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Nodulation, Growth and Yield of Soybean [*Glycine max* (L.) Merrill] as Influenced by Biofertilizer and Inorganic Fertilizers in Assosa Zone, Western Ethiopia

Abiyot Abeje[1], Getachew Alemayehu[1], Tesfaye Feyisa[2]

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ABSTRACT

Background: The productivity of soybean in Assosa Zone particularly in Assosa and Bambassi districts is very low due to poor soil fertility management practices which resulted in severe soil acidity and low N-fixing inoculant in the soil. Hence, this experiment was conducted to evaluate the influence of biofertilizer and inorganic fertilizers on nodulation, growth and yield of soybean [*Glycine max* (L.) Merrill].

Methods: During the period 2019-2020 factorial combinations of four levels of biofertilizer inoculants [without inoculant (B1), SB12 inoculant (B2), MAR1495 inoculant (B3) and SB12 plus MAR1495 inoculants (B4); and four inorganic fertilizer types NP (F1), NPS (F2), NPB (F3) and NPSB (F4) at their recommended rates for soybean] were laid out in a randomized complete block design (RCBD) with three replications in Assosa and Bambassi districts, Assosa Zone, Western Ethiopia. Number of effective nodules per plant, leaf area index and grain yield were collected following the standard procedures and were analyzed using SAS software version 9.1.3 and significant mean differences were separated using Duncan's multiple range test (DMRT) at 5% significance level.

Result: Number of effective nodules per plant, leaf area index and grain yield were highly significantly ($P<0.01$) affected by the interactions of biofertilizer and inorganic fertilizers at both locations and years. Thus, the maximum grain yield (2621.67 kg) was obtained from (SB12+MAR1495) + NPSB at Assosa and the maximum grain yield (2460.20 kg) was obtained from SB12+NPS at Bambassi. Hence, (SB12+MAR1495) + NPSB and SB12+NPS are recommended for higher soybean grain yield for Assosa and Bambassi districts and similar agro-ecologies, respectively.

Key words: Effective nodule, Grain yield, Leaf area index, Productivity, Soil fertility.

INTRODUCTION

Soybean [*Glycine max* (L.) Merrill] is an economically important leguminous crop containing substantial amounts of essential amino acids, oil, minerals and vitamins and is regarded as a nutrient storage (Tefera, 2010). It is also the most important legume worldwide, which can be used for a variety of purposes including human food like soy milk, oil, animal feed and also for soil amelioration (Zinaw *et al*., 2013). Soybean has an average protein content of 40% and is more protein-rich than any of the common vegetable or animal food sources (Collombet, 2013). Soybean seeds also contain about 20% oil on a dry matter basis and this is 85% unsaturated and cholesterol-free (Dugje *et al*., 2009). It is highly industrialized in developed countries, providing more than a quarter of world's food (CSA, 2017). Globally, over 349.31 million metric tons of soybean was produced in 2016 with average productivity of 3.21 t ha^{-1}. From 349.31 million metric tons, USA accounts for 34% (leading producer), followed by Brazil (30%) and Argentina (18%) (USDA, 2017).

Soybean contributes nearly 10 per cent of total oil seeds production of Ethiopia and accounts for only 4 per cent of area planted under oilseeds. Recently, it has been a cash crop and earns a substantial amount of foreign currency contributing 15.7 million USD with the export of 34,264 metric ton in 2016 (CSA, 2017). Due to the increasing demand for soybean as a cash crop, the production has reached to 86,467.9 tons with average productivity of 2.271 t ha^{-1}. Despite the increasing demand for soybean as a cash crop in the country, the average productivity of soybean in Ethiopia is still below the world average productivity of 3.21 t ha^{-1} and its potential productivity which could go up to 4 t ha^{-1}, which may be related to poor soil fertility management practices (CSA, 2018). Poor soil management practices such as continuous cropping and continuous application of inorganic fertilizers resulted in nutrient mining and soil acidity as a result soybean productivity is still far below global averages (Zelleke *et al.,* 2010).

[1]College of Agriculture and Environmental Sciences, Bahir Dar University, Bahir Dar, Ethiopia.
[2]Amhara Agricultural Research Institute (ARARI), Bahir Dar, Ethiopia.

Corresponding Author: Abiyot Abeje, Department of Plant Science, College of Agriculture and Environmental Sciences, Bahir Dar University, Bahir Dar, Ethiopia. Email: abiyotabeje@gmail.com

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In addition, total production of soybean is still below the expected level and does not meet the countries oil demand and other soybean products. Due to this fact, still Ethiopia imported 522,000 metric tons of cooking oil, valued at nearly $530 million in the year 2017. Of this total money, import of soybean oil was of worth 15 million while that of soybean products it was nearly 11 million USD, while more than 87 per cent by volume was palm oil (CSA, 2018).

Soybean production is increasing in Western Ethiopia, driven by its high value for food, oil, feed, raw material for the newly established Agro Industry parks and its ability to improve soil fertility (Sinclair *et al*., 2014). Despite the increasing demand for soybean in Western Ethiopia, its average productivity (2.138 t ha^{-1}) in Assosa and Bambassi districts is very low compared to the national average productivity (CSA, 2018). The major factors which limit the productivity of soybean in Western Ethiopia particularly in Assosa and Bambassi districts are soil acidity, low/no presence of N-fixing *Bradyrhizobium japonicum* strains in the soil and poor soil fertility management practices (AsARC, 2017).

According to Assosa Agricultural Research Center (2017), most of the soils in Assosa and Bambassi districts are acidic with pH ranging from 5.2-6.0. Soil acidity in both districts affected legume-*Rhizobium* symbiosis (decreases legume nodulation) and availability of nutrients like N, P, S and B. Hence, poor growth and yield reduction occur as a result of inadequate nutrition (Tisdall, 1993). According to Zelleke *et al.* (2010), *Bradyrhizobium japonicum* strains found in the soil was very low in Assosa and Bambassi districts. Assosa Agricultural Research Center (2017) has also reported that there were poor soil management practices in Assosa and Bambassi districts as a result nutrient deficiencies have been observed. According to Asgelil (2000) most agricultural soils of the Western Ethiopia were deficient in nitrogen, phosphorus, sulphur and boron nutrients.

Furthermore, the combined use of these resources has not really been given much attention by researchers with respect to the production of soybean especially in the Western Ethiopia. The long-term use of inorganic fertilizers without biofertilizer inoculation reduces the productivity of soybean in Western Ethiopia (Zelleke *et al.,* 2010). According to Khaliq *et al.* (2015), degradation of soil as a result of repeated application of inorganic fertilizers to the farm land has been observed in Western Ethiopia. These problems make farmers not to meet soybean nutrient demand over large area. It is therefore justifiable to introduce integrated application of soil amendments such as biofertilizer and inorganic fertilizers in Assosa and Bambassi districts, Assosa zone, Western Ethiopia (Zinaw *et al*., 2013).

The combined application of *Bradyrhizobium japonicum* strains and inorganic fertilizers was found more effective in increasing the productivity of soybean (Abbasi *et al*., 2008). Marschner (1995) who reported that effective nodule number per plant was significantly affected by combined application of biofertilizer and inorganic fertilizer across the years. In addition, Mahmood *et al.* (2017) also reported that combined use of biofertilizers with inorganic fertilizers resulted in maximum leaf area index. Moreover, Kumar *et al*. (2005) reported that the maximum leaf area index was recorded from the application of 100% NPS with SB12 strain over the control. Bandyopadhyay *et al*. (2010) reported that greater leaf area index in combined application of NPS + SB12 was attributed to the production of new leaves and also increase in size of the existing leaves. Furthermore, Mishra *et al*. (2010) reported that leaf area index was significantly influenced by main and interaction of bio- and inorganic fertilizers. Dubey (1998) who obtained the highest soybean grain yield when the plant was inoculated with *B. japonicum strains* in combination with N, P, S and B fertilizers. Lourduraj (2000) has also reported that the combined application of' biofertilizers and inorganic fertilizers significantly enhanced the growth attributes and yield of' soybean as compared to the sole application of either of them. As a result, optimum amount of nutrient can be supplied through the integrated application of biofertilizers and inorganic fertilizers. Thus, this experiment was conducted to evaluate the effects of biofertilizer and inorganic fertilizers on nodulation, growth and yield of soybean in Assosa and Bambassi districts, Assosa Zone, Western Ethiopia.

MATERIALS AND METHODS

Descriptions of the experimental sites

The experiment was carried out for two years (2019-2020) during the main rainy season in Assosa and Bambassi districts, Assosa Zone, Western Ethiopia. Geographically, Assosa is located at 10° 02′ 05″ N latitude and 34° 34′ 09″ E longitude at an elevation of 1570 meter above sea level, while Bambassi is located at 9° 23′22″ N latitude and 34° 00′12″ W longitude (Fig 1) at an elevation of 1470 meter above sea level. Both experimental sites are characterized by hot humid agro-ecology having mono-modal rainfall distribution pattern, which starts at the end of April and extends to mid-November, with maximum rainfall received in June, to October. The mean annual rainfall during 2019 and 2020 cropping season in Assosa was 1221.7 mm and 1235.4 mm, respectively (Fig 2), while it was 1209.1 mm and 1226.2 mm at Bambassi, respectively (Fig 3). In addition, the minimum and maximum temperatures of Assosa in 2019 cropping season were 16.5°C and 27.5°C and in 2020 were 16.7°C and 27.9 °C, (Fig 2). Whereas, the minimum and maximum temperatures of Bambassi in 2019 were 17.2°C and 28.9°C and in 2020 were 17.4°C and 29.7°C (Fig 3). The dominant soil type and soil textural of both experimental sites was Nitisols and clay, respectively. The soil pH at Assosa was 5.32 and 5.50 at Bambassi (Table 1). Sorghum, maize, haricot bean and soybean are the dominant crops grown at both study sites (BGBOARD, 2017).

Experimental treatments and design

Factorial combinations of four levels of biofertilizer [without biofertilizer (B1), *SB12* biofertilizer (B2), *MAR1495* biofertilizer (B3) and *SB12* plus *MAR1495* biofertilizers (B4); and four inorganic fertilizer types nitrogen and phosphorus (F1), nitrogen, phosphorus and sulphur (F2), nitrogen, phosphorus and boron (F3) and nitrogen, phosphorus, sulphur and boron (F4)] were laid out in a randomized complete block design (RCBD) with three replications. The recommended rates of N, P_2O_5, S and B for soybean in the study areas were 19 kg N ha^{-1}, 46 kg P_2O_5 ha^{-1}, 7 kg S ha^{-1} and 0.1 kg B ha^{-1}. The source of NP were 41.3 kg ha^{-1} Urea (46% N) and 100 kg ha^{-1} TSP (46% P_2O_5), while the source of NPS were 100kg ha^{-1} NPS (19 % N, 38% P_2O_5 and 7% S) and 17.4 kg ha^{-1} TSP (46% P_2O_5). The source of NPB were 41.3 kg ha^{-1} Urea (46% N) and 100 kg ha^{-1} TSP (46% P_2O_5) and 1 kg ha^{-1} Borax (0.1% B), while the source of NPSB

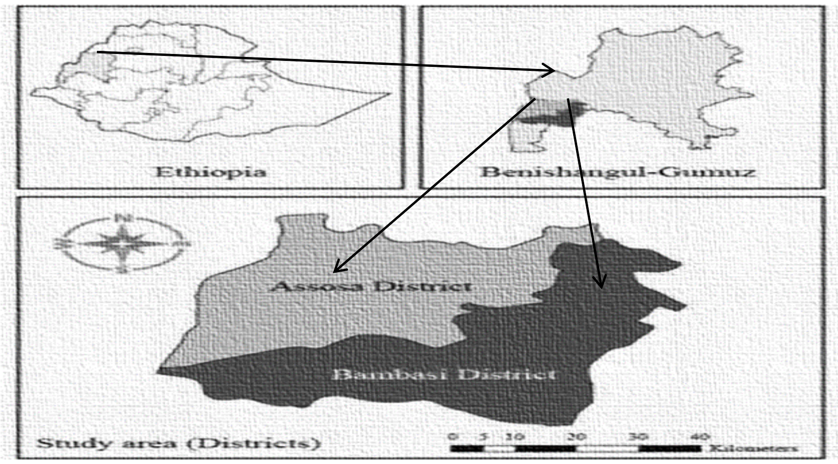

Fig 1: Location map of Assosa and Bambassi districts.

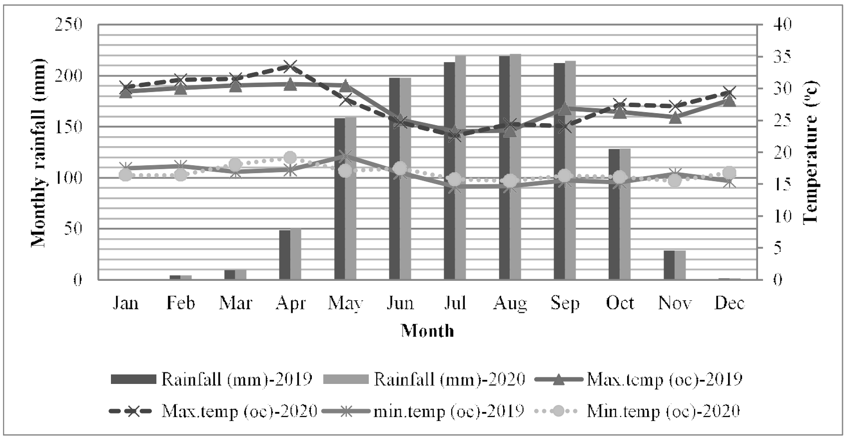

Fig 2: Average monthly rainfall and temperature distribution during 2019 and 2020 experimental years in Assosa.

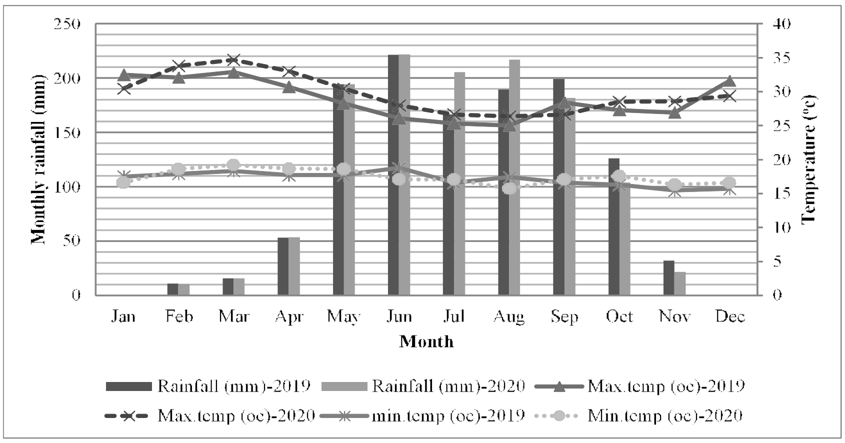

Fig 3: Average monthly rainfall and temperature distribution during 2019 and 2020 experimental years in Bambassi.

were 100kg ha^{-1} NPS (19 % N, 38% P_2O_5 and 7% S), 17.4 kg ha^{-1} TSP (46% P_2O_5) and 1 kg ha^{-1} Borax (0.1% B). The source of fertilizers such as NPS, TSP, Urea and Borax were mixed fertilizers. Improved soybean variety ''Gishama" was used as a planting material. There were 48 experimental plots having the gross plot size of 3 m × 2 m (6 m^2) and the net plot size of 2.4 m × 1.9 m (4.56 m^2). Within the net plot, there were five planting rows. The spacing between rows was 60 cm, while the spacing between plants was 5cm. Adjacent plots and blocks were separated by 0.5 and 1 m, respectively.

Experimental procedures

Prior to sowing, the land was finely ploughed and harrowed manually. Seeds were inoculated prior to drilling with inoculum of *SB12* and *MAR1495* at 500 g ha^{-1} to all plots except the control. With regards to inoculation procedures, initially, 500 gram of sugar was applied to 1.25 liters of water and was heated for 15 minutes. Consequently, 500 gram of *SB12* and 500 gram of *MAR1495* were added and mixed in to the above sugar suspension to form slurry. Then, the recommended rate of seed (80 kg ha^{-1}) was added to the above slurry and mixed by hand. Finally, the inoculated seed was dried in a shade on a plastic sheet for 15 minutes and was sown on furrow (Somasegaran and Hoben, 1994). All fertilizers types were applied immediately before planting to rows prepared to sow soybean and slightly mixed with soil to prevent direct contact of the fertilizer with the seed. Soon after seeding, the furrows were covered by soils. Besides, all other agronomic practices for soybean crop were done as per the recommendation. Finally, the data were collected following the appropriate procedures.

Crop data collection

Data of effective nodules per plant, leaf area index and grain yield of soybean were collected following their respective standard methods and procedures. To determine effective nodules, five plants were randomly sampled from destructive rows of each experimental plot at 50% flowering stage (mid-flowering stage) of the plant. Then after, selected samples were randomly uprooted by carefully digging around the plant using a spade. Then, it was washed with clean tap water to remove all attached soil from the roots and the nodules. The nodules were then detached from the roots and dissect each nodule to identify effective nodules. Then, the cross section of the nodules was observed to identify the effectiveness of the nodules. When the colors showed pink to dark red it was considered as effective while green, brown, or white color it was considered as ineffective nodules. Finally, total number of effective nodules per plant was counted.

To measure leaf area index, field photograph pictures were taken using digital camera in typical growth stages at initial flower stage. The pictures were then imported immediately to the computer for analysis of leaf area index by using leaf area index calculator called Hemisphere software (Thimonier *et al*., 2010). Soybean plants were harvested at physiological maturity just above ground level from net plot area to determine grain yield. Then, the grain yield was recorded per plot and converted to hectare basis and the average yield was expressed in to kilogram per hectare after adjusting the grain yield by 10% moisture content.

Data analysis

The data were further subjected to analysis of variance (ANOVA) using SAS version 9.1.3 (SAS, 2002). For parameters whose ANOVA results showed significant differences between treatments, mean separation was done using DMRT at 1% or 5% level of probability.

RESULTS AND DISCUSSION

Number of effective nodules per plant

The interaction effect of biofertilizer and inorganic fertilizers showed highly significant variation on number of effective nodules per plant at both locations in 2019 (Table 1). Thus, the interaction of SB12+MAR1495 (B4) and NPSB (F4) gave the maximum number of effective nodules (43.67) at Assosa, while the interaction of SB12 (B2) and NPSB (F4) gave the maximum number of effective nodules (39.33) at Bambassi. However, un-inoculated (B1) and NP (F1) gave the minimum number of effective nodules 2.33 and 4.00 at Assosa and Bambassi, respectively.

Likewise, the interaction effect of biofertilizer and inorganic fertilizers showed highly significant variation on number of effective nodules at both locations in 2020 (Table 1). As a result, the interaction of SB12+MAR1495 (B4) and NPSB (F4) gave the maximum number of effective nodules per plant (52.67) at Assosa and the interaction of SB12 (B2) and NPSB (F4) gave the maximum number of effective nodules (52.33) at Bambassi. However, the minimum number of effective nodules per plant was recorded from the interaction of un-inoculated (B1) and NP (F1) at Assosa (2.67) and Bambassi (5.00).

Generally, the highest effective nodules were recorded from the interaction of SB12+MAR1495 (B4) and NPSB (F4) (52.67) at Assosa and SB12 (B2) and NPSB (F4) (52.33) at Bambassi in 2020. The presence of higher number of effective nodules might be due to the synergetic effect of SB12+MAR1495 (B4) inoculation and NPSB (F4) application. This means the nitrogen fixed from combined application of SB12+MAR1495 (B4) and the nitrogen, phosphorus, sulfur and boron obtained from NPSB (B4) might have contributed in forming effective nodules. This result is in line with Marschner (1995) who reported that effective nodule number per plant was significantly affected by combined application of biofertilizer and inorganic fertilizer across years. Lourduraj (2000) also reported that the combined application of' biofertiliers and inorganic fertilizers significantly enhanced the growth attributes and yield of' soybean as compared to the sole application of either of them.

Table 1: Interaction effects of biofertilizer and inorganic fertilizers on effective nodules, leaf area index and grain yield of soybean at both locations and years in Assosa Zone, Western Ethiopia.

Treatment combinations		Assosa						2275Bambassi					
Nitrogen	Inorganic	ENPP		LAI		GY		ENPP		LAI		GY	
fixing inoculants	fertilizers	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
B1	F1	2.33^{h}	2.67^{j}	3.72^{efcd}	4.08^{hg}	1893.70^{ecd}	1960.67^{ed}	4.00^{i}	5.00^{h}	2.77^{g}	3.84^{f}	1447.00^{fg}	1578.50^{ef}
	F2	8.00g	9.00^{i}	4.00^{ecd}	4.61^{f}	1811.70^{ecd}	1896.67^{e}	9.67^{h}	10.67^{g}	2.95^{gf}	4.63^{def}	1523.00^{fg}	1650.40^{edf}
	F3	3.00^{h}	3.33^{j}	3.41^{efg}	3.96^{h}	1788.30^{ecd}	1863.33^{e}	4.67^{i}	5.33^{h}	2.85^{g}	3.90^{ef}	1411.30^{g}	1527.00^{f}
	F4	7.33^{g}	8.67^{i}	3.39 ^{efg}	3.86^{h}	1738.00^{ed}	1833.00^{e}	8.67^{h}	9.33^{g}	2.89 ^{g}	4.14^{ef}	1507.00^{fg}	1636.50^{edf}
B2	F1	15.33^{f}	24.33^{h}	3.40^{efg}	4.60^{f}	2031.00^{becd}	2156.00^{dc}	23.00^{g}	31.67^{f}	3.91^{b}	6.02^{bc}	1777.00^{fbdec}	1922.40^{ebdfc}
	F2	19.67^{e}	34.67^{ed}	3.76 ^{efcd}	5.46^{d}	2284.70^{ba}	2415.67^{bac}	27.00^{f}	38.00^{ed}	4.42^{a}	6.97^{a}	2275.00^{a}	2460.20^{a}
	F3	31.00^{c}	37.00^{d}	3.54^{efd}	5.14^{e}	2098.00^{bc}	2233.00^{bc}	30.67^{ed}	38.67^{cd}	3.36^{ed}	5.81^{bc}	1775.30^{fbdec}	1916.80^{ebdfc}
	F4	35.67^{b}	42.67^{c}	4.15^{bcd}	5.85^{c}	2347.7^{ba}	2478.67^{ba}	39.33^{a}	52.33^{a}	4.32^{a}	6.24^{ba}	2058.70^{ba}	2226.10^{ba}
B3	F1	23.00^{ed}	29.00^{g}	2.72^{h}	4.02^{hg}	1714.00^{e}	1863.33^{e}	27.00^{f}	35.00^{e}	3.12^{ef}	4.67^{de}	1632.00^{fgde}	1761.70^{edfc}
	F2	28.00^{c}	32.67^{ef}	3.11^{hfg}	4.61^{f}	2109.7^{bc}	2226.67^{bc}	31.00^{ed}	42.00^{cb}	3.33^{ed}	5.38^{dc}	1888.30^{bdec}	2029.90^{ebdac}
	F3	31.33^{c}	37.33^{d}	3.69^{efcd}	5.19^{e}	1753.7^{ed}	1865.67^{e}	35.33^{cb}	44.33^{b}	3.27^{ed}	5.22^{dc}	1602.70^{fge}	1735.10^{edfc}
	F4	29.67^{c}	36.67^{d}	2.73^{hg}	4.23^{g}	2272.7^{ba}	2391.67^{bac}	39.00^{a}	50.00^{a}	3.17^{ef}	5.22^{dc}	1663.70^{fgdec}	1799.00^{ebdfc}
B4	F1	23.67^{d}	29.67^{gf}	4.72^{ba}	5.82^{c}	2053.0^{bcd}	2184.00^{dc}	29.00^{ef}	37.00^{ed}	3.25^{ed}	5.34^{dc}	1585.00^{fge}	1717.30^{edfc}
	F2	38.00^{b}	48.00^{b}	5.04^{a}	6.24^{b}	2358.3^{ba}	2503.33^{a}	33.00^{cd}	42.00^{cb}	3.49^{cd}	5.86^{bc}	2006.00^{bac}	2147.50^{bac}
	F3	31.33^{c}	38.00^{d}	4.30^{bc}	5.25^{ed}	2037.3^{becd}	2162.33^{dc}	29.33^{ef}	36.33^{ed}	3.43^{d}	5.54^{bc}	1698.70^{fgdec}	1838.20^{ebdfc}
	F4	43.67^{a}	52.67^{a}	5.29^{a}	6.79^{a}	2464.7^{a}	2621.67^{a}	35.67^{b}	43.67^{b}	3.71^{cb}	5.96^{bc}	1961.30^{bdac}	2100.30^{bdac}
	Sig. difference	**	**	**	**	**	**	**	**	**	**	**	**
	SE (d) ±	2.50	3.06	0.14	0.17	48.77	51.63	2.37	3.14	0.09	0.18	49.66	53.72
	CV (%)	6.7	4.81	7.17	2.00	6.21	4.76	4.40	4.33	2. 90	6.14	7.94	9.45

Means within a column followed by the same letter(s) are not significantly different; B1=without biofertilizer, B2 = SB12 biofertilizer, B3 = MAR1495 biofertilizer, B4 = SB12+MAR1495 biofertilizers; F1= NP fertilizer, F2 = NPS fertilizer, F3 = NPB fertilizer, F4 = NPSB fertilizer; ENPP=effective nodules per plant; LAI=leaf area index; GY=grain yield; ** = highly significant at $P<0.01$; CV=coefficient of variation; SE=standard error.

Leaf area index

The interaction effect of biofertilizer and inorganic fertilizers showed highly significant variation on leaf area index at both locations in 2019 (Table 1). Thus, the interaction of SB12 + MAR1495 (B4) and NPSB (F4) gave the maximum leaf area index (5.29) at Assosa, while the interaction of SB12 (B2) and NPS (F2) gave the maximum leaf area index (4.42) at Bambassi. On the contrary, the interaction of SB12 (B2) and NP (F1) gave the minimum leaf area index 2.72 at Assosa and the interaction of un-inoculated (B1) and NP (F1) fertilizer gave the minimum leaf area index (2.77) at Bambassi.

Furthermore, the interaction of biofertilizer and inorganic fertilizers showed highly significant ($P<0.01$) variation on leaf area index at both locations in 2020 (Table 1). As a result, the maximum leaf area index of (6.79 cm) was obtained from the interaction of SB12 + MAR1495 (B4) and NPSB (F4) at Assosa, while the maximum leaf area index (6.97 cm) was obtained from the interaction of SB12 (B2) and NPS (F2) at Bambassi. However, the minimum (3.84cm) leaf area index was obtained from the interaction of un-inoculated (B1) and NP (F1) at Bambassi compared to the other treatments.

Generally, in both years, combined use of SB12 + MAR1495 (B4) and NPSB (F4) gave the maximum leaf area index at Assosa, while combined use of SB12 (B2) and NPS (F2) gave maximum leaf area index at Bambassi. Furthermore, the value of leaf area index varied among locations and years. The varied leaf area index at both locations and years might be due to the variation in genetic adaptability of the strain, initial soil conditions, temperature and rainfall. From all treatments, the highest leaf area index of 6.97 was recorded from the combined effect of SB12 (B2) and NPS (F2). The maximum leaf area index could be resulted from the synergetic effect of SB12 (B2) inoculation and NPS (F2) fertilizer application. This means the nitrogen fixed from SB12 (B2) inoculation and the nitrogen, phosphorus and sulfur obtained from NPS (F2) fertilizer might have contributed in the formation of maximum leaf area index. This finding was in agreement with Mahmood *et al.* (2017) who investigated that combined use of biofertilizers with inorganic fertilizers resulted in maximum leaf area index. This result is also in conformity with Kumar *et al*. (2005) who reported that the maximum leaf area index was recorded from the application of 100% NPS with SB12 bacterial strain over the control. The result is also similar with the finding of Bandyopadhyay *et al*. (2010) who reported that greater leaf area index in combined application of NPS + SB12 was attributed to the production of new leaves and also increase in size of the existing leaves. Mishra *et al*. (2010) also reported leaf area index was significantly influenced by main and interaction of bio- and inorganic fertilizers.

Grain yield

The interaction effect of biofertilizer and inorganic fertilizers showed highly significant variation on grain yield at both locations in 2019 (Table 1). As a result, the interaction of SB12 (B2) and NPS (F2) gave the maximum grain yield (2275.00 kg) at Bambassi, while the interaction of SB12 (B2) + MAR1495 (B4) and NPSB (F4) gave the maximum grain yield of (2464.70kg) at Assosa. However, the interaction of un-inoculated (B1) and NPB (F3) gave the minimum grain yield of 1411.30kg at Bambassi, while the interaction of SB12 (B2) and NP (F1) gave the minimum grain yield of 1714.00kg at Assosa (Table 1).

Similarly, the interaction of biofertilizer and inorganic fertilizers showed highly significant variation on grain yield at both locations in 2020 (Table 1). Thus, the interaction of SB12 (B2) and NPS (F2) gave the maximum grain yield (2460.20kg) at Bambassi, while the interaction of SB12 + MAR1495 (B4) and NPSB (F4) gave the maximum grain yield (2621.67kg) at Assosa. However, the interaction of un-inoculated (B1) and NPB (F3) gave the minimum grain yield (1527.00kg) at Bambassi and the interaction of un-inoculated (B1) and NPSB (B4) gave the minimum grain yield of (1833.00kg) at Assosa (Table 1).

Hence, in both years, maximum grain yield was recorded from the interaction of SB12 + MAR1495 (B4) + NPSB (F4) and SB12 (B2) + NPS (F2) at Assosa and Bambassi, respectively. Besides, the recorded grain yield varied among years and location. This might be due to the variation in initial soil conditions, the residual effects of the supplied nutrients in the first year and the effectiveness of the strains at locations. Hence, from cumulative interaction effects, the highest grain yield (2621.67kg) was recorded from the interaction of SB12 + MAR1495 (B4) + NPSB (F4). This could be because of the synergetic effects resulted from both application of NPSB fertilizer and combined use of SB12 + MAR1495. This result is supported with the finding of Dubey (1998) who obtained highest grain yield of soybean when the plant was inoculated with *B. japonicum strains* in combination with N, P, S and B fertilizers. Lourduraj (2000) has also reported that the combined application of' biofertiliers and inorganic fertilizers significantly enhanced the growth attributes and yield of' soybean as compared to the sole application of either of them.

CONCLUSION

As a conclusion, from this experiment it was noted that the interaction effects of biofertilizer and inorganic fertilizers had highly significant ($P<0.01$) effect on number of effective nodules per plant, leaf area index and grain yield. The highest number of effective nodules per plant was recorded from the interaction of SB12+MAR1495 and NPSB. Whereas, the highest leaf area index was recorded from the interaction of SB12 and NPS. Maximum grain yield (2621.67kg) was obtained from the interaction of (SB12 + MAR1495) along with NPSB at Assosa and the maximum grain yield (2460.20 kg) was obtained from SB12 along with NPS at Bambassi. Finally, it is recommended that using the interaction of (SB12 + MAR1495) along with NPSB and the interaction of SB12 along with NPS is critical for higher grain yield of soybean at Assosa and Bambassi districts, respectively and should be adopted appropriately to enhance the productivity of soybean in the areas and similar agro-ecologies.

REFERENCES

Abbasi, M.K., Majeed, A., Sadiq, A. and Khan, S.R. (2008). Application of Bradyrhizobium japonicum and phosphorus fertilization improved growth, yield and nodulation of soybean in the sub-humid hilly region of Azad Jammu and Kashmir. Pakistan. Pak. J. Plant Prod. Sci. 58: 368-376.

Asgelil, D. (2000). Effect of fertilizer on the yield and nodulation pattern of faba bean on a Nitosol of Adet, North Western Ethiopia. Ethio. J. Nat. Res. 2: 237-244.

Assosa Agricultural Research Center (AsARC). (2017). Annual Report, Assosa, Ethiopia.

Bandyopadhyay, K.K., Misra, A.K., Ghosh, P.K. and Hati, K.M. (2010). Effect of integrated use of farmyard manure and chemical fertilizers on soil physical properties and productivity of soybean. Soil and Tillage Research. 110(1): 115-125.

Benishangul Gumuz Beauro of Agriculture and Rural Development (BGBOARD). (2017). Annual Report, Assosa, Ethiopia.

Collombet R. N. (2013). Investigating Soybean Market Situation in Western Kenya: Constraints and Opportunities for Smallholder Producers. Wageningen University, pp. 1-43.

CSA (Central Statistics Agency of Ethiopia). (2018). Report on Area and Crop Production Forecast for Major Crops, Addis Ababa, Ethiopia.

CSA (Central Statistics Agency of Ethiopia). (2017). Report on Area and Crop Production Forecast for Major Crops, Addis Ababa, Ethiopia.

Dubey, S.K. (1998). Response of soybean to biofertilizers with and without nitrogen, phosphorus and potassium on swell-shrink soil. Ind. J. Agron. 43: 546-549.

Dugje, I.Y., Omoigui, L.O., Ekeleme, F., Bandyopadhyay, R., Kumar, P.L. and Kamara, A.Y. (2009). Farmers Guide to Soybean Production in Northern Nigeria. International Institute of Tropical Agriculture, Ibadan, Nigeria, pp. 1-16.

Khaliq, A. and Abbasi, M.K. (2015). Soybean Response to single or mixed soil amendments in Kashmir. Pakistan. Agronomy Journal. 107(3): 887-895.

Kumar A., Guatam, R.C., Ranbir, S. and Rana, K.S. (2005). Growth, yield and economics of maize- wheat cropping sequence as influenced by integrated nutrient management. Indian J. Agric. Sci. 75(11): 709-711.

Lourduraj, C.A. (2000). Effect of irrigation and manure application on growth and yield of groundnut. Acta Agron Hungarica 48: 83-88.

Mahmood, F., Khan, I., Ashraf, U., Shahzad, T., Hussain, S., Shahid, M., Abid, M. and Ullah, S. (2017). Effects of organic and inorganic manures on maize and their residual impact on soil physico-chemical properties. Journal of Soil Science and Plant Nutrition. 17(1): 22-32.

Marschner, H. (1995). Mineral Nutrition of Higher Plants. London, Academic Press, London. P. 889.

Mishra, A, Prasad, K, Rai, G. (2010). Effect of bio-fertilizer inoculations on growth and yield of dwarf field pea (*Pisum sativum* L.) in conjunction with different doses of chemical fertilizers. J. Agron. 9: 163-168.

SAS (Statistical Analysis System) Institute. (2002). The SAS System for Windows, version 9.1.3 SAS Institute Inc., Cary, NC., USA.

Sinclair, T.R., Marrou, H., Soltani, A., Vadez, V., Chandolu, KC. (2014). Soybean production potential in Africa. Glob. Food Sec., 3, 31-40. 10.1016/j.gfs.2013.12.001.

Somasegaran, P. and Hoben, H.J. (1994). Handbook for Rhizobia: Methods in Legume - Rhizobium Technology. Springer-Verkag, New York, USA, p 366.

Tefera, H. (2010). Breeding for promiscuous soybeans at IITA, soybean- molecular aspects of Breeding. Sudaric, A. (Ed.), ISBN: 978-953-307-240-1, In: Tech, available from: http://www.intechopen.com/books/soybean-molecular-aspects-of-breeding/beeding-for-promiscuous-soybeans-at-iita.

Thimonier, A., Sedivy, I. and Schleppi, P. (2010). Estimating leaf area index in different types of mature forest stands in Switzerland: A comparison of methods. European Journal of Forest Research 129(4): 543-562. DOI: 10.1007/s10342-009-0353-8.

Tisdale, S.L., Nelson, W.L., Beaton, J.D. and Havlin, J.L. (1993). Soil Acidity and Basicity. In: Soil Fertility and Fertilizers. 5th ed. Macmillan Publ., New York. p. 364-404.

United States Department of Agriculture (USDA). (2017). Annual Report, Washington DC, USA.

Zelleke, G., Agegnehu, G., Abera, D. and Rashid, S. (2010). Fertilizer and soil fertility potential in Ethiopia: Constraints and opportunities for enhancing the system. Working Paper, International Food Policy Research Institute.

Zinaw, D., Seltene, A., Addisu, G. (2013). Genetic variability and heritability of soybean [*Glycine max* (L.) Merrill] genotypes in Pawe district, Metekel zone, Benishangul Gumuz regional state, northwestern Ethiopia. Wudpecker J. Agric. Res. 2(9): 240-245.