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The economic importance of effective Rhizobial nodulating and yield of Soybean (*Glycine max* L.) at Assosa Western Ethiopia

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ABSTRACT

A field experiment was conducted on Nitisols of Asossa Agricultural Research Centre during the 2016/17 to 2017/2018 cropping season to investigate the effect of rhizobia nodulation on yield and yield components of soybean. The rhizobia and inorganic phosphorous fertilizer treatments considered in the study consisted of three rhizobia strains and three rhizobia strains plus phosphorous fertilizer including one. The treatments consist of negative control (T1), rhizobia MAR-1495-SB, (T2), rhizobia SB12 (T3), TAL 379 (T4), rhizobia MAR-1495-SB+50kg DAP (T5), rhizobia SB12+50kg DAP (T6) and Rhizobia TAL 379 +50kg DAP (T7). The treatments were laid out as a Randomized Complete Block Design with three replications. The analysis of variance revealed that rhizobia had non-significantly (P >0.05) affected grain yield. The maximum (2187.9 kg ha^{-1}) grain yield was recorded from rhizobia MAR-1495-SB bio-fertilizer at Asossa district. The application of MAR-1495-SB rhizobia biofertilizer had the highest net benefit of 26,094.8 ETB, followed by rhizobia MAR-1495-SB+50kg DAP biofertilizer which also had a total of 23,518.6 ETB net benefit at Asossa district. The application of MAR-1495-SB rhizobia bio-fertilizer had the highest net benefit. Therefore, we recommended the treatment MAR-1495-SB rhizobia since it produced a high marginal rate of return, high net benefit and relatively small total cost of production, for soybean production in the Asossa area.

KEY WORDS: *Rhizobia*; *Inoculant*; *Strain*; *Net Benefit*; *Marginal rate of return*

1. Introduction

The Leguminosae is one of the most important and largest plant families and is composed of about 750 genera containing 16,000–19,000 species distributed worldwide. Leguminosae has major impacts on agriculture, the environment, animal/human nutrition, and health, of which soybean is one of the world's most important and miraculous pulse crops. It accounts for 29.7% of the world's processed vegetable oil and is rich in dietary protein both for human food and animal feed (Graham and Vance, 2003). In Ethiopia, the area allocated for soybean and the corresponding total annual production has been 31,876 ha and 63,653 tons, respectively, with a productivity less than 2 ton ha^{-1} (CSA, 2012), while the potential soybean yield has been estimated to be in the range of 6 – 8 tons ha^{-1} in USA (Cooper, 2003). Biological nitrogen fixation (BNF) and mineral soil or N fertilizers are the main sources for meeting the N requirement of high-yielding soybean varieties. BNF is an effective and efficient source of N supply to plants under

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favorable atmospheric and environmental conditions (Chen *et al*., 2002). More than 50–83% of the necessary N requirement for soybean can be derived from BNF (Schipanski *et al*., 2010) by symbiotic association with either the genus *Bradyrhizobium* or *Sinorhizobium*. Several research findings clearly showed that soil nitrate repressed nodulation and the effect was magnified as soil nitrate concentrations increased (Hungria *et al*., 2006). BNF is very useful for smallholder farmers as it is cost-effective, environmentally friendly, meets the N requirement of the legumes and reduces the N demand of the succeeding crops. Inoculation with compatible and effective rhizobia may be necessary to optimize the nitrogen fixation and hence legume grain yields, where a low population of native rhizobial strains predominates (Mastrodomenico and Purcell, 2012). Therefore, evaluation and identification of appropriate and effective rhizobial strains are crucial to enhance nitrogen fixation and yield of soybean.

In the present investigation, therefore, the influences of soybean maturities group and effectiveness of *Bradyrhizobium* spp., in soil with high N and having no rhizobial association with soybean were thoroughly examined under greenhouse and field conditions using drip irrigation. This research work hypothesized that high soil N decreases the effectiveness of *Bradyrhizobium* sp. inoculation in medium-maturing soybean genotypes but may not be observed with late-maturing soybean genotypes. Therefore, the specific objective of this piece of research work was to evaluate the influence of symbiotic effectiveness of isolates of *Bradyrhizobium* spp on the soybean at the nitosol of Asossa.

2. Material and Methods

2.1 Description of the study area

The study was conducted at the Assosa Agricultural Research Center which is located in Assosa District in the Benishangul-Gumuz Regional State. The Benishangul-Gumuz Regional State is located in the western part of Ethiopia between 9°30' to 11° 39" N and 34° 20' to 36° 30" E covering a total land area of 50,000 square kilometers (km^2). The Assosa District is characterized by hot to warm moist lowland plain with a uni-modal rainfall pattern. The rainy season starts at the end of April and lasts at the end of October with a maximum of June, July, August and September. The total annual average (2007-2014) rainfall is 1316 mm. The annual mean minimum and mean maximum temperatures of the District for the periods from 2007 to 2014 are 16.75 and 27.92 °C, respectively.

2.2 Experimental treatments and design

The treatments consisted of six rhizobial strains (Strain MAR-1495, Strain SB12, TAL 379, Strain MAR-1495 + 50kg TSP, Strain SB12+50kg TSP, TAL 379 +50kg TSP) and control (without any fertilizer). The experiment was laid out as a randomized complete block design (RCBD) with a replicated three times. The plot size was 3m×4m and the spacing of between rows and between plants 60cm and 5cm, respectively. The blocks were separated by a 1.5m wide open space whereas the plots within a block were separated by a 0.75m wide space. Soil bunds were constructed around each plot and around the entire experimental field to minimize nutrient, water movement, and cross-contamination from plot to plot. Weed control was achieved manually by hand picking. Crop growth was then monitored until harvest.

2.3 Soil sampling and preparation

Before the field experimentation, ten random samples (0-20m depth) were collected and composite soil samples were prepared. These composite samples were used for soil physical and chemical analysis. Similarly, post-crop harvest soil samples were collected plot-wise from each replication from the surface 0-20 cm depth for selected soil chemical analysis. The soil samples were air dried, sieved to pass through a 2 mm sieve, and placed in labeled plastic bags.

2.4 Sources of seeds and inoculum

The soybean genotype used for this study was provided by the Asossa Agricultural Research Center, Ethiopia, which has been approved to be superior under Asossa field conditions. One soybean genotype, which was late maturing (Belsa 95), was used for the field experiment. Rhizobial isolates, namely *Bradyrhizobium japonicum* (TAL-379 isolate), MAR 1495 isolate and SB12 isolate were used as inoculants. These isolates were obtained from Holleta Agricultural Research Center (UK- isolate) and National Soil Research Center in Addis Ababa (TAL-379 isolate).

2.5 Plant data collection and analysis

Central row plants were used for data collection. Growth-indicating parameters such as plant height, number of seeds per pod number of pods per plant and grain yield were collected. The plant height (cm) was measured from the base of the plant to upper the top most leaves of the plant. The data was taken from five randomly selected plants a few days after the fully filled seed. Five plants from the central rows were randomly taken to count the number of nodules per plant. The number of pod per plant and number of seed per pod was computed from five plants. For the number of seeds per pod, five plants and from each five randomly selected seed per pod was recorded. Finally, after threshing the soybean, the grain yield from five plants was recorded and grain yield per hectare was calculated. The grain yield was adjusted at 11.5% grain moisture content.

2.6 Partial budget analysis

The mean grain yield of the selected treatment was used in the partial budget analysis (CIMMYT, 1988). Economic analysis was performed to investigate the economic feasibility of the treatments (fertilizer rates). A partial budget, dominance and marginal analysis were used. The average open market price (Birr kg^{-1}) for ground nut and the official prices of Urea and biofertilizers were used for economic analysis. The dominance analysis procedure as detailed in CIMMYT (1988) was used to select potentially profitable treatments from the range that was tested. The selected and discarded treatments using this technique are referred to as undominated and dominated treatments, respectively. The undominated treatments were ranked from the lowest (the farmers' practice) to the highest-cost treatment. For each pair of ranked treatments, a percent marginal rate of return (MRR) was calculated. The percent MRR between any pair of undominated treatments denotes the return per unit of investment in fertilizer expressed as a percentage.

2.7 Statistical data analysis

Analyses of variances for the data were recorded and conducted using the SAS GLM procedure (SAS 1998). Least significant difference (LSD) test at 5% probability used for mean separation when the analyses of variance indicate the presence of significant differences.

3. Results and Discussion

3.1 Soil Physical and Chemical Properties

According to the laboratory analysis, the soil texture of the experimental area is clay (Table 1). Maize usually grows well under good soil conditions. A fertile, medium textured, sandy or clay loam and alluvial soils of good fertility with optimum soil pH of 5.5 to 7 soil usually is best (Barrow, 2017). The pH of the soil is 6.2, which is moderately acidic. According to Sharma *et al*. (2015), this value is considered to be a low pH value. At low pH values, phosphate ions combine with iron and aluminum to form compounds, which are not readily available to plants.

However, Miller and Donahue (1997) indicated that plants grow well between pH 5.5 and pH 8.5. Maize response to applied P depends on soil acidity, soil OM level and clay content. Clay content affects the interpretation of soil test values obtained by extraction, and values for clay soils will likely be very different from those for sandy soils. Therefore, P fertilizer recommendations will depend on soil texture (Abdulaziz, 2013). The CEC of the soil of the experimental site is 22.6 cmol kg^{-1} of soil. According to Landon (1984), this value lays in the lower range (15-25 cmol kg^{-1}), which means the soil is not satisfactory for agricultural production. Further, the analysis indicated that the experimental soil has values of 0.29%, 2.46%, 11.5 ppm and 0.1443 mill-equivalents/100g soil for total N, OM, available P, and exchangeable K, respectively (Table 1). When the results of the analysis are compared with the broad ratings made by Metson (1961), the values lie in the lower range for plant growth except for total N and available phosphorous.

3.2 Seed yield of soybean and yield components

Analysis variance of two locations revealed that non-significant difference ($P < 0.05$) due to the application of treatments for the means of seed yield. Mean grain yield was non-significantly ($P < 0.05$), however, enhanced by 55.7% with the application of strain MAR1495, 24.5 % with the application of strain TAL365 and 18.1 with the application of strain SB12 over zero-strain or -ve control (Table 2). However, there was no significant difference observed between strains

Table 1: Major soil chemical characteristics of the experimental site

Sl. No.	Soil Character	Values	Remark
1	Soil pH (by 1:2.5 soil water ratio)	6.2	Moderately Acidic
2	Total Nitrogen (%)	0.29	High
3	Organic matter content (%)	2.46	Moderate
4	Available phosphorous (ppm)	11.5	High
5	Cation exchange capacity (cmol (+) kg^{-1})	22.6	Low
6	Exchangeable potassium (meq/100 g soil)	0.1443	Very Low
7	Soil texture		
	Clay (%)	59.4	
	Sand (%)	30.5	
	Silt (%)	10.1	
	Textural class	Clay	

Table 2: Evaluation of strains on yield and major yield determinant parameters of soybean at Asossa zone of Benshal-gul Gumuz

Treatments	PH (cm)	PPP	SPP	GY (kg)
Control	68.2	18.9	2.5	1404.6
Strain MAR-1495	64.9	21.5	2.5	2187.9
Strain SB 12	66.7	22.4	2.4	1714.1
TAL 379	68.2	20.7	2.5	1748.5
Strain MAR-1495 + 50 kg DAP ha^{-1}	67.3	19.6	2.4	2025.3
Strain SB 12+ 50 kg DAP ha^{-1}	65	19.1	2.5	1764.8
TAL 379 + 50 kg DAP ha^{-1}	68.4	20.3	2.5	1705.1
LSD	8.3	6.7	0.3	584.1
F-test	NS	NS	NS	NS
CV%	7	18.5	7.37	18.3

**= P<0.01, *=P<0.05 and NS = Non Significant at P>0.05, PH = Plant height, PPP = Number of pod per plant, SPP = Number of seed per pod, GY = Grain yield

MAR1495, SB12, TAL365 and zero strain.

This study is non-consistent with the result of Rugheim and Abdelgani (2012), who reported that inoculation of rhizobia strains significantly increased faba bean yield. Desta *et al*. (2015) also confirmed that application of effective rhizobia strains alone and/or in combination with zinc significantly increases faba bean yield. The report by Youseif *et al*., 2017 also shows that application of effective strains increases faba bean grain yield by up to 44-47%. The highest grain yield of 2187.9 kg ha^{-1} was recorded from the plot that received strain MAR1495 and it was at par with Strain MAR-1495 + 50 kg DAP ha^{-1}. The lowest grain yield of 1404.6 kg ha^{-1} was recorded in from a zero strain plot or plot that no received any things. Antenah (2014) has also described that, soybean plants treated with the UK isolate inoculation produced the highest total biomass yield, exceeding the total biomass yield produced by plants in the control treatment by about 47.3%. In line with Tahir *et al.* (2009) reported that combined application of rhizobia inoculation and phosphorous application resulted in 21% increased grain yield.

Based on the present findings, it can be concluded that despite the availability of adequate soil N, symbiotic N does, indeed, increase yield in late-maturing soybean genotypes. Treatment Strain SB 12+ 50 kg DAP ha^{-1} had the lowest number of pods per plant among inoculation treatments, but this was not significantly (P>0.05) different from Strain MAR-1495, Strain SB 12, TAL 379, Strain MAR-1495 + 50 kg DAP ha^{-1}, TAL 379 + 50 kg DAP ha^{-1} and the control (Table 2). Treatment Strain SB 12 had the largest number of pods per plant, but this was comparable with yields of treatments Strain MAR-1495, TAL 379, Strain MAR-1495 + 50 kg DAP ha^{-1}, TAL 379 + 50 kg DAP ha^{-1} (Table 2).

3.3 Partial budget analysis

The increased production of the crop due to the application of inputs might or might not be beneficiary to farmers (CIMMYT, 1988).

Therefore, partial budget analysis (CIMMYT, 1988) was employed to estimate the net benefit, dominance analysis and marginal rate of return that could be obtained from various alternative treatments (CIMMYT, 1988). The MAR 1495-SB rhizobia had the highest net-benefit of 26,094.8 Ethiopian birr, followed by Strain MAR-1495-SB + 50 kg DAP ha^{-1} rhizobia which also had a total of 23,518.6 Ethiopian birr net benefit. The lowest net benefit was obtained by the application of the Negative control and TAL 379 inoculant + 50 kg DAP ha^{-1} with net benefit of 16,855.2 and 19,676.2 ETB the respectively (Table 3).

The profitability of the study showed that application of MAR 1495-SB rhizobia which provided the relatively highest net benefit (26,094.8 ETB), was recommended to apply bio fertilizers. The highest net benefits from the application of inputs for the production of the crop might not be sufficient for the farmers to accept as good practices. In most cases, farmers prefer the highest profit (with low cost and high income). For this purpose it is necessary to conduct dominated treatment analysis (CIMMITY, 1988).

The dominance analysis showed that the net benefits of all treatments were dominated except application of MAR 1495-SB and MAR-1495-SB + 50 kg DAP ha^{-1}. The % MRR between any pair of undominated treatments denotes the return per unit of investment in fertilizer expressed as a percentage. Economic analysis revealed that maximum marginal rate of return was recorded with application of MAR 1495-SB (5774.5). The marginal rate of this treatment was well above the 100% minimum (CIMMYT, 1988). Accordingly, the study revealed that application of MAR 1495-SB was considered as the best for recommendation. The best recommendation for treatments subjected to marginal rate of return is not necessarily based on the highest marginal rate of return, rather based on the minimum acceptable marginal rate of return and the treatment with the highest net benefit, relatively low variable cost together with an acceptable MRR becomes the tentative recommendation (CIMMYT, 1988).

4. Conclusion

In recent years, crop productivity in Ethiopia in general and in Benshal-gul Gumuz region in

Table 3: Economic and Partial budget analysis of bio-fertilizer and inorganic fertilizer

Treatments	GY (kg)	VC	TGR (ETB ha^{-1})	NB (ETB ha^{-1})	MRR%
Control	1404.6	0	16,855.2	16,855.2	0
Strain MAR-1495-SB	2187.9	160	26,254.8	26,094.8	5774.5
Strain SB 12	1714.1	160	20,569.2	20,409.2	D
TAL 379	1748.5	160	20,982	20,822.0	D
Strain MAR-1495-SB + 50 kg DAP ha^{-1}	2025.3	785	24,303.6	23,518.6	497.5
Strain SB 12+ 50 kg DAP ha^{-1}	1764.8	785	21,177.6	20,392.6	D
TAL 379 + 50 kg DAP ha^{-1}	1705.1	785	20,461.2	19,676.2	D

Note: Prices: Urea= 8.24 birr kg^{-1}, TSP=12.75 birr kg^{-1}, Price of soybean=12 birr kg^{-1}, Seed=15 birr kg^{-1}and Labor cost =30 birr/ person/day for 8 hours, TC=Total cost, Gross return (Return from Grain) = Price /kg* yield in kg and Net return = Gross return – Total cost, VC = Variable cost, GR= Growth return, TGR = Total growth return from grain, NB = Net benefit particular has shown a declining trend, in spite of the best use of improved varieties. The most possible causes of this decline soil fertility depletion and the continuous use of the traditional fertilizer, which have limited the yield and crop quality. Therefore this experiment was designed for the purpose of evaluated the rhizobial strain types and inorganic P for soybean under field condition of Asossa District. The rhizobia strain on nodulation parameters had highly significant difference ($P < 0.001$), however there was no significant differences ($p > 0.05$) between the rhizobia strain and rhizobia strain plus inorganic phosphorus fertilizer on grain yield. Accordingly, the study revealed that application of Strain MAR-1495 as the best strain recommended agronomical for soybean production at Assosa area. For all parameters the Strain MAR-1495 rhizobial strain alone increased yield and yield components as compared with 1495 + 50 kg DAP ha^{-1}. A substantial increase in nodulation directly affected growth and yield due to the N_2 fixation potential of soybean. Application of rhizobium inoculation alone also increased nodulation, growth and yield of soybean because of high ppm-P (phosphorous availability) of the study area during experimentation. The profitability of the study showed that MAR 1495-SB strain which provided the relatively highest net benefit (26,094.8 ETB), was the best strain for Asossa district. The best recommendation for treatments subjected to marginal rate of return is not necessarily based on the highest marginal rate of return, rather based on the minimum acceptable marginal rate of return and the treatment with the high net benefit, relatively low variable cost together with an acceptable MRR becomes the tentative recommendation. Therefore economically we recommend the treatments MAR 1495-SB that have acceptable marginal rate of return, relatively high net benefit and relatively small total cost of production for soybean production at Asossa district. It can be recommended to demonstrate Strain MAR-1495 rhizobial strain to increase productivity and sustainability of soybean for study area and similar agro-ecology with its area.

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