non-significant

Table 4.4 Interaction effect of variety and fertilizers on pods plant^{-1}, seeds plant^{-1}, 100-seed weight, seed yield and stover yield of soybean

Variety × Fertilizer		Pods plant^{-1} (no.)	Seeds plant^{-1} (no.)	100-seed weight (g)	Seed yield (kg ha^{-1})	Stover yield (kg ha^{-1})
G-2	Control	27.0	45.4	8.44	1300	2075
	Inoculum	35.6	60.3	8.20	1400	2200
	P + Inoculum	37.3	61.0	8.27	1416	2311
	Mo + Inoculum	37.8	62.2	8.87	1525	2450
	P+Mo+Inoculum	39.4	70.3	8.94	1725	2777
Pb-1	Control	25.6	42.0	12.8	1350	2175
	Inoculum	27.0	54.9	13.0	1625	2600
	P + Inoculum	30.0	60.5	13.7	1675	2675
	Mo + Inoculum	33.9	64.0	13.6	1700	2725
	P+Mo+Inoculum	34.4	65.3	14.3	1825	2925
$S\bar{x}$		NS	NS	NS	NS	NS
CV (%)		9.67	8.13	4.82	7.49	7.86

In column figures having same letter(s) do not differ significantly by DMRT at 5% level of probability, NS = Non significant

4.3 Nutrient content

4.3.1 Nitrogen content in stover

There was significant variation in N-content in stover of the two varieties of soybean (Table 4.5). Variety Pb-1 showed significantly higher (0.84%) N-content in stover compared to that found in variety G-2 (0.77%).

The application of P, Mo and *Bradyrhizobium* inoculant showed significant variation in nitrogen content of stover. (Table 4.5). N-content in stover ranged from 0.74% in P+*Bradyrhizobium* inoculant to 0.90% with P+Mo+*Bradyrhizobium* inoculant. Application of *Bradyrhizobium* inoculant showed significantly higher N-content in stover compared to that of control. Nitrogen content in shoot obtained due to application of P or Mo or P+Mo in presence of *Bradyrhizobium* inoculant did not significantly increase over to that observed in *Bradyrhizobium* inoculant only. Ezedeen-Osman *et al.* (2002) and Yanni (1990)found the similar results..

Results presented in Table 4.6 showed that interaction of varieties, P, Mo and *Bradyrhizobium* inoculant did not show any significant variation on N-content in shoot. In variety G-2, N-content in shoot ranged from 0.65% in the application of P+ *Bradyrhizobium* inoculant to 0.89% when P+Mo+*Bradyrhizobium* inoculant was used while in variety Pb-1, it ranged from 0.81% in control to 0.91% when P+Mo+*Bradyrhizobium* inoculant was used.

4.3.2 Nitrogen content in seed

Results presented in Table 4.5 showed that there was no significant variation in N-content in seed of two soybean varieties. Variety Pb-1 showed slightly higher (6.90%) N-content in grain compared to that found in variety G-2 (6.87%).

Application of P, Mo and *Bradyrhizobium* inoculant showed significant variation in N-content in seed (Table 4.5). Nitrogen content in seed ranged from 6.36% in control to 7.17% due to application of Mo+*Bradyrhizobium* inoculant. The use of *Bradyrhizobium* inoculant significantly increased the seed–N content of soybean compared to that found in control. The application of P or Mo or P+Mo with *Bradyrhizobium* inoculant slightly increased the N content in soybean seed but such increase was not statistically significant. Yanni (1990)reported that the use of *Bradyrhizobium* inoculant with Mo significantly increased seed N-content of soybean.

Results presented in Table 4.6 showed that there was no significant interaction effect of varieties, P, Mo and *Bradyrhizobium* inoculant in respect to N-content in seed. In variety Pb-1, N-content in seed ranged from 6.30% in control to 7.19% when P+*Bradyrhizobium* inoculant and P+Mo+*Bradyrhizobium* inoculant was used while in variety G-2, it ranged from 6.43% in control to 7.15% when Mo+*Bradyrhizobium* inoculant was used.

4.3.3 Phosphorus content in stover

Results presented in Table 4.5 showed that there was no significant variation in P-content in shoot of two soybean varieties. variety G-2, showed slightly higher (0.135%) P-content in shoot compared to that found in variety Pb-1 (0.134%).

The different chemical fertilizers (P and Mo) and *Bradyrhizobium* inoculant showed significant variation in P-content in stover of soybean (Table 4.5). P-content in stover ranged from 0.110% in control to 0.149% with combined application of P+Mo+*Bradyrhizobium* inoculant. The use of *Bradyrhizobium* inoculant significantly increased the P-content of soybean compared to that found in control. The application of Mo or P+Mo with *Bradyrhizobium* inoculant slightly increased the P-content in shoot but such effect was not statistically significant. Similar results were found by Kumar and Singh (1980) and Singh *et al.*(1986)

Results presented in Table 4.6 showed that there was no significant interaction effect due to varieties, P, Mo and *Bradyrhizobium* inoculant In variety G-2, P-content in shoot it ranged from 0.105% in control to 0.149% when P+Mo+*Bradyrhizobium* inoculant was used while in variety Pb-1, it ranged from 0.116% in control to 0.149% when P+Mo+*Bradyrhizobium* inoculant was used.

4.3.4 Phosphorus content in seed

There was significant variation in P-content in seed of two varieties of soybean (Table 4.5). Variety G-2 showed significantly higher (0.510%) P-content in seed compared to that found in variety Pb-1 (0.471%).

The application of P, Mo and *Bradyrhizobium* inoculant showed significant variation in P-content in seed (Table 4.5). P-content in seed ranged from 0.442% in control of 0.543% with the combined application of P+Mo+*Bradyrhizobium* inoculant.The highest P content in soybean seed of 0.543% was found when P+Mo+*Bradyrhizobium* inoculant was used which was statistically identical to that found with Mo+*Bradyrhizobium* inoculant. The P content obtained due to Mo+*Bradyrhizobium* inoculant was statistically identical to these found with *Bradyrhizobium* inoculant and control.

Results presented in Table 4.6 showed that there was significant interaction effect due to varieties, P, Mo and *Bradyrhizobium* inoculant on P-content in seed. In variety Pb-1, P-content in seed ranged from 0.480% in control to 0.593% when Mo+*Bradyrhizobium* inoculant was used while in variety G-2, it ranged from 0.480% in control to 0.510% when *Bradyrhizobium* inoculant was used.

Table 4.5 Effect of variety and fertilizers on nitrogen and phosphorus contents in seed and stover of soybean

Factor	N-content in shoot (%)	N-content in grain (%)	P-content in shoot (%)	P-content in grain (%)
Variety				
G-2	0.77 b	6.87	0.135	0.510 a
Pb-1	0.84 a	6.90	0.134	0.471b
$S\bar{x}$	0.018	NS	NS	0.008
Fertilizer				
Control	0.78 b	6.36 b	0.110 c	0.502 b
Inoculum	0.81 ab	6.83 a	0.138 ab	0.480 bc
P + Inoculum	0.74 b	7.11 a	0.132 b	0.442 c
Mo + Inoculum	0.82 ab	7.17 a	0.142 ab	0.510 ab
P + Mo + Inoculum	0.90 a	6.95 a	0.149 a	0.543 a
$S\bar{x}$	0.028	0.138	0.004	0.012
CV (%)	8.49	4.93	4.47	4.88

In a column figures having same letter(s) do not differ significantly by DMRT at 5% level of probability

NS = Non-significant

Table 4.6 Interaction effect of variety and fertilizers on nitrogen and phosphorus contents in seed and stover of soybean

Variety × Fertilizer		N-content in shoot (%)	N-content in grain (%)	P-content in shoot (%)	P-content in grain (%)
G-2	Control	0.75	6.43	0.105	0.480 c
	Inoculum	0.81	6.77	0.142	0.510 bc
	P + Inoculum	0.65	7.04	0.136	0.502 bc
	Mo + Inoculum	0.78	7.15	0.145	0.451 cd
	P+Mo+Inoculum	0.89	6.97	0.149	0.402 d
Pb-1	Control	0.81	6.30	0.116	0.480 c
	Inoculum	0.82	6.90	0.134	0.561 ab
	P + Inoculum	0.84	7.19	0.129	0.471 c
	Mo + Inoculum	0.83	7.19	0.140	0.593 a
	P+Mo+Inoculum	0.91	6.93	0.149	0.490c
$S\bar{x}$		NS	NS	NS	0.018
CV (%)		8.49	4.93	4.47	4.88

In a column figures having same letter(s) do not differ significantly by DMRT at 5% level of probability

NS = Non significant

4.4 Nutrient uptake

4.4.1 Nitrogen uptake by seed

There was significant variation in seed-N uptake of two soybean varieties (Table 4.7). Variety Pb-1 showed significantly higher (113.4 kg ha^{-1}) amount of N uptake compared to that found in variety G-2 (102.0 kg ha^{-1}).

The nitrogen uptake by soybean seed increased significantly due to application of P, Mo and *Bradyrhizobium* inoculant (Table 4.7). The N-uptake ranged from 84.4 kg ha^{-1} in control to 123.5 kg ha^{-1} in combined application of P+Mo+*Bradyrhizobium* inoculant. N-uptake by seed due to the application of P or Mo with presence of *Bradyrhizobium* inoculant. compared to that found in *Bradyrhizobium* inoculant only. The highest (123.5 kg ha^{-1}) N-uptake obtained by the application of P+Mo+*Bradyrhizobium* inoculant which was statistically significant. Similar results were found by Ezedeen-Osman *et al.* (2002) and Ali *et al.* (1993).

Results presented in Table 4.8 showed that there was a significant effect due to varieties, P, Mo and *Bradyrhizobium* inoculant increased of seed-N uptake by soybean. In variety G-2, N-uptake ranged from 83.6kg ha^{-1} in control to 120.3 kg ha^{-1} when P+Mo+*Bradyrhizobium* inoculant was used while in variety Pb-1, it ranged from 85.1 kg ha^{-1} in control to 126.6 kg ha^{-1} when P+Mo+*Bradyrhizobium* inoculant was used.

4.4.2 Nitrogen uptake by stover

There was significant variation in N-uptake by stover of two varieties of soybean (Table 4.7). Variety Pb-1 showed significantly higher (22.2 kg ha^{-1}) amount of N-uptake in stover compared to that found in variety G-2 (18.1 kg ha^{-1}).

The nitrogen uptake by stover was also increased significantly due to application of P, Mo and *Bradyrhizobium* inoculant (Table 4.7). The N-uptake by stover ranged from 16.6 kg ha^{-1} in control to 24.7 kg ha^{-1} when P+Mo+*Bradyrhizobium* inoculant was used. The use of P or Mo with *Bradyrhizobium* inoculant showed significantly superior effect on N-uptake by stover compared to that found in *Bradyrhizobium* inoculant only. The highest N-uptake by stover statistically significantly over all other treatments. Similar results were found by Ezedeen-Osman *et al*. (2002) and Ali *et al*. (1993).

There was significant variation in N-uptake by stover due to the interaction of varieties, P, Mo and *Bradyrhizobium* inoculant (Table 4.8). The N-uptake by stover in variety G-2 ranged from 15.3 kg ha^{-1} in control to 22.6 kg ha^{-1} when combined application of P+Mo+ *Bradyrhizobium* inoculant was used while in variety Pb-1, it ranged from 17.6 kg ha^{-1} in control to 26.7 kg ha^{-1} when P+Mo+ *Bradyrhizobium* inoculant was used.

4.4.3 Total Nitrogen uptake of soybean

There was significant variation in total (seed and stover) N-uptake by two soybean varieties (Table 4.7). Variety Pb-1 showed significantly higher (133.2 kg ha^{-1}) total N-uptake compared to that found in variety G-2 (120.6 kg ha^{-1}).

Application of P, Mo and *Bradyrhizobium* inoculant showed significant variation in total N-uptake by soybean (Table 4.7). The total N-uptake ranged from 101.0 kg ha^{-1} in control to 143.1 kg ha^{-1} when P+Mo+*Bradyrhizobium* inoculant was used. The application of P+Mo with the presence of *Bradyrhizobium* inoculant produced the highest total N-uptake compared to that found in *Bradyrhizobium* inoculant only and which was not statistically significant but statistically identical with Mo+ *Bradyrhizobium* inoculant. Similar results were found by Ezedeen-Osman *et al.* (2002) and Ali *et al.* (1993).

Interaction effect of varieties, P, Mo and *Bradyrhizobium* inoculant showed significant variation in respect of total N-uptake (Table 4.8). The total N-uptake in variety G-2 ranged from 99.2 kg ha^{-1} in control to 145.1 kg ha^{-1} when P+Mo+*Bradyrhizobium* inoculant was used while in variety Pb-1, it ranged from 102.8 kg ha^{-1} in control to 153.1 kg ha^{-1} when P+Mo+*Bradyrhizobium* inoculant was used.

Table 4.7 Effect of variety and fertilizers on nitrogen uptake by seed and stover and total nitrogen uptake of soybean

Factor	Nitrogen uptake by seed (kg ha^{-1})	Nitrogen uptake by stover (kg ha^{-1})	Total nitrogen uptake (kg ha^{-1})
Variety			
G-2	102.0 b	18.1 b	120.6 b
Pb-1	113.4 a	22.2 a	133.2 a
S $\bar{x}$	1.379	0.231	1.751
Fertilizer			
Control	84.4 d	16.6 d	101.0 d
Inoculum	105.4 c	19.6 c	125.2 c
P + Inoculum	109.5 bc	19.0 c	128.5 bc
Mo + Inoculum	115.7 b	20.9 b	136.7 ab
P + Mo + Inoculum	123.5 a	24.7 a	143.1 a
S $\bar{x}$	2.180	0.365	2.769
CV (%)	4.96	4.43	5.34

In a column figures having same letter(s) do not differ significantly by DMRT at 5% level of probability

Table 4.8 Interaction effect of variety and fertilizers on N-uptake by grain and stover and total N-uptake of soybean

Variety × Fertilizer		N-uptake by grain (kg ha^{-1})	N-uptake by stover (kg ha^{-1})	Total N-uptake (kg ha^{-1})
G-2	Control	83.6 e	15.3 d	99.2 e
	Inoculum	98.1 d	17.9 c	116.4 c
	P + Inoculum	98.6 d	15.6 d	114.0 cd
	Mo + Inoculum	109.2 c	19.1 c	128.4 b
	P+Mo+Inoculum	120.3 ab	22.6 b	145.1 a
Pb-1	Control	85.1 e	17.6 c	102.8 de
	Inoculum	112.7 bc	21.3 b	134.0 ab
	P + Inoculum	120.4 ab	22.7 b	143.1 a
	Mo + Inoculum	122.2 ab	22.7 b	145.0 a
	P+Mo+Inoculum	126.6 a	26.7 a	153.1 a
$S\bar{x}$		3.083	0.516	3.916
CV (%)		4.96	4.43	5.34

In a column figures having same letter(s) do not differ significantly by DMRT at 5% level of probability.

4.4.4 Phosphorus uptake by seed

There was no significant variation in seed P-uptake of two soybean varieties (Table 4.9). Variety Pb-1 showed slightly higher (7.80 kg ha^{-1}) amount of seed P-uptake compared to that found in variety G-2 (7.77 kg ha^{-1}).

The P-uptake by soybean seed increased significantly due to application of P, Mo and *Bradyrhizobium* inoculant (Table 4.9). The seed P-uptake ranged from 6.64 kg ha^{-1} in control to 9.61 kg ha^{-1} in the combined application P+Mo+*Bradyrhizobium* inoculant. The use of *Bradyrhizobium* inoculant significantly increased the P uptake by soybean seed compared to that found in control. The use of Mo+ *Bradyrhizobium* inoculant significantly increased P uptake by soybean seed compared to that found in *Bradyrhizobium* inoculant. The combined use of P+Mo in presence of *Bradyrhizobium* inoculant significantly increased in P uptake by soybean seed compared to all others. Rooge *et al.*(1998) reported that combined application of P+*Bradyrhizobium* inoculant increased P-uptake by soybean seed.

Results presented in Table 4.10 showed that there was significant variation due to the effect of varieties, P, Mo and *Bradyrhizobium* inoculant in respect of seed P-uptake by soybean. In variety G-2, seed P-uptake ranged from 6.72 kg ha^{-1} in control to 10.26 kg ha^{-1} when P+Mo+*Bradyrhizobium* inoculant was used while in variety Pb-1, it ranged from 6.56 kg ha^{-1} in control to 8.97 kg ha^{-1} when P+Mo+*Bradyrhizobium* inoculant was used.

4.4.5 Phosphorus uptake by stover

There was significant variation in P-uptake by stover of the two soybean varieties (Table 4.9). Variety Pb-1 showed significantly higher (3.46 kg ha^{-1}) amount of P-uptake by stover compared to that found in variety G-2 (3.22 kg ha^{-1}).

The phosphorus uptake by stover was also increased significantly due to application of P, Mo and *Bradyrhizobium* inoculant (Table 4.9). The P-uptake by stover ranged from 2.34 kg ha^{-1} in control to 4.05 kg ha^{-1} when P+Mo+*Bradyrhizobium* inoculant was used. The use of *Bradyrhizobium* inoculant significantly increased P-uptake by stover compared to that found in control. The use of P in presence of *Bradyrhizobium* inoculant recorded the same amount of P uptake as recorded with *Bradyrhizobium* inoculant. The use of Mo in presence of significantly increased P-uptake by stover compared to that found with *Bradyrhizobium* inoculant . The highest (4.05 kg ha^{-1}) P-uptake by stover recorded in P+Mo+*Bradyrhizobium* inoculant was statistically superior to all others. Results are in harmony with the findings of Ghosh and Ghosh (1988) and Rooge *et al.*(1998).

There was no significant variation in P-uptake by stover due to the interaction of varieties, P, Mo and *Bradyrhizobium* inoculant (Table 4.10). The P-uptake by stover in variety G-2 ranged from 2.17 kg ha^{-1} in control to 4.13 kg ha^{-1} when P+Mo+*Bradyrhizobium* inoculant was used while in variety Pb-1, it ranged from 2.52 kg ha^{-1} in control to 3.98 kg ha^{-1} when P+Mo+*Bradyrhizobium* inoculant was used.

4.4.6 Total Phosphorus uptake of soybean

There was no significant variation in (grain and stover) total P-uptake by two soybean varieties (Table 4.9). Variety Pb-1 showed higher (11.3 kg ha^{-1}) total P-uptake compared to that found in variety G-2 (10.9 kg ha^{-1}).

The use of P, Mo and *Bradyrhizobium* inoculant showed significant variation in total P-uptake by soybean (Table 4.9). The total P-uptake ranged from 8.98 kg ha^{-1} in control to 13.8 kg ha^{-1} when P+Mo+*Bradyrhizobium* inoculant was used. The use of Mo or P+Mo with the presence of *Bradyrhizobium* inoculant significantly increased the total P-uptake of soybean compared to that found in control. The highest (13.8 kg ha^{-1}) total P-uptake observed due to application of P+Mo+*Bradyrhizobium* inoculant which was statistically significant.

Interaction effect of varieties, P, Mo and *Bradyrhizobium* inoculant showed significant variation in respect of total P-uptake of soybean (Table 4.10). The total P-uptake in variety G-2 ranged from 8.89 kg ha^{-1} in control to 14.3 kg ha^{-1} when P+Mo+*Bradyrhizobium* inoculant was used while in variety Pb-1, it ranged from 9.08 kg ha^{-1} in control to 13.3 kg ha^{-1} when P+Mo+*Bradyrhizobium* inoculant was used.

Table 4.9 Effect of variety and fertilizers on phosphorus uptake by soybean at harvest

Factor	P-uptake by seed (kg ha^{-1})	P-uptake by stover (kg ha^{-1})	Total P-uptake (kg ha^{-1})
Variety			
G-2	7.77	3.22 b	10.9
Pb-1	7.80	3.46 a	11.3
$S\bar{x}$	NS	0.046	NS
Fertilizer			
Control	6.64 d	2.34 d	8.98 d
Inoculum	7.41 c	3.30 c	10.5 c
P + Inoculum	6.99 cd	3.30 c	10.3 c
Mo + Inoculum	8.28 b	3.72 b	12.0 b
P + Mo + Inoculum	9.61 a	4.05 a	13.8 a
$S\bar{x}$	0.163	0.073	0.268
CV (%)	5.14	5.36	5.90

In a column figures having same letter(s) do not differ significantly by DMRT at 5% level of probability.

NS = Non significant

Table 4.10 Interaction effect of variety and fertilizer on P-uptake by soybean at harvest

Variety × Fertilizer		P-uptake by grain (kg ha^{-1})	P-uptake by stover (kg ha^{-1})	Total P-uptake (kg ha^{-1})
G-2	Control	6.72 ef	2.17	8.89 e
	Inoculum	7.42 de	3.12	10.2 cd
	P + Inoculum	6.91 g	3.16	9.07 de
	Mo + Inoculum	8.54 bc	3.55	12.0 b
	P+Mo+Inoculum	10.2 a	4.13	14.3 a
Pb-1	Control	6.56 fg	2.52	9.08 e
	Inoculum	7.41 de	3.48	10.8 bc
	P + Inoculum	8.07 cd	3.45	11.5 b
	Mo + Inoculum	8.03 cd	3.89	11.9 b
	P+Mo+Inoculum	8.97 b	3.98	13.3 a
$S\bar{x}$		0.231	NS	0.379
CV (%)		5.14	5.36	5.90

In a column figures having same letter(s) do not differ significantly by DMRT at 5% level of probability.

NS = Non-significant.

4.5 Correlation and Regression studies

Statistical relationship between number of nodules plant^{-1} and plant height; number of nodules plant^{-1} and shoot weight; number of nodules plant^{-1} and root weight; number of nodules plant^{-1} and pod plant^{-1} ; number of nodules plant^{-1} and seed yield; number of nodules plant^{-1} and stover yield have been calculated. The relationships are in the following paragraphs and have been presented in figures and response equation.

The correlation between number of nodules plant^{-1} and plant height showed a positive relationship. The regression co-efficient (R^2=0.9052) was found significant. The regression line with Y (plant height) on X (number of nodules plant^{-1}) can be shown as Y= 0.398X+27.272 (Fig. 4.2)

The correlation between number of nodules plant^{-1} and shoot weight showed a positive relationship. The regression co-efficient (R^2=0.8185) was found significant. The regression line with Y (shoot weight) on X (number of nodules plant^{-1}) can be shown as Y= 0.1988X+7.2722 (Fig. 4.3)

The correlation between number of nodules plant^{-1} and pod plant^{-1} showed a positive relationship. The regression co-efficient (R^2=0.8736) was found significant. The regression line with Y(pod plant^{-1}) on X (number of nodules plant^{-1}) can be shown as Y= 0.2856X+19.412 (Fig. 4.4)

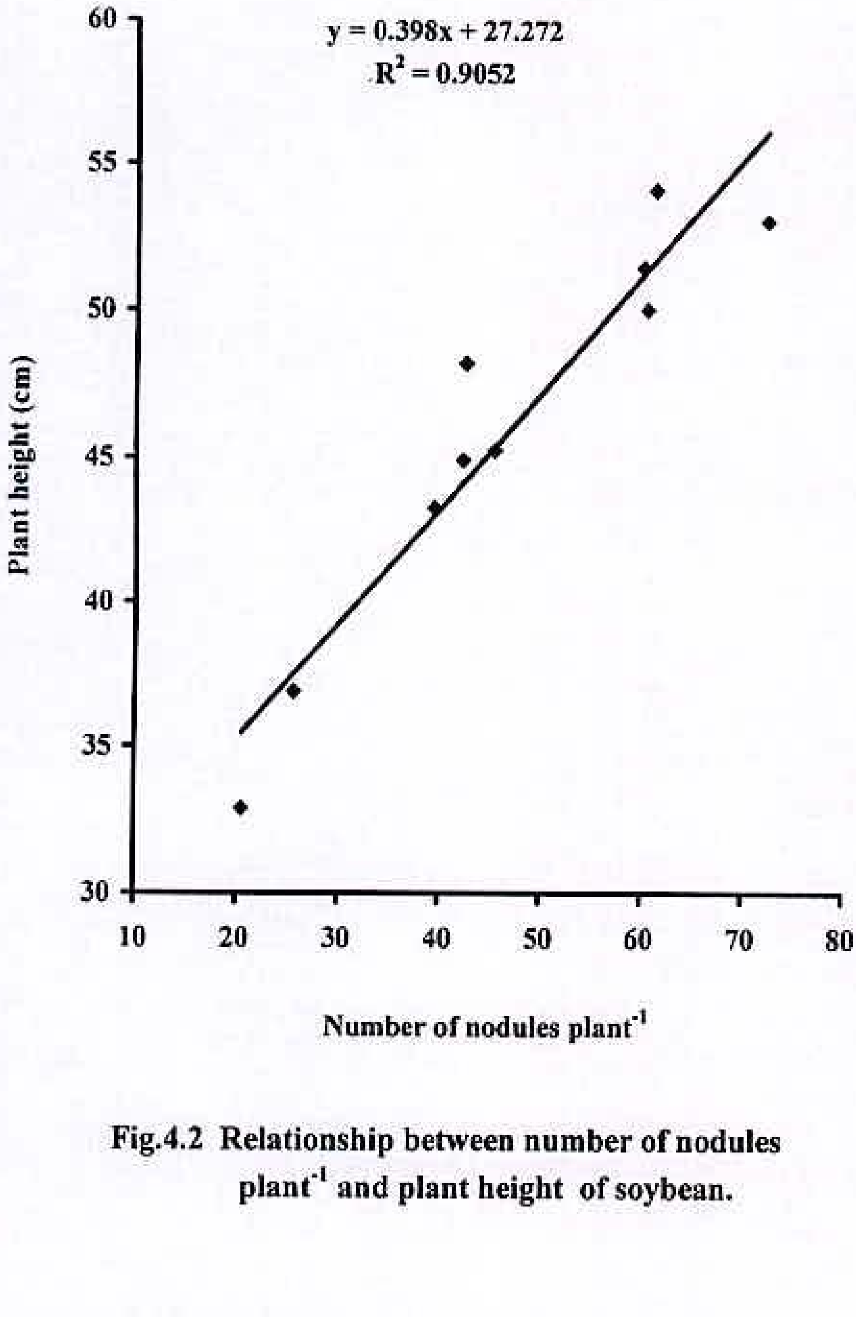

Fig.4.2 Relationship between number of nodules plant^{-1} and plant height of soybean.

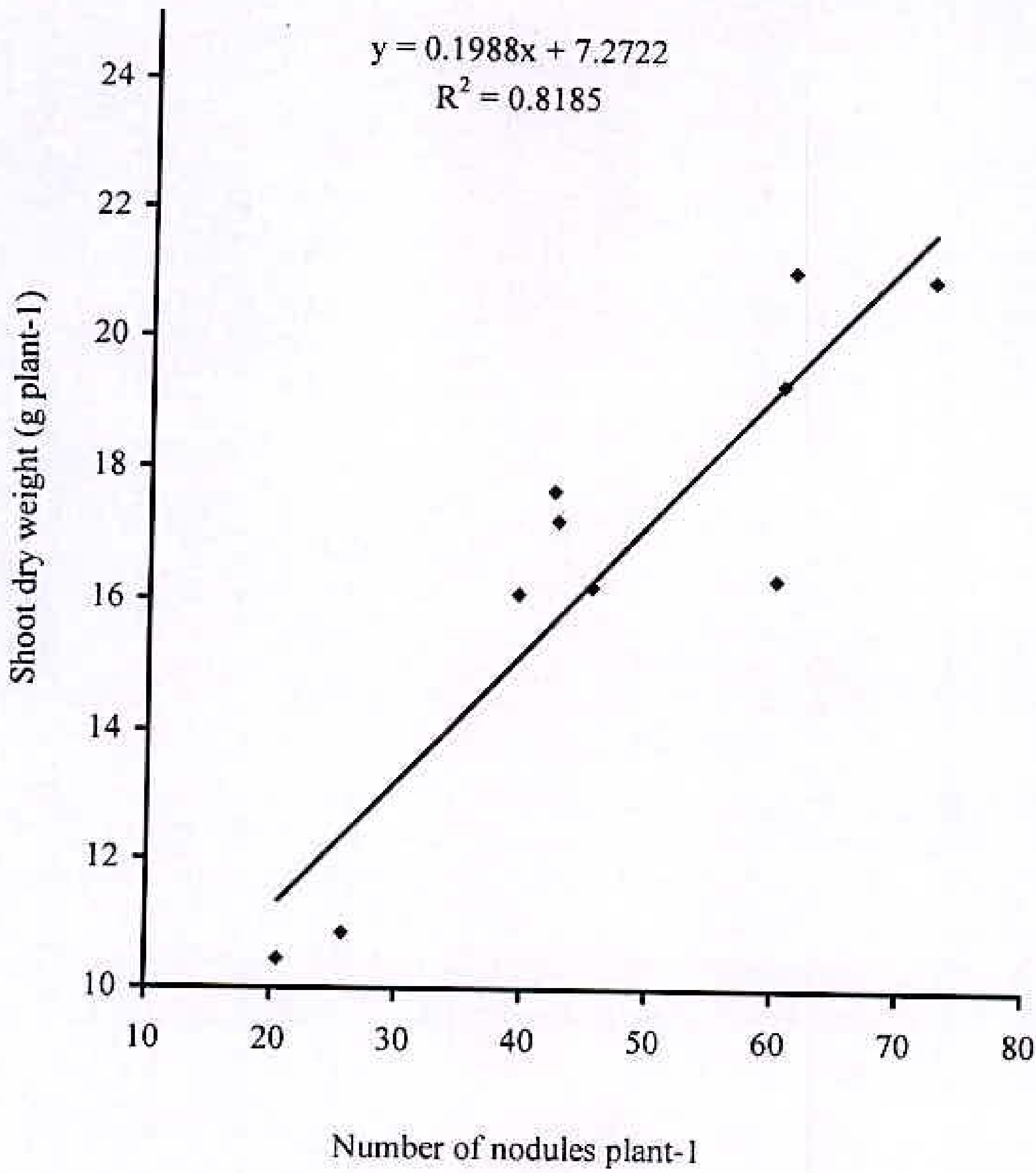

Fig.4. 3 Relationship between number of nodules plant-1 and shoot dry weight of soybean.

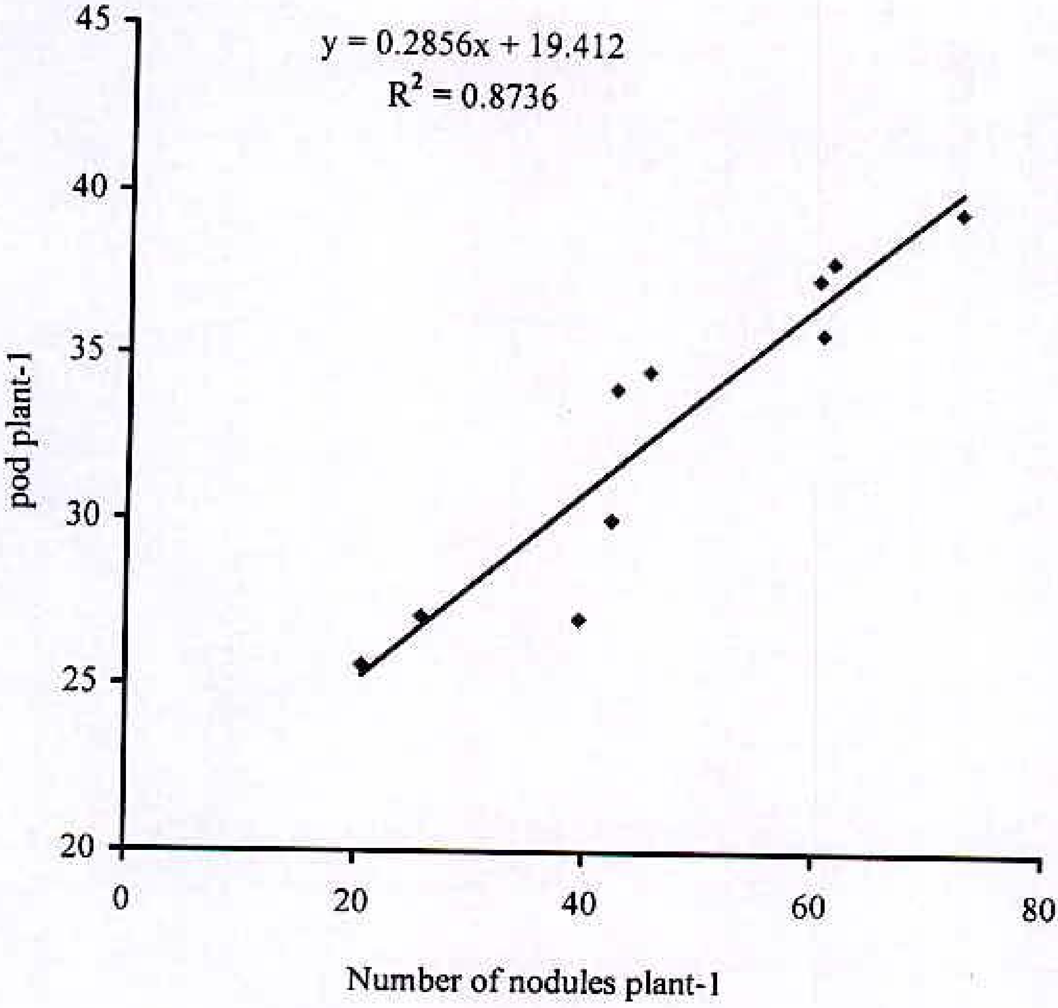

Fig.4. 4 Relationship between number of nodules plant -1 and pod plant-1 of soybean.

Chapter 5

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

A field experiment was conducted at the experimental field of the Department of Soil Science, Bangladesh Agricultural University, Mymensingh during January to May 2003 to study the effect of added P, Mo and *Bradyrhizobium* inoculant on nodulation, yield and yield contributing characters of two soybean cultivars Pb-1 and G-2. The treatments were Control, Inoculum, P+Inoculum, Mo+Inoculum, and P+Mo+Inoculum. The rates of P, Mo and *Bradyrhizobium* inoculant were 40 kg P ha^{-1}, 1 kg Mo ha^{-1} and 15 g inoculant kg^{-1} seed, respectively. Basal application of 40 kg K ha^{-1}, 15kg S ha^{-1} and 2 kg Zn ha^{-1} was applied to all plots for crop raising. The variety was placed in the main plots and the fertilizer and *Bradyrhizobium* inoculant were placed in the sub-plots. At 75 DAS, 10 plants were uprooted from each plot for nodulation study. The crop was harvested at maturity after 120 DAS.

Growth characters (plant height, number of nodule, nodule dry weight, shoot and root dry weight) varied significantly due to varieties, P, Mo and *Bradyrhizobium* inoculant. Interaction of varieties, P, Mo and *Bradyrhizobium* inoculant also significantly affected the above mentioned growth characters except plant height. Variety Pb-1 showed significantly higher growth parameters and superior values compared to that found in G-2 except plant height, shoot and root weights. The highest values of growth characters were recorded due to the combined application of Mo+*Bradyrhizobium* inoculant and P+Mo+ *Bradyrhizobium* inoculant whereas the lowest values were observed in control. The highest (51.1cm.) plant height was obtained with Mo+*Bradyrhizobium* inoculant application.

The highest (58.9 plant^{-1}) number of nodules was obtained with P+Mo+ *Bradyrhizobium* inoculant. The highest (135.4 mg) nodule dry weight was obtained with the combined application of P+Mo+*Bradyrhizobium* inoculant. The highest (19.1 g and 1.65 g) shoot and root weight were obtained with the combined application of Mo+ *Bradyrhizobium* inoculant over control (10.6 g and 1.23 g). The maximum (0.90% and 7.17%) N-content in stover and seed were noted due to application of P+Mo+*Bradyrhizobium* inoculant. The highest (0.149% and 0.54%) P-content in stover and seed were obtained with the combined application of P+Mo+*Bradyrhizobium* inoculant over control (0.110% and 0.442%). In case of interaction (variety × fertilizer) the highest values of growth character, except plant height and root weight were noted for combined application of P+Mo+*Bradyrhizobium* inoculant compared to P, Mo and *Bradyrhizobium* inoculant. Pod plant^{-1}, 100-seed weight, seed yield and stover yield significantly due to soybean varieties except seeds plant^{-1}. Variety Pb-1 showed higher values (except pods plant^{-1} and seeds plant^{-1}) compared to that of variety G-2.

The application of P, Mo and *Bradyrhizobium* inoculant showed a significant variation in relation to pods plant^{-1}, seeds plant^{-1}, 100-seed weight, seed yield and stover yield. The highest values for each of the said characters were recorded for combined application of P+Mo+*Bradyrhizobium* inoculant whereas their corresponding values were the lowest in control except 100-seed weight. The highest values for pods plant^{-1}, seeds plant^{-1} and 100-seed weight were obtained with combined application of P+Mo+*Bradyrhizobium* inoculant over the control. The highest seed yield (1775 kg ha^{-1}) and stover yield (2851 kg ha^{-1}) were obtained with combined application of P+Mo+ *Bradyrhizobium* inoculant. The seed yield of soybean due to P+Mo+ *Bradyrhizobium* inoculant was 34.0% higher over the control. In case of interaction the highest seed (1825 kg ha^{-1}) stover (2925 kg ha^{-1}) yields were noted in variety Pb-1 when combined application of P+Mo+ *Bradyrhizobium* inoculant was used while in variety G-2 and 2777 kg ha^{-1} were also observed when combined application of P+Mo+ *Bradyrhizobium* inoculant was used.

The N-uptake due to varieties were significant variety Pb-1 showed higher values in relation to N-uptake in case of both seed and stover compared to that found in variety G-2. Nitrogen uptake varied significantly due to application of P, Mo and *Bradyrhizobium* inoculant. The highest N-uptake in seed (123.4 kg ha^{-1}) and stover (24.70 kg ha^{-1}) were obtained due to combined application of P+Mo+*Bradyrhizobium* inoculant. Total N-uptake (seed and stover) obtained with combined application of P+Mo+ *Bradyrhizobium* inoculant was the highest compared to that of P, Mo application.

The P-uptake by seed due to varieties was not significant. In variety Pb-1 showed higher value in relation to P-uptake incase of both seed and stover compared to that found in varieties G-2. P-uptake varied significantly due to application of P, Mo and *Bradyrhizobium* inoculant. The highest P-uptake in seed (9.61 kg ha^{-1}) and stover (4.05 kg ha^{-1}) were obtained due to inoculation of P+Mo+*Bradyrhizobium* inoculant. Total P-uptake (seed and stover) obtained with combined application of P+Mo+*Bradyrhizobium* inoculant was the highest compared to that of P, Mo application.

From over all observation it may be inferred that the combined application of P and Mo with *Bradyrhizobium* inoculant markedly increased the nodulation and yield of soybean varieties. *Bradyrhizobium* inoculation is essential for soybean cultivation at BAU Farm and the application of P and Mo may further increase the yield potentiality of soybean.

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Appendices

APPENDICES

Appendix I. Monthly mean of daily maximum, minimum and average temperature, relative humidity, total rainfall and sunshine hours during the period from January 2003 to May 2003 at BAU campus

Month	** Air temperature (°C)			** Relative humidity (%)	* Rainfall (mm)	* Sunshine (hrs)
	Maximum	Minimum	Average			
January, 2003	21.77	10.17	15.97	83.65	Trace	165.6
February, 2003	23.77	15.49	21.23	75.21	27.1	229.2
March, 2003	27.95	18.11	23.03	75.39	114.0	199.3
April 2003	28.97	18.54	23.76	82.53	83.1	235.0
May 2003	31.29	22.89	27.09	84.77	105.8	235.6

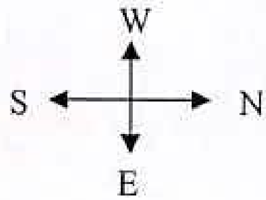
Source: Weather yard, Department of Irrigation and Water Management, BAU, Mymensingh

* = Monthly total
** = Monthly average

Appendix II. LAYOUT PLAN OF EXPERIMENTAL PLOT

R_1	R_2	R_3
T_4V_1	T_2V_1	T_2V_1
T_1V_1	T_3V_1	T_1V_1
T_3V_1	T_4V_1	T_0V_1
T_0V_1	T_0V_1	T_4V_1
T_2V_1	T_1V_1	T_3V_1
T_1V_2	T_4V_2	T_3V_2
T_3V_2	T_0V_2	T_4V_2
T_4V_2	T_1V_2	T_0V_2
T_0V_2	T_3V_2	T_2V_2
T_2V_2	T_2V_2	T_1V_2

V_1 = BS-4 (G-2), V_2 = Sohag (Pb-1),
T_0 = Control, T_1 = Inoculum,
T_2 = P + Inoculum, T_3 = Mo + Inoculum
T_4 = P + Mo + Inoculum



BIOGRAPHICAL SKETCH

The author is identified as **Mohammad Mosharraf Hossain**. He was born on 1st May 1976 at village-Chowbaria, Thana–Tangail under the district of Tangail in Bangladesh. He is the first son **of Mr. Md. Abdul Mazid** (Headmaster, Govt. Primary School) and **Mrs. Taheron Begum** (Housewife). He completed his S.S.C. in 1991 and H.S.C. in 1993 from Anuhala High School, Tangail and Government M. M. Ali College, Kagmari, Tangail respectively. He secured first division in both S.S.C. and H. S.C. He obtained **Bachelor of Science in Agriculture (B.Sc.Ag.)** degree in 1997 (Exam. held on 2001) from Sher-e-Bangla Agricultural University, Dhaka (Former Bangladesh Agricultural Institute, Dhaka.) and secured first class. Now, he is a Lecturer of the Department of Soil Science, Sher-e-Bangla Agricultural University, Dhaka. He enrolled of this University in January-June, 2002 for completion of his MS in the department of Soil Science.