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Effects of soybean precursor crop and nitrogen rates on subsequent maize grain yield and nitrogen use efficiency at Bako, West Ethiopia

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ABSTRACT

Maintaining soil fertility using legumes precursor crop and minimum nitrogen, is of paramount importance for of sustaining maize production. A study was carried out at Bako Agricultural Research Center to assess the effects of soybean precursor crop and nitrogen rates on subsequent maize grain yield and nitrogen use efficiency. Maize varieties planted were significantly varied following soybean precursor crop. Significantly higher mean grain yield and dry biomass of maize were harvested from BH-661 varieties planted following soybean precursor crop indicating variations of maize varieties in yielding potential following soybean. Application of nitrogen fertilizer following soybean precursor crop was significantly affected mean grain yield of maize. 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. 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. Agronomic efficiency, plant N uptake efficiency, nitrogen use efficiency and fertilizer N (recovery) use efficiency were increased with lower rates of nitrogen fertilizer. Production of BH-661 and BH-543 maize varieties following soybean precursor crop with half recommended (55 kg N ha^{-1}) application improved mean grain yield and recommended for maize in mid altitude areas of western Ethiopia.

Key words: Nitrogen fixation, Rhizobia, Soil nitrogen

INTRODUCTION

Soil fertility depletion is considered as the major threats to food security and crop production facing severe nutrient deficiencies in Ethiopia. Low soil fertility stands the most bottlenecks to production and productivity of maize in western Ethiopia. Conventional agriculture (continuous cropping with inputs) has certain limitations in terms of maintaining long-term soil fertility (Charpentier et al., 1999).

Wu et al. (2003) longer cultivation has further depleted the soil organic-matter content and fertility of these soils. Wakene (2001) reported that continuous monocropping with heavy applications of NP fertilizers and intensive mechanized tillage practice leads to enhanced soil acidity, degradation of organic carbon and leaching of the exchangeable bases. However, decreasing productivity can be alleviated by different methods such as use of inorganic nitrogen and use of legumes in a cropping system. Consequently, the use of legumes in a cropping system for biological nitrogen fixation becomes an alternative source of nitrogen for crop production. Legumes contribute to the maintenance and restoration of soil fertility by fixing N_2 from the atmosphere (Giller and Wilson, 1991). Azam and Farooq (2003) reported symbiotic nitrogen fixation by legumes is the major natural process of adding nitrogen into the biosphere amounting to about 35 million tons annually. 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). Yusuf et al. (2009) found maize following legumes on average had higher grain yield of 1.2 and 1.3 fold compared with maize after fallow or maize after maize. Corn rotated annually with soybean and first-year corn after 5 year of consecutive soybean yielded 12 % more than continuous grown corn (Pedersen and Lauer, 2002). Crookston et al. (1991) reported a 5 % yield advantage for first-year corn after several years of soybean compared with corn rotated annually with soybean.

First year corn after 5 year soybean and annually rotated corn produced the highest yield averaging 8.8, 11.6, and 10.1 Mg ha^{-1} for the 3 year (Pedersen and Lauer, 2002). Raimbault and Vyn (1991) reported that first-year corn grown in rotation yielded 4 and 8 % more than continuous corn under fall moldboard plow and fall chisel. Thus, soybean precursor crop is important management considera- tion for better grain yield of maize varieties.

The input of fixed N from grain legumes may be a significant contributing factor in relation to sustaining productivity in smallholder systems (Sanginga, 2003). Lassaletta et al. (2014) suggested that an increase in the contribution of symbiotic N fixation would result in increasing NUE. Yusuf et al. (2009) found soybean rotation resulted in significant increase in total N uptake compared to continuous maize. N agronomic efficiency (AEN) and N fertilizer recovery efficiency (REN) of maize following grain legumes were on average 14 and 34% greater than of maize following maize and 12 and 20 % greater than of maize following fallow respectively (Yusuf et al., 2009). Information is scanty on the soybean precursor crop with nitrogen rates on corn grain yield and nitrogen efficiency of maize varieties Peterson and Varvel (1989) found that corn grown in a 4 years rotation and fertilized with 160 lb N A^{-1} yielded 22% more than continuous corn fertilized at the same rate. Similarly, a 3 years rotation with legume yielded 16 and 22 % more under high chemical inputs and chisel plow, and moldboard plow than continuous corn (Katsvairo and Cox, 2000). Peoples et al. (2009) reported that the potential of symbiotic nitrogen fixation is currently largely underexploited, given that very few countries have a fraction of arable land devoted to legume crops greater than a few percent. 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).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. Hence, the objective is to determine the effects of soybean precursor crop, maize varieties, nitrogen rates and its integrated effect on subsequent maize yield and nitrogen use efficiency at Bako, West Ethiopia.

MATERIALS AND METHODS

Soybean precursor crop experiment was conducted from 2013 to 2014 cropping seasons at Bako Agricultural Research Center (BARC), East Wollega Zone of the of Oromia national Regional State western Ethiopia. Geographically, BARC 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. The long-term (1961-2014) mean annual rainfall at BARC is 1266 mm with unimodal distribution (Table 9) (MBARC, 2014). It has a warm humid climate with the mean minimum, mean maximum and average air temperatures of 13.2, 28 and 21^{o}C, respectively (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).The soil sample was collected at the depth 0- 20 cm with augur two times first before application of the treatment (2013), second after harvesting of the rotation crops when the field ready for maize planting in 2014. 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 were extracted with 1.0 Molar ammonium acetate at pH7. 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 NO_3^-N and NH_4^-N as described by (Keeney and Nelson, 1982).

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. The rotation crop with rhizobium strain as factor A, maize varieties as factor B and nitrogen rates 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 crop. The necessary data were collected at right time and crop growth stage. Grain yield and dry biomass after harvesting of maize were collected. The grain yield was harvested from the net plot (3 m x 5.1m=15 m^2). The harvested grain yield 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.

Plant tissues (dry tissue at 50 % flowering, and grain at harvesting) in 2013 for soybean and (dry tissue at 50 % tasseling and grain at harvesting) in 2014 for maize were collected. The collected tissue and grain was 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 colorimeterically according to Murphy and Riley (1962), and the S content of the plant tissue was determined by using an ICP-AES (Varain model Vista MPX).

The total nitrogen fixation of faba bean and soybean were 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. Agronomic efficiency is calculated as the amount of harvestable product, i.e. kg of cereal per kg of applied nutrient (N) (Cleemput *et al.* 2008). NAE $=Y_N-Y_0/F_N$, Where Y_N and Y_0 are the grain yield with and without N applied, respectively; and FN is the amount of N fertilizer applied. The N uptake efficiency (UEN) is the total amount of N absorbed (including that present in the roots, often disregarded) per kg of applied N. $UEN=U_N-U_0/F_N$ .Plant nitrogen use efficiency is calculated as total dry matter or grain yield produced per unit of N absorbed. N utilization efficiency was calculated as described by (Haegele, 2012). $PEN= U_N-U_0/Y_N-Y_0$. Apparent fertilizer N use (recovery) efficiency (ANRE) is the amount of fertilizer N taken up by the plant per kg of N applied as fertilizer. Apparent N fertilizer recovery (ANRE) was calculated as it is described by (Azizian, and Sepaskhah, 2014; Cleemput et al. 2008). % fertilizer nutrient recovery= (TNF-TNU/R)*100. The N harvest index (NHI) at maturity was calculated (Jones et al., 1990) and also N accumulation (kg N ha^{-1}) in the shoots or grains was calculated (Seleiman et al., 2013; Xu et al. 2006) as follows: N harvest index= grain N accumulation (kg ha^{-1})/Total N accumulation (kg ha^{-1}).

Where, the total N accumulation includes all N that accumulated in leaves, stem, shank, cobs and husk organs in addition to the grain.

Shoot Analyses for agronomic data were carried out using statistical packages and procedures of SAS computer software (SAS, 2008). Mean separation was done using least significance difference (LSD) and Duncan's multiple range test (DMRT) procedure at 5% probability level (Steel and Torrie, 1980) and (Duncan, 1955).

$$Shoot\,N\,accumulation\,(kg\,ha^{-1}) = \frac{shoot\,N\,content\;(g\,kg^{-1}) \times shoot\,DM\,(kg\,ha^{-1})}{1000}$$

$$Grain\,N\,accumulation\,(kg\,ha^{-1}) = \frac{grain\,N\,content\;(g\,kg^{-1}) \times grain\,DM\,(kg\,ha^{-1})}{1000}$$

RESULTS AND DISCUSSION

Soil physical and chemical properties of the experimental site

The laboratory analyses of the selected physic-chemical properties of the soils are indicated (Table 1). 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 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 need crop rotation and application integrated use organic with inorganic fertilizer to sustain under production. The $N03^{-}N$ 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 al., 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 in (in 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 have medium nutrient holding capacity level, higher water holding capacity, less susceptible to leaching losses of Mg^{2+} and K^+ and high organic matter contents. The soil is deficient in K concentration. The soil requires better management practices for sustainable crop productions.

Table 1: Some physico-chemical properties soil of farmer's field before planting maize in Bako Agricultural Research Center, western Ethiopia.

Soil parameters	Soybean +0	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

RI= rhizobium inoculation, 0= soybean without Rhizobium

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

Seed yield of soybean was different between soybean planted with and without rhizobia inoculation (Table 2). 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 3). 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. 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.

Grain yield and dry biomass of maize

Mean analysis of grain yield and dry biomass of maize varieties are indicated in Table 4 and 5. Main effect of rhizobium inoculation of soybean was non-significantly influenced mean grain yield, and dry biomass of maize varieties.Non-significantly higher mean grain yield, of 7104 kg ha^{-1} was produced from maize planted following soybean precursor crop with rhizobium inoculation as compared to others (Table 4) indicating less difference in the first year but gradual improvement yield over time. KÖpke and Nemecek (2010) reported only small amounts originating from residual N are taken up by the following crop. 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 gave greater grain yields of 10 to 17% than monocropped one (Higgs et al., 1990). Porter et al. (1997); Pedersen and Lauer (2002, 2003) reported corn is grown in rotation with soybean gavegreater yields than corn following corn. Crop rotation also significantly affected grain yield of maize (Riedell et al., 2009).

Higher mean dry biomass of maize varieties were collected from continuous maize and maize following soybean precursor without fertilizer, indicating without nitrogen fertilizer both varieties were grow better up to 50 % tasseling and reduced productivity. Use of maize varieties following soybean precursor crop was significantly varied to mean grain and dry biomass yield potential. Significantly, higher mean grain and dry biomass 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 5). Non-significantly higher, mean harvest index of maize varieties were collected from BH-543 as compared to BH-661(Table 4).

Table 2: 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)	Nr. of pods plant^{-1}	Nr. 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

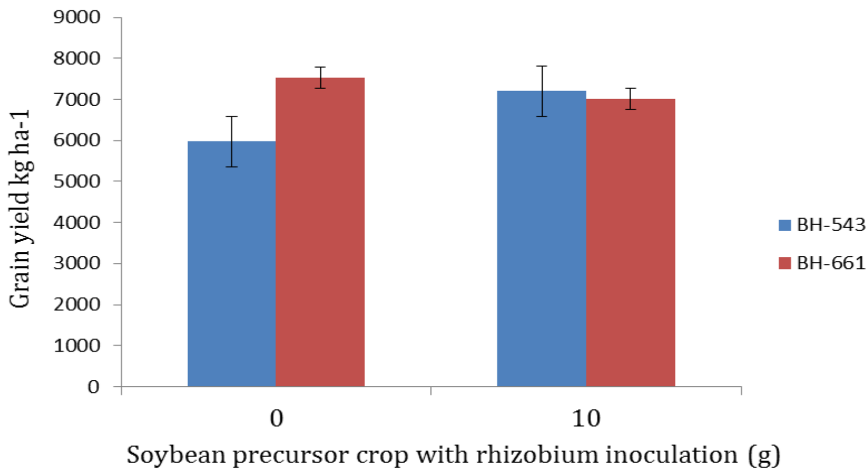

Figure 1: Interaction of Soybean precursor crop with rhizobium inoculation and maize varieties on mean grain yield of maize at Bako Agricultural Research Center, western Ethiopia.

Table 3: Nutrients concentrations, uptake and biological N_2- fixation of soybean and maize at Bako Agricultural Research center, western Ethiopia.

Crop	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	

Main effect of nitrogen fertilizer application was significantly affected mean grain yield of maize varieties and harvest index (Table 4). 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 5). 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 4), 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.

Table 4: Effects of rhizobium inoculation, variety and nitrogen rate on mean grain yield, and dry biomass of maize at BARC, western Ethiopia.

Rhizobium inoculation	Grain yield (kg ha^{-1})	Dry biomass (kg ha^{-1})
Without inoculation	6750	17643
With inoculation	7104	16431
With inoculation + 0 N	5830	21938
Control	5430	21919
LSD (5 %)	NS	NS
CV (%)	8.85	19.89
Varieties		
BH-543	6590	16757
BH-661	7264	18714
LSD (5 %)	423.76	2359
CV (%)	8.85	19.89
Nitrogen (kg ha^{-1})		
0	6486	17444
55	7021	16883
110	7274	16784
Control	5830	15238
LSD (5 %)	519	NS
CV (%)	8.85	19.89

NS=Non-significant difference at 5 % probability level

Table 5: Combination effects of rhizobium inoculation, variety and nitrogen rate on mean grain yield and dry biomass of maize at BARC, western Ethiopia

RI (g) + MV + N kg ha^{-1}	Grain yield (kg ha^{-1})	Dry biomass (kg ha^{-1})
0+BH-543 +0	5878	17984
0+BH-543 +55	5934	14876
0+BH-543+110	6237	15736
0+BH-661 +0	7029	19819
0+BH-661 + 55	7672	18889
0+BH-661 +110	7870	18554
10+BH-543 +0	6507	15320
10+BH-543 +55	7446	15560
10+BH-543+110	7658	15888
10+BH-661 +0	6652	16652
10+BH-661 + 55	7032	18208
10+BH-661 +110	7330	16959
BH-543(with precursor)	5830	15238
BH-543 (Continuous)	5430	14119
LSD (5 %)	1079.1	6196.3
CV (%)	9.54	20.81

RI= Rhizobium inoculum, MV= maize varieties, N= nitrogen, NS=Non-significant difference at 5 % probability level.

Interaction of rhizobium inoculation of soybean with maize varieties and nitrogen fertilizer rates were significantly affected mean grain yield and dry biomass of maize varieties (Table 5). The mean grain yield of BH-540 and BH-661 maize varieties were ranged between 5758 to 7658 kg ha^{-1} and 6652 to 7870 kg ha^{-1}, respectively (Table 5). Significantly higher mean grain yields 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 ertilizer. 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. Reducing the nitrogen requirements of maize varieties about to half were agronomically optimum for sustainable maize production in the agroecology. Mean dry biomass of maize varieties were significantly affected by interaction of soybean precursor crop with rhizobium inoculation with maize varieties and application of nitrogen fertilizer (Table 4). Significantly mean dry biomass of maize varieties were ranged from 14876 to 17984 kg ha^{-1} and 16652 to 19819 kg ha^{-1} for BH-543 and BH-661, respectively (Table 6). Significantly, higher mean dry biomass of 17984 and 19819 kg ha^{-1} for BH-543 and BH-661 were produced from planting following soybean precursor crop without rhizobium inoculation and without nitrogen fertilizer application. This indicates the nitrogen from precursor crop and soil were maintained maize dry biomass more up to grain filling stages of maize. Nitrogen uptake, agronomic efficiency, N uptake efficiency, plant nitrogen use efficiency and fertilizer N (recovery) use efficiency of maize.

The mean analysis result of nitrogen uptake, agronomic efficiency, N uptake efficiency, plant nitrogen use efficiency and fertilizer N (recovery) use efficiency of maize are indicated in Tables 6 and 7. The nitrogen uptake of maize was ranged 436 to 650. The use of soybean precursor crop gave 618 and 558 kg ha^{-1} without and with rhizobium inoculation. Maize planted following soybean without rhizobium was gave 10.8 % higher nitrogen uptake as compared to following soybean with rhizobium inoculation. This implies the local indigenous rhizobium strain from farm history plays a significant role as compared to exotic strains in improving soil organic matter and nitrogen status which enhance the total nitrogen uptake of maize varieties. BH-661 maize variety planted following soybean without and with rhizobia, inoculation had higher nitrogen uptake as compared to BH-543 maize variety. BH-661 maize variety had total nitrogen uptake advantages of 3.8 and 13.8 % as compared to BH-543 when planted following soybean without rhizobium inoculation and with rhizobium inoculation. BH-543 and BH-661 maize varieties planted with 0 and 55 kg N ha^{-1} had higher total nitrogen uptake of 640 and 648; and 575 and 650 kg N ha^{-1} when planted following soybean without and with rhizobium strain inoculation. This indicates soybean precursor crop with effective rhizobium strain present in soil and inoculation improved the amount of nitrogen uptake for maize production. Thus soybean precursor crop was improved the total nitrogen uptake of maize varieties.

The agronomic efficiency of maize varieties was varied with soybean precursor crop and application of nitrogen rates. BH-543 and BH-661 maize varieties planted following soybean precursor crop without rhizobium strain inoculation were gave higher agronomic efficiency of 48 and 1199; and 448 and 1599 as compared maize planted following soybean without fertilizer and continuous maize. Furthermore, BH-543 and BH-661 maize varieties planted following soybean precursor crop with rhizobium strain inoculation were gave higher agronomic efficiency of 67 and 822; and 1077 and 1222 as compared maize planted following soybean without fertilizer and continuous maize (Tables 6). BH-543 maize variety planted without nitrogen fertilizer following soybean precursor crop without rhizobium inoculation gave higher mean agronomic efficiency advantage of 4409 % as compared maize planted with 55 and 110 kg N ha^{-1} application. BH-661 maize varieties planted without nitrogen fertilizer following soybean precursor crop without rhizobium inoculation gave higher mean agronomic efficiency advantage of 3681 and 6724 % as compared maize planted with 55 and 110 kg N ha^{-1} application. BH-543 and BH-661 maize varieties planted without nitrogen fertilizer following soybean precursor crop with rhizobium inoculation gave higher mean agronomic efficiency advantage of 2558 and 3908; and 4641 and 5912 % as compared maize planted with 55 and 110 kg N ha^{-1} application. For both maize varieties, higher agronomic efficiency was produced from lower rates of nitrogen fertilizer rates. Mean agronomic efficiency of 0>55>110 kg N ha^{-1} was obtained from both maize varieties planted following soybean precursor crop without and with rhizobium inoculation. Planting of maize varieties following soybean precursor crop was increased agronomic efficiency and recommended for sustainable maize production.

Interaction of maize varieties with rhizobium inoculation of soybean was significantly affected mean grain yield of maize (Fig 1). 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.

The nitrogen uptake efficiency of maize varieties differed with soybean precursor crop and application of nitrogen fertilizer (Table 7). Significantly higher nitrogen uptake efficiency of maize varieties was obtained from maize varieties planted following soybean precursor crop without rhizobium inoculation with application of 110 kg N ha^{-1} and with rhizobium with application of 55 kg ha^{-1} in relation to maize planted following soybean and continuous maize without fertilizer application. Rahimizadeh (2010) found nitrogen uptake efficiency (NUpE) in wheat was significantly affected by preceding crop. Lopez-Bellido and Lopez-Bellido (2001) indicated that differences between rotations with respect to grain yield, which is directly related to crop N uptake, account for the variation in the NUpE index.

Lee et al., (2004) indicated that NUpE was positively correlated with plant dry matter, leaf area index and leaf nitrogen content. Application of nitrogen fertilizer to maize varieties following soybean precursor crop was improved the nitrogen uptake efficiency of maize varieties. BH-543 and BH-661 maize varieties planted following soybean precursor crop without rhizobium inoculation with application recommended (110 kg N ha^{-1}) were gave nitrogen uptake efficiency of 225 and 191; and 15 and 5.67 % as compared to maize planted without and with 55 kg N ha^{-1}. This implies application of recommended nitrogen fertilizer was significantly increased mean nitrogen uptake efficiency of maize varieties. Rahimizadeh et al. (2010) found application of N fertilizer rate on preceding crops, significantly influenced NUpE of wheat. BH-543 and BH-661 maize varieties planted following soybean precursor crop with rhizobium inoculation with application half recommended (55 kg N ha^{-1}) were gave nitrogen uptake efficiency of 706 and 530; and 18.54 and 8.59 % as compared to maize planted without and with recommended (110 kg N ha^{-1}) application.

This indicates maize planted following soybean precursor crop with rhizobium inoculation was improved the nitrogen uptake efficiency of maize varieties. BH-543 and BH-661 maize varieties were had higher mean nitrogen uptake efficiency of 625 and 632; and 567 and 642 kg ha^{-1} when planted following soybean precursor crop without and with rhizobium inoculation. BH-543 and BH-661 maize varieties planted following soybean precursor crop without rhizobium inoculation was gave higher mean nitrogen uptake efficiency of 23 and 8.38 % as compared to following soybean precursor crop with rhizobium inoculation. This indicates the local rhizobium strain in soil from soybean history in farm was contributed much for fixation of biological nitrogen which enhances the nitrogen uptake efficiency of maize varieties. BH-661 maize variety lanted following soybean precursor crop without and with rhizobium inoculation was had higher nitrogen uptake efficiency as compared to BH-543. Higher combined mean nitrogen uptake efficiency of 2.39 % maize varieties was obtained from maize calculated in relation to continuous maize as compared to soybean precursor crop without fertilizer application. Therefore planting of maize varieties following soybean precursor crop was improved the nitrogen uptake efficiency of maize.

The plant nitrogen use efficiency of maize varieties was different between soybean precursor crop, application of nitrogen rates and varieties of maize used (Table 6). Higher combined mean plant nitrogen use efficiency of 236 % was obtained from maize measured in relation to maize planted following soybean precursor crop without fertilizer as compared to continuous maize without nitrogen fertilizer application. Pikul Jr (2003) reported nitrogen use efficiencies for one, three and five years rotations were ordered corn soybean > corn-soybean-spring wheat > corn-soybean-oat/pea hay companion seeded with alfalfa > corn-soybean-oat/pea and continuous corn had the lowest NUE at 32.2 kg grain / kg N .

Table 6: Effects of rhizobium inoculation, maize variety and nitrogen rate on nitrogen uptake, agronomic efficiency, N up take efficiency and plant nitrogen use efficiency of maize at BARC, western Ethiopia.

RI (g) + MV + N kg ha-1	Nitrogen up take (kg ha-1)	Agronomic efficiency			Nitrogen uptake efficiency (kg ha-1)			Plant nitrogen use efficiency (Kg ha-1)		
		Precursor	Continues	Mean	Precursor	Continues	Mean	precursor	Continues	Mean
0+BH-543 +0	640	48	448	248	174	204	189	3.62	0.46	2.04
0+BH-543 +55	552	2	9	5.5	543	544	544	0.82	0.23	0.53
0+BH-543+110	629	4	7	5.5	625	625	625	0.40	0.24	0.32
0+BH-661 +0	648	1199	1599	1399	182	212	197	0.15	0.13	0.14
0+BH-661 + 55	606	33	41	37	598	598	598	0.08	0.08	0.08
0+BH-661 +110	636	19	22	20.5	632	632	632	0.08	0.08	0.08
10+BH-543 +0	509	677	1077	877	42	72	57	0.06	0.07	0.06
10+BH-543 +55	576	29	37	33	567	568	568	0.07	0.07	0.07
10+BH-543+110	483	17	20	18.5	479	479	479	0.01	0.02	0.02
10+BH-661 +0	538	822	1222	1022	72	102	87	0.09	0.08	0.09
10+BH-661 + 55	650	22	29	25.5	642	642	642	0.15	0.13	0.14
10+BH-661 +110	595	14	17	15.5	591	591	591	0.09	0.08	0.08
BH-543(soybean precursor)	466									
BH-543 (Continuous)	436									

RI= Rhizobium inoculation, MV= maize varieties

Table 7: Effects of rhizobium inoculation, maize variety and nitrogen rate on Fertilizer N (recovery) use efficiency of maize around BARC, western Ethiopia.

Soybean + RI	Maize Varieties	Nitrogen rate (Kg N ha^{-1})						Mean
		0		55		100		
		Precursor	Continues	Precursor	Continues	Precursor	Continues	
SB + 0RI	BH-543	17400	20400	156	211	148	175	6415
SB + 0RI	BH-661	18200	21200	255	309	155	182	6717
SB + 10RI	BH-543	4300	7300	200	255	15	43	2019
SB + 10RI	BH-661	7200	10200	335	389	117	145	3064
Mean		11775	14775	236	291	109	136	

SB + 0RI= soybean without rhizobium inoculation, SB +10RI= Soybean precursor crop with rhizobium inoculation.

Table 8: Effects of rhizobium inoculation, maize variety and nitrogen rate on shoot N accumulation, grain N accumulation and N harvest index of maize at BARC, western Ethiopia.

RI (g) + MV + N kg ha^{-1}	Shoot N accumulation (kg ha^{-1})	Grain N accumulation (kg ha^{-1})	N harvest index (%)
0+BH-543 +0	110	81	0.42
0+BH-543 +55	109	93	0.46
0+BH-543+110	154	90	0.37
0+BH-661 +0	128	95	0.42
0+BH-661 + 55	131	108	0.45
0+BH-661 +110	204	103	0.34
10+BH-543 +0	102	87	0.46
10+BH-543 +55	138	115	0.45
10+BH-543+110	115	108	0.48
10+BH-661 +0	86	91	0.51
10+BH-661 + 55	153	90	0.37
10+BH-661 +110	153	97	0.39
BH-543(with precursor)	85	79	0.48
BH-543 (Continuous)	90	74	0.45

RI= Rhizobium inoculation, MV= maize varieties

The higher NUE of maize varieties following soybean precursor crop was due to the higher NUpE in this rotation. Similar result was reported by (Rahimizadeh et al., 2010) in wheat. Muurinen et al. (2007) concluded increasing grain yield and HI increased NUtE, reported a strong relationship between NUtE and HI. Lopez-Bellido and Lopez-Bellido (2001) crop rotation has marked influence on the utilization of resources. Higher mean maize nitrogen use efficiency was obtained from maize varieties planted following soybean precursor crop without rhizobium strain inoculation as compared to following soybean precursor crop with rhizobium inoculation. Maize planted following soybean precursor crop without rhizobium inoculation was gave higher mean advantages of 1000 and 171 % and combined mean of 591 % as compared to maize planted following soybean with rhizobium inoculation when calculated in relation to maize planted following soybean precursor crop and continuous maize with nitrogen fertilizer application. Rahimizadeh (2010) found Nitrogen use efficiency (NUE) in wheat was significantly affected by preceding crop. This implies planting of soybean without rhizobium inoculation fixed enormous amount of nitrogen due to past farm history which enhance the maize nitrogen efficiency. Mean maize nitrogen use efficiency of 0.96 and 0.10 Kg ha^{-1} was obtained from BH-543 and BH-661 maize varieties planted following soybean precursor crop without rhizobium inoculation. BH-543 maize varieties were had higher nitrogen use efficiency of 860 % as compared to BH-661 planted following soybean precursor crop without rhizobium inoculation. BH-661 maize variety was showed higher nitrogen use efficiency when planted following soybean with precursor crop with rhizobium inoculation as compared to BH-543 and gave mean advantage of 106 % nitrogen use efficiency (Table 6). BH-661 maize variety was had equal nitrogen use efficiency when planted following soybean precursor crop without and with rhizobium inoculation. Both maize varieties were had higher nitrogen use efficiency with lower rates of nitrogen fertilizer applied when planted following soybean precursor crop without and with rhizobium inoculation. Similar result was reported by (Rahimizadeh et al., 2010) on wheat Lopez-Bellido and Lopez-Bellido (2001) showed that nitrogen efficiency indices significantly affected by crop rotation and N fertilizer rate. N use efficiency indices are greater in crop rotation systems than in monoculture systems (Yamoah et al., 1998). Nitrogen efficiency indices decrease with increasing N level, especially under dry soil condition (Huggins and Pan, 1993). Sowers et al. (1994), the application of high N rates may result in poor N uptake and low NUE due to excessive N losses. The two maize varieties had good characters for production under marginal soil fertility and use for further low nitrogen stress breeding purposes. Thus, uses of these two varieties maize are crucial for sustainable maize production under smallholder farmers and other breeding program.

The fertilizer N (recovery) use efficiency of maize varieties were varied among varieties with the application of nitrogen fertilizer rates following soybean precursor crop without and with rhizobium inoculation. BH-661 maize variety was gave higher fertilizer N use efficiency as compared to BH-543 when planted following soybean precursor crop without and with rhizobium inoculation and application of different rates of nitrogen. Rahimizadeh (2010) found nitrogen utilization efficiency (NUtE) in wheat was significantly affected by preceding crop. Planting of BH-661 maize variety following soybean precursor crop without and with rhizobium inoculation were gave higher fertilizer N (recovery) use efficiency of 4.71 and 52 % as compared to BH-543. This implies BH-661 maize variety was responded better to nitrogen fertilizer application. Both maize varieties were gave significantly higher fertilizer N (recovery) use efficiency when measured in relation to maize planted following precursor crop without nitrogen fertilizer as compared to continuous maize. The mean fertilizer N (recovery) use efficiency was reduced with increasing rates of nitrogen application. The mean fertilizer N (recovery) use efficiency of 13275, 264 and 124 Kg N ha^{-1} were obtained from 0, 55 and 110 kg N ha^{-1} application to maize varieties. Maize varieties planted following soybean precursor crop without rhizobium inoculation were gave higher fertilizer N (recovery) use efficiency of 4024 kg ha^{-1} or 158 % as compared maize varieties planted following soybean precursor crop with rhizobium inoculation. This revealed that soybean precursor crop without rhizobium inoculation due to availability of effective rhizobium strain in the soil was promoted the fertilizer nitrogen (recovery) use efficiency of maize varieties. Therefore, planting of maize following soybean precursor crop showed better advantages as compared to continuous maize which might be due to the rotation benefits of legumes in sustainable cropping system. Reduction of applied N fertilizer rate to an optimized level can reduce soil nitrate leaching (Power et al., 2000). Mahler et al. (1994) indicated increase in crop NUE and profitability to develop sustainable farming systems in response to continually increasing economic and environmental pressures. Crop rotation was reduces reliance on agricultural chemicals and improves crop nutrient use efficiency (Halvorson et al., 2001. Riedell et al., 2009). Hence, use of precursor crop with low rates of nitrogen fertilizer could indeed a key factor for sustainable maize production.

Shoot N accumulation, grain N accumulation and N harvest index of maize varieties

The result of mean shoot N accumulation, grain N accumulation and N harvest index of maize varieties are indicted in (Table 8). Shoot N accumulation of maize varieties were ranged from 86 to 204 kg ha^{-1}. The shoot N accumulation of maize varieties planted following soybean precursor crop without and with rhizobium inoculation were ranged from 109 to 204 kg ha^{-1} and 86 to 153 kg ha^{-1}. Higher shoot N accumulation was harvested from maize varieties planted following soybean precursor crop without rhizobium inoculation. Higher shoot accumulation advantage of 11.2 % was produced from maize varieties planted following soybean precursor crop without rhizobium inoculation as compared to with rhizobium inoculation. This implies the local rhizobium strain in soil was more effective in biological N_2-fixation of soybean which contributed significant increase in shoot N accumulation of maize varieties. Riedell et al. (2009) found significant input × rotation interactions was gave less shoot concentrations of N. BH-661 and BH-543 maize varieties were gave mean shoot accumulation of 154 and 124 kg ha^{-1}; and 131 and 118 kg ha^{-1} following soybean precursor crop without rhizobium inoculation and with rhizobium inoculation. Relatively higher shoot N accumulation was obtained from maize BH-660 maize variety as compared to BH-543. Therefore identifying the shoot N accumulation was helps to know the residual effects of maize residue on improvements of nitrogen status and organic matter of the soil.

The grain N accumulation of maize varieties were ranged from 74 kg ha^{-1} with continuous maize to 115 kg ha^{-1} with BH-543 maize varieties planted following soybean precursor crop with rhizobium inoculation. The mean grain N accumulation of maize varieties were 95 and 98 kg ha^{-1} planted following soybean precursor crop without rhizobium inoculation and with rhizobium inoculation and 3.16 % grain N accumulation advantage from maize planted following soybean precursor crop with rhizobium inoculation as compared to without rhizobium inoculation. Kernel N concentration increases rapidly in response to excess soil N supply after the yield response levels off (Deckard et al., 1984). BH-543 and BH-661 maize varieties were had mean grain N accumulation of 8.81 and 10.21; and 10.33 and 9.26 kg ha^{-1} when planted following soybean precursor crop without rhizobium and with rhizobium inoculation. This implies that the two maize hybrids were varied in grain N accumulation at harvest which contributed to differences in protein concentration the maize varieties. Higher grain N accumulation of 93 and 115 kg ha^{-1} for BH-543 was obtained from planted following soybean precursor crop without and with rhizobium inoculation with application 55 kg N ha^{-1}. Increased grain N concentrations were most important in differentiating crop rotations (Riedell et al., 2009).

Riedell et al. (2009) reported significant N input × rotation interactions for seed N concentration suggest that these dependent variables responded differently to N input. Therefore, the amount grain N accumulation was for most important to know the amount of nitrogen left over in the soil with maize stover and protein concentration of the seed. The N harvest indexes of maize arieties were ranged from 0.34 to 0.51 % (Table 8).

The mean N harvest index of 0.41 and 0.44 % were obtained from maize varieties planted following soybean precursor crop without rhizobium inoculation and with rhizobium inoculation. The mean N harvest index of 0.42 and 0.40 %; and 0.46 and 0.42 % were obtained from BH-543 and BH-661 maize varieties planted following soybean precursor crop without and with rhizobium inoculation fields. The N harvest index of both maize varieties was almost equivalent and or relatively low following soybean precursor crop fields. Rahimizadeh (2010) found harvest index (NHI) in wheat were significantly affected by preceding crop. This implies the N concentration of maize varieties was higher in tissue as compared to grain in hybrid maize varieties. The higher amount N concentration was at 50 % tasseling of maize varieties. Therefore, the N harvest index of hybrid maize varieties was low at time of harvest.

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 soil nutrient concentrations are 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 and dry biomass yield potential of maize varieties. 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 grain yield and dry biomass and of maize varieties. Soybean precursor crop with effective rhizobium strain present in soil and inoculation improved the amount of nitrogen uptake for maize varieties. Planting of maize varieties following soybean precursor crop was had increased nitrogen uptake efficiency.

Table 9: 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

Higher mean maize nitrogen use efficiency was obtained from maize varieties planted following soybean precursor crop without rhizobium strain inoculation as compared to following soybean precursor crop with rhizobium inoculation.. Soybean precursor crop without rhizobium inoculation due to availability of effective rhizobium strain in the soil was promoted the fertilizer nitrogen (recovery) use efficiency of maize varieties. Agronomic efficiency, nitrogen use efficiency and fertilizer N (recovery) use efficiency of maize varieties planted following soybean precursor crop were higher with low rate nitrogen fertilizer application. Shoot N accumulation, grain N accumulation and N harvest index were varied with soybean precursor crop without and with rhizobium inoculation, maize varieties and application of nitrogen fertilizer rates to hybrid maize varieties. Production of BH-661 and BH-543 maize varieties following soybean precursor crop with half recommended (55 kg N ha^{-1}) application improved mean grain yield and recommended for maize in mid altitude areas of western Ethiopia.

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