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On-farm verification of elite soybean rhizobial inoculant and nutrient integrations across the acidic soil areas of Asossa, Western Ethiopia

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Abstract: Soil fertility depletion and acidity are critical issues for soybean production in western Ethiopia. Biofertilizers and inorganic fertilisers can improve crop productivity and soil health. Tests were conducted on farms using elite soybean rhizobial inoculant and nutrient integrations in acidic soil. Results showed that the application of differentiated application (N + TSP + Inoculant) was the best fertiliser combination for soybean production in the Assosa area. The study found that the differential application yielded the maximum amount of seed yield (1410.1 kg ha-1). However, it was not significantly different from other treatments. The study also found that rhizobium inoculation alone also increased soybean seed yield, possibly at a medium level of phosphorous availability in the area.

Keywords: Soybean, Rhizobial inoculant, Nutrient integration, On-farm verification
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INTRODUCTION

Background

Low soil fertility is one of the bottlenecks to sustaining agricultural production and productivity in Ethiopia. Continuous nutrient depletion and low soil fertility have not only led to the development of integrated soil fertility management technologies that offer the potential for improving soil fertility in Africa (Tilahun, 2003), but almost simultaneously caused extensive studies on nutrient balance in various African farming systems. The application of inorganic fertiliser is intended to increase crop yield, but it has become a chronic problem due to its cost and the deterioration of soil physical, chemical, and biological properties. Additionally, inorganic fertilisers often fail to achieve long-term productivity on many soils due to their ineffectiveness in maintaining soil fertility. Researchers have recognized the application of biofertilizers as an effective method to enhance soil aggregation, structure, and fertility, boost microbial diversity and populations, enhance soil moisture-holding capacity, boost the soil cation exchange capacity (CEC), and boost crop yields (Hargreaves et al., 2008).

Application of biofertilisers along with inorganic fertilisers into the soil leads to an increase in productivity of the crop and sustains the soil health for a longer period of time (Manna et al., 2007). Rhizobia is one of the dominant symbiotic nitrogen-fixing bacteria with legumes, but a number of factors lead to poor nodulation and nitrogen fixation in legumes. High-yielding soybean varieties primarily meet their N requirements through the application of biofertilizer, biological nitrogen fixation (BNF), mineral soil, or N fertilisers. BNF is an effective and efficient source of N supply for plants under favorable atmospheric and environmental conditions (Chen et al., 2002). By symbiotic association with either the genus Bradyrhizobium or Sinorhizobium, BNF can provide more than 50–83% of the necessary N requirement for soybean (Schipanski et al. 2010). Several research findings clearly demonstrated that soil nitrate repressed nodulation, with the effect intensifying 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 nitrogen fixation and, hence, legume grain yields, where a low population of native rhizobial strains predominates (Chianu et al., 2011). Therefore, the evaluation and identification of appropriate and effective rhizobial strains are crucial to enhancing nitrogen fixation and yield in soybeans. Therefore, the research work aimed to confirm the promising performance of elite soybean rhizobial inoculants in their interaction with various nutrient inputs, particularly in terms of grain and biomass yield.

MATERIALS AND METHODS

Description of the Study Area

The Assosa Agricultural Research Centre, located in the Assosa District of the Benishangul-Gumuz Regional State, conducted the study. 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 kilometres (km2). The Assosa District is characterized by a hot-to-warm, moist lowland plain with a unimodal 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 (2010–2015) rainfall is 1316 mm.

Experimental treatments and designs

Each farm randomly selects and replicates the six treatments. Plots are replicated on a farm. The Asossa Agricultural Research Centre, Ethiopia, provided the soybean genotype for this study, deemed superior under Asossa field conditions. One soybean genotype, which was late maturing (Belsa 95), was used for the field experiment. Rhizobial isolates, MAR 1495 isolate, and SB12 isolate were used as inoculants. These isolates were obtained from Holleta Agricultural Research Center. The preparation of the RI followed Abere et al. (2019), while the application of both types of inoculants adhered to Getahun et al. (2018). The phosphate sources will be applied at a rate of 46 kg P2O5 ha-1 and at planting time, respectively. The rate of the rhizobial biofertilizer will be 10 g kg1 of seed.

Locally adapted soybean variety seeds of Belesa-95 were planted at a 60 kg/ha rate, with inter-row spacing of 60 cm and within-row spacing of 5 cm. Rows will be 5 m long, and there were 10 rows per plot. Plots were separated by 1 to 1.5 m just to limit the chance of contamination from one plot to another. A border space of 1.5 m in width was left along the length and width of the trial site. The remaining agronomic management was applied uniformly to all plots according to the local recommendations.

Seeds were drilled at 3-5 cm depth and gently covered with soil. 15 days after germination, we thinned the seedlings to 5 cm between plants within rows to reach the optimum plant density per hectare. During planting, we drilled phosphorus fertilisers along the cropping rows.

Treatment and lay outs

S/N	Treatments Name	Remark
1	Negative control	No fertilizer
2	TSP alone	46kg P_2O_5/ha
3	Inoculant alone	10g /kg of seed
4	TSP + Inoculant	46kg P_2O_5/ha +10g /kg of seed
5	Recommended local practice (NPS + inoculant)	121kg NPS/ha (23/46/9 N/ P_2O_5/S) +10g /kg of seed
6	Differentiated application (N + TSP+ Inoculant)	23kg N + 46kg P_2O_5/ha + 10g /kg of seed

Note: The rhizobial inoculants will bee ither MAR-1495/SB-Murd or SB-12.

Site selection

The current study was conducted at on-farm conditions in the Asossa zone, where soybean is dominantly produced. The demo and trial execution kebeles/villages were differently selected. Commercial or soybean-growing company farms, as well as farmer training centres (FTCs), were considered during the selection. In collaboration with local development agents, we selected a total of 10 farms with no-inoculation history, non-steep slope, agro-ecological diversity, and pH 5 to 6.. Ten farms each represented the Assosa clusters. The selected farms were geo-referenced, and pre-plant surface (0-20 cm) soil samples were composited from 20 auger holes/farm and brought to the laboratory for the determination of selected parameters like Total N, available phosphorus, organic matter, and cation exchange capacity following Nelson and Sommers 1973, Bray and Kurtz 1945, Walkley and Black 1934, and Van Reeuwijk 2002, respectively. Soil pH was measured in the supernatant suspension of a 1:2.5 soil and water mixture by using a pH meter.

Plant Data Collection and Analysis

Data collection involved the use of central row plants. Growth-indicating parameters such as plant height, number of seeds per pod, number of pods per plant, and grain yield were collected. The grain yield was adjusted at 11.5% grain moisture content. All the above-ground biomass from a 2 sq m sub-plot area (random quadrant) was harvested and weighed to get the field biomass weight and converted to hectare bases (kg/ha). After threshing and winnowing the biomass, we collected all the harvested grains into a sack, weighed them (adjusted to 11.5% moisture), and converted them into hectare bases (kg/ha). 1000 grains will be randomly sampled from each treatment and weighed.

Field Day

In the field day and experience sharing, farmers, development agents (DAs), experts, heads of agricultural and rural development offices, and researchers participated. Finally, we organized field days in the fields of beneficiary farmers to assess the vermicompost's performance and final outputs, and to share the lessons learned with various stakeholders. During the field days, participants included farmers, development agents (DAs), experts, heads of agricultural and rural development offices, Woreda administrators, researchers from the Asossa Agricultural Research Centre, and other stakeholders from Bambasi.

Soil Sampling and Analysis

The chemical properties studied included pH, CEC, exchangeable acidity, exchangeable bases (Ca, Mg, Na, K), organic carbon, total nitrogen, and availability of P. Carter (1993) described the process of determining soil pH using a pH meter with a combined glass electrode in water (H2O) at a soil:water ratio of 1:2.5. Organic carbon was determined by oxidising carbon with potassium dichromate in a sulphuric acid solution following the Walkley and Black method (1934). Finally, we calculated the soil's organic matter content by multiplying the organic carbon percentage by 1.724. The total nitrogen contents in soils were determined using the Kjeldahl procedure by oxidising the organic matter with sulphuric acid and converting the nitrogen into NH4+ as ammonium sulphate (Sahlemedhin and Taye, 2000). Mclean (1965) described saturating the soil samples with potassium chloride solution and titrating them with sodium hydroxide to determine exchangeable acidity. Olsen methods determined the available phosphorus. The Olsen procedure involved shaking the soil samples with 0.5 M sodium bicarbonate at a nearly constant pH of 8.5 in a 1:20 soil-to-solution ratio for half an hour, followed by filtering the suspension to obtain the extract, as suggested by Olsen et al. (1954). The ammonium acetate (1M NH4OAc at pH 7) extraction method estimated the exchangeable bases (Ca, Mg, K, and Na) in the soil. In this procedure, we extracted the soil samples with an excess NH4OAc solution, determined the Ca and Mg in the extracts using an atomic absorption spectrophotometer, and used a flame photometer to determine the contents of exchangeable K and Na, following Rowell's (1994) description. Soil cation exchange capacity (CEC) was measured after leaching the ammonium acetate extracted (ammonium ion standard) soil samples with a 10% sodium chloride solution.

Yield advantage % = Yield advantage of fertilized– Negative control of N X100

Negative control of N

Yield advantage of the demonstrated varieties was calculated using

Data analysis

The collected agronomic data was analyzed using descriptive statistics and excel. The grain yield and fruit weight data were analyzed using excel and presented using figures.

RESULT AND DISCUSSION

Soil Chemical Properties of the study area

The southern part of Ethiopia identified the extent of the soil fertility problem as an issue requiring urgent attention. Information on soil fertility status Understanding the impact of land use type on Ethiopian farmland area is crucial for the development of effective soil management systems that promote sustainable and improved agricultural productivity. The study area's pH value varied depending on the land uses and slope, as shown in Table 1. Franche 2009, classified pH values into five classes: strongly acidic < 5.5, moderately acidic 5.6-66.5, neutral 6.6-77.3, moderately alkaline 7.3-8.5, and strongly alkaline > 8.4. The soil in Table 5 categorizes the soil pH of the study area from 5.29 (strongly acidic) to 5.67 (moderately the most favorable pH for the availability of most plant nutrients corresponds roughly with the optimum range of 6 to 7 (Brook, 1983). The range of soil reactions in Mima Learning Watershed may limit crop production by influencing the availability of important plant nutrients. According to Landon (1991), a soil pH value below 5.5 may indicate the presence of a significant amount of exchangeable acidity and exchangeable Al+3, as well as the removal of exchangeable cations like calcium and magnesium. oil pH levels could also suggest a decrease in phosphorus availability due to the binding effects of Al and Fe. Similarly, the studied area's exchangeable acidity and exchangeable Al+3 value displayed irregularities (Table 1). Exchangeable acidity consists of any aluminium or iron, as well as any exchangeable H that may be present in the exchange sites (Bohn et al., 2001).

Table. 1: Soil chemical properties of the studied area.

Location	PH	%OC	%OM	%TN	Pppm	CEC in Meq/100g	EA in Meq/100g
Farmer 1	5.51	1.07	1.84	0.072	9.04	9.89	0.4
Farmer 2	5.63	1.66	2.86	0.103	10.45	10.34	0.24
Farmer 3	5.67	1.83	3.15	0.098	11.37	10.45	0.16
Farmer 4	5.65	1.47	2.53	0.101	11.76	10.18	0.24
Farmer 5	5.52	1.23	2.12	0.103	8.20	9.34	0.48
Farmer 6	5.46	1.30	2.24	0.088	7.45	9.08	0.8
Farmer 7	5.39	1.16	2.00	0.078	6.72	8.39	0.96
Farmer 8	5.29	1.14	1.97	0.082	7.08	5.89	1.36

The limited available data indicated that the soil organic carbon revealed slight variation across farmers's fields. The soil %OC of the studied area varied from 1.07 (very low) to 1.87 (low) across the farmer's field. On the other hand, the soil %OC of the studied area was categorised from very low to low thought all farmers farm. Total nitrogen contents of the soils and %OM also showed the same trend as soil organic carbon. Therefore, the study soils are classified as having low to very low total nitrogen across the entire studied area. The very low organic carbon and low to very low total nitrogen content in the study area indicate low fertility status of the soil. This result is similar to Bekele et al. (2016c), who report very low OC and very low to medium N content of the Asossa area of Benshal-Gul gumuz, indicating low fertility status of the soil could be due to continuous cultivation and lack of incorporation of organic materials.

According to Landon (1991), an available (Olsen extractable) soil P level of less than 5 mg kg1 is rated as low, 5–15 mg kg1 as medium, and greater than 15 mg kg1 is rated as high. Thus, the available (Olsen extractable) P throughout the study area was at a medium level. The medium P content of the soils of study could be relatively related to P fixation by Al and Fe. Consequently, medium-level available P of the soils could form one of the major soil fertility-limiting factors in the study area as well as in the other similar environments of Asossa district. This is slightly similar to Getahun et al. (2016), who reported that most locations of Asossa wereda of the Benshagul-Gumuz Region had very low (bray II extractable) available phosphorous. Also, studies in Ethiopia indicate that Ethiopian agricultural soils, particularly Nitisols and other acidic soils, due to their inherently low P content and high P fixation capacity, have low available phosphorous contents (Yihenew, 2002).

Farmers' Field Day

As part of the intervention activities, training on verm-compost and earthworm was given to farmers, DAs, and experts. Finally, in order to evaluate the performance, share the lesson with different stakeholders' field days and experience sharing were organised in the fields of beneficiary farmers. In the field day and experience sharing, famers, development agents (DAs), experts, heads of agricultural and rural development offices, and researchers participated. The vermicompost demonstrated was compared based on farmers' preferences and the field data recorded and analysed by descriptive statistics. The participant farmers preferred vermin compost plus NPS fertiliser during the field day and their first choice.

List of participant on the day of field day								
Farmers			**Researchers**			**Expert and development agents**		
male	women	Total	male	Women	Total	Male	women	Total
20	10	30	4	1	7	7	3	10

Seed yield, Biomass yield and thousand seed weight of soybean as affected by different fertilizer sources.

Analysis variance of nine locations revealed that there were highly significant differences ($P < 0.01$) due to the application of treatments for the means of seed yield. However, Table 2 did not reveal any significant differences in the applications of different fertiliser combinations. The differentiated application of N + TSP + Inoculant outperformed the zero-strain or -ve control by 29.8% (Table 2). The differential application (N + TSP + Inoculant) resulted in the maximum seed yield (1410.1 kg ha-1). However, it was not significantly different from other treatments: T2, T3, T4, and T5. This study is consistent with the results of Rugheim AME and Abdelgani ME (2012), who reported that inoculation with Rhizobia strains significantly increased faba bean yield. Desta et al. (2015) also confirmed that the application of effective Rhizobia strains alone and/or in combination with zinc significantly increases the faba bean yield.

Table 1: Seed yield, Biomass yield and thousand seed weight of soybean as affected by different fertilizer sources.

Treatments	Seed yield kg ha^{-1}	Biomass yield kg ha^{-1}	Thousand seed weight g.
Control (No Fertilizer)	1085.9^{B}	3460.9^{B}	112.37
TSP alone	1330.3^{A}	4481.3^{A}	112.51
Inoculant alone (No fertilizer)	1306.9^{A}	4073.1^{AB}	115.29
TSP + Inoculant	1362.3^{A}	4370.7^{A}	111.29
Recommended practice (NPS + inoculant)	1364.1^{A}	4693.9^{A}	112.20
Differentiated application (N + TSP+ Inoculant)	1410.1^{A}	4617.3^{A}	115.62
LSD	170.75**	751.53*	NS
CV	11.94	16.97	4.94

The plot that received the recommended practice (NPS + inoculant) recorded the highest biomass yield of 4693.9 kg ha-1, which was comparable to strain-differentiated application (N + TSP + inoculant), TSP + inoculant, inoculant alone (no fertilizer), and TSP alone. A zero strain plot or a plot that received no treatment recorded the lowest biomass yield of 3460.9 kg ha-1. Antenah Argew (2014) also reported that soybean plants treated with the UK isolate inoculation yielded the highest total biomass, surpassing the total biomass yield of plants in the control treatment by approximately 47.3%. Tahir et al. (2009) reported that the combination of rhizobia inoculation and phosphorous application led to a 21% increase in grain yield. The treatment TSP + Inoculant had the lowest weight of thousand seed (111.29 g), but this was not significantly ($P > 0.05$) different from all treatments and the -ve control (Table 2). The treatment-differentiated application (N + TSP + Inoculant) had the largest thousand seed weights (115.62 g), but this was comparable with yields obtained from all treatments.

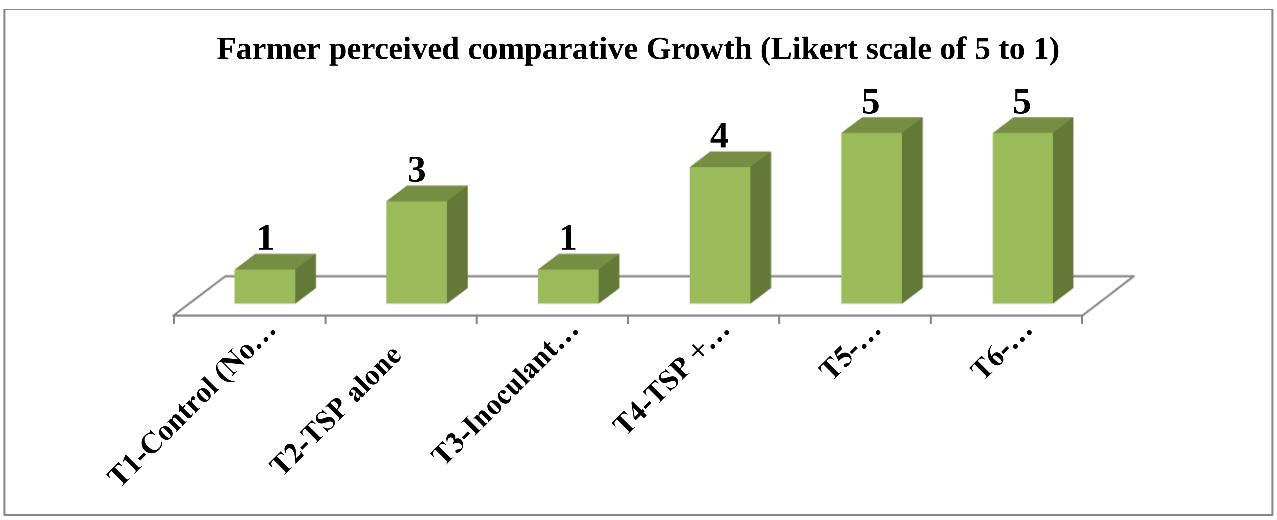

Figure 1: Farmers perception and scaled from scale 1 to scale 5.

Farmers perception and scaled from scale 1 to 5.

The total number of respondents selected for the study forms the sample size. We divide the total population into 5 strata based on sex and age. In order to get equal representation of all 38 respondents, Abramo and Bambasi were selected. A weighted average rank test helps rank the given data based on the mean values obtained for the responses. The participating farmers from both wereda (Bambasi and Abramo) ranked the negative control and the plot that received only inoculation on a scale of 1, indicating their strong disagreement with the negative control and the plot that received only inoculation. On the other hand, the farmers strongly agreed with the plot that received the recommended local practice (NPS + inoculant) and the differentiated application (N + TSP + inoculant), ranking it at scale 5. This could potentially be attributed to the contribution of microorganisms, whose microbial activity enhances the availability of nutrients for plants. For natural and ecofriendly farming practices that maintain the soil structure and biodiversity, we highly recommend the application of integrated inorganic and organic fertilisers (biofertilisers).

Recommendation and conclusion

The main issues with the soil's chemical properties that were studied are low to medium levels of basic cations (Ca, Mg, K, and Mg); low to medium levels of available P could be because Al and Fe fix P; very low levels of organic carbon and medium to very low levels of total nitrogen in the study area show that the soil is not fertile. Given these limitations, we suggest that the recommended soil management practices and approaches enhance soil chemical properties through the application of basic materials such as vermin-compost, biofertilizer, compost, farmyard manure, and lime. Similarly, the farm should determine crop residue management strategies and the complementary use of organic and inorganic materials to enhance soil productivity. Additionally, it is crucial to conduct periodic soil tests at the site to accurately monitor the soil fertility indices and prevent any potential decline or degradation of soil fertility. We need to amend the low TN and OC contents in the soils through N-fertilizer management and the application of integrated nutrients management (INM).

The most probable causes of this decline are the depletion of soil fertility and the continuous use of traditional fertilisers, which have limited the yield and crop quality. Therefore, we designed this experiment to evaluate different fertiliser sources (organic and inorganic, and their combinations) for soybeans under the field conditions of Asossa District. The application of treatments had a highly significant difference (P< 001) on seed yield of soybean; however, there were no significant differences ($p > 0.05$) among treatments observed on thousand seed weight. Therefore, the study concluded that a differentiated application of N + TSP + Inoculant was the most effective fertiliser combination for soybean production in the Assosa area, taking into account the farmers' scale and the yield data analyzed. However, there were no significant differences ($p > 0.05$) among all treatments except the negative control. The application of rhizobium inoculation alone also increased the seed yield of soybeans, potentially reaching a medium level of ppmP (phosphorous availability) in the study area during the experimentation period. We recommend using a differentiated fertiliser combination (N + TSP + inoculant) to boost the productivity and sustainability of soybeans in the study area, ensuring a similar agro-ecology to the surrounding area. Additionally, based on farmer selection and yield data, farmers in the Asossa area could implement the recommended practice of using NPS + inoculant fertiliser sources in addition to the differentiated application of N + TSP + inoculant fertiliser combinations.

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