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Effects of Soybean Break Crop on Subsequent Nitrogen Response of Maize Varieties at Bako Agricultural Research Center, Western Ethiopia

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Soil fertility is declined in our soils and yield of maize are tremendously low. Legume break is important measures to sustain soil fertility and enhance productivity of maize. The biological nitrogen fixation from atmosphere in soybean-maize sequence helps to enhance maize yield and reduce the amount of nitrogen fertilizer applied. This in view the experiment was conducted to determine the effects of soybean break crop on subsequent nitrogen response of maize varieties at Bako Agricultural Research Center, Western Ethiopia. Significantly higher mean grain yield of maize was produced from maize planted with application of half and full recommended rate of nitrogen fertilizer following soybean precursor crop showing importance of nitrogen application in cropping sequence. Significantly higher mean leaf area and leaf area index were obtained from BH-543 maize variety planted with half recommended nitrogen fertilizer following soybean planted with rhizobium. Higher mean grain yield of 7870 kg ha^{-1} was obtained from BH-661 maize varieties planted following soybean without rhizobium application. Higher mean grain yield of maize varieties was obtained from maize planted following soybean with rhizobium application. Therefore, planting of maize following soybean precursor crop with rhizobium with half recommended nitrogen fertilizer application or soybean precursor crop without rhizobium with full recommended nitrogen fertilizer application was recommended for sustainable maize production. The net economic returns of maize varieties planted following soybean precursor crop without and with rhizobium inoculation was higher than continuous maize. Soybean precursor crop was increased total N uptake and agronomic efficiency of maize varieties. Application of nitrogen rates was significantly reduced agronomic efficiency of maize varieties. Therefore, production of BH-661 and BH-543 maize varieties following soybean break crop with half recommended (55 kg N ha^{-1}) application was improved mean grain yield and economic return and recommended for maize in mid altitude areas of western Ethiopia.

Key words: nitrogen fixation, rhizobium, soil nitrogen

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INTRODUCTION

Land degradation, low soil fertility, limited and erratic rainfall with ever increasing population pressure is very common features of large parts of sub-Saharan Africa (Vesterager *et al*., 2008). Soil fertility depletion is considered as the major threats to food security and crop production is facing severe nutrient deficiencies in Ethiopia. Low soil fertility stands the most bottlenecks to production and productivity maize in Western Ethiopia. Kabir et al. (2011) declining land productivity with negative nutrient balance is the main concerns against the food security problems in the country. Monocropping, nutrient mining, unbalanced nutrient application, removal of crop residues and inadequate supplies of nutrients have contributed to decline in crop yield (Nyamangara, 2001). Fertilization is one of the most important remarkable measures that help to increase crop production. Nitrogen (N) is the most limiting nutrient and its supply with phosphorus (P) is essential for increased production of most cereals (Fugger, 1999). Nitrogen fertilizer is universally accepted as a key input to high corn grain yield and optimum economic return (Stanger and Lauer, 2008). Frink et al. (1999) reported that nitrogen fertilizers have been used for a long period of time to increase N availability and plant uptake. Currently the rate of N fertilizer application has increased tremendously, a trend which is expected to continue (Adesemoye and Kloepper, 2009). Nitrogenous fertilizers have contributed much to the remarkable increase in food production that has occurred during the past 50 years (Smil, 2001). Adesemoye et al. (2010) reported large fractions of the applied N (often half or more) are lost from agricultural systems as N2, trace gases, and nitrate leaching is a major concern. Increasing N fertilizer use portends grave environmental consequences that are usually long-term and are seen as significant drivers of global change (Vitousek et al., 1997; Diaz and Rosenberg, 2008). Chemical fertilizers which are required to raise crop production levels are too expensive and most smallholder farmers cannot afford them, even not accessible at need time. Nitrogen has been considered one of the best crop-input investments that a farmer can make in terms of return on dollars spent (Pikul et al., 2005); however, N is the most expensive nutrient for growing grain crops (Stanger and Lauer, 2008).The application of mineral fertilizer as sole soil fertility management method under intensive continuous cropping is also no longer feasible due to scarcity, high cost (Akinrinde and Okeleye, 2005) where available and the numerous side effects on the soil (Anetor and Akinrinde, 2006). Hoekenge *et al.* (2003) reported that continuous use of ammonia fertilizers under intensive agriculture is capable of further acidifying the soil. Adesemoye et al. (2010) suggested that for agricultural production to keep pace with the growing global population the use of chemical fertilizers will continue and proper management techniques must be designed and implemented against the pollution potential of fertilizers to achieve sustainability. Smil (1999) estimated that only about half of all anthropogenic N inputs to cropland are taken up by harvested crops and their residues, with the remainder contributing significantly to Nr enrichment of the atmosphere, ground and surface waters. Increasing cost of production, storage and transportation of nitrogen fertilizers have stimulated biological nitrogen fixing systems (Cheema and Ahmad, 2000). One possible solution for sustainable crop production that use legume break supplemented with chemical fertilizers. Giller et al. (1997) stated that proposed interventions in soil fertility management must generate cropping systems that are productive, sustainable and economically attractive for small holder subsistence farmers.

The input of fixed N from grain legumes may be a significant contributing factor in relation to sustaining productivity in smallholder systems (Sanginga, 2003). Soybean is recently introduced in the area and use of appropriate strains could help to increase the yield the crop. Dobereiner and Campelo (1977) reported that inoculation of soybean is essential in new areas and in acid soils. They further stated that selection of the appropriate Rhizobium strains is essential for new cultivars and consideration must be given to the soil and climate into which the crop is being introduced. The soybean-Brady rhizobium symbiosis can fix up to 300 kg N ha^{-1} under good conditions (Keyser and Li, 1992). LaRue and Patterson (1981) reported an average estimate of N_2-fixation in soybean to be 75 kg N ha^{-1}, using average commercial yields and assuming that 50% of the N was from fixation. Bezdicek *et al*. (1978) reported soybeans were capable of fixing over 300 kg N ha^{-1} when the soil was low in available N and when effective strains of brady rhizobia are supplied in high number. The N_2-fixing potential of soybean was 88-188 kg N/ha/year (Giller, 2001), between 41-50 kg ha^{-1} (Yusuf *et al.,* 2006), and 31-64% (Ali *et al.,* 2002). On average, 50 to 60% of soybean N demand was met by biological N_2 fixation (Salvagiotti, 2008). The most important form of nitrogen fixation in Africa is still BNF, with an annual amount of 25.9 Tg N fixed per year naturally and 1.8 Tg N yr^{-1} is fixed during cultivation (Galloway et al., 2004).

Rotating cereals with legumes like soybean have proved to be beneficial for subsistence farmers of the tropics and subtropics where they are limited by low crop productivity and also inflexible land tenure systems. Biological nitrogen fixation plays an essential role in crop establishment and yield, since no N fertilizer is applied and it fulfills most of plants need for nitrogen (Vargas and Hungria, 1997; Chen *et al*., 2002). Positive net N-balances of up to 136 kg ha^{-1} for several food legumes following seed harvest have been reported (Kumar Rao *et al.,* 1996). Fertilizer N inputs and symbiotic biological N fixation of atmospheric N_2 by soybean are the largest N inputs to the cropping systems considered (David et al., 2001; and Gentry et al., 2009). Giller (2001) stated that inclusion of grain legumes in rotations provides nitrogen inputs into the systems in addition to valuable grain yields. Maize grain yields increased significantly following rotation crops compared to continuous cropping (Tolera et al., 2009). Hardy (1998) reported that the rotation of maize with grain legumes such as promiscuous soybean, groundnut or bambaranut is one of the more promising technological options in Malawi. Rao and Mathuva (2000) found that maize following annual legumes were 32 - 49 % more profitable than continuous maize. Corn rotated annually with soybean and first-year corn after 5 yr. of consecutive soybean yielded 12% more than continuous grown corn (Pedersen and Lauer, 2002). However, Becke et al. (1986) stated that optimal growth and yield of cultivated plants cannot be obtained by symbiotically fixed nitrogen only. Appropriate cropping sequence with continuous use of chemical fertilizers can increase the yield of annual crops in Alfisols (Henao and Bannante, 1999), which may be true for maize at Bako. Heichel (1978) and Pimentel et al. (1978) reported that continuous rotation of corn and soybean cannot be sustained without substantial additions of fertilizers. Singh *et al*. (1987) reported that maize-wheat cropping systems with chemical fertilizers increased the grain yield of maize by 202 % compared to non-fertilized controls. Crop rotations produced greater yield advantage of maize compared to continuous maize with recommended and half recommended fertilizer rates; and crop rotations with recommended fertilizer application produced better grain yield of maize (Tolera et al., 2009). A corn grain yield trend of corn- soybean rotation was decreased by 161 kg ha^{-1} $yr.^{-1}$ if no N was added (Stanger and Lauer, 2008). Tolera et al. (2009) residual benefits of crop rotation with N-P fertilizer have enhanced the grain yields and fertility of the soil. Sayre (1999) suggest that sustainable crop production practices involve the use of break crops and optimum fertilizer application which minimize nutrient losses. Crop rotation significantly influenced total N uptake, being significantly lower in fallow-maize and continuous maize systems than in any of the rotation consistent with lower grain yield (Yusuf et al., 2009). Therefore, estimating the crop biological nitrogen fixation by soybean with and without rhizobium strain and determining its effects of Nitrogen requirement of subsequent maize are a potential for sustainable maize production. The objective was to determine quantities of nitrogen fixed by soybean and its effect integrated with nitrogen on increasing of subsequent maize yield.

MATERIALS AND METHODS

Crop rotation experiment with soybean was conducted from 2013 to 2014 cropping seasons at Bako Agricultural Research Center (BARC), situated in East Wollega Zone of the Oromia National Regional State (Figure 1). Geographically, it is located between $9^{o}6'$N latitude and $37^{o}09'$E longitude and at an altitude of the 1650 meter above sea level (Figure 1). The long-term (1961 - 2014) mean annual rainfall at BARC is 1265 mm with unimodal distribution (Table 1). It has a warm humid climate with the mean minimum, mean maximum and average air temperatures of 13.4, 28.49 and $20.95^{o}{}_{C}$, respectively (Table 1) (MBARC, 2014). Sixty percent of the soil (1400 ha) of Bako Research Center, is reddish brown in colour clay and loam in texture (Wakene, 2001) and Alfisol type (FAO, 2007). The relative humidity is ranged from 46 to 65 %.

During the 2013 cropping season, the trial field was planted to soybean without and with rhizobium strains. One soybean variety (Didessa from medium set) with two levels of rhizobium inoculations (without and with rhizobium strain inoculation) was used as factors A with one control. The factor B was two maize varieties (BH-543 and BH-661) currently released and used by farmers. The factor C were three levels nitrogen [without fertilizer (o kg N ha^{-1}), half of the recommended (55 kg N ha^{-1}) and recommended (110 kg N ha^{-1})] used for subsequent maize. Twelve treatment combinations were conducted with the main crop (maize). The rhizobium strain (SB-12) was used to inoculate the soybean seed receiving inoculation strain. First year in 2013 cropping season rotation crop (soybean (*Glycine max*) without and with rhizobium strains and continuous maize were sown respectively. During the 2014 cropping season maize hybrid (BH-543 and BH-661) were sown with three levels of fertilizers (0, 55, and 110 kg N ha^{-1}) rate for the area.

The experiment was laid out in factorial arrangement with randomized complete block design in. The rotation crop with rhizobium strain as factor A, maize varieties as factor B and nitrogen rate as factor C. The total gross plot size was 5.1 x 4.5 m with 3 x 5.1m net plots. The spacing was 75 x 30 cm. The seed rate used for maize was 25 kg ha^{-1}. Sowing dates followed recommended date of planting ranged May 1 - 30. Full dose of phosphorus (as TSP) was applied once at planting, while nitrogen (as Urea) was applied in spilt doses, half at planting and the remaining half applied 30 to 40 days after planting. All other agronomic management practices were applied as per recommendation for the variety. The necessary data were collected at right time and crop growth stage.

Crop parameters: Leaf area and leaf area index were collected at 50% tasseling of maize; and plant height, grain yield thousand seed weight and harvest index after maturity of maize. The grain yield was harvested from the net plot (3 m x 5.1m=15 m^2). The harvested grain yield

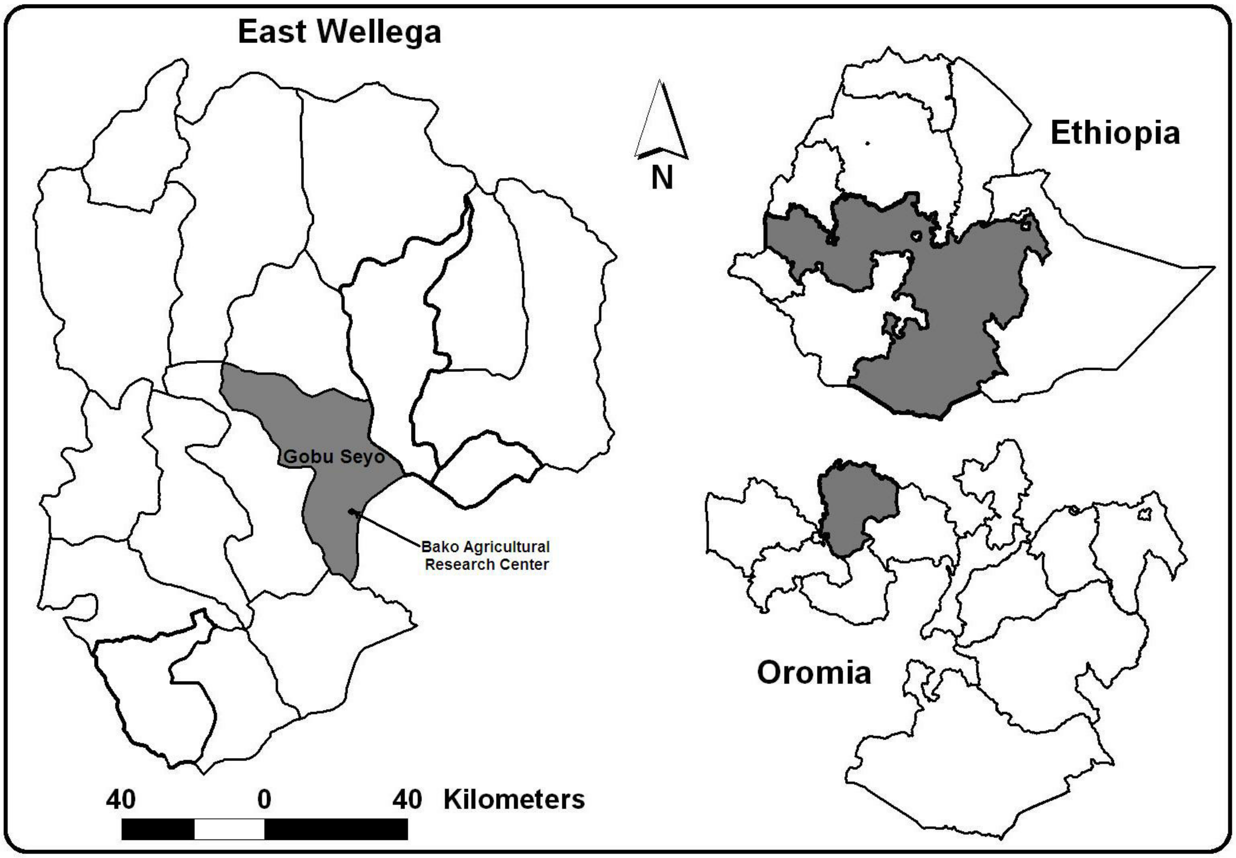

Figure 1. Aerial map study district in East Wollega Zone of Oromia National Regional State, Ethiopia.

was adjusted to 12.5 % moisture level (Birru, 1979 and Nelson *et al.,* 1985). The adjusted seed yield at 12.5 % moisture level per plot was converted to grain yield as kilogram per hectare.

The soil sample was collected at the depth 0- 20 cm with augur three times first before application of the treatment (2013), second after harvesting of the rotation crops when the field ready for maize planting in 2014. Third soil sample was collected after harvesting of maize from three plots and composited one for each treatment. Determination of soil particle size distribution was carried out using the hydrometer method (Dewis and Freitas, 1984). Soil pH was measured using digital pH meter in 1:2.5 soil to solution ratio with H_2O. Exchangeable basis was extracted with 1.0 Molar ammonium acetate at pH 7. Ca and Mg in the extract were measured by atomic absorption spectrophotometer while Na and K were determined using flame photometry (Van Reeuwijk, 1992). Cation exchange capacity of the soil was determined following the modified Kjeldahl procedure (Chapman, 1965) and reported as CEC of the soil. Percent base saturation was calculated from the sum of exchangeable basis as a percent of the CEC of the soil. Exchangeable acidity was determined by extracting the soil samples with M KCL solution and titrating with sodium hydroxide as described by McLean (1965). Organic carbon was determined following wet digestion methods as described by Walkley and Black (1934) whereas kjeldahl procedure was used for the determination of total N as described by Jackson (1958). The available P was measured by Bray II method (Bray and Kurtz, 1945). The electrical conductivity was estimated from saturated extracts of soil samples. The steam distillation method was used for determination of NO3-N and NH4-N as described by (Keeney and Nelson, 1982).

Plant tissues (dry tissue at 50 % flowering, and grain at harvesting) in 2013 for soybean were collected. The collected tissue and grain were prepared following standard procedures and analyzed at Holleta and Debre Zeit Agricultural Research Center Soil and Plant Analysis Laboratory using standard procedures for different selected nutrient compositions. The maize tissues and grain were subjected to wet digestion (Jones and Case, 1990). The N content of the plant tissue was determined by Kjeldahl procedure, whereas the P content was determined by calorimetrically according to Murphy and Riley (1962), and the S content of the plant tissue was

Table 1. Long term rainfall, temperature and relative humidity data for the Bako Agricultural Research Center.

Year	Rainfall (mm)												
	J	F	M	A	M	J	J	A	S	O	N	D	Total
1961-1999	13.07	17.16	56.86	65.51	150.19	208.22	237.32	228.97	150.50	72.67	18.61	10.87	1214
2000	0.00	0.00	0.00	79.30	135.10	378.20	236.90	289.60	162.00	103.40	48.40	12.60	1446
2001	0.00	42.80	87.20	57.80	161.30	219.30	328.90	264.30	96.70	92.70	1.50	7.70	1354
2002	23.50	15.10	88.80	73.00	68.30	236.00	239.20	205.90	42.10	0.00	6.80	42.20	1041
2003	4.00	34.30	51.70	59.10	5.70	265.10	420.10	434.40	69.90	21.50	1.20	27.60	1395
2004	9.40	5.00	23.60	66.10	114.10	268.60	225.50	257.80	85.20	43.50	48.20	14.30	1161
2005	10.40	0.00	43.00	99.50	79.00	221.20	268.80	230.80	242.20	26.20	37.10	0.00	1258
2006	0.00	6.10	32.70	12.80	124.70	288.90	255.70	335.30	145.20	109.70	8.00	46.00	1365
2007	0.20	55.50	36.30	47.00	179.50	297.40	254.70	216.60	138.80	51.40	0.00	0.00	1287
2008	6.50	0.00	0.60	87.20	280.60	396.70	289.10	146.30	167.20	73.90	78.40	1.10	1527
2009	0.00	10.30	57.60	90.40	9.20	192.40	278.30	203.90	101.10	90.90	0.00	2.70	1036
2010	8.10	10.50	7.30	44.90	299.00	277.60	228.50	215.30	153.90	33.40	35.90	23.80	1338
2011	15.90	2.00	58.80	68.10	222.20	295.00	224.10	294.60	131.30	53.20	60.10	0.00	1425
2012	0.0	4.4	15.7	29.7	92.8	153.3	136.5	263.4	163.7	6.0	17.1	6.7	889
2013	13	0.1	38	4	149.3	287.8	342	300.9	139.8	113.1	44.6	0	1433
2014	5.20	0.00	43.00	37.70	151.00	260.10	222.40	135.30	136.50	71.30	4.60	0.00	1067
Mean	6.83	12.70	40.07	57.63	138.87	265.36	261.75	251.46	132.88	60.18	25.66	12.22	12663
Temperature (0c)													Mean
Minimum	11.48	11.60	13.42	13.79	14.63	14.49	14.67	14.77	14.39	13.81	12.72	11.02	13.40
Maximum	30.37	31.84	31.92	31.57	29.50	25.83	24.65	24.43	25.30	27.75	28.91	29.84	28.49
Mean	20.93	21.72	22.67	22.68	22.06	20.16	19.66	19.60	19.85	20.78	20.81	20.43	20.95
Relative humidity (%)	49	46	47	51	53	65	64	62	64	55	53	50	54.80

determined by using an ICP-AES (Varain model Vista MPX). The total nitrogen fixation of soybean was determined using the N difference method (Ndfa) (Munroe and Davies, 1974), using the formula: Ndfa (kg ha^{-1}) = Total N (fixing crop) – total N (non-fixing crop). Total N uptake was calculated as = nutrient concentration x dry biomass weight (kg ha^{-1}) of maize/100.

The data analyses for agronomic data were carried out using statistical packages and procedures of SAS computer software (SAS, 2010). Mean separation was done using least significance difference (LSD) procedure at 5 % probability level (Steel and Torrie, 1980). For partial budget and marginal rate of return analysis, maize grain yield was valued at an average open market price of EB 375 per 100 kg for the last 10 Labour cost for field operation was EB 21 per man-day. The yield was adjusted down by 10 % to reflect actual production conditions (CIMMYT, 1988). The cost of fertilizer (Urea and DAP) were EB 12.75 and 15.00 kg^{-} with current market price.

RESULTS AND DISCUSSION

Soil chemical and physical properties of the experimental site

The laboratory analytical results of selected physicochemical properties of the soil are indicated (Table 2). The texture of the soil is clay before and after soybean with and without rhizobium inoculation precursor crop. The soil pH in H_2O was ranged from 4.43 to 4.65 and found very strongly acidic Landon (1991) for tropical soils. This might be due to continuous monocropping with heavy application urea fertilizer for hybrid maize production which attributed to acidity of the soil reaction. Similar result was reported by Wakene (2001); and Wakene et al. (2004). The organic carbon and organic matter concentration are in were found medium range (FAO, 1990; and Landon, 1991). The organic carbon of the soil is medium range and need soil management practices to keep soil under production. The total N concentration of the soils are 0.21% (before soybean planting), 0.16 and 0.18 % after soybean planting without rhizobium and with rhizobium inoculation and found in low range (FAO, 1990; and Landon, 1991). The low N fertility could be attributed to the continuous monocropping and cultivation through heavy applications of NP fertilizers and intensive mechanized tillage practices (Wakene et al., 2004). The soil needs crop rotation and application integrated use organic with inorganic fertilizer to sustain under production. The $N0_3$-N and NH_4-N concentration of the soil are found medium to high range found in high to very high range (Bashour, 2002; and FAO, 2006); excessive range (Marx et la.,

Table 2. Some physicochemical properties soil of farmer's field before planting maize in Bako Agricultural Research Center, western Ethiopia.

Soil parameters	Soybean + 0 RI	Soybean + 10 g RI kg seed -1	Before soybean
pH	4.65	4.43	4.54
Total P(ppm)	3.83	15.79	10.87
Total N (%)	0.16	0.18	0.21
OC (%)	2.14	2.18	2.46
OM (%)	3.68	3.75	4.23
CEC (meq /100g)	13.65	11.25	21.72
K (meq /100g)	0.19	0.12	1.13
Exchangeable acidity (meq /100g)	0.28	0.5	0.18
$N0_3$-N (ppm)	37.8	46.2	44.01
NH_4-N (ppm)	11.2	15.4	17.6
Texture	Clay	Clay	Clay

0 RI= soybean without rhizobium inoculation, 10= Soybean inoculation with 10 g kg^{-1} of seed

Table 3. Some soil chemical nutrient concentrations at harvesting of maize at BARC, western Ethiopia.

Soybean RI (g) + MV + N kg ha^{-1}	pH	Total N %	Available P (ppm)	Organic carbon %
0+BH-543 +0	4.73	0.15	10.14	1.95
0+BH-543 +55	4.69	0.15	16.80	1.87
0+BH-543+110	4.63	0.15	9.22	1.91
0+BH-661 +0	4.68	0.15	10.95	1.91
0+BH-661 + 55	4.63	0.15	20.12	1.52
0+BH-661 +110	4.53	0.13	9.93	1.95
10+BH-543 +0	4.75	0.14	18.75	2.07
10+BH-543 +55	4.69	0.14	26.00	1.91
10+BH-543+110	4.75	0.15	17.07	1.99
10+BH-661 +0	4.88	0.16	15.29	2.14
10+BH-661 + 55	4.90	0.15	19.80	1.99
10+BH-661 +110	4.74	0.14	19.15	1.71
BH-543 (with precursor)	4.95	0.17	7.70	2.03
BH-543(Continuous)	4.94	0.17	13.57	2.10

Soybean RI+0= soybean without rhizobium inoculum, Soybean +10= Soybean inoculation with 10 g kg^{-1} of seed, MV= maize varieties, N= nitrogen, NS=Non-significant difference at 5 % probability level

1999). This implies biological nitrogen fixation soybean could be limited since it is available free.

The total phosphorous contents of the soil 10.87 ppm (before soybean planting), 3.87 and 15.79 ppm after soybean planting without rhizobium and with rhizobium inoculation and found low (after soybean planting without rhizobium) to medium range (FAO, 1990; and Landon, 1991). Planting of soybean with rhizobium inoculation improved the total phosphorous concentration of the soil. The tropical soils contain considerable reserves of P that are fixed in unavailable or less labile forms i.e. highly weathered tropical soils are severely depleted in mineral P and also have high P fixation capacity (Grierson et al., 2004). The low available soil P is presumably attributed to the high phosphorus fixing capacity of the Alfisol in these areas, which in turn is accounted for its strongly acidic nature. In agreement with this result Wakene (2001) reported research data indicating considerable fixation of available P by Al, Fe, and Ca in the Alfisol of the same region. The CEC of the soil is ranged from 11.25 to 21.72 meq 100g-1 and found low to medium range (FAO, 1990; and Landon, 1991). The soil is deficient in K concentration. The soil requires better management practices for sustainable crop productions.

The soil pH in H_2O after harvest was ranged from 4.55 to 4.95 (Table 3). According to FAO, 1990 and Landon, 1991 such soils are strongly acidic. Total N ranged from 0.13 to 0.17 % (Table 3), which is categorized as low range according to FAO (1990 and Landon, 1991). The result was in agreement with Chimdi et al. (2012) found lowest total N in the cultivated land. The lowest total N might be due to continuous cultivation of maize farm fields without appropriate managements system by smallholder farmers. Similar findings were reported by

Table 4. Plant height, number of pods plant^{-1}, number of seed pod^{-1}, Seed yield, thousand seed weight and dry biomass of soybean precursor crop and maize in 2013 cropping season at BARC, western Ethiopia.

Soybean + rhizobia inoculation	Plant height (cm)	Number of pods plant^{-1}	Number of seed pods^{-1}	Seed yield (kg ha^{-1})	1000 seed weight (g)	Dry biomass (kg ha^{-1})
With rhizobia inoculation	62	8	2	2520	330	5600
Without rhizobia inoculation	59	8	2	2940	360	6400
Maize	260			2223	365	12523

BARC= Bako Agricultural Research Center

(Abbasi *et al*., 2007; Heluf and Wakene, 2006; and Jaiyeoba, 2003). Organic carbon contents of the soil ranged from 1.52 to 2.14 % (Table 3) found in low range (FAO, 1990 and Landon, 1991). This might be due to continuous cultivation of the field for the past three decades. Soil organic carbon contents declined regardless of inputs application for continuously cultivated land (Kapkiyai, 1996). According to (Barthes *et al*., 1999 and Stevenson, 1994) soil organic carbon dynamics and composition are influenced by land-use changes, agricultural and management practices. Similarly, Chimdi et al. (2012) found lower soil organic carbon for cultivated land and higher depletion of soil OC in cultivated land. Likewise, studies conducted by Lal, (1996); Mandiringana *et al*. (2005) and Michel *et al*. (2010) found the low soil OC content in cultivated land. Available P was ranged from 7.7 to 26 36 ppm (Table 3). This situation can be attributed to the high phosphorous fixing capacity of acid soil. The phosphorous content of the soil was found to be between moderate to adequate range for maize production (FAO, 1990 and Landon, 1991). Similarly, Paulos (1996) found variations in available P contents in soils are related with the intensity of soil disturbance, the degree of P- fixation with Fe and Ca ions. The result was in agreement with Dawit *et al*. (2002) who reported SOM as the main source of available P and the availability of P in most soils of Ethiopia decline by the impacts of fixation, abundant crop harvest and erosion. The Result of this study was in consistent with Chimdi et al. (2012). The pre-plant soil analysis results were higher than postharvest soil analysis for different nutrients. The relatively low soil nutrient concentrations were due to continuous monocropping and cultivation over the last three decades which is consistent with Wakene *et al*. (2001). The total N of soil was reduced as compared to the pre-plant soil analysis result indicating high nutrient up take hybrid maize varieties. Therefore, integrated soil fertility management was advisable for sustainable maize production in the area.

Yield components, nutrient concentrations, uptake and biological N_2-fixation of Soybean

Seed yield of soybean was different between soybean planted with and without rhizobia inoculation (Table 4). Higher seed yield advantage of 420 kg ha^{-1}, or 16.67 %, was produced from soybean planted without rhizobia strain inoculation. This indicates that soybean had been planted in the field previously. Continuous cultivation of legumes may be necessary to help the build-up of high rhizobia populations in soil, resulting in increases in nodulation and yield (Raposeiras *et al*., 2006). The higher thousand seed weight and dry biomass of soybean were from soybean seed planted without inoculation as compared to those inoculated indicates the local rhizobia were more competitive and effective as compared to the introduced strain. Planting of soybean without inoculation was recommended for soybean production where farm history showed that soybean had been grown previously. Furthermore, appropriate site selection is recommended to identify the effectiveness and competitiveness of exotic rhizobium as compared to locally available rhizobia strains in a soil.

Higher total phosphorus, nitrogen, and SO_4 concentrations of soybean tissue were obtained from soybean seed planted with rhizobia inoculation as compared to without rhizobia (Table 5). Higher nitrogen uptake and biological N_2-fixation of 163.8 and 198.3 kg ha^{-1} was produced from soybean seed planted without rhizobia inoculation. Similarly, Sanginga et al. (2002) found plant total N accumulation in soybeans for two years was ranged from 137 to 199 kg N ha^{-1}. Better nodulation of soybean was obtained from field planted without inoculation with rhizobia. Maximum N_2-fixation in a legume requires that the legume be adequately nodulated (Zahran, 1999). Total phosphorous 106.4 kg ha^{-1} concentration was produced from soybean seed planted with rhizobia inoculation, indicating increased phosphorous uptake of soybean. The presence effective local rhizobia in the soil increased the quantity of N_2 fixed by soybean. Therefore, knowing farm field history is recommended before using the rhizobia inoculation for faba bean and soybean production.

Leaf area, leaf area index and plant height of maize

The mean analysis results of leaf area, leaf area index and plant height of maize varieties are indicated in Tables

Table 5. Nutrients concentrations, uptake and biologic of biomass and seed of soybean and maize at Bako Agricultural Research center, western Ethiopia.

	Rhizobium inoculation	Nutrient concentration			Nutrient Uptake		Ndfa (kg ha^{-1})
		Total p (%)	Total N (%)	$S0_4$=S (%)	N (kg ha^{-1})	P (kg ha^{-1})	
Soybean	With rhizobium	0.19	2.77	0.029	155.12	106.4	111.1
	Without rhizobium	0.15	2.56	0.023	163.84	96.0	198.3
	Control (maize)	0.17	1.15	0.026	144.01	212.9	

Table 6. Effects of soybean break crop, maize varieties and nitrogen rate on mean leaf area, leaf area index and plant height of maize at Bako Agricultural Research Center, western Ethiopia.

Soybean rhizobium inoculation	Leaf area (cm^2)	Leaf area index	Plant height (cm)
Without inoculation	6380	3.04	245
With inoculation	6465	3.08	244
With inoculation + 0	7017	3.34	247
BH-543	5356	2.55	234
LSD (5 %)	NS	NS	NS
CV (%)	14.24	14.24	11.99
Variety			
BH-543	6436	3.06	237
BH-661	6341	3.02	251
LSD (5 %)	NS	NS	NS
CV (%)	14.24	14.24	11.99
Nitrogen (kg ha^{-1})			
0	6323	3.01	243
55	6662	3.17	248
110	6282	2.99	243
BH-543	5356	2.55	234
LSD (5 %)	NS	NS	NS
CV (%)	14.24	14.24	11.99

Soybean RI+0= soybean without rhizobium inoculum, Soybean +10= Soybean inoculation with 10 g kg^{-1} of seed, MV= maize varieties, N= nitrogen, NS=Non-significant difference at 5 % probability level

6 and 7. Mean leaf area, leaf area index and plant height of maize varieties were non-significantly affected by main effects of rhizobium inoculation of soybean, maize varieties and rate of nitrogen fertilizer application (Table 6). Even though the analysis of variance were showed non-significant difference due to main effects, variations was observed between maize varieties used. Higher mean leaf area, leaf area index and plant height of maize varieties were obtained from application half recommended nitrogen fertilizer as compared to other treatments.

The interaction of rhizobium inoculation of soybean with maize varieties and nitrogen fertilizer rates were significantly affected mean leaf area and leaf area index of maize varieties (Table 7). BH-543 maize variety was produced higher mean leaf area of 7464 cm2 followed by 6900 cm2 and leaf area index of 3.55 and 3.29 from planting following soybean precursor crop with rhizobium inoculation and application of half recommended nitrogen fertilizer; and soybean precursor crop without rhizobium inoculation and application of half recommended nitrogen fertilizer. Higher mean leaf area of 6350 and 6346 cm2 and leaf area index of 3.02 was measured from BH-661 maize varieties planted following soybean precursor crop with rhizobium inoculation and without application of nitrogen fertilizer; and soybean precursor crop without rhizobium inoculation and application of full recommended nitrogen fertilizer (Table 6). Higher mean leaf area was recorded from BH-543 as compared BH-661 maize varieties. This indicates BH-543 maize variety was produced wider leaf size than BH-661 which might be due to genetic characteristics of the variety. Therefore,

Table 7. Interaction effects of soybean break crop, maize varieties and nitrogen rate on mean leaf area, leaf area index and plant height of maize at Bako Agricultural Research Center, western Ethiopia.

SRI (g) + MV + N kg ha^{-1}	Leaf area (cm^2)	Leaf Area index	Plant height (cm)
0+BH-543 +0	6448	3.07	217
0+BH-543 +55	6900	3.29	261
0+BH-543+110	6368	3.03	236
0+BH-661 +0	6226	2.96	247
0+BH-661 + 55	5989	2.85	254
0+BH-661 +110	6346	3.02	255
10+BH-543 +0	6267	2.98	249
10+BH-543 +55	7464	3.55	223
10+BH-543+110	6250	2.98	238
10+BH-661 +0	6350	3.02	259
10+BH-661 + 55	6294	3.00	253
10+BH-661 +110	6163	2.93	241
BH-543 (with precursor)	7017	3.34	247
BH-543(Continuous)	5356	2.55	234
LSD (5 %)	1593.8	0.7589	NS
CV (%)	14.86	14.86	12.02

SRI+0= soybean without rhizobium inoculum, Soybean +10= Soybean inoculation with 10 g kg^{-1} of seed, MV= maize varieties, N= nitrogen, NS=Non-significant difference at 5 % probability level.

Table 8. Effects of soybean break crop, variety and nitrogen rate on mean grain yield, thousand seed weight and harvest index of maize at Bako Agricultural Research Center, western Ethiopia.

Soybean with rhizobium inoculation	Grain yield (kg ha^{-1})	Thousand seed weight (g)	Harvesting index (%)
Without inoculation	6750	386	39.58
With inoculation	7104	395	44.21
With inoculation + 0 N	5830	358	28.23
BH-543	5430	386	25.52
LSD (5 %)	NS	NS	NS
CV (%)	8.85	8.16	20.83
Maize Varieties			
BH-543	6590	389	43.49
BH-661	7264	387	40.30
LSD (5 %)	423.76	NS	NS
CV (%)	8.85	8.16	20.83
Nitrogen (kg ha-1)			
0	6486	382	37.12
55	7021	394	43.22
110	7274	396	45.34
BH-543	5830	358	28.23
LSD (5 %)	519	NS	7.3873
CV (%)	8.85	8.16	20.83

Soybean without rhizobium inoculum, Soybean inoculation with 10 g kg^{-1} of seed, N= nitrogen, NS=Non-significant difference at 5 % probability level

integrated uses of different soil fertility management systems were very crucial for sustainable maize production in the region.

Grain yield, thousand seed weight and harvest index of maize

Mean analysis of grain yield, thousand seed weight and harvest index of maize varieties are indicated in Tables 8

Table 9. Interactions effects of soybean break crops, maize varieties and nitrogen rate on mean grain yield, thousand seed weight and harvest index of maize at Bako Agricultural Research Center, western Ethiopia.

Soybean RI (g) + MV + N kg ha^{-1}	Grain yield (kg ha^{-1})	Thousand seed weight (g)	Harvesting index (%)
0+BH-543 +0	5878	371	32.28
0+BH-543 +55	5934	406	40.11
0+BH-543+110	6237	394	45.63
0+BH-661 +0	7029	381	34.46
0+BH-661 + 55	7672	395	42.48
0+BH-661 +110	7870	369	42.51
10+BH-543 +0	6507	384	42.28
10+BH-543 +55	7446	388	51.33
10+BH-543+110	7658	421	49.29
10+BH-661 +0	6652	393	39.48
10+BH-661 + 55	7032	386	38.95
10+BH-661 +110	7330	399	43.94
BH-543(with precursor)	5830	358	28.23
BH-543 (Continuous)	5430	386	25.52
LSD (5 %)	1079.1	55.356	13.622
CV (%)	9.54	8.50	20.43

Soybean RI+0= soybean without rhizobium inoculum, Soybean +10= Soybean inoculation with 10 g kg^{-1} of seed, MV= maize varieties, N= nitrogen, NS=Non-significant difference at 5 % probability level

and 9. Main effect of rhizobium inoculation of soybean was non-significantly influenced mean grain yield, thousand seed weight and harvest index of maize varieties. Non-significantly higher mean grain yield, thousand seed weight and harvest index of 7104 kg ha^{-1}, 395 g and 44.21 % were produced from maize planted following soybean precursor crop with rhizobium inoculation as compared to others (Table 8) indicating less difference in the first year but gradual improvement yield over time. Higher mean grain yield of maize varieties was obtained from following soybean precursor crop as compared to continuous maize. Similarly, Yusuf et al. (2009) found rotation with grain legumes provided higher yields than maize after fallow and continuous maize. He further indicated grain yield of maize following soybean genotypes was significantly higher than following cowpea Genotype. KÖpke and Nemecek (2010) reported only small amounts originating from residual N are taken up by the following crop which influence yield of maize. Maize growing on previous soybean plots took up less soil and fertilizer-N than maize grown after maize, thus giving rise to an apparent soil-N conserving effect (Sanginga et al., 2002). Rotating corn significantly improved grain yield over time for the first-year of corn when compared to continuous corn (Stanger and Lauer, 2008). Higgs et al. (1976) and Welch (1976) who found corn grown in rotation had higher yields than corn grown in monoculture, even in the presence of N, P, or K fertility levels that were not limiting yields. Rotation maize was giving greater grain yield of 10 to 17% than monoculture (Higgs et al., 1990). Maize yields increase when grown in crop rotations with soybeans compared to maize grown after maize in the northern Guinea savanna (Carsky et al., 1997). Soybean can supply up to 45 kg N ha^{-1} for a subsequent corn crop (Bundy et al., 1990), explaining the yield improvement at the 112 kg N ha^{-1} rate (Stanger and Lauer, 2008). Porter et al. (1997); Pedersen and Lauer (2002, 2003) reported corn is grown in rotation with soybean; it yields greater than corn following corn. Crop rotation also significantly affected grain yield of maize (Riedell et al., 2009). Crookston et al. (1991) found that annually rotated corn produced about 5 % lower yields than first year corn after 5 years of soybean. Maize growing on previous soybean plots took up less soil and fertilizer-N than maize grown after maize, thus giving rise to an apparent soil-N conserving effect (Sanginga et al., 2002).

Use of maize varieties following soybean precursor crop was significantly varied to mean grain yield potential. Significantly higher mean grain yield advantage of 10.23 and 11.68 % were collected from BH-661 as compared to BH-543. This revealed BH-661 was produced better grain and biological yield potential as compared to BH-543 (Table 8). Non-significantly higher mean harvest index of maize varieties was collected from BH-543 as compared to BH-661(Table 8).

A main effect of nitrogen fertilizer application was significantly affected mean grain yield of maize varieties and harvest index (Table 8). Significantly higher mean grain yield of 7274 kg ha^{-1} followed by 7021 kg ha^{-1} were collected from maize varieties planted with full and half recommended nitrogen fertilizer (Table 8). This indicates the importance optimum nitrogen fertilizer following soybean precursor crop for sustainable maize production. The N fertilizer rate had a significant effect on grain yield slopes of the third year of corn within their respective rotations (Stanger and Lauer, 2008). Riedell et al. (2009) found maize grain yield was significantly affected by N input and grain yields in the intermediate and high N input were significantly greater compared with the no N input. Soybean precursor crop was reduced the amount of nitrogen fertilizer for maize production since the yield increment of maize with full recommended nitrogen fertilizer is too low. The residual soil N and mineralized N (Carpenter-Boggs et al., 2000) in continuous and one year rotation plots were insufficient to prevent N deficiency in the absence of fertilizer N. Application of N fertilizer alleviated this deficiency which resulted in increased grain yield (Riedell et al., 2009). Non-significantly higher mean thousand seed weight of 394 g followed by 394 g were obtained from maize planted with application of full and half recommended nitrogen fertilizer (Table 8), indicating the crucial role of nitrogen for seed size increase and stored food in the seed coats. Higher mean dry biomass maize varieties were harvested from maize varieties planted continuous and following soybean precursor crop without nitrogen fertilizer application, indicating the available nitrogen from the soil could sustain better growth of maize up to 50 % tasseling and then reduced.

Significantly higher mean harvest index of maize was produced from maize planted with application of nitrogen fertilizer as compared to without nitrogen fertilizer (Table 8). Application of full recommended nitrogen fertilizer for maize varieties was produced higher mean harvest index of 4.91, 22.14 and 60.61 % as compared to maize varieties planted following precursor crop with half recommended nitrogen fertilizer, without nitrogen fertilizer and continuous maize without fertilizer (Table 8). Maize planted with half recommended nitrogen fertilizer was gave mean harvest index advantage of 16.43 and 53 % as compared to maize planted without nitrogen fertilizer following soybean precursor crop and continuous maize (Table 8). Therefore, maize planting following soybean precursor crop with half recommended nitrogen fertilizer was recommended for producing better harvest index of maize.

Interaction of rhizobium inoculation of soybean with maize varieties and nitrogen fertilizer rates were significantly affected mean grain yield, thousand seed weight and harvest index of maize varieties (Table 9). The mean grain yield of BH-54 and BH-661 maize varieties were ranged between 5758 to 7658 kg ha^{-1} and 6652 to 7870 kg ha^{-1}, respectively (Table 9). Significantly higher mean grain yield of 7658 kg ha^{-1} followed by 7446 kg ha^{-1} were obtained from BH-543 maize varieties planted following soybean precursor crop with rhizobium inoculum and application of full and half recommended nitrogen fertilizer respectively. For BH-661 maize varieties, significantly higher mean grain yield of 7870 kg ha^{-1} followed by 7672 kg ha^{-1} were produced from planting following soybean precursor crop without rhizobium inoculum and application of full and half recommended nitrogen fertilizer. Corn-oat –alfalfa and corn-soybean- oat with alfalfa seeding-alfalfa rotations were improved grain yield by 25 and 33 kg ha^{-1} yr.$^{-1}$, respectively, when compared to continuous corn for the 56 kg N ha^{-1} treatment (Stanger and Lauer, 2008). Significant N input × rotation interactions for grain yield suggest that these dependent variables responded differently to N input (Riedell et al., 2009). The amount of mean maize grain yield increased with application of full recommended nitrogen fertilizer was 212 and 198 kg ha^{-1} as compared to half recommended nitrogen fertilizer for BH-543 and BH-661, which is agronomically very low. This indicates use soybean precursor crop was requiring optimum nitrogen fertilizer for sustainable maize production. Riedell et al. (2009) suggested the importance of N fertilizer applications to monoculture maize or maize rotated with soybean is strongly demonstrated. Varvel (2000) and Pikul et al. (2005) also found that, in monoculture maize, a high rate of N fertilizer was required to achieve yields similar to those obtained in 4-yr rotational systems containing legume hay crops. A single legume crop year was only beneficial in maintaining corn yields over time if N was added to the system (Stanger and Lauer, 2008). Reducing the nitrogen requirements of maize varieties about to half were agronomically optimum for sustainable maize production in the agroecology.

Thousand seed weight of maize varieties was significantly affected by interaction of soybean precursor crop with rhizobium inoculum with varieties and application of nitrogen fertilizer rates (Table 9). Significantly higher mean thousand seed weight of 399 and 421 g for BH-661 and BH-543 were measured from maize varieties planted following soybean precursor crop with rhizobium inoculation and application full recommended nitrogen fertilizer. Application of nitrogen fertilizer significantly affected mean thousand grain weight of maize (El-Gizawy, 2009). This indicates application of nitrogen fertilizer was necessary for increased seed size of maize varieties in the agroecology.

The interaction of soybean precursor crop with rhizobium inoculation with maize varieties and application of nitrogen fertilizer were significantly affected mean harvest index of maize varieties. The mean harvest indexes of maize varieties were ranged from 32.28 to 51.33 % and 34.46 to 43.94 % for BH-543 and BH-661 maize varieties (Table 9). Significantly higher mean harvest index of 51.33 % followed by 49.29 % for BH-543 were obtained from maize planted following soybean precursor crop with inoculation and application half and

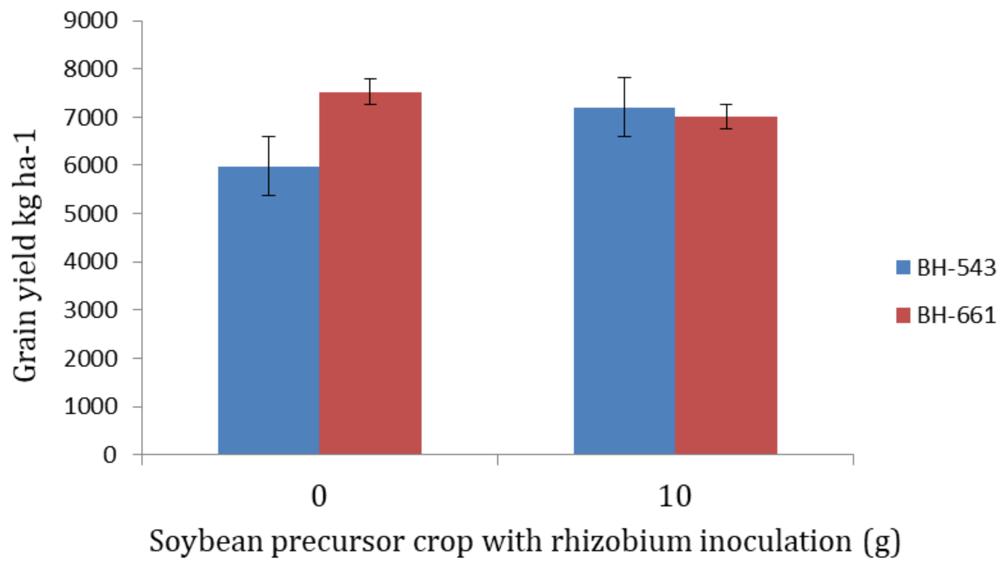

Figure 2. Interaction of soybean break crop with rhizobium inoculation and maize varieties on mean grain yield of maize at BARC, western Ethiopia.

full recommended nitrogen fertilizer; while 43.94 % followed by 42.51 % for BH-661 were produced from maize planted following soybean precursor crop with inoculation and application full recommended nitrogen fertilizer and maize planted following soybean precursor crop without inoculation and application full recommended nitrogen fertilizer. This justifies application of nitrogen was very crucial for producing higher mean harvest index of maize varieties.

Interaction of maize varieties with rhizobium inoculation of soybean was significantly affected mean grain yield of maize (Figure 2). BH-661 maize variety was produced higher mean grain yield with soybean precursor crop planted without rhizobium inoculation. Significantly higher mean grain yield of BH-543 maize variety was harvested from soybean precursor crop planted with rhizobium inoculation. Both maize varieties were responded differently to soybean precursor crop planted with and without rhizobium inoculation. Both maize varieties were responded similar following soybean precursor crop with rhizobium inoculation. Maize varieties planted following soybean precursor crop without rhizobium inoculation were significantly differed in mean grain yield. This indicates the yield potential of BH-661 was better as compared BH-543 at low level of fixed nitrogen.

Interaction effects of soybean precursor crop, maize varieties and nitrogen rates on economic viability of maize production

The results of economic analysis for interaction effects of soybean precursor crop, maize varieties and nitrogen rates were indicated in (Table 10). The highest net benefit of EB 24505 ha-1 and marginal rate of return 56 % was obtained from BH-661 maize varieties planted following soybean precursor crop with rhizobium inoculation and application of half recommended (55 kg N ha^{-1}). The values to cost ratio was ranged from EB 4.20 to 186 per unit of investment was obtained from BH-543 maize varieties planted following soybean precursor crop without rhizobium inoculation and application of recommended rate (110 kg N ha^{-1}) and BH-661 maize variety planted following soybean precursor crop with rhizobium inoculation and without nitrogen application. The second and third net benefits were EB 23723 and 23622 ha^{-1} obtained from BH-66 maize varieties planted following soybean precursor crop without rhizobium inoculation and without nitrogen fertilizer application; and BH-543 maize varieties planted following soybean precursor crop with rhizobium inoculation and application of 55 kg ha^{-1} nitrogen fertilizer. The net economic returns of maize varieties planted following soybean precursor crop without and with rhizobium inoculation was higher than continuous maize. This indicates planting of maize varieties following soybean precursor crop was improved the fertility status of maize which had enhanced the nutrient uptake of maize. It was found that mean grain yield and economic return from the soybean precursor crop were significantly higher than from the continuous cropping. Rotating maize improved profit more than did adding inputs to continuous maize.

Table 10. Mean interaction effects of soybean break crop, maize varieties and nitrogen rate on partial budget and marginal rate of return mean grain yield of maize at BARC, western Ethiopia.

Items	BH-543 (C)	SB + 0RI +0 kg N ha^{-1}		SB +10RI +0 kg N ha^{-1}		BH-543 (SBP)	SB + 0RI +55 kg N ha^{-1}		SB +10RI +55 kg N ha^{-1}		SB + 0RI +110 kg N ha^{-1}		SB + 10RI +110 kg N ha^{-1}	
		BH-543	BH-661	BH-543	BH-661		BH-543	BH-661	BH-543	BH-661	BH-543	BH-661	BH-543	BH-661
Grain yield kg ha^{-1}	5430	5878	7029	6507	6652	5830	5934	7672	7446	7032	6237	7658	7870	7330
Adjusted grain yield kg ha^{-1}	4887	5290	6326	5856	5987	5247	5341	6905	6701	6329	5613	6892	7083	6597
Gross field benefit EB ha^{-1}	18326	19838	23723	21961	22451	19676	20027	25893	25130	23733	21050	25846	26561	24739
Total field cost EB ha-1	0	0	0	120	120	120	1388	1388	1508	1508	4050	4050	4170	4170
Net benefit EB ha^{-1}	18326	19838	23723	21841^{d}	22331^{d}	19556^{d}	18639^{d}	24505	23622^{d}	22225^{d}	17000^{d}	21796^{d}	22391^{d}	20569^{d}
Values to cost ratio				182.01	186.09	162.97	13.43	17.65	15.66	14.74	4.20	5.38	5.37	4.93
Marginal rate of return (MRR)								56						

Note: Grain price= EB 3.75 kg-1, Yield was down adjusted with 10 % coefficient, Cost of Urea = EB 12.75 kg -1 DAP = EB 15.00 kg-1, d= dominated treatment, SB+ 0RI=soybean without rhizobium inoculation, SB +10RI= soybean with rhizobium inoculation.

CONCLUSION

Soybean precursor crop without and with rhizobium inoculation integrated with nitrogen fertilizer have potential to increase hybrid maize varieties productivity through better efficiency in utilization of inputs and other resources due to improved soil fertility situations. The result soil analysis indicates most of the nutrient concentrations below the critical level and was requires better management practices for sustainable maize productions. Planting of maize varieties following soybean precursor crop was significantly affected to mean grain yield potential. Application of nitrogen fertilizer following soybean precursor crop to maize varieties was significantly affected mean grain yield and harvest index maize varieties. Soybean precursor crop was reduced the amount of nitrogen fertilizer for maize production since the yield increment of maize with full recommended nitrogen fertilizer is minimum as compared application of half recommended. Maize varieties planted following soybean precursor crop with half recommended nitrogen fertilizer was recommended for producing better harvest index of maize. BH-661 and BH-543 maize varieties were significantly produced higher mean grain yield with soybean precursor crop planted without and with rhizobium inoculation. Interaction of rhizobium inoculation of soybean with maize varieties and nitrogen fertilizer rates were produced significantly higher mean number of leafs plant^{-1}, leaf area, leaf area index, grain yield, thousand seed weight, dry biomass and harvest index of maize varieties. Application 55 kg N ha-1 to maize varieties following soybean precursor crop was agronomically optimum for sustainable maize production in the agroecology. The net economic returns of maize varieties planted following soybean precursor crop without and with rhizobium inoculation was higher than continuous maize. Production of BH-661 and BH-543 maize varieties following soybean precursor crop with half recommended (55 kg N ha^{-1}) application was improved mean grain yield and economic return and recommended for maize in mid altitude areas of western Ethiopia.

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