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Evaluation of Different NP Fertilizer Rates and Bradyrhizobium Inoculation on Yield and Yield Components of Soybean [*Glycine Max* (L.) Merrill], at Jinka, Southern Ethiopia

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Abstract – **A field experiment was carried out at Jinka Agricultural Research Center to determine the effect of NP fertilizers application rate and bradyrhizobium inoculation on yield and yield components of soybean [Glycine max (L.) Merrill] in 2008 under rain fed condition. The experiment was conducted with two levels of nitrogen in the form of urea (0 and 46 kg ha^{-1}), two levels of bradyrhizobium (0 and Str-TAL-379) and four levels of phosphorous fertilizer in the form of TSP (0, 25, 50 and 75 kg ha^{-1}). The experimental design was split-split plot with four replications where, N was arranged as main plot factor, bradyrhizobium and P were arranged as sub and sub-sub plot factors, respectively. Phenological and growth parameters such as yield and yield components, total biomass, harvest index were studied. The result showed that all phenological and growth parameters except number of branches per plant were significantly affected by nitrogen fertilization. The number of days required to reach at each of the phenological stages were delayed as nitrogen was applied. Application of nitrogen increased both plant height and leaf area index. Grain yield and pods per plant were significantly affected by nitrogen application. The grain yield obtained from 46 kg N ha^{-1} application (1.39 t ha^{-1}) was higher by 25.23% compared to 0 kg N ha^{-1}(1.11 t ha^{-1}). Both total biomass and harvest index were significantly influenced by nitrogen application. Inoculation did not affect significantly phonological and growth parameters except flowering and pod setting dates. Inoculation did not bring significant variation on grain yield but it affected significantly yield components except number of pods per plant. Inoculation had significant affected total biomass and harvest index. The highest total biomass (3.16 ton ha^{-1}) and the highest harvest index (0.54), obtained from inoculation were 25.40% and 31.71% increase over non inoculated treatments, respectively. All the phenological, and growth parameters except number of branches per plant were significantly affected by phosphorus fertilization. Phenological stages of soybean were reduced as the level of phosphorus increased. Phosphorus application significantly affected grain yield, yield components and harvest index but it did not affect significantly total biomass. The highest grain yield (1.42 t ha^{-1}) was obtained from the highest phosphorus rate of 75 kg P ha^{-1} showing 59.55% increase over 0 kg P ha^{-1}. The highest grain yield from 75 kg P ha^{-1} was contributed by increased number of pods per plant and heavier seed weight. There was no significant interaction between nitrogen fertilizer, inoculation and phosphorous fertilizer for all studied parameters except days to pod setting, plant height, and number of pods per plant and harvest index. Application of 46 kg N ha^{-1}, inoculation or P fertilization of 25 kg P ha^{-1} resulted in higher net benefit and maximum MRR (%). Therefore, it can be concluded from this result that nitrogen application of 46 kg N ha$^{-1,}$ inoculation or phosphorous application at the rate of 25 kg P ha^{-1} is advisable and could be appropriate for soybean production in the test area even though further testing is required to put the recommendation on a strong basis.**

Keywords – **Bradyrhizobium, Inoculation, Nitrogen Fertilizer, Phosphorous Fertilizer, Soybean.**

I. Introduction

Soybean [*Glycine max (L.*) Merrill] is a species of legume native to East Asia. It is a member of the Leguminosae family. According to FAO (2005), total land area under soybean in the world was 95.2 million ha and total production was 212.6 million tones. Soybean was introduced to Ethiopia in the 1950's and it has adapted to diverse ecological niches and provided wider yield range (Hammer and Haraldson, 1975; Amare, 1987). Throughout the 1970's Ethiopia produced 6,000 tons of soybeans annually, making it one of the top four African soybean producing countries (FAO, 1984). According to CSA (2004) the area under soybean during 2001/02 main growing seasons was 4, 923 ha with total production of 4288 tones with an average yield of 870 kg ha^{-1}. The average yield of 870 kg ha^{-1} is very low as compared to the world's average of 2300-4000 kg ha^{-1} (NSRL, 2007). This indicates that there is a wide gap between the potential and the actual yield. This gap needs to be narrowed by applying optimum agronomic management packages such as NP fertilization and inoculation. Although most parts of the southern regions of Ethiopia have a potential for soybean production, cultivation is limited to only some areas. So far, there is no research conducted in the area investigating the response of the crop to NP fertilization and bradyrhizobium inoculation. Thus, for inclusion of the crop in the existing cropping systems and increasing its productivity, some of the packages that could increase productivity of soybean such as NP fertilization and inoculating the crop with specific rhizobium strains should be worked out. Yields of the soybean crop will decrease when essential nutrients are deficient. Therefore, profitable fertilizer programs must be developed to maximize yields for this crop. In addition, bradyrhizobium inoculation of soybean plays an important role in contributing to high yield because it promotes nitrogen fixation. According to Bhangoo and Albritton (1996), practical use of the biological nitrogen-fixing (BNF) system are being increasingly important, since BNF contributes significantly to the maintenance and promotion of sustainable agricultural production.

The research station is newly opened, there is no data regarding the basic physicochemical properties of the soil. Moreover, the response of the soybean crop to NP fertilization and inoculation is lacking. Thus, this research was initiated with the following objectives:

1. To determine the effect of *Bradyrhizobium japonicum* strain inoculation and NP fertilization on yield and yield components of soybean [*Glycine max* (L.) Merrill] cultivar at Jinka, Southern Ethiopia
2. To determine the optimum rate and combinations of NP fertilizer with the specific bradyrhizobium inoculation for profitable soybean production at Jinka.

II. Materials and Methods

2.1. Description of the Study Area

The experiment was conducted at Jinka Agricultural Research Center located at 5°52' N latitude and 36°38' E longitude. Jinka is situated in south Ethiopia at 750 kms from Addis Ababa, at an altitude of 1450 m above sea level. The average annual rainfall of the area for the last twelve years is 1294 mm with a range of 994.1 to 1675.8 mm, while the average annual minimum and maximum temperatures were 16.1ºc and 27.6ºc, respectively. The main rainy season extends from March to June interrupted by some dry periods in May. The experiment was conducted during the second cropping season (July to October, 2008) under rain fed condition.

Table 1: Weather data for Jinka, during the year 2008.

Month	Maximum Temp. (ºc)	Minimum Temp. (ºc)	Rainfall (mm)
January	29.8	15	22.8
February	30.5	15.7	58.6
March	30.1	16.7	77.8
April	27.2	17.1	145.1
May	27.4	17.5	79.5
June	26.4	16.4	197.8
July	25.5	16.8	99.1
August	26	17.4	76.9
September	26.9	17.4	178.4
October	26	16.9	213
November	27.1	15.1	96.6
December	29.2	14.2	20.2

2.2. Treatments and Experimental Design

Treatments were made from a combination of three factors. Four levels of phosphate fertilizer (0 kg, 25 kg and 50 kg and 75 kg P ha^{-1}) in the form of (TSP), two levels of nitrogen fertilizer (0 kg ha^{-1} and 46 kg N ha^{-1}) in the form of urea and inoculation (inoculation with strain of bradyrhizobium strain, Str-TAL-379 from national soil research center or without inoculation) were used. One variety of soybean namely Williams, which is early maturing was selected for the study based on its yielding potential and protein content.

The experiment consisted of 16 treatments with a total of 64 plots. The field experiment was laid out in a split-split-plot design with four replications. Nitrogen levels, inoculation and phosphorous levels were used as main plot, sub-plot and sub-sub plot factors, respectively. The seeds of soybean for the inoculation treatments were inoculated with carrier- based inoculants of *Bradyrhizobium japonicum* (Str-TAL-379) at the rate of 10 g kg^{-1} of seed applied to the moistened seeds. All inoculations were done just before planting under shade to maintain the viability of the Bradyrhizobium bacteria. Seeds were air dried for a few minutes before planting.

2.3. Agronomic Management

Soybean was sown on July1, 2008 in eight rows per plot with spacing of 40 cm between rows and 10 cm between plants within a row. Each plot was 3 m long and 3.2 m wide. Plots receiving no inoculants were planted before others following those receiving inoculants in order to reduce the possibility of contamination. A single person, on a single factor level basis has made the planting for the inoculation factor. Ridges were made between each plot to reduce the movement of bacteria from plot to plots by rainwater.

2.4. Data Collection

Phenological Parameters

Phenological parameters such as days to emergence, days to flowering, days to pod setting and days to maturity were recorded. Days to emergence was recorded when 50 % the plants per plot emerged while days to flowering and days to pod setting were recorded by counting the number of days after emergence when 50 % of the plants per plot had the first open flower and form pod, respectively. Days to maturity were recorded when 80% of pods matured per plot.

Growth Parameters

At mid flowering stages five plants from each of the plots were selected randomly and uprooted carefully to determine crop growth parameters such as plant height, dry matter, number of branches, leaf area and leaf area index. Dry matter was determined by drying the above ground parts of the five sampled plants at 70 $^{o}{}_{C}$ for 48 hours in an air-ventilated oven. Roots were excavated to a depth of 30 cm to take nodulation parameters.

Grain Yield, Yield Components, Total Biomass and Harvest Index

Two central rows (3 m x 0.8 m = 2.4 m^2) were harvested for determination of grain yield. Grain yield was adjusted to 12.5% moisture content. Five plants were randomly selected from the two central rows to determine yield and yield components, which consisted of number of pods per plant, number of seeds per pod and hundred seeds weight. Pod number per plant was determined by counting pods of the five randomly selected plants while number of seeds per pod was recorded by counting the total number of seeds in a pod from ten randomly sampled pods taken from the five randomly selected plants. Seed weight was determined by taking a random sample of 100 seeds and adjusted them to 12.5% moisture content. Total biomass yield was measured from the two middle rows when the plant reached harvest maturity. Harvest index was calculated as the ratio of seed yield to total above ground biomass yield.

2.5. Soil Sampling, Sample Preparation and Analysis

A composite sample for laboratory chemical and physicochemical characterization was collected from a depth of up to 30 cm from each of the plots before planting. After harvest, five random samples were collected from each plot and a composite sample weighing 0.5 kg per treatment was made in order to determine specific chemical characteristics using the formula indicated for band-applied fertilizers by Havlin *et al.* (1999) as:

S = 8(row spacing)/30, where:

S stands for the ratio of off-band to on-band samples.

The samples were air dried at room temperature, mixed well and ground to pass through a 2 mm sieve. Soil analysis for pH (by water suspension method), available P (Olsen method), organic matter (multiplying% organic carbon by 1.724), total N (by Kjeldahl procedure) and soil textural class of the study area was carried out according to the procedures by Sahelemedhin and Taye (2000).

2.6. Statistical Analysis

Analysis of variance was performed using the GLM procedure of SAS Statistical Software Version 6.12 (SAS, 1997). Effects were considered significant in all statistical calculations if the P-values were $\leq$ 0.05. Means were separated using Fisher's Least Significant Difference (LSD) test.

2.7. Economic Analysis

Simple partial budget analysis was employed for economic analysis of fertilizers and inoculum. The price of fertilizers and inoculum and the crop potential response towards the added fertilizers and inoculum were used to determine the economic feasibility of fertilizers and inoculum. To estimate the total costs, mean market price of soybean, N and P fertilizers and inoculum were taken from market assessment at the time of harvesting. The economic analysis was based on the formula developed by CIMMYT (1988).

Adjusted yield (ton ha^{-1}): the average yield adjusted downward by a 10% to reflect the difference between the experimental yield and yield of farmers.

Gross field benefit: calculated by multiplying field price that farmers receive for the crop when they sale it by adjusted yield and subtracting all costs associated with harvest and sale.

Net benefit: calculated by subtracting the total variable costs from the GFB for each treatment.

Marginal rate of return (MRR%): calculated by dividing change in net benefit by the marginal cost, that is change in cost.

III. Results and Discussion

3.1. Physicochemical Properties of the Experimental Soil

The selected physical and chemical characteristics of the experimental soil for analysis were pH, soil texture, available P, total nitrogen, cation exchange capacity and organic matter (Table 2). The soil analytical results before planting indicated a pH value of 6.41. The best soil pH range for soybean production is 6.5 to 7.0 (Jordan, 1982) indicating that the soil pH of the experimental area is suitable for soybean production. The textural class of the experimental soil was sandy loam. The soil organic carbon before planting was 3.41%, which is in the low range, whereas, the soil organic matter content before planting was 5.88, which is in the high range. The soil organic matter content ranges of 1-2, 2-4 and 4-6% are rated as low, medium and high, respectively (Landon, 1991). Organic matter is the main storehouse of many nutrients such as nitrates, phosphates, sulphates and others (Tisdale *et al*., 1993). There was no marked change in the organic matter content of the soil after planting.

The analytical results before planting also indicated that the available P of the experimental soil was 3.413 mg kg^{-1} (Table 2). According to Landon (1991), when Olsen P content is less than 4 mg kg^{-1}, it is considered to be deficient and application of P is required to correct the deficiency. The data after harvest showed that the available P increased irrespective of treatment though the results under P application showed some inconsistency. The increased tendency of P after harvest could be attributed to the applied P during planting time.

Total N before planting was 0.224%, which is in the medium range (Table 2). Total nitrogen in the range of 0.5-1, is considered as high while in the range of 0.2-0.5 and 0.1-0.2 are considered to be low and very low, respectively (Landon, 1991).

The cation exchange capacity of the soil before planting, 32.4 cmol kg^{-1}, is in the high range, which is suitable for crop production. The CEC ranges of 5-15, 15-25, 25-40 cmol kg^{-1} are rated as low, medium and high, respectively (Landon, 1991). Cation exchange capacity of the soil, which is essentially the property of the colloidal fraction, is the capacity of the soil to retain exchangeable cations to plants. The cation exchange capacity of the soil after harvest under various treatments ranged from 32.95 to 37.23 cmol kg^{-1}, showing a slight increase.

Table 2: Selected Physical and Chemical Properties of Soil of the Experimental Site at Jinka, in 2008.

	pH	Soil textural class	Total N (%)	Avail.P (mg kg^{-1})	CEC (cmol kg^{-1})	Organic matter (%)
Before Planting	6.41	Sandy loam	0.224	3.413	32.4	5.88
After Harvest						
N rate (N kg ha^{-1})						
0	5.94		0.27	6	34.75	5.44
46	5.91		0.24	5.13	33.15	5.35
Inoculation						
Non inoculated	5.94		0.25	5.38	32.95	5.21

Inoculated	5.9	0.26	5.71	34.95	5.58
P rate (P kg ha^{-1})					
0	5.94	0.23	5.09	37.23	5.35
25	5.99	0.27	5.48	34.93	5.46
50	5.88	0.26	7.11	35.35	5.43
75	5.88	0.27	6.51	33.3	5.34

3.2. Crop Phenology and Growth Parameters

Emergence required about 7 days after planting in all the experimental plots regardless of the treatments used. The application of N fertilizer had brought significant difference on days to flowering, days to pod setting and days to maturity (Table 3). Maximum numbers of days to flowering (60), to pod setting (64) and maturity (94) were recorded for N application at the rate 46 kg N ha^{-1} (Table 3). The results showed that nitrogen had delayed flowering, pod setting and maturity dates of soybean in this experiment because nitrogen enhances vegetative growth. Wood *et al*. (1993) reported that application of N fertilizer significantly delayed physiological maturity of soybean. Michael *et al*. (1998) also indicated that application of N fertilizer is beneficial to vegetative growth and prolongs maturity period.

Nitrogen application showed a significant effect on plant height and leaf area index while it did not bring significant effect on number of branches per plant (Table 3). The highest plant height (33.5 cm) was recorded for 46 kg N ha^{-1} while the shortest (29.5 cm) from 0 kg N ha^{-1} (Table 3). The reasons for increase in plant height under N application might be due to the increased vegetative growth with increasing in N level. Similarly, Varon *et al.* (1984), recorded maximum plant height from application of 50 kg N ha^{-1} as urea compared to 0 kg N ha^{-1}.

Greater leaf area index (LAI), (2.99) was produced from 46 kg N ha^{-1}and the smaller (2.51) was from 0 kg N ha^{-1} (Table 4). The increase in LAI due to N application might be attributed to increased leaf area due enhanced cell division. Bomar *et al*. (1991) obtained a greater LAI of 3.2 when N fertilizer was added at the rate of 69 kg ha^{-1} compared to control (0 kg N ha^{-1}).

Table 3: Mean Square Values for Crop Phenology and Growth Parameters as Influenced by Nitrogen, Inoculation and Phosphorous at Jinka, in 2008.

		Mean square					
Source	DF	Days to flowering	Days to Pod setting	Days to maturity	Plant height (cm)	Number of branches	Leaf area index
Replication(R)	3	7.27^{ns}	1.97^{ns}	44^{ns}	19.38^{ns}	0.63^{ns}	0.02^{ns}
Nitrogen (N)	1	3321^{***}	1733^{***}	2639^{***}	263^{***}	0.05^{ns}	0.08^{*}
Error a	3	4.93	1.93	95.39	23.39	0.32	0.01
Inoculation (I)	1	1182^{***}	234^{***}	24^{ns}	0.26^{ns}	1.16^{ns}	0.03^{ns}
N*I	1	32^{ns}	62^{ns}	153^{ns}	1487^{ns}	0.006^{ns}	0.03
Error b	6	2.89	3.85	76.91	16.59	0.19	0.01
Phosphorus (P)	3	22^{**}	80^{***}	35*	202^{***}	0.12^{ns}	0.06^{*}
N*P	3	7^{ns}	22**	46^{ns}	216	0.22^{ns}	0.07^{ns}
I*P	3	45^{ns}	23**	5^{ns}	61.94	0.69^{ns}	0.01^{ns}
N*I*P	3	4^{ns}	63^{ns}	10^{ns}	174	0.84^{ns}	0.01^{ns}
Error c	36	4.08	2.96	17.79	12.41	0.58	0.02

*, **, *** indicate significance at $P < 0.05$, $P < 0.01$, $P < 0.001$, respectively, 'ns' not significant.

Table 4: Crop Phenology and Growth Parameters of Soybean as Affected by Nitrogen, Inoculation and Phosphorus at Jinka, in 2008.

Treatments	Days to flowering	Days to pod setting	Days to Maturity	Plant height (cm)	Number of branches	Leaf area index
Nitrogen (N kg ha^{-1})						
0	45.88b	53.53b	80.69b	29.5b	3.32a	2.51b
46	60.28a	63.94a	93.53a	33.5a	3.38a	2.99a
LSD 0.05	**1.77**	**1.11**	**7.78**	**3.85**	**NS**	**0.14**
CV%	**4.18**	**2.37**	**11.21**	**15.35**	**16.89**	**6.29**
Inoculation (I)						
Non inoculated (I_0)	48.78b	57b	87.7a	31.58a	3.48a	2.79a
Inoculated (I_1)	57.38a	60a	86.5a	31.45a	3.21a	2.69a
LSD 0.05	**1.04**	**1.2**	**NS**	**NS**	**NS**	**NS**

CV%	**3.2**	**3.34**	**10.06**	**12.93**	**13.01**	**8.13**
Phosphorous(P kg ha^{-1})						
0	54.31a	61.19a	88.13a	26.19b	3.32a	2.63b
25	53.75a	60.06a	86.98ab	32.93a	3.25a	2.68b
50	52.56a	57.0b	86.94ab	33.a	3.36a	2.68b
75	51.69a	56.69b	85.12b	33.66a	3.46a	3.0a
LSD 0.05	**NS**	**1.23**	**3.02**	**2.53**	**NS**	**0.15**
CV%	**3.84**	**2.93**	**4.84**	**11.17**	**22.7**	**7.36**

Note: Means with the same letters within the columns are not significantly different at $P < 0.05$.

Inoculation significantly affected days to flowering and pod setting, but did not show significant effect on days to maturity (Table 3). A longer duration for days to flowering (57) and for days to pod setting (60) was obtained from inoculated treatment (Table 3). Days to flowering and days to pod setting were increased by 17.6 and 5.3%, respectively due to inoculation (Table 4). The reason might be attributed to the contribution of inoculation in enhancing nitrogen supply. This inturn encouraged vegetative growth and as a result days to flowering and pod setting were delayed. Bruawal *et al.* (2004) reported that days to flowering and pod setting of soybean were increased due to rhizobial inoculation.

Inoculation did not bring significant effect on number of branches per plant, plant height and leaf area index (Table 3). The lack of response of growth parameters of soybean to inoculation could be due to the poor performance of the rhizobium strain to the prevailing soil and climatic conditions. There was poor distribution of rainfall during the vegetative growth period of the experiment. Morgan *et al.* (1990) reported that rhizobial inoculation did not bring a marked change in number of branches. However, Maroko *et al.* (1998) reported that rhizobium inoculation had significantly increased plant height (37 cm) and number of pods per plant (68).

Phosphorous fertilization had brought significant effect on days to flowering, days to pod setting and days to maturity (Table 3). Days to flowering, pod setting and maturity were decreased with increasing level of P fertilization (Table 4). The result was due to phosphorous effect on initiation of flowering and enhancement of pod setting. Brady and Weil (2002) stated that phosphorous is helpful in flowering and hastens maturity of crops.

Phosphorous application significantly affected plant height and leaf area index while it did not bring significant variation on branch number (Table 3). Phosphorous application increased the growth parameters since it promotes plant growth. Similarly, Islam *et al.* (2004) reported that the highest plant height of 51.7 cm was obtained from 69 kg P ha^{-1} in soybean compared to 0 kg P ha^{-1}. Bothe *et al.* (2000) also reported that application of 75 kg P ha^{-1} on soybean produced higher plant height.

Leaf area index (LAI) was significantly affected by P application (Table 3). The higher leaf area index was obtained for the highest P level (Table 4). The greater LAI at the higher P level was probably contributed from a relatively greater cell division. This result is in line with that of Richard (1998) who reported that application of 69 kg P ha^{-1} has significantly increased leaf area index.

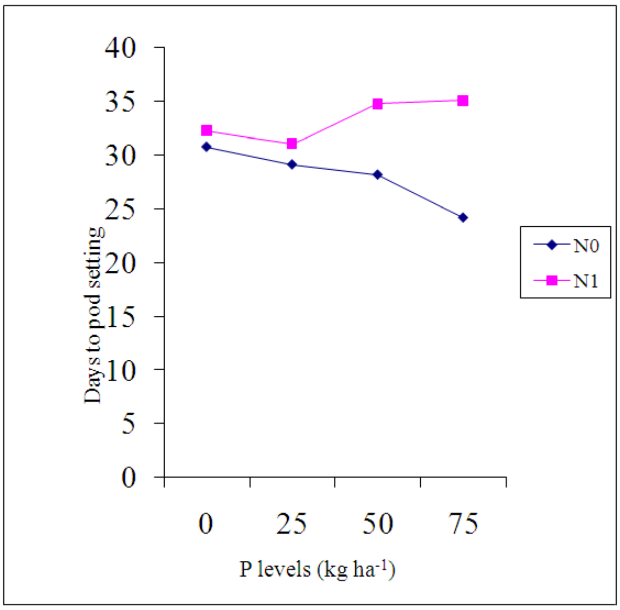

Fig.1. Interaction effect of P and N fertilizers on days to pod setting, at Jinka, 2008.
N0, (0 kg N ha^{-1}), N1, (46 kg N ha^{-1})

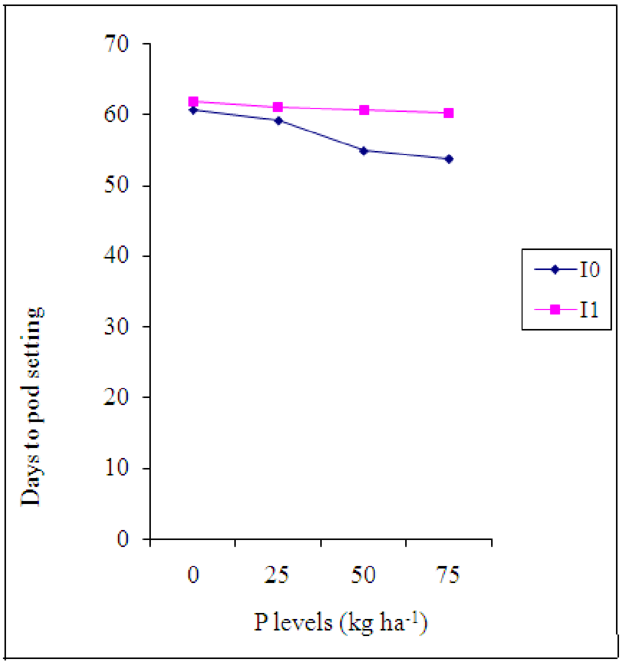

Fig.2. Interaction effect of P fertilizer and inoculation on days to pod setting, at Jinka, in 2008.
I0, non inoculated, I1, inoculated

Interaction effect of N and P has significantly affected days to pod setting (Table 3). Days to pod setting increased with rising in P level under N application while it decreased with increasing P level under no N application (Figure 1). The rise in days to pod setting at N application could be attributed due to the counteracting effect of N fertilizer application. The interaction effect of inoculation and P has significantly affected days to pod setting (Table 3). The interaction showed a marked decreasing trend in pod setting duration as the level of P increased under non inoculated compared to inoculated (Figure 2). The marked drop in pod setting at the highest P level under non inoculated treatment could be attributed to the role of P in hastening reproductive growth. It seems that nitrogen has a more dominant effect on the inference of P in determining the days to pod setting.

3. 3. Grain Yield and Yield Components

3. 3.1. Grain Yield

Nitrogen fertilization had brought a significant difference on grain yield of soybean (Table 5). A higher grain yield (1.39 t ha^{-1}) was recorded from 46 kg N ha^{-1} while the lower (1.11 t ha^{-1}) from 0 kg N ha^{-1} (Table 6). The grain yield increase from N application could be attributed to the improved leaf area development, which increases assimilation of leaves. However, nitrogen plays an important role in the synthesis of chlorophyll and amino acids, which are the indispensable ingredients of the process of autotrophization. Nitrogen influenced grain yield through source–sink relationships resulting in higher production of photosynthates (Tripathi *et al.*, 1992). Dereje (2007) reported that as application of 46 kg N ha^{-1} to the soybean variety Nova, resulted in grain yield of 2.69 t ha^{-1} which was significantly higher than that of the control (2.14 t ha^{-1}). Mehmet (2008) also reported that soybean grain yield was increased by 38.7% when application of N increased from 0 kg N ha^{-1} to 90 kgN ha^{-1}.

Table 5: MeanSquare Values for Yield and Yield Components, Total Biomass and Harvest Index in Soybean at Jinka, in 2008.

Source	DF	Grain yield (t ha^{-1})	Pods plant^{-1}	Seeds pod^{-1}	100 seeds wt (gm)	Total biomass (t ha^{-1})	Harvest index
Replication(R)	3	0.11*	1.16^{ns}	0.13^{ns}	0.98^{ns}	0.18^{ns}	0.009^{ns}
Nitrogen (N)	1	1.32***	12.39*	0.05	2.44^{ns}	0.14**	0.18***
Error a	3	0.01	0.91	0.06	2.63	0.98	0.04
Inoculation (I)	1	0.001^{ns}	1.16^{ns}	1.16**	0.47*	4.0*	0.28***
N*I	1	0.01^{ns}	68^{ns}	0.23	0.66^{ns}	0.25^{ns}	0.19
Error b	6	0.02	0.63	0.13	1.63	0.5	0.005
Phosphorous (P)	3	1.00***	147***	1.50***	2.70*	1.00^{ns}	0.10***
N*P	3	0.34^{ns}	20.96^{ns}	0.4^{ns}	0.92^{ns}	1.12^{ns}	0.01^{ns}
I*P	3	0.17^{ns}	11.86**	0.74^{ns}	0.36^{ns}	2.26^{ns}	0.02**
N*I*P	3	0.10^{ns}	1.95^{ns}	0.21^{ns}	1.18^{ns}	0.19^{ns}	0.04***
Error c	36	0.03	1.75	0.14	0.92	0.45	0.05

*, **, *** indicate Significance at P < 0.05, P < 0.01, P < 0.001, respectively, ns = not significant.

Table 6: Yield and Yield Components of Soybean as Affected by Nitrogen, Inoculation and Phosphorous at Jinka, in 2008.

Treatments	Grain yield (t ha^{-1})	Pods plant^{-1}	Seeds pod^{-1} (gm)	100 seeds	Total biomass wt (t ha^{-1})	Harvest index
Nitrogen (N kg ha^{-1})						
0	1.11b	25b	2.46a	15.44a	2.59a	0.53a
46	1.39a	26a	2.52a	15.53a	3.09a	0.42b
LSD 0.05	**0.14**	**0.76**	**NS**	**NS**	**NS**	**0.05**
CV%	**7.69**	**3.78**	**9.84**	**10.48**	**24.32**	**13.18**
Inoculation (I)						
Non inoculated (I_0)	1.26a	25a	2.4b	12.4b	2.52b	0.54a
Inoculated (I_1)	1.25a	25a	3.0a	15.23a	3.16a	0.41b
LSD 0.05	**NS**	**NS**	**0.22**	**1.3**	**0.43**	**0.04**
CV%	**10.88**	**3.14**	**14.48**	**8.25**	**24.89**	**14.73**
Phosphorous (P kg ha^{-1})						
0	0.89b	21d	2.08c	15.63b	2.66a	0.42b
25	1.34a	26c	2.56ab	16.28a	2.76a	0.5a
50	1.37a	27b	2.52b	14.19c	2.73ba	0.54a
75	1.42a	28a	2.81a	15.88ab	3.21a	0.44b
LSD 0.05	**0.13**	**0.95**	**0.27**	**0.69**	**NS**	**0.05**
CV%	**14.03**	**5.24**	**15.15**	**6.19**	**23.59**	**14.78**

Note: Means with the same letters within the columns are not significantly different at P <0.05.

Grain yield was not significantly affected by inoculation (Table 5). The non significant effect of inoculation on grain yield might be because the assimilates were not allocated to grain but may have been remained in the vegetative parts as indicated by the lower harvest index. Absence of yield improvement from inoculation might also be attributed to poor distribution of rainfall during the growth period, which may have impaired nitrogen fixation and translocation. Moreover, the inoculant used in the experiment was from strain isolated and developed elsewhere and may not have expressed its maximum potential for nitrogen fixation. Similarly, Maroko *et al.* (1998) observed that yield of soybean was not significantly affected by bradyhizobium inoculation. It was also reported that there was no significant difference in soybean yield between inoculated and non-inoculated plots (IAR, 1987). On the other hand, Dereje (2007) reported that grain yield of soybean was significantly increased by inoculation with bradyrhizobium while Cruz *et al*. (1997) reported similar results in yam bean and faba bean.

Application of phosphorous showed significant effect on grain yield (Table 5). The lowest grain yield (0.89 t ha^{-1}) was obtained from no P application where as the highest (1.42 t ha^{-1}) was obtained from the largest P application (75 kg P ha^{-1}) (Table 6). However, there was no significant difference among 25, 50 and 75, kg P ha^{-1}. Yield improvement due to P application was mainly attributed to the accompanying improvement in pod number per plant and number of seeds per pod. Increased leaf area index observed with increased P level could have contributed to higher photosynthate production and thus higher grain yield. Ayodel *et al* (1982) reported that a significant yield response of soybean was observed when P was applied at the rate of 60 kg P ha^{-1}. Similarly, Taylor and Philadelphia (2006) reported that grain yield per unit area was significantly affected by phosphorous fertilization. Also, Asfaw and Angaw (2003) observed that application of 120 kg P ha^{-1} in faba bean at Holleta provided three times higher grain yield compared to the control, 0 kg P ha^{-1}. Differences in the amount of P fertilizer inputs required to obtain significant yield improvement may have been due to inherent soil properties and weather conditions.

An overall mean grain yield of 1.3 t ha^{-1} was obtained in this experiment. The yield is lower than reported from previous findings. This may be attributed to the poor and low amount of rainfall in Jinka during the growing period. The highest amount of rainfall (213 mm) was recorded in October followed by (178.4 mm) in September but the amount of rainfall during early growth stages in July and August were 99.1 and 76.9 mm, respectively.

3. 3. 2. Yield components

Nitrogen had significantly affected pod number per plant while it did not affect significantly seed number per pod and 100 seeds weight (Table 5). A greater number of pods per plant were produced when N fertilizer was applied (Table 6). Similar result was reported when nitrogen fertilization at the rate 50 kg N ha^{-1} increased number of pods in soybean up to 66 pods per plant. The author also stated that as the level of N fertilizer increases, the crop has the tendency to utilize the nutrients and resulted in increased number of pods per plant.

Inoculation showed significant effect on number of seeds per pod and 100 seeds weight but not on pod number per plant (Table 5). Higher number of seeds per pod (3.0) was recorded for inoculation as compared to non inoculation (2.4) (Table 6). However, it seemed insufficient to bring improvement in grain yield under inoculated treatments.

Phosphorous fertilization had significantly affected number of pods per plant, seeds per pod and 100 seeds weight (Table 5). The lower number of pods per plant (21) was obtained at plots without P while the greatest number (28) was obtained from 75 kg P ha^{-1} application (Table 6). The number of pods per plant increased with rising P application levels. Number of seeds per pod has shown a similar trend of increase with rising P levels, generally. However, the response of seed weight to P rates was inconsistent. Assefa and Kedir (2003) reported that phosphorous fertilization had significantly affected some of the yield components in field pea.

The interaction effect of inoculation and P significantly affected number of pods per plant (Table 5). The interaction indicated that the change in umber of pods per plant with rising P rate is more pronounced under non inoculated treatments than inoculated ones (Figure 3). However, the interaction effect on pod number per plant seemed not large enough to influence the grain yield in a similar way.

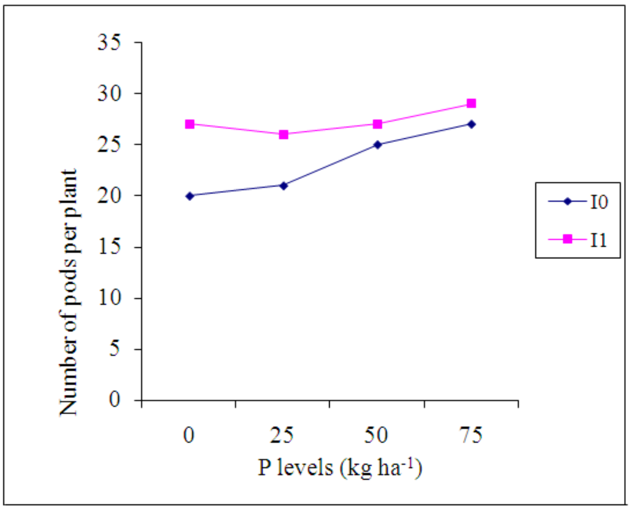

Fig.3. Interaction effect of P fertilizer and inoculation on number of pods per plant, at Jinka, in 2008.
I0, non inoculated, I1, inoculated treatments

3. 4. Total Biomass

Nitrogen fertilization significantly influenced total biomass (Table 5). Maximum biomass of (3.01 t ha^{-1}) was recorded at nitrogen application rate of 46 kg N ha^{-1} while the minimum (2.59 t ha^{-1}) was from 0 kg N ha^{-1} (Table 6). The trend was similar to what has been observed for grain yield. The reason is related to the fact that application of N improves the above ground biomass of plants. Varon *et al.* (1984) reported that N being an essential component for vegetative growth produced significant number of leaves and brought increment in total biomass of soybean.

Significant variation on total biomass was observed due to inoculation (Table 5). Maximum total biomass (3.16 t ha^{-1}) was obtained from inoculated while the minimum (2.52 t ha^{-1}) was from the uninoculated treatment (Table 6). Since inoculation increased nodulation, it enhanced nitrogen fixation leading to increase above ground biomass. The result is in agreement with the findings of Dubey *et al*. (1995) who reported that there were appreciable increases in total biomass in inoculated seeds as compared with uninfected ones. Okereke and Onochie (1996) stated that inoculation of soybean by *bradyrhizobium japonicum* significantly increased biomass yield.

There was no significant variation on total biomass due to phosphorous application (Table 5). However, the highest total biomass yield of (3.21 t ha^{-1}) was recorded from 75 kg P ha^{-1} while the lowest (2.66 t ha^{-1}) was recorded for 0 kg P ha^{-1} with the P value of 0.102 (Table 6). On the other hand, Taylor and Philadelphia (2006) reported that phosphorus supply increased the top dry matter production at flowering and the dry matter production of seeds, pod shells, and roots at late pod filling of inoculated soybeans.

3. 5. Harvest Index

Nitrogen application significantly affected harvest index (HI) (Table 5). A higher harvest index (0.53) was recorded for 0 kg N ha^{-1} while the minimum (0.42) was from 46 kg N ha^{-1} (Table 6). The reason might be that as N level increased there would be an increment in total biomass and the ratio of economic yield to biological yield got decreased since N promotes vegetative growth. Sayapaul (1998) suggested that application of 60 kg N ha^{-1} produced a harvest index of 0.49 in soybean. However, Malik *et al.* (2006) reported N application has no effect on harvest index of soybean.

Inoculation significantly affected harvest index (Table 5). Maximum harvest index (0.54) was obtained from non inoculated while the minimum (0.41) was from the inoculated treatment (Table 6). The reason could be that inoculation promotes nitrogen fixation as a result of which vegetative growth is promoted. Moawad *et al*. (1991) reported that rhizobium inoculation did increase significantly harvest index of faba bean.

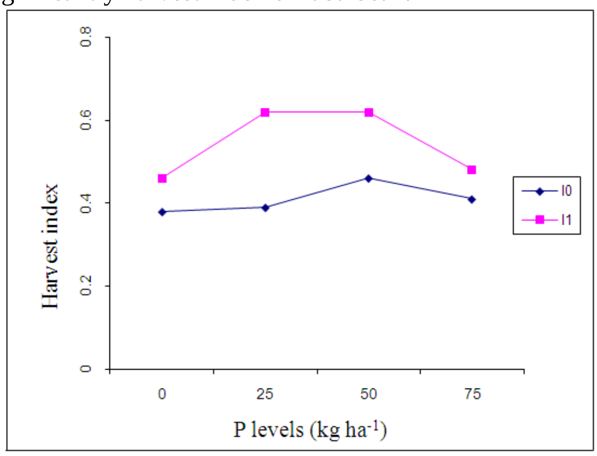

Fig.4: Interaction effect of P fertilizer and inoculation on harvest index, at Jinka, in 2008.
I0, non inoculated, I1, inoculated

Phosphorous application significantly influenced harvest index (Table 5). Application of 50 kg P ha^{-1} gave the highest harvest index (0.54) (Table 6). Assefa and Kedir (2003) reported that application of 50 kg P_2O_5 ha^{-1} gave the highest harvest index in field pea.

There was also significant phosphorus by inoculation interaction for harvest index (Table 5). The interaction indicated that differences in harvest index between the two inoculation levels were smaller at the tow P level extremes, i.e., 0 and 75 kg P ha^{-1} (Figure 4). Phosphorus seemed to influence the harvest index of soybean seriously at medium application rates.

3.6. Partial Budget Analysis

In the partial budget analysis of the two nitrogen levels, two inoculation levels and four phosphorus rates, the highest net benefit (6092.7 ETB ha^{-1}) was obtained from application of 46 kg N ha^{-1} and the lowest (3714.63ETB ha^{-1}) was recorded from no N fertilizer application (Table 7). In the case of inoculation the highest net benefit (5851.88 ETB ha^{-1}) was obtained from inoculated treatment while the lowest net benefit (4827.47ETB ha^{-1}) from the non inoculated treatments. The highest net benefit of (5993.32 ETB ha^{-1}) was obtained from application of 25 kg P ha^{-1} while the least net benefit (4450.41ETB ha^{-1}) was from no P fertilizer application (Table 7).

Dominance analysis showed that there were no dominated N fertilizer and inoculation levels while among P fertilizer rates, 50 and 75 kg P ha^{-1} were dominated. Phosphorus rate of 25 kg P ha^{-1} was better than no P application and P level of 75 kg P ha^{-1} was better than 50 kg P ha^{-1}. It indicates that the value of the increase in yields of the dominated treatments is not enough to compensate for the increased costs and gave lower net benefits as compared to the net benefit obtained by application of P fertilizer with lower total costs that vary. Therefore, no one would choose technology that incurs additional costs with lower net benefits; the dominated treatments were, therefore, eliminated from further analysis.

Marginal analysis revealed that application of 46 kg ha^{-1} N fertilizer, inoculation and P fertilizer application at the rate of 25 kg ha^{-1} gave marginal rate of return (MRR) extremely above the minimum acceptable rate of return (100%). Marginal rate of return for nitrogen and phosphorous resulted in values above the minimum rate of return recommended.

In this experiment, the marginal rate of return for changing from no N fertilizer application to 46 kg N ha^{-1} was 883.1% (Table 7). This means that for every ETB a farmer invests he or she earns 8.831ETB. Moreover, the marginal rate of return in changing from no P fertilizer application to 25 kg P ha^{-1} was 153.2% (Table 7). Hence, it could be suggested that it is advisable to use on P fertilization of 25 kg P ha^{-1} as long as the return to each extra unit invested which was higher (153.2%) than the cost of extra unit invested (100%). Therefore, nitrogen fertilization at the rate of 46 kg N ha^{-1}, inoculation and P fertilization at the rate of 25 kg P ha^{-1} was economically the most feasible options for soybean production in this study. Regarding inoculation, since there was no significant difference for grain yield between inoculated and non inoculated treatments. Inoculation with the suitable strain or checking viability of the strain before conducting the experiment is preferred.

Table 7: Partial Budget Analysis of Nitrogen, Inoculation and Phosphorous Fertilizer Application on Soybean

Treatments	Adjusted yield (t/ha)	Gross Field benefit (ETB/ha)	Total variable cost (ETB/ha)	Marginal cost (ETB/ha)	Net benefit (ETB/ha)	Marginal benefit (ETB/ha)	Marginal rate of Return MRR (%)
Nitrogen (N kg ha^{-1})							
0	0.776	3880	1653.8		3714.63		
46	1.257	6285	1923.1	269.3	6092.7	2378.07	883.1
Inoculation							
Non inoculated (I_0)	0.984395	4921.973	945		4827.47		
Inoculated (I_1)	1.208503	6042.516	1906.4	961.4	5851.88	1024.41	106.6
Phosphorus (P kg ha^{-1})							
0	0.904781	4523.906	735		4450.41		
25	1.233506	6167.531	1742.1	1007.1	5993.32	1542.91	153.2
50	1.041058	5205.291	1909.2		5014.37d		
75	1.20645	6032.25	2076.3		5824.62d		

Note: 'd' represents dominance and MRR indicates marginal rate of return, 'ETB' Ethiopian Birr
Out put price = 5 ETB kg^{-1}
Input price:
Cost of N fertilizer = 6.55 ETB kg^{-1}
Cost of inoculant =335ETB ha^{-1}
Cost of P fertilizer = 8.59 ETB kg^{-1}

IV. Summary and Conclusion

Growing soybean by application of NP fertilizer and bradyrhizobium inoculation could make an important contribution to increase agricultural production and productivity in areas like Jinka district where there is low practice of using inorganic fertilizers and inoculation. To this end, NP fertilizer rate and bradyrhizobium inoculation of soybean could be one of the alternatives to improve productivity by small farmers. However, the agronomic management and efficiency of NP fertilizer rate and bradyrhizobium inoculation is not studied in the area. Thus, this research work is initiated to investigate the impact of NP fertilizer rates and bradyrhizobium inoculation on the performance of soybean.

A field experiment was conducted at Jinka Agricultural Research Center, 5^{o}52' N latitude and 36^o 38' E longitude, during 2008 cropping season to investigate the effect of NP fertilizers rate and inoculation on soybean yield and yield components.

The results discussed in the preceding sections have indicated that application of nitrogen fertilizer showed significant variation on some of the observed characters including phenology, growth parameters, yield and yield components. Longer duration for days to flowering, pod setting and maturity were recorded for 46 kg N ha^{-1} compared to no N application indicating a delay in development. Greater values of plant height and leaf area index were observed under N application at the rate of 46 kg N ha^{-1}. Nitrogen application at the rate of 46 kg ha^{-1} significantly improved grain yield and number of pods plant^{-1} compared to no application.

Inoculation significantly affected two of the developmental parameters namely, days to flowering and pod setting. Inoculated treatments had a longer duration of these phases compared to non inoculated ones. Inoculation significantly affected two of the yield components namely, seeds per pod and 100 seeds weight though the impact on grain yield was non significant. Inoculation significantly affected total biomass and harvest index.

Phosphorus fertilization significantly affected all the phonological parameters. Developmental phases were shortened as the level of P rose. Grain yield, number of pods per plant, number of seeds pod^{-1} and hundred seeds weight of soybean were significantly affected by phosphorous fertilization. P fertilization significantly increased grain yield though there was no significant variation among the upper three levels. The increase in grain yield was attributed to a higher number of pods per plant and seeds per pod.

The interaction effect of N by P and inoculation by P had significant effect on days to pod setting. Similarly, the interaction effect of inoculation by P had significant effect on harvest index.

Net benefit was varied in relation to nitrogen fertilizer application, inoculation and phosphorus fertilizer application. Higher net benefit was obtained from application of 46 kg N ha^{-1} (6092.70 ETBha^{-1}), inoculation (5851.88 ETB ha^{-1}) and phosphorus fertilizer application at the rate of 25 kg P ha^{-1} (5993.32 ETB ha^{-1}). Similarly, higher MRR% was obtained from application of 46 kg N ha^{-1} (883.1 %), inoculation (106.6%) and P application at the rate of 25 kg P ha^{-1} (153.2%), respectively. These MRR values are higher than the minimum acceptable rate of return (100 %) required for adoption and can therefore be taken into account and could be considered in recommendation domain. However, since the grain yield was not significantly different between inoculated and non inoculated treatments. It is better to use another suitable strain or to check the viability of the strain before planting. Based on the above findings, application of 46 kg ha^{-1} N fertilizer, inoculation with another suitable strain or checking the viability of the strain before conducting the experiment and P fertilization at the rate of 25 kg P ha^{-1} could be considered as an alternative by small farmers of the experimental area for increasing productivity of soybean. However, there is a need to repeat the experiment to account for weather variability preferably by including the other growing season (March to June).

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