# Effects of faba bean break crop and N rates on subsequent grain yield and nitrogen use efficiency of highland maize varieties in Toke Kutaye, western Ethiopia

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**Abstract**

The biological $N_2$-fixation in faba bean on subsequent nitrogen fertilizer requirement of highland maize varieties would be useful in guiding application of additional nitrogen fertilizer in cropping sequence. Maize planted following faba bean precursor crop without rhizobium inoculation was produced significantly higher mean grain yield at full recommended nitrogen fertilizer. Significantly higher mean grain yield maize was obtained from application half recommended nitrogen fertilizer following faba bean precursor crop with rhizobium inoculation. Faba bean planted with rhizobium inoculation was contributed for nitrogen status improvement soil and nitrogen response of subsequent maize to. The planting of faba bean varieties with and without rhizobium inoculation was improved N status of the soil and nitrogen fertilizer response maize varieties. Integrated use of faba bean precursor crop with/without rhizobium inoculation with maize varieties and nitrogen fertilizer were recommended for sustainable production of maize varieties. Significantly higher mean agronomic efficiency and nitrogen uptake efficiency of both maize varieties were obtained from lower rates of N application as compared to the higher rates used. Agronomic and economic analyses confirmed production of maize varieties following faba bean precursor crop without and with rhizobium inoculation and applying half recommended nitrogen fertilizer were profitable for sustainable maize production in high altitude areas of western Ethiopia.

**Key words**: precursor crop, rhizobium inoculation, fertilizer, varieties

{**Citation**: Tolera Abera, Ernest Semu, Tolessa Debele, Dagne Wegary, Haekoo Kim. Effects of faba bean break crop and N rates on subsequent grain yield and nitrogen use efficiency of highland maize varieties in Toke Kutaye, western Ethiopia. American Journal of Research Communication, 2015, 3(10): 32-72} www.usa-journals.com, ISSN: 2325-4076.

## 1. Introduction

Cropping systems involving monoculture of cereals can cause reduction of yields and depletion of soil nitrogen. It can be alleviated by different methods such as use of inorganic nitrogen and use of legumes in cropping system. Currently sky rocketed prices of synthetic fertilizer have made difficult for smallholder farmers to use inorganic nitrogen for crop production. In addition the nitrogen applied is not used by the crop, lost each year along with the money you paid for it due to volatilization, leaching and other factors. Consequently, the use of legumes in cropping system as biological nitrogen fixation becomes an alternative source of nitrogen for crop production. Jensen *et al. (*2012); and Peoples *et al.* (2009) reported the symbiotic relationship between legumes and rhizobia represents the most important nitrogen-fixation association in the world, with an annual production of approximately 200 million tons of nitrogen. Optimizing this symbiosis can increase crop yields and enhance soil fertility, whilst reducing the negative monetary costs and environmental impacts associated with nitrogen fertilizer use (Canfield *et al.*, 2010; Hirel et al., 2007; and Peoples *et al.*, 2009). Legumes are used commonly in agricultural systems as a source of N for subsequent crops and for maintaining soil N levels (Glasener *et al.*, 2002). Rahman *et al*. (2009) reported reducing fertilizer N use in maize based cropping systems while maintaining the native soil N resource and enhancing crop N output is desirable from both environmental and economic perspectives. The ability of legumes to fix N and their residual impact on soil N status has long been recognized, but many farmers also realize that the accrued N benefits will vary between different legume systems (Rochester and Peoples, 2005). Cropping systems that include legumes have the potential for contributing N to following crops and may moderate $NO_3$ levels in the soil to avoid potential for $NO_3$ leaching (Grant *et al.*, 2002).Quantities of N fixed in faba bean vary greatly, but estimates of rates of fixation vary from 40 (Duc *et al.*, 1988); 93% (Brunner and Zapata, 1984) to 120 kg N $ha^{-1}$ (Danso, 1992) of crop N, and from 16 to 300 kg aboveground N per ha per crop. Khan *et al.* (2002) harvested plant parts and found that root-zone soil represented 39 % of total plant N for faba bean. The soil N contents were improved 10.6 times more than the original soil N content (0.014 %) from the plots where faba beans were grown (Fassile, 2010). Significant yield increases of faba bean for biological N-fixation of 82 kg N $ha^{-1}$ of 1.4 t $ha^{-1}$ grain yields were obtained (Beck and Duc, 1991); representing 35% to 69% increase due to the inoculation (Khosravi et al., 2001).

Inoculation of faba bean cultivars was significant for total biological yield, grain yield and total nitrogen (Beck and Duc, 1991). Therefore, symbiotically effective rhizobia increase nodulation, N-fixation, growth and yields of their host plant (Kiros and Singh, 2006). Walley *et al*. (2007) reported that a well-inoculated pulse crop can fix sufficient quantities of N to eliminate the need for N fertilizer inputs. The extent to which a legume crop can benefit a subsequent crop depends on the quantity of N the legume fixed and N which is incorporated into the soil and the rate and time-span of decomposition of residues and synchrony with nutrient need of the subsequent crop and its efficiency of N utilization (Giller *et al.*, 1998). Faba bean acts as a break crop in intensive cereal-dominated crop rotations (KÖpke and Nemecek, 2010). Broad bean is capable of producing large amounts of dry matter and accumulating large quantities of nitrogen (N) and fixed substantial quantities of N for subsequent crops (Evans *et al.*, 2001). Rahman *et al*. (2009) found Broad bean fixed 27.5 g N $m^{-2}$ and 16.3 to 26.0 g N $m^{-2}$ in 2002 and 2003 and appreciably higher when N fertilizer was not applied. The average plant N derived from $N_2$ fixation (% Ndfa) in broad bean was 78 % of total plant N using N-difference method and 82 % and 31 % in Ndifference method and $^{15}N$ natural abundance method (Rahman *et al.*, 2009). Lopez et al., (2006) found that nitrogen derived from the atmosphere (Ndfa) percentages ranged between 70 and 96%, and $N_2$-fixed between 39 and 144 kg N $ha^{-1}$in faba bean. Grain yield and ANE of maize significantly affected by interaction of preceding crop and N fertilizer application) and maize precedes faba bean and applied with 120 kg N $ha^{-1}$ was gave higher yield (El-Gizawy, 2009). Faba bean can fix atmospheric nitrogen symbiotically under a broad spectrum of environmental conditions and making this renewable resource available to show positive precrop effects in diversified crop rotations (KÖpke and Nemecek, 2010). Positive precrop effects of faba bean are predominantly the result of nitrogen made available and substantially contributing to the nitrogen economy of the subsequent crops (Lo´ pez-Bellido et al., 1998; Turpin et al., 2002; Walley et al., 2007).Safeguarding of the soil fertility at the economic optimum level with appropriate crop rotation and affordable fertilizer rate is essential for sustainable maize production in the region. Identification of suitable crop rotation with optimum fertilizer was more reliable and usually maximize maize grain yield. Therefore, the objective was to determine effects of faba bean break crop and N rates on subsequent grain yield and nitrogen use efficiency of highland maize varieties in Toke Kutaye, western Ethiopia.

## 2. Materials and methods

The experiment was conducted during the 2013 and 2014 cropping seasons on two farmers field in humid highlands of Toke Kutaye, Oromia National Regional State, western Ethiopian (Fig 1). The area lies between 8$^o$98'N latitude and 37$^o$72'E longitude at an altitude of 2262 meter above sea level and 2322 meter above sea level. Mean annual rainfall of 1045 mm (NMSA, 2014). It has a cool humid climate with the mean minimum, mean maximum, and average air temperatures of 8.15, 15.72 and 11.94$^o{}_C$, respectively. The soil properties of the two sites are indicated in Table 1. The experiment was laid in Randomized Complete Block Design in factorial arrangement with three replications. The factorial arrangement were faba bean variety(Moti) with and without rhizobium strain inoculation as factor A, maize varieties (Wenchi and Jibat)as factor B and three nitrogen rate as factor C. The rhizobium strain (FB-1035 which was released by Land and Water Resources Research Process of Holetta Agricultural Research Center) was used for inoculation of faba bean seed receiving inoculation. Three levels of nitrogen rate (0, half recommended (55 kg N ha$^{-1}$ and recommended (110 kg NP ha$^{-1}$), respectively.

The faba bean (Vicia faba) variety (Moti) without and with rhizobium strain was planted in 2013 cropping season respectively. Second year, two maize varieties were sown with three levels of nitrogen rate in 2014 cropping season. Twelve treatment combinations were conducted with the main crop (maize). For precursor crop (faba bean) recommended seed rate 200 kg ha$^{-1}$ and fertilizer rate of 18/20 NP kg ha$^{-1}$ were used. During the 2014 cropping season maize hybrid

(Wenchi and Jibat) were sown with three levels of fertilizers (0, half recommended (55 kg N $ha^{-1}$ and recommended (110 kg N $ha^{-1}$) rate for the area.

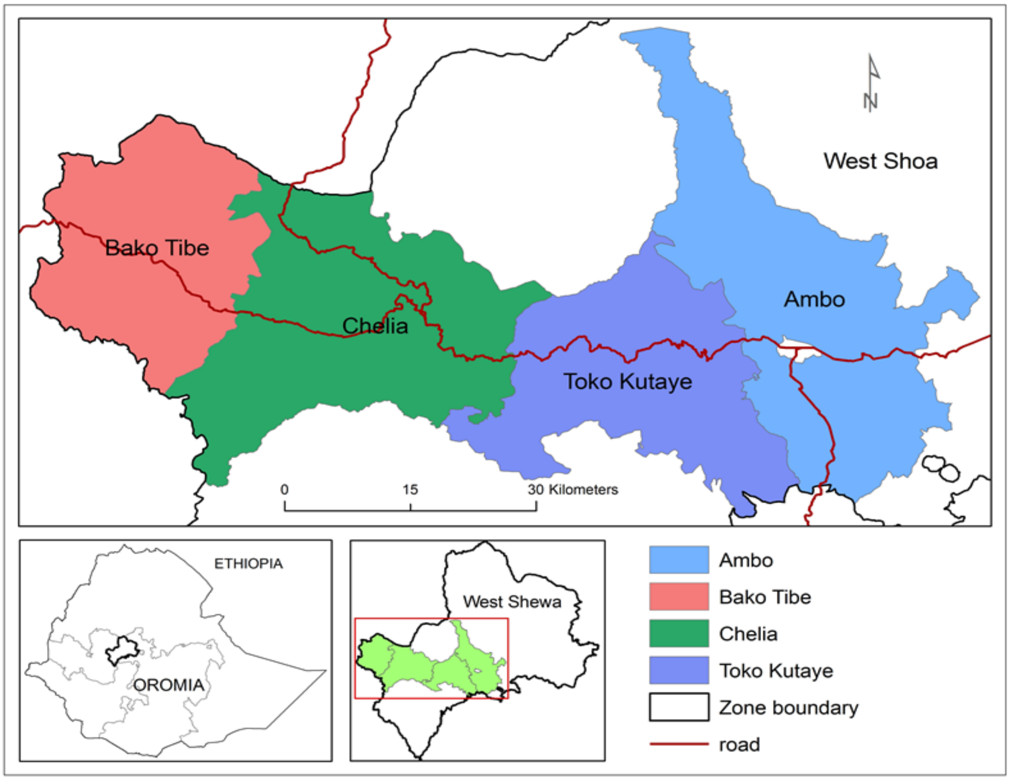


**Figure 1. Study district in West Shewa Zone of Oromia, Ethiopia.**

The experiment was laid out in factorial arrangement with randomized complete block design. The rotation crop with rhizobium strain was used as factor A, maize varieties as factor B and three level of nitrogen 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 25 cm. The seed rate used for maize was 25 kg $ha^{-1}$. Sowing dates followed recommended date of planting ranged April 15-30. 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. Data were collected on leaf area $plant^{-1}$ and leaf area index were collected at 50% tasseling of maize; plant height, dry biomass, 1000 seed weight, grain yields kg $ha^{-1}$ and harvest index at maturity of maize and after harvesting. . 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 $hectare^{-1}$.

Plant tissues (leaves and stalk at 50 % flowering, and grain at harvesting) in 2013 for soybean and (leaves and stalk 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 Holetta and Debre Zeit Agricultural Research Center Soil and Plant Analysis Laboratory. 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

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

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

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 were 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 $NO_3$ and $NH_4$ as described by (Keeney and Nelson, 1982).

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).

## 3. Results and discussion

### 3.1. Soil texture and nutrient concentrations of the experimental site

The soil analysis results of the two farms before main crop (maize) planting are indicated (Table 1). The texture of the soil was clay and clay loam. The soil pH in $H_2O$ was 4.4, 5.57, and 5.77 and 4.36, 5.07, and 5.66 before planting, after planting faba bean without and with rhizobium inoculation from farm 1 and farm 2. The soil reaction is found in very strongly acidic to moderately acidic (Landon (1991). Faba bean planting without and with rhizobium strains inoculation was significantly improved the pH of the two farms. Faba bean planting without and with rhizobium inoculation was improved soil pH by 26.59 and 15.85; and 31.14 and 29.82 % from farm 1 and farm 2. This implies faba bean planting without and with rhizobium inoculation was contributed for changing the soil reaction. Similar Tolera et al. (2009) crop rotation and N-P amendment significantly increased pH of the soil. Total N ranged from 0.17 to 0.0.25 % in farm 1 and 0.16 to 0.23 % in farm 2. The total N concentrations the two farms were found in low to medium range (Bruce and Rayment, 1982; FAO, 1990; and Landon, 1991). The total nitrogen concentration of farm 2 was increased from before plating by 37.5 and 43.75 % from planting faba bean without and with rhizobium inoculation. This might be attributed due to biological nitrogen fixation of faba bean. Similarly Kumar et al. (1983); and Holford and Crocker (1997) reported legumes in crop rotation improve soil fertility, particularly soil N content. A cumulative enhancement of the N-supplying power of the soil in wheat-lentil rotation was reported by Campbell et al. (1992); in maize haricot bean rotation Tolera et al. (2009). The increase in total N following faba bean helps to reduce the amount of N required to optimize maize yield. Available P Bray II method was ranged from 5.43 to 8.21 and 4.97 to 6.69 ppm and found in low to medium range (FAO, 1990; and Landon, 1991). This situation can be attributed due to the high phosphorous fixing capacity of acid soil. In farm 1 planting of faba bean with rhizobium inoculation was improved the available P by 51.20 and 72.48 % as compared to before planting and planting of faba bean without rhizobium inoculation. In farm 2 planting of faba bean without rhizobium and with rhizobium inoculation was reduced the amount available P by 25.41 and 25.71 %.

Organic carbon and matter contents of the soil ranged from 1.91 to 2.57; and 2.46 to 257 %; and 3.29 to 4.16; and 4.23 to 4.42 % in farm 1 and farm 2, found in low to medium range (FAO, 1990; and Landon 1991). The exchangeable K contents of the soil was ranged from 0.28 to 0.84; and 0.14 to 1.46 meq $100g^{-1}$ (Table 1) found in low to medium; and low to high range. The CEC of the soil ranged 18.5 to 27.78 and 19.44 to 25.57 Meq 100 g of $soil^{-1}$ (Table 1) and found in medium to high range (FAO, 1990; and Landon, 1991). These soils have medium nutrient holding capacity level, water holding capacity, less susceptible to leaching losses of $Mg^{2+}$ and $K^{+}$ and medium organic matter contents for crop production. The soil $N0_{3-}N$ concentration was ranged between 46.2 to 71.4 ppm in farm1 found in high range; and 2.43 to 64.4 ppm for farm 2, found in low to high range (FAO, 2006; and Bashour, 2002); and high to excessive (Marx et al., 1999). Planting of faba bean was improved $N0_{3-}N$ by 20.43 and 2089 %; without rhizobium inoculation; and 54.55 and 2550 % with rhizobium inoculation from farm 1 and farm2 as compared to before planting result. This implies use faba bean with and with rhizobium inoculation was significantly contributed for biological nitrogen fixation which left in the field and used for next crops. The soil $NH_4$-N concentration was 19.6 to 40.6 ppm for farm1 and found in high range; and 2.92 to 39.2 ppm in farm 2 found in optimum to high range (Marx et al., 1999). Horneck et al. (2011); and Marx et al. (1999) reported ammonium-nitrogen concentrations of 2–10 ppm are typical. The soil $NH_4$-N concentration was increased by 19.54 and 1243 %; and 107 and 619 % with planting faba bean without and with rhizobium inoculation as compared to before planting from farm 1 and farm 2 (Table 1). Faba bean can maintain high rates of BNF in the presence of high amounts of available N in the soil (Hardarson et al., 1991; Schwenke et al., 1998; Turpin et al., 2002), a fact that can be attributed to its low rooting density and rooting depth compared with other pulses and most notably fodder legumes (KÖpke and Nemecek, 2010). Increased concentrations of inorganic N in the soil profile after faba bean cropping can result from “spared N” remaining in the soil as a result of a relatively inefficient recovery of soil mineral N compared to other crops (Turpin et al., 2002). The amounts of NO3-N and NH4-N concentration of the soils were significantly higher due to planting of faba bean without and with rhizobium inoculation. Planting faba in cropping sequence without rhizobium inoculation where farm history was showed faba bean production in the area and with rhizobium inoculation where faba bean new for the area is the key in solving the soil N fertility status for maize production and reduce green gas effects of nitrogen to environment and secure sustainable maize production and food security.

**Table 1. Some soil physical and chemical concentration before main crop (maize) at Toke Kutaye districts, western Ethiopia**

| Soil parameters | Farm 1 | | | Farm 2 | | |
|---|---|---|---|---|---|---|
| | Before faba bean | Faba bean + 0 RI | Faba bean + 10 g RI kg seed $^{-1}$ | Before faba bean | Faba bean + 0 RI | Faba bean + 10 g RI kg seed $^{-1}$ |
| pH (1:2.5) | 4.4 | 5.57 | 5.77 | 4.36 | 5.05 | 5.66 |
| P (ppm | 5.43 | 4.76 | 8.21 | 6.69 | 4.99 | 4.97 |
| TN (%) | 0.25 | 0.19 | 0.17 | 0.16 | 0.22 | 0.23 |
| OC (%) | 2.42 | 2.22 | 1.91 | 2.49 | 2.57 | 2.46 |
| OM (%) | 4.16 | 3.82 | 3.29 | 4.28 | 4.42 | 4.23 |
| CEC (meq/100g) | 18.5 | 25.93 | 27.78 | 19.44 | 23.85 | 25.57 |
| k ( meq/100g) | 0.28 | 0.7 | 0.84 | 0.14 | 1.41 | 1.46 |
| Exc. Acidity ( meq/100g) | 0.35 | 0.18 | 0.15 | 0.42 | 0.23 | 0.18 |
| $N0_3^-N$ (ppm) | 55.64 | 71.4 | 46.2 | 2.43 | 64.4 | 53.2 |
| $NH_4^+N$ (ppm) | 23.43 | 40.6 | 19.6 | 2.92 | 39.2 | 21 |
| Texture | clay loam | clay loam | clay loam | clay | clay | clay |

Farm 1= Gadisa Beksisa, Farm 2= Sisay Belete

### 3.2 Effects of rhizobium inoculation on seed yield and yield components of faba bean break crop

Mean seed yield and yield components of faba bean were varied among farms due to rhizobium inoculation (Table 2). Higher plant heights of faba bean in farm 1 were observed from faba bean planted with rhizobia inoculation as compared with without inoculation (Table), while in farms 2 and 3, higher plant height of faba bean were recorded from faba bean planted without rhizobia inoculation as compared to with inoculation. Higher seed yield of 1677 kg ha$^{-1}$ followed by 1354 and 1158 kg ha$^{-1}$ were recorded from farm 2, farm 3 and farm 1, respectively (Table 2). This indicates the three farms were different in soil fertility status. Faba bean planted with rhizobia inoculation produced higher seed yield in farm 1 and farm 3, while in farm 2 it was the vice versa (Table 2 ). Adamu *et al*. (2001) reported significant variations in shoot length, dry matter and nodule fresh weights of faba bean when fertilized and inoculated in various soil types. Dry matter and grain yields of faba bean were significantly different among the treatments with various concentrations of fertilizers in the field conditions (Dibabe, 2000). Mean thousand seed weight of 764 g followed by 693 and 665 g were obtained from farm 2, farm 1 and farm 3, respectively (Table 2), indicating variations among farms. This might be due to differential soil fertility status of the different farms. Mean dry biomass of 22458 followed by 22375 and 14875 kg $ha^{-1}$ were obtained from farm 3, farm 2 and farm 1, respectively (Table 2), again indicating variations among farms. An increase of 13 to 24 % of shoot dry matter was obtained by inoculating with effective rhizobia and fertilizer use (Amanuel et al., 2000). Therefore, the different farms presently varied with respect to soil fertility status and management systems applied. 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.

**Table 2. Plant height, number of pods plant$^{-1}$, number of seeds pod$^{-1}$, seed yields, thousand seed weight and dry biomass of faba bean break crop on different farmers' fields in Toke Kutaye, western Ethiopia.**

| Farms | Faba bean | 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 $ha^{-1}$) |
|---|---|---|---|---|---|---|---|
| Farm-1 | With rhizobia inoculation | 130 | 10 | 2 | 1258 | 683 | 15000 |
| | Without rhizobia inoculation | 109 | 9 | 2 | 1058 | 702 | 14750 |
| | Maize | 204 | | | 3040 | 366 | 15745 |
| Farm-2 | With rhizobia inoculation | 142 | 15 | 3 | 1563 | 759 | 22,000 |
| | Without rhizobia inoculation | 172 | 22 | 2 | 1791 | 770 | 22750 |
| | Maize | 214 | | | 3138 | 404 | 17458 |
| Farm-3 | With fertilizer inoculation | 165 | 13 | 2 | 1514 | 670 | 21375 |
| | With rhizobia inoculation | 154 | 17 | 2 | 1394 | 685 | 21750 |
| | Without rhizobia inoculation | 166 | 16 | 2 | 1154 | 640 | 24250 |
| | Maize | 238 | | | 4045 | 366 | 14614 |

Farm 1-3= Solomon Belete, Farm 2= Gadisa Beksisa, Farm 3= Gutuma Kuma

### 3.3. **Nutrient concentrations, nutrient uptake, and biological $N_2$-fixation by faba bean**

The nutrient concentrations, nutrient uptake and biological $N_2$-fixation of faba bean is indicated in Table 3. The nutrient concentrations varied among farms for faba bean. Total phosphorous concentrations of faba bean tissue were higher for faba bean planted without rhizobia inoculation in farm 2 and farm3, but the opposite was true for farm1 with rhizobia inoculated faba bean. This might be due to soil fertility status variation of the different farm fields.

The total nitrogen concentration of faba bean tissue was higher for faba bean seed planted with rhizobium inoculation for farm 1 and farm 2, but higher without inoculation for farm 3 (Table 3). Assefa et al. (2010) found the native rhizobia strains of the Wollo region to be more competitive than the two exotic rhizobia strains. The highest total nitrogen concentration (2.94 %) of the faba bean tissue was obtained from faba bean seed planted without inoculation from farm 3. The total $SO_{4=}S$ (%) concentration of faba bean tissue was higher for faba bean seed planted with rhizobia inoculation as compared to without inoculation for farm 1 and farm 2. The total nitrogen concentration of seed of faba bean varied among farms and between faba bean seed planted with and without rhizobia inoculation (Table 3). The total nitrogen concentration of 1.11 % of seeds was obtained from faba bean seed planted without rhizobia inoculation (Table 3). The total phosphorous and nitrogen uptake by faba bean were obtained from faba bean seeds planted with inoculation for farm 1 (Table 3). For farm 2 and farm 3 higher total phosphorous and nitrogen uptake of faba bean were recorded from faba bean seed planted without inoculation as compared to with inoculation. The highest total phosphorous and nitrogen uptake of 982.1 and 606.3 kg $ha^{-1}$ followed by 787.2 and 568.8 kg $ha^{-1}$ were obtained from faba bean planted without seed inoculation from farm 3 and farm 2 (Table 3).

The biological $N_2$-fixation varied among farms and between rhizobia inoculations. Higher biological $N_2$-fixation of 765.8 kg $ha^{-1}$ followed by 542.7 kg $ha^{-1}$ was produced from faba bean planted without seed inoculation from farm 3 and farm 2. Percentage of nitrogen fixation is also higher for native rhizobia strains, with these isolates found to be superior to the exotic ones in stimulating growth, promoting dry matter yield, nodulation and nodule wet weight of faba bean in pouch culture (Assefa et al., 2010). In farm 1 greater biological $N_2$-fixation of 254.4 kg N $ha^{-1}$ was harvested from faba bean seed planted with rhizobia inoculation (Table 3). This indicates faba was fixed enormous amounts of $N_2$ with local rhizobia strains and inoculated with exotic rhizobium strains. McVicar et al. (2005) reported faba bean to be the most efficient nitrogen fixer of all cool season pulse crops. The amounts of $N_2$-fixed by faba bean are estimated to be between 240 and 325 kg N $ha^{-1}$ (Somasegaran and Hoben, 1994; Maidl et al., 1996), with percentage efficiency (66 % Ndfa [Nitrogen derived from the air]) (Jensen, 1986) and fulfills 80 % of its nitrogen requirements (Zapta et al., 1987). In farm 3 nitrogen fertilizer lower biological nitrogen fixation by faba bean was recorded as compared to with and without rhizobia inoculation (Table 3). Danso and Eskew (1984) reported that the amount of nitrogen actually fixed by a legume depends on types of rhizobia strains, host plant, environment and agricultural practices. They further stated that in legumes grown in soils with high available nitrogen, the nitrogen fixation rate was reduced. High soil N and low pH can depress fixation rates (Belnap, 2001). An efficient rhizobia strain is not expected to express its full capacity for nitrogen fixation if limiting factors impose limitations on the vigor of the host legume (Nogales et al., 2002). Belnap (2001) found that phosphorous addition can stimulate fixation rates and effective rhizobia strains may increase rates of fixation. BNF by legumes is a key process in Low External Input Agriculture (LEIA) technologies as it potentially results in a net addition of N to the system (Thobatsi, 2009). Therefore in legumes production consideration should be given to selection of rhizobium strains, host plant, environment and agricultural practices as options for sustainable productivity.

**Table 3. Nutrients concentrations, uptake and biological $N_2$-fixation of faba bean break crop in Toke Kutaye, western Ethiopia.**

| Farms | Faba bean | Nutrient concentration | | | Seed | Nutrient Uptake | | Ndfa (kg ha-1) |
|---|---|---|---|---|---|---|---|---|
| | | Total p (%) | Total N (%) | $SO_4$=S (%) | Total N (%) | N (kg ha-1) | P (kg ha-1) | |
| | With rhizobium | 0.16 | 2.69 | 0.055 | 1.00 | 553.5 | 240.0 | 254.34 |
| Farm 1 | Without rhizobium | 0.13 | 2.38 | 0.031 | 0.95 | 491.18 | 191.8 | 192.0 |
| | Maize | 0.16 | 1.56 | 0.039 | 0.34 | 299.16 | 251.9 | |
| | With rhizobium | 0.20 | 2.39 | 0.047 | 1.06 | 759.00 | 440.0 | 514.59 |
| Farm 2 | Without rhizobium | 0.25 | 2.37 | 0.032 | 1.09 | 787.15 | 568.8 | 542.7 |
| | Maize | 0.33 | 1.07 | 0.047 | 0.33 | 244.41 | 576.1 | |
| | With fertilizer | 0.16 | 2.29 | 0.032 | 1.09 | 722.48 | 342.0 | 506.2 |
| | With rhizobium | 0.2 | 2.55 | 0.063 | 1.09 | 791.70 | 435.0 | 575.4 |
| Farm 3 | Without rhizobium | 0.25 | 2.94 | 0.063 | 1.11 | 982.13 | 606.3 | 765.8 |
| | Maize | 0.20 | 1.19 | 0.031 | 0.29 | 216.29 | 292.3 | |

Farm 1= Solomon Belete, Farm 2= Gadisa Beksisa, Farm 3= Gutuma Kuma

### 3.4. Grain yield, dry biomass and harvest index of maize

Mean grain yield of maize was non-significantly affected by following rhizobium application and variety after break crop (Tables 4, 5, 6 and 7). Maize planted following rhizobium strain applied faba bean was produced 111 kg ha$^{-1}$ mean grain yield advantages over maize planted following faba bean planted without rhizobium strains. Maize planted preceding faba bean without and with rhizobium inoculum was gave mean grain yield advantages of 33.22 and 35.77 % as compared to continuous maize indicating significant role of precursor faba bean on soil N improvement. Faba bean can improve the economic value of a following crop by enhancing the yield (Lopez-Bellido et al., 1998). Wright (1990) also observed significant yield increases (12%) in the second cereal following faba bean compared to N fertilized continuous cereals. Faba bean incorporated field remarkable increased preceding maize yield and yield of 8.32 Mg ha-1 for maize seed was possible under no fertilization (Beslemes et al., 2013). Similarly El-Gizawy (2009) found significantly higher mean grain yield of maize was obtained after faba bean and suggested which might be due to enriching the soil with N and organic matter. In addition the result was in agreement with Badr (1999); and Shams (2000) found grain yield of maize following faba bean increased as compared to cereals. Faba bean break crop enhanced the average yield in the subsequent barley and wheat crops by 21 and 12 %, which was equivalent to providing the cereals with around 120 kg N ha-1 of N fertilizer (Wright, 1990). Rochester et al. (2001) observed that the optimum N fertilizer rate required to be applied to cotton following non-legume rotation crops was on average 180 kg N ha-1, whereas after sequences including either faba bean, soybean or pea the requirement was only c. 90 kg N ha$^{-1}$. Muller and Sundman, (1988); and Peoples et al. (2009) reported using $^{15}$N-labeled residue wheat, barley or cotton crop following faba bean may recover between 11-17 % of the plant N remaining after faba bean, although this may represent only 2-19 % of the total N requirement of those following crops. Faba bean can make residual phosphorus available that otherwise would remain fixed (Nuruzzaman et al., 2005) and may indirectly make more phosphorus and potassium available for subsequent crops (KÖpke and Nemecek, 2010) and the rotational benefit of faba bean to improve the P availability for subsequent crops also is considered to be closely related to the mineralization of its P-rich crop residues rather than to residual effects of root exudates on soil chemistry. Legumes in rotations also generally result in greater microbial activity and diversity in soils (Lupwayi and Kennedy, 2007) which may enhance the nutrient uptake and availability of soil nutrients. The increase grain yield maize varieties after faba bean precursor might be due to change in soil organic matter with faba bean residue. El-Gizawy (2009) stated faba bean residue was improved soil physical, chemical and biological characters of the soil. Positive precrop effects of faba bean are predominantly the result of nitrogen made available by the pulses and substantially contributing to the nitrogen economy of the subsequent crops (Lo´ pez-Bellido et al., 1998; Turpin et al., 2002; Walley et al., 2007). Rochester et al. (2001) stated faba bean may improve the structure of poorly structured soil by stabilizing soil aggregates and demonstrated the vigorous tap-roots of faba bean and other legumes can reduce the soil strength for a succeeding cotton crop compared to continuous cotton and cereals as pre-crops. Dyke and Prew (1983) reported that faba bean roots and stubble contributed 44–50 kg N $ha^{-1}$ to the requirements of the following crop in a temperate climate. Faba bean produce high levels of rhizodeposition which will improve the soil N balance, assist in maintaining soil organic fertility, and appear to provide an important source of N for following crops in the rotation (Jensen et al., 2010). Faba bean is considered a promising precrop in cereal crop rotations on neutral to alkaline loam and clay soils of South Western Australia (Loss et al., 1997) which true in highland area of western Ethiopia. Faba bean has been deposited up to 100 kg N $ha^{-1}$ of additional N being below-ground (Rochester et al., 1998; Schwenke et al., 1998; Walley et al., 2007; Hauggaard-Nielsen et al., 2009). Therefor faba bean precursor crop could improve the economic value of following maize varieties.

Application of nitrogen fertilizer following faba bean precursor crop was significantly affected mean grain yield of maize (Tables 4, 5, 6 and 7). Significantly higher mean grain yield of maize were collected from maize planted with application full recommended nitrogen fertilizer following faba bean precursor crop on farm1 and farm 2 (Table 6). Similarly El-Gizawy (2009) found application of nitrogen fertilizer significantly affected mean grain yield of maize and higher N rate (120 kg N $fed^{-1}$ was more effective in increasing grain yield of maize. Similar result was reported by (Gungula et al., 2005). Mean grain yield advantages of 5.14, 28.26 and 45.01 % from farm1; 18, 34.91 and 66 % from farm 2; and 9.79, 36.04 and 52.50 % combined mean were obtained from maize planted with recommended nitrogen fertilizer as compared without and half recommended nitrogen fertilizer application following faba bean precursor crop and continuous maize without nitrogen fertilizer application. Beslemes et al. (2013) found maize grain yield following faba bean green was increased in response to nitrogen application and modest application was produced higher grain yield of maize. This indicates applications of nitrogen fertilizer were necessary following legume precursor crop for sustainable maize production in the region.

**Table 4. Mean square of grain yield, dry biomass and harvest index of maize due to faba bean rhizobium inoculation, variety and nitrogen rate around Toke Kutaye, western Ethiopia**

| Source of variation | DF | Mean square | | | | | |
|---|---|---|---|---|---|---|---|
| | | Grain yield (kg ha-1) | | Dry biomass(kg ha-1) | | Harvest index (%) | |
| | | Farm-1 | Farm-2 | Farm-1 | Farm-2 | Farm-1 | Farm-2 |
| Replication | 2 | 9553430.10 | 53316.38 | 38363824.9 | 3682965.00 | 198.5939236 | 5.3134176 |
| Rhizobium inoculation (RI) | 1 | 2573984.31 | 880809.06 | 35869399.7 | 2416365.26 | 2.5452007 | 15.4011452 |
| Varieties (V) | 1 | 323137.15 | 1152645.83 | 343985309.5 * | 3866064.10 | 287.5145370* | 127.7895037* |
| Nitrogen (N) | 2 | 16190746.58* | 5351309.37* | 88038138.2 | 31202216.86* | 232.0503746* | 22.7372528 |
| RI X V | 1 | 36997.93 | 2393203.80 | 45466961.9 | 16660269.55* | 53.2619898 | 6.3882149 |
| RI X N | 2 | 2057277.03 | 272548.80 | 19376028.2 | 6977979.74 | 57.7262133 | 6.4480072 |
| V X N | 2 | 3159448.25 | 1510045.44* | 15906451.0 | 10189294.48* | 18.8789580 | 46.7907894* |
| RI X VXN | 2 | 6834685.74 | 241763.88 | 141888509.2 | 2340534.98 | 15.7759639 | 12.7135430 |
| Error | 22 | 2573531.5 | 296691.63 | 64465001 | 606.87493 | 35.556253 | 14.4951116 |
| CV (%) | | 22.11 | 12.30 | 24.46 | 11.65 | 25.84 | 12.40 |
| Replication | 2 | 9553430.10 | 53316.38 | 38363824.9 | 3682965.0 | 198.5939236 | 5.3134176 |
| Treatments | 13 | 5401675.87* | 1743453.97 | 86885447.7 | 11305704.6* | 90.1986134* | 14.4951116 |
| Error | 26 | 2573531.5 | 296691.63 | 64465001 | 2837931.3 | 35.556253 | 14.4951116 |
| CV (%) | | 22.11 | 12.30 | 24.46 | 11.65 | 25.84 | 12.40 |

*= Significant at 5 % probability level

Mean dry biomass and harvest index of maize was non-significantly affected by main effects of following faba bean with and without rhizobium strain inoculation (Tables 4, 5, 6 and 7). Pare et al. (1993) was able to demonstrate that maize whole-plant dry matter yields were enhanced in the third corn crop following faba bean as compared to continuous maize. Significant difference of mean dry biomass of maize was observed due to maize varieties used on farm 1 and combined mean (Table 2). Significantly higher mean dry biomass of maize was collected from Jibat variety as compared to Wenchi. This indicates different varieties were varied in biomass accumulation of above ground plant parts. Nitrogen fertilizer application on farm 1 was significantly affected mean dry biomass of maize. Higher mean dry above ground biomass of maize was harvested from application of half recommended nitrogen fertilizer as compared without and full recommended nitrogen fertilizer applications.

**Table 5. Mean square of combined grain yield, dry biomass and harvest index of maize due to faba bean rhizobium inoculation, variety and nitrogen rate around Toke Kutaye, western Ethiopia**

| Source of variation | DF | Mean square | | |
|---|---|---|---|---|
| | | Grain yield (kg ha-1) | Dry biomass(kg ha-1) | Harvest index (%) |
| Replication | 2 | 7264739.4 | 16035259 | 139.350275 |
| Rhizobium inoculation (RI) | 1 | 221678.0 | 803879 | 18.028476 |
| Farm (FM) | 1 | 143902656.7* | 6805555556* | 1923.726661* |
| Varieties (V) | 1 | 1348188.7 | 321220129* | 928.967318* |
| Nitrogen (N) | 2 | 19135053.4* | 74234698 | 177.784435 |
| FM X RI | 1 | 3233115.4 | 57354617 | 42.278437 |
| FM X V | 1 | 127594.3 | 68999255 | 42.239618 |
| FM X N | 2 | 2407002.5 | 62919055 | 109.684032 |
| RI X V | 1 | 1512663.6 | 43474257 | 15.484340 |
| RI X N | 2 | 1648086.6 | 20377825 | 45.271173 |
| V X N | 2 | 4460471.9 | 29005091 | 8.619361 |
| RI X VXN | 2 | 2252781.3 | 66174223 | 62.805627 |
| FM X RI X VXN | 7 | 1763771.0 | 28346451 | 46.133648 |
| Error | 46 | 2995450.8 | 38832130 | 68.132526 |
| CV (%) | | 21.54 | 24.24 | 19.37 |
| Replication | 2 | 4769875.8 | 27259933 | 130.285652 |
| Treatments | 13 | 5279574.2* | 53384182 | 93.583056* |
| Farm (FM) | 1 | 143902656.7* | 6068347222* | 1046.694399* |
| Error | 46 | 1583014.1 | 32831266 | 27.138552 |
| CV (%) | | 21.54 | 24.24 | 19.37 |

*= Significant at 5 % probability level

Mean harvest index of maize was varied between varieties of maize planted following faba precursor crop (Table 6). Significantly higher mean harvest index of maize was obtained from Wenchi as compared to Jibat variety. This revealed there was variation between varieties of maize in grain yield to biological yield ratio. Application of nitrogen fertilizer rates were significantly affected mean harvest index of maize on two farms and combined over farms to. Significantly higher mean harvest index was produced from maize varieties planted following precursor crops with recommended nitrogen fertilizer as compared to others. Therefore application of recommended nitrogen fertilizer was very crucial for sustainable maize production in the agroecology.

**Table 6. Effects of rhizobium inoculation, variety and nitrogen rate on mean grain yield, dry biomass and harvest index of maize around Toke Kutaye, western Ethiopia**

| Rhizobium inoculation (g) | Grain yield (kg ha$^{-1}$) | | | Dry biomass (kg ha$^{-1}$) | | | Harvesting index (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Farm 1 | Farm 2 | Mean | Farm 1 | Farm 2 | Mean | Farm 1 | Farm 2 | Mean |
| 0 | 6988 | 4585 | 5787 | 31826 | 14722 | 23274 | 23.34 | 31.36 | 27.35 |
| 10 g kg-1 seed | 7523 | 4272 | 5898 | 33822 | 14204 | 24013 | 22.81 | 30.05 | 26.43 |
| Control | 5596 | 30914 | 4344 | 22381 | 11632 | 17006 | 17.52 | 26.19 | 21.86 |
| LSD (%) | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| CV (%) | 22.11 | 12.30 | 29.62 | 24.46 | 11.65 | 26.97 | 25.84 | 12.40 | 29.22 |
| Variety | | | | | | | | | |
| Wenchi | 7351 | 4607 | 5979 | 29733 | 14135 | 21934 | 25.91 | 32.59 | 29.25 |
| Jibat | 7161 | 4249 | 5705 | 35915 | 14790 | 25353 | 20.25 | 28.82 | 24.54 |
| LSD (%) | NS | NS | NS | 5550 | NS | 2956.5 | 4.122 | 2.6319 | 3.916 |
| CV (%) | 22.11 | 12.30 | 29.62 | 24.46 | 28.59 | 26.97 | 25.84 | 30.05 | 29.22 |
| N (kg ha-1) | | | | | | | | | |
| 0 | 5934 | 3804 | 4869 | 31414 | 13045 | 22229 | 19.12 | 29.27 | 24.19 |
| 55 | 7718 | 4349 | 6034 | 35947 | 14127 | 25037 | 22.31 | 30.84 | 26.58 |
| 110 | 8115 | 5132 | 6624 | 31111 | 16217 | 23664 | 27.81 | 32.01 | 29.91 |
| Control | 5596 | 30914 | 4344 | 22381 | 11632 | 17006 | 17.52 | 26.19 | 21.86 |
| LSD (%) | 1358.2 | 461.1 | 1005. | NS | 1426. | NS | 5.048 | 1426.3 | NS |
| CV (%) | 22.11 | 12.30 | 29.62 | 24.46 | 28.59 | 26.97 | 25.84 | 30.05 | 29.22 |

Farm 1-Farm 2= two farmers field (Gadisa Beksisa and Sisay Belete), NS=Non-significant difference at 5 % probability level, 50 % and 100 % RR= half and full doses (110 kg N ha$^{-1}$) recommended for maize production.

Interaction rhizobium inoculation with maize varieties and nitrogen fertilizer were significantly affected mean grain yield, dry biomass and harvest index maize (Tables 5 and 7). Mean grain yield, dry biomass and harvest index of maize varieties were varied between farms indicating the difference between two farms with soil fertility status and other micro-environments due to light direction and rainfall distribution and amounts. Wenchi variety was produce higher yield following faba bean precursor crop with and without rhizobium inoculation and with half recommended nitrogen fertilizer while Jibat with application of recommended nitrogen fertilizer. Jibat variety was produced higher mean grain yield 7607 followed 6136 kg ha-1 by planting following faba bean precursor crop without rhizobium inoculation with application of recommended nitrogen fertilizer rate; and faba bean precursor crop with rhizobium inoculation and application of recommended nitrogen fertilizer rate (Table 7). Beslemes et al. (2013) found maize planted following faba bean green manure and maximum inorganic fertilization, exhibited higher seed production (12.24 Mg $ha^{-1}$) compared to the control unfertilized plots. Grain yield of maize significantly affected by interaction of preceding crop and N fertilizer application (El-Gizawy, 2009) and maize precedes faba bean and applied with 120 kg N ha-1 was gave higher yield. KÖpke and Nemecek (2010) reported Non-nitrogen precrop effects of Faba bean entail potential benefits via increased availability of soil phosphorus to the subsequent crops. Wenchi variety was gave higher mean grain yield 6739 followed by 6617 kg $ha^{-1}$ planted following faba bean precursor crop with rhizobium inoculation and applied with half recommended nitrogen fertilizer; and faba bean precursor crop with rhizobium inoculation and applied with recommended nitrogen fertilizer. This indicates nitrogen fertilizer response variation of the two varieties following faba bean precursor crop. In conclusion knowing nitrogen fertilizer response maize varieties was very crucial for sustainable maize production in the region.

The mean dry biomass of maize varieties were 21667, and 30708 and 12625 kg $ha^{-1}$ for farm 1 and farm 2, respectively (Table 6). Significantly higher mean dry biomass was harvested from farm 1 as compared to farm 2 indicating the difference of the two farms with soil fertility status. Significantly higher mean dry biomass (26117 and 25054 kg $ha^{-1}$) of Jibat variety was obtained from planting following faba bean precursor crop with rhizobium and with application of recommended nitrogen fertilizer; and faba bean precursor crop without rhizobium and with application of recommended nitrogen fertilizer. For Wenchi varieties higher mean dry biomass of 23054 and 22289 kg $ha^{-1}$ were obtained by planting following faba bean precursor crop with rhizobium inoculation and with application of half recommended nitrogen fertilizer; and recommended nitrogen fertilizer. Beslemes et al. (2013) found maize planted following faba beans green manure and maximum inorganic fertilization, exhibited higher total biomass production (19.66 Mg ha-1), compared to the control unfertilized plots. Higher biomass production levels may result for both soil types mainly due to the increase in N-mineralization (base uptake) and the enhanced fertilizer recovery fraction (10-15%) (Beslemes et al., 2013). Therefore dry biomass production of two maize varieties was varied with faba bean precursor crop and nitrogen fertilizer application.

**Table 7. Combination effects of rhizobium inoculation, variety and nitrogen rate on mean grain yield, dry biomass and harvest index of maize around Toke-Kutaye, western Ethiopia**

| RS g + MV + N kg $ha^{-1}$ | Grain yield (kg $ha^{-1}$) | | | Dry biomass (kg $ha^{-1}$) | | | Harvesting index (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Farm 1 | Farm 2 | Mean | Farm | Farm 2 | Mean | Farm 1 | Farm 2 | Mean |
| 0+W +0 | 6201 | 3733 | 4967 | 20237 | 11222 | 15729 | 30.64 | 33.27 | 31.58 |
| 0+W +55 | 8514 | 4554 | 6534 | 30126 | 11922 | 21024 | 28.26 | 38.20 | 31.08 |
| 0+W +110 | 7038 | 5231 | 6135 | 19403 | 13471 | 16437 | 36.08 | 38.83 | 37.46 |
| 0+J +0 | 5073 | 4225 | 4649 | 33206 | 11483 | 22345 | 15.37 | 36.37 | 25.87 |
| 0+J + 55 | 6116 | 4139 | 5128 | 36013 | 13379 | 24696 | 16.92 | 30.87 | 23.90 |
| 0+J +110 | 9588 | 5627 | 7607 | 35131 | 17103 | 26117 | 28.13 | 33.46 | 30.80 |
| 10 +W +0 | 6375 | 3990 | 5182 | 27019 | 12033 | 19526 | 23.30 | 33.55 | 28.42 |
| 10 +W +55 | 8176 | 5302 | 6739 | 32555 | 13549 | 23052 | 25.50 | 39.66 | 32.58 |
| 10 +W +110 | 8399 | 4835 | 6617 | 31842 | 12736 | 22289 | 28.26 | 38.06 | 33.16 |
| 10 +J +0 | 6688 | 3267 | 4977 | 33328 | 10780 | 22054 | 19.84 | 31.24 | 25.54 |
| 10 +J + 55 | 8065 | 3403 | 5734 | 38969 | 11179 | 25074 | 20.93 | 30.71 | 25.82 |
| 10 +J +110 | 7437 | 4836 | 6136 | 31000 | 13637 | 22319 | 25.62 | 35.61 | 30.62 |
| Wenchi | 5596 | 3214 | 4405 | 19381 | 11232 | 15306 | 28.26 | 38.20 | 31.08 |
| LSD (%) | 2716.4 | 922.34 | 1462.2 | 13596 | 2852.6 | 6658.9 | 10.097 | 6.4468 | 6.0542 |
| CV (%) | 22.11 | 12.30 | 21.54 | 24.46 | 11.65 | 24.24 | 25.84 | 12.40 | 19.37 |

Farm 1-2= farmers (Gadisa Beksisa and Sisay Belete), W and J= Wenchi and Jibat maize variety, NS=Non-significant difference at 5 % probability level, 50 % and 100 % RR= half and full doses (110 kg N $ha^{-1}$) recommended for maize production

Mean harvest index of maize varieties was significantly varied between two farms. Mean harvest index of 28.85; 23.64 and 34.09 % on farm 1 and farm 2, respectively, showing variations of the two fields. Wenchi variety was gave higher harvest index as compared Jibat variety following faba bean precursor crop with and without rhizobium and with application of nitrogen fertilizer. Mean harvest index of 37.46 and 34.67 % were obtained from Wenchi variety planted following faba precursor crop without rhizobium and with application of full recommended; and half recommended nitrogen fertilizer. For Jibat variety higher mean of 30.8 and 30.62 % were harvested from planting following faba bean precursor crop without rhizobium inoculation and with application of full recommended nitrogen fertilizer and with rhizobium inoculation and with application of full recommended nitrogen fertilizer. Therefore the harvest index of maize varieties were varied with soil fertility management applied.

### 3.5. Nitrogen uptake, agronomic efficiency, N uptake efficiency, plant N use efficiency and fertilizer N (recovery) use efficiency of maize

The mean result total nitrogen uptake, agronomic efficiency, N up take efficiency, plant N use efficiency and fertilizer N (recovery) use efficiency of maize are indicated in (Tables 8 and 9). The total nitrogen uptake was ranged from 581 to 5214; 251 to 499 and 417 to 2752 kg $ha^{-1}$ obtained from farm 1, farm 2 and combined mean. Higher mean nitrogen uptake of 125 % was obtained from planting of maize varieties following faba bean precursor crop with rhizobium inoculation as compared to following faba bean without rhizobium inoculation in farm1 indicating the effectiveness variation of the stains in two farms. In farm 2 significantly higher mean nitrogen uptake of 9.92 % was obtained from planting of maize varieties following faba bean precursor crop without rhizobium inoculation as compared to following faba bean with rhizobium inoculation. This indicates the two farms were different and heterogeneous in nitrogen status due to faba bean planting and/or nature of soil in the two farms. El-Gizawy (2009) found higher grain N uptake was obtained when maize planted after faba bean as compared to wheat. The total N uptake maize was low might be to low availability of the residual N in the first year. KÖpke and Nemecek (2010) reported only small amounts originating from residual N are taken up by the following crop. Using $^{15}$Nmarked faba bean shoot and root residues subsequent wheat took up only 3–5 % of the residual shoot and root nitrogen of faba bean (Huber et al., 1989). Mayer et al. (2003) found up to 12.1 % of the residual N in subsequent non-legumes. Peoples et al. (2009) found low fractions of faba bean N (11–17%) taken up by the following wheat, cotton or barley. Wenchi maize variety was produced higher mean total nitrogen uptake with application of half recommended dose (55 kg N $ha^{-1}$) and full recommended (110 kg N $ha^{-1}$) application when planted following faba bean without rhizobium inoculation and following faba bean with rhizobium inoculation. While Jibat maize variety was produced mean higher total nitrogen uptake with application of full recommended (110 kg N $ha^{-1}$) and half recommended (55 kg N $ha^{-1}$) application when planted following faba bean without rhizobium inoculation and following faba bean with rhizobium inoculation. This implies the total nitrogen uptake of maize varieties were varied following faba bean precursor crop. Higher total N uptake maize varieties were obtained from maize planted preceding faba bean with application of nitrogen fertilizer. Maize after faba bean and receiving 120 kg N ha-1 was gave higher grain N uptake (El-Gizawy, 2009). Therefore the total N uptakes of maize varieties were markedly increased with application of nitrogen as compared to continuous maize indicating better improvement soil N status and organic matter following precursor crop which enhance nitrogen uptake of maize.

Agronomic efficiency is the amount of harvestable grain yield maize per kg of applied nutrient (N). The agronomic efficiency of maize varieties was varied among farms, maize varieties and precursor crop without/with rhizobium (Table 8). The mean agronomic efficiency was ranged from 13 to 562 and 20 to 778 when planted following faba bean precursor crop without and with rhizobium inoculation. Significantly higher agronomic efficiency of maize varieties was 741 % obtained from farm 2 as compared to farm 1 when maize varieties planted following faba bean precursor crop without rhizobium inoculum. While when following faba bean precursor crop with rhizobium inoculation higher agronomic efficiency advantage of 123 % was obtained from farm1 as compared to farm 2. Considerably higher mean agronomic efficiency advantage of 60.27 % was achieved from maize planted following faba bean with rhizobium inoculation. Significantly higher mean agronomic efficiency of both maize varieties was obtained from lower rates of N application as compared to the higher rates used. El-Gizawy (2009) found agronomic efficiency of maize was decreased with increased N. The mean agronomic efficiency of maize varieties were 0>55>110 kg N ha-1, respectively (Table 4) when planted faba bean precursor crop without and with rhizobium inoculation. Similar results were reported by El-Gizawy (2005); and Berenger et al. (2009). El-Gizawy (2009) found agronomic nitrogen efficiency of maize significantly affected by interaction of preceding crop and N fertilizer application. Wenchi maize variety was produced significantly higher agronomic efficiency when planted following faba bean precursor crop without rhizobium inoculation and with rhizobium inoculation fields. Higher mean agronomic efficiency advantage of 117 and 38 % were harvested from Wenchi maize variety planted following faba bean precursor crop without and with rhizobium inoculation as compared to Jibat variety. This implies that Wenchi maize varieties were better agronomic efficiency and grain yield as compared to Jibat.

**Table 8. Effects of rhizobium inoculation, maize variety and nitrogen rate on nitrogen uptake and agronomic efficiency of maize around Toke Kutaye, western Ethiopia**

| RI g + MV + N kg ha-1 | Nitrogen up take (kg ha-1) | | | Agronomic efficiency | | |
|---|---|---|---|---|---|---|
| | Farm 1 | Farm 2 | Mean | Farm 1 | Farm 2 | Mean |
| 0+W +0 | 654 | 251 | 453 | 605 | 519 | 562 |
| 0+W +55 | 1362 | 356 | 859 | 53 | 24 | 39 |
| 0+W +110 | 1005 | 474 | 740 | 13 | 18 | 16 |
| 0+J +0 | 1909 | 313 | 1111 | -523 | 1011 | 244 |
| 0+J + 55 | 2507 | 432 | 1469 | 9 | 17 | 13 |
| 0+J +110 | 2986 | 499 | 1743 | 36 | 22 | 29 |
| 10 +W +0 | 2440 | 273 | 1356 | 779 | 776 | 778 |
| 10 +W +55 | 3327 | 473 | 1900 | 47 | 38 | 42 |
| 10 +W +110 | 3754 | 369 | 2062 | 25 | 15 | 20 |
| 10 +J +0 | 4106 | 308 | 2207 | 1092 | 53 | 573 |
| 10 +J + 55 | 5214 | 291 | 2752 | 45 | 3 | 24 |
| 10 +J +110 | 4600 | 406 | 2503 | 17 | 15 | 16 |
| Wenchi | 581 | 252 | 417 | | | |

Farm 1= Gadissa Beksisa, Farm 2= Sisay Belete, RI=Rhizobium inoculum, MV= Maize varieties, W= Wenchi, J= Jibat, 0= faba bean without inoculation, 10 RI= faba bean with rhizobium inoculation.

Nitrogen uptake efficiency is the total amount of N absorbed (including that present in the roots, often disregarded) per kg of applied N (kg $ha^{-1}$). The Nitrogen uptake efficiency of maize varieties were varied between farms, maize varieties, faba bean precursor crop and applied nitrogen rates (Table 9). Maize varieties were had higher nitrogen uptake efficiency in farm1 as compared to farm 2 when planted following faba bean precursor crop without and with rhizobium inoculation fields. Considerably higher mean nitrogen uptake efficiency advantages of 1950 and 6550 % were found from maize varieties planted following faba bean precursor crop without and with rhizobium inoculation fields from farm 1 as compared to farm 2. This indicates farm 1 had better soil fertility status as compared to farm 2 which enhance the nitrogen uptake efficiency of maize varieties. Increased N uptake by subsequent crops can result from “spared N” remaining in the soil as a result of a relatively inefficient recovery of soil mineral N compared to other crops (Turpin et al., 2002). Maize varieties were gave higher men nitrogen uptake efficiency advantage of 266 % when planted following faba bean precursor crop with rhizobium inoculation field as compared to without rhizobium inoculation fields. Jibat maize variety was had significantly higher mean nitrogen uptake efficiency of 1413 and 90 % as compared to Wenchi when planted following faba bean precursor crop without and with rhizobium inoculation fields. This indicates Jibat maize variety was better characteristics in nitrogen uptake efficiency which significantly improved the yield. Both maize varieties were had higher nitrogen uptake efficiency with lower rate of fertilizer and decreased as rates of nitrogen increased.  Maize varieties planted following faba bean precursor crop without rhizobium inoculation was gave higher nitrogen uptake efficiency advantage of 350 and 3558 %; and 1100 and 5692 % from Wenchi and Jibat without application of nitrogen as compared to with application 55 and 110 kg N $ha^{-1}$. Higher nitrogen uptake efficiency advantage of 3382 and 4162 %; and 6167 and 9321 % were gained from Wenchi and Jibat varieties planted without nitrogen fertilizer as compared to 55 and 110 kg N $ha^{-1}$ following faba bean precursor crop with rhizobium inoculation field. Both maize varieties had better nitrogen uptake efficiency and recommend for further use in breeding program and wide scale up of production on farmers field.

Maize nitrogen use efficiency is the total dry matter or grain yield produced per unit of N absorbed. The maize nitrogen use efficiency of maize varieties were differed between farms, maize varieties, faba bean precursor field and application of nitrogen fertilizer rates (Table 9). The maize nitrogen use efficiency was ranged from negative to 3.228, 1.057; and 2.142 kg $ha^{-1}$ found from farm 1, farm 2 and combined over farms. The mean plant nitrogen use efficiency of 1.19, 0.175 and 0.68 kg $ha^{-1}$ were attained from maize planted on farm1, farm2 and combined over farms. Maize planted in Farm 1 gave higher maize nitrogen use efficiency of 582 % as compared farm 2. This justifies farm 1 had considerable better soil fertility status as compared to farm 2 which enhance the maize nitrogen use efficiency. Maize varieties planted following faba bean precursor crop with rhizobium inoculation was produced higher maize nitrogen use efficiency advantage of 385, 186, and 349 % from farm 1, farm 2 and combined over farm as compared to faba bean precursor crop without rhizobium inoculation fields. This implies planting of maize varieties following faba bean precursor crop with rhizobium inoculation were improved the maize nitrogen use efficiency due to changing the organic matter and N status of the soil. Jibat maize variety was produced maize nitrogen use efficiency as compared to Wenchi in both farms and combined over farms to. Beslemes et al. (2013) found significant differences for faba bean green manure management and N fertilization on NUE of maize. Higher mean maize nitrogen use efficiency advantage of 144 and 80.45 % were attained from Jibat maize varieties planted following faba bean precursor crop without and with rhizobium inoculation as compared Wenchi. This indicates Jibat maize variety had better nitrogen use efficiency which was promoted to resource poor smallholder farmers for sustainable maize production. Both maize varieties planted following faba bean precursor crop with rhizobium inoculation were had higher nitrogen use efficiency with lower rates of nitrogen as compared to 55 and 110 kg N ha-1 application. Goodroad and Jellum (1988) found higher nitrogen use efficiency was obtained when nutrients concentration was near the critical level and bounded with the lowest rates of nitrogen applied to maize. Similar result was reported by (Shams, 2000). While faba bean precursor crop without rhizobium inoculation field planted with maize varieties were gave better nitrogen use efficiency with application 55 kg N $ha^{-1}$ as compared to without fertilizer and recommended rate nitrogen fertilizer application. This justifies the importance of rhizobium application to faba bean in improving the soil organic matter and nitrogen status of the soil which enhanced the nitrogen use efficiency of maize varieties. Therefore further promotion work using Jibat variety was recommended for sustainable maize production in smallholder farmers.

The fertilizer N (recovery) use efficiency of maize varieties were varied between farms, maize varieties, faba bean precursor crop and nitrogen fertilizer rates (Table 10). The fertilizer N (recovery) use efficiency of maize varieties were significantly higher with all rates of nitrogen from farm 1 as compared to farm 2 which might be due to better soil fertility status of the field. Jibat maize variety planted following faba bean precursor crop without and with rhizobium inoculation was gave significantly higher mean fertilizer N (recovery) use efficiency of 1448 and 89 % as compared to Wenchi variety. Faba bean was found to represent a savings of 30 kg fertilizer N ha$^{-1}$ compared to a wheat-wheat sequence (McEwen et al., 1989). The fertilizer N (recovery) use efficiency was decreased as the rates of nitrogen fertilizer increased. N recovery gradual decreased with increase N (El-Gizawy, 2009). El-Gizawy (2005); and Berenger et al. (2009) reported similar results. The two maize varieties were better in fertilizer N (recovery) use efficiency. The fertilizer N (recovery) use efficiency of maize varieties was increased with faba bean precursor crop. The N recovery fraction was enhanced by 10-15 % after faba bean cover cropping, for sandy and clayey soil (Beslemes et al., 2013). Higher fertilizer N (recovery) use efficiency of maize varieties was obtained when maize varieties planted following faba bean precursor with rhizobium inoculation as compared to following without rhizobium. Therefore the wide productions of these two maize varieties were desirable options for sustainable maize production under smallholder farmers in the region.

**Table 9. Effects of rhizobium inoculation, maize variety and nitrogen rate on N up take efficiency and plant nitrogen use efficiency of maize around Toke Kutaye, western Ethiopia**

| RI g + MV + N kg ha$^{-1}$ | Nitrogen uptake efficiency(kg ha$^{-1}$) | | | Plant nitrogen use efficiency (kg ha$^{-1}$) | | |
|---|---|---|---|---|---|---|
| | Farm 1 | Farm 2 | Mean | Farm 1 | Farm 2 | Mean |
| 0+Wenchi +0 | 72 | -0.90 | 36 | 0.119 | -0.002 | 0.059 |
| 0+wenchi +55 | 14 | 1.89 | 8 | 0.267 | 0.078 | 0.173 |
| 0+Wenchi +110 | 4 | 2.02 | 3 | 0.294 | 0.110 | 0.202 |
| 0+Jibat +0 | 1328 | 61.22 | 695 | -2.539 | 0.061 | -1.239 |
| 0+Jibat + 55 | 35 | 3.27 | 19 | 3.702 | 0.194 | 1.948 |
| 0+Jibat+110 | 22 | 2.25 | 12 | 0.602 | 0.102 | 0.352 |
| 10 +Wenchi +0 | 1858 | 20.88 | 940 | 2.386 | 0.027 | 1.206 |
| 10 +Wenchi +55 | 50 | 4.01 | 27 | 1.064 | 0.106 | 0.585 |
| 10 +Wenchi +110 | 29 | 1.06 | 15 | 1.132 | 0.072 | 0.602 |
| 10 +Jibat +0 | 3525 | 56.04 | 1790 | 3.228 | 1.057 | 2.142 |
| 10 +Jibat + 55 | 84 | 0.70 | 42 | 1.876 | 0.203 | 1.040 |
| 10 +Jibat +110 | 37 | 1.40 | 19 | 2.183 | 0.095 | 1.139 |

RI=Rhizobium inoculum, MV= maize varieties, 0= faba bean without inoculation, 10 RI= faba bean with rhizobium inoculation, Farm 1= Gadissa Beksisa, Farm 2= Sisay Belete.

**Table 10. Effects of rhizobium inoculation, maize variety and nitrogen rate on fertilizer N (recovery) use efficiency of maize around Toke Kutaye, western Ethiopia**

| Faba bean+ RI | Maize Varieties | Nitrogen (kg N ha$^{-1}$) | | | | | | Mean |
|---|---|---|---|---|---|---|---|---|
| | | 0 | | 55 | | 110 | | |
| | | Farm1 | Farm2 | Farm1 | Farm2 | Farm1 | Farm2 | |
| FB+0 | Wenchi | 7266 | -63 | 1419 | 190 | 386 | 202 | 1567 |
| FB+0 | Jibat | 132835 | 6149 | 3501 | 328 | 2186 | 225 | 24204 |
| FB+ 10g RI | Wenchi | 185882 | 2115 | 4993 | 402 | 2885 | 107 | 32730 |
| FB+ 10 RI | Jibat | 352501 | 5631 | 8424 | 70 | 3654 | 140 | 61737 |
| Mean | | 169621 | 3458 | 4584 | 247 | 2278 | 168 | |

RI=Rhizobium inoculum, Fb+0= faba bean without rhizobium inoculation, FB+10 g RI= faba bean with rhizobium inoculation, Farm 1= Gadissa Beksisa, Farm 2= Sisay Belete

**Table 11. Effects of rhizobium inoculation, maize variety and nitrogen rate on shoot N accumulation, grain N accumulation and N harvest index of maize around Toke Kutaye, western Ethiopia**

| RI g + MV + N kg ha-1 | Shoot N accumulation (kg ha-1) | | | Grain N accumulation (kg ha-1) | | | N Harvesting index (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Farm 1 | Farm 2 | Mean | Farm 1 | Farm 2 | Mean | Farm 1 | Farm 2 | Mean |
| 0+W +0 | 62.20 | 40.12 | 51.16 | 70.07 | 40.31 | 55.19 | 0.53 | 0.50 | 0.52 |
| 0+W +55 | 110.92 | 67.89 | 89.40 | 103.87 | 56.92 | 80.40 | 0.48 | 0.46 | 0.47 |
| 0+W +110 | 78.16 | 67.25 | 72.71 | 91.49 | 70.10 | 80.80 | 0.54 | 0.51 | 0.52 |
| 0+J +0 | 27.38 | 41.92 | 34.65 | 60.88 | 53.24 | 57.06 | 0.69 | 0.56 | 0.62 |
| 0+J + 55 | 37.53 | 51.57 | 44.55 | 75.23 | 59.60 | 67.42 | 0.67 | 0.54 | 0.60 |
| 0+J +110 | 62.85 | 44.54 | 53.70 | 137.11 | 81.59 | 109.35 | 0.69 | 0.65 | 0.67 |
| 10 +W +0 | 49.59 | 32.98 | 41.28 | 70.13 | 50.27 | 60.20 | 0.59 | 0.60 | 0.59 |
| 10 +W +55 | 50.69 | 71.58 | 61.13 | 105.47 | 70.51 | 87.99 | 0.68 | 0.50 | 0.59 |
| 10 +W +110 | 88.27 | 56.84 | 72.55 | 106.67 | 65.75 | 86.21 | 0.55 | 0.54 | 0.54 |
| 10 +J +0 | 63.33 | 54.26 | 58.79 | 85.61 | 46.72 | 66.16 | 0.57 | 0.46 | 0.52 |
| 10 +J + 55 | 58.94 | 39.52 | 49.23 | 108.07 | 51.04 | 79.56 | 0.65 | 0.56 | 0.61 |
| 10 +J +110 | 88.23 | 48.92 | 68.57 | 104.12 | 74.47 | 89.30 | 0.54 | 0.60 | 0.57 |
| Wenchi | 62.36 | 46.79 | 54.58 | 61.00 | 32.14 | 46.57 | 0.49 | 0.41 | 0.45 |

RI=Rhizobium inoculum, W=Wenchi, J=Jibat, MV= maize varieties 0= faba bean without rhizobium inoculation, 10 g RI= faba bean with rhizobium inoculation, Farm 1= Gadissa Beksisa, Farm 2= Sisay Belete.

The use of faba bean crop rotation had a significant effects by reducing the amount of chemical nitrogen applied to soil for crop production. KÖpke and Nemecek (2010) reported the key environmental benefits of faba bean are its ability to fix atmospheric nitrogen symbiotically under a broad spectrum of environmental conditions and making this renewable resource available to show positive precrop effects in diversified crop rotations. He further stated that faba bean in intensive crop rotations with a high proportion of cereals and intensive N fertilization is likely to reduce energy use and $CO_2$ emission. Faba bean crop may prove to be a key component of future arable cropping systems where declining supplies and high prices of fossil energy are likely to constrain the affordability and use of fertilizers (Jensen et al., 2010). The production, distribution and application of fertilizer N, and the health and environmental implications of the losses of large amounts of N from fertilized soils as a consequence of inefficiencies in plant use of fertilizer N (Peoples et al., 2004; Crews and Peoples, 2005), suggests that it is timely to reassess the potential role of legumes, such as faba bean, as a source of N for future cropping systems (Jensen and Hauggaard-Nielsen, 2003; Crews and Peoples, 2004). Herridge et al. (2008) calculated a global estimate of the total amount of $N_2$-fixed by faba bean to be in the order of 290,000 t N each year out of around 22 million t N by all grain legume crops including soybean. Thus faba bean having a higher dependence upon $N_{2-}$ fixation for growth and fixing larger amounts of N. Faba bean precursor crop helps to address the increasing demand by consumers and governments for agriculture to reduce its impact on the environment and climate through new, more sustainable approaches to food production (Jensen et al., 2010). Jensen et al. (2010) suggested crop sequencing to enhance crop yields with improved resource use efficiency and a reduced risk of negative impacts on the environment via integration of ecological and agricultural science. Therefore the second total global area of production of faba bean world area was in Ethiopia following China (FAOSTAT, 2008). Further research work will be recommended for economic and environmental benefits of faba bean in the country.

### 3.6. Shoot N accumulation, grain N accumulation and N harvest of maize

The mean result of shoot N accumulation, grain N accumulation and N harvest index of maize varieties are indicated in (Table 11). The shoot N accumulation of maize varieties were differed between farms, precursor crop, maize varieties and rates of nitrogen fertilizer applied. Shoot N accumulation was ranged from 27.4 to 111, 33.0 to 72.55 and 34.65 to 89.4 kg ha-1 for farm 1, farm2 and combined over farms. The mean average shoot N accumulation was 64.65 and 51.1 kg ha$^{-1}$ for farm 1 and farm2 and farm 1 had advantage of 26.52 % as compared farm 2 which might be due to the fertility status and management practices difference between two farms. The mean shoot N accumulation of 63 and 52; and 67 and 51 kg ha$^{-1}$ were achieved from maize varieties planted following precursor crop without and with inoculation fields of farm1 and farm 2 and justifying that farm 1 which is rich in soil fertility status. Wenchi and Jibat maize varieties were had mean shoot accumulation of 71 and 44; and 58 and 59 kg ha$^{-1}$ from faba bean precursor crop without and with rhizobium inoculation fields. N accumulated by the wheat grown after the faba bean was compared to wheat following barley the apparent recovery of legume N (40 %) was calculated to be 4-fold higher than indicated from the wheat's direct recovery of faba bean $^{15}$N (11% total; 3% from faba bean's above-ground residues, and 8 % derived from a below-ground pool associated with N from the nodulated roots and rhizodeposition (Jensen et al., 2010). Higher shoot N accumulation of 89.4 kg ha$^{-1}$ was obtained from Wenchi maize variety planted following faba bean precursor crop without rhizobium inoculation fields with application of 55 kg ha$^{-1}$ N.

The grain N accumulation of maize varieties was varied across farms, precursor crop, maize varieties and rates of nitrogen (Table 11). The grain N accumulation was ranged from 61 to 137; and 40 to 82 kg ha$^{-1}$ achieved from farm1 and farm2 indicating better soil fertility status could influence the grain accumulation. The mean grain N accumulation of Wenchi and Jibat were 88 and 91; 94 and 99 kg ha$^{-1}$; and 56 and 65; and 62 and 57 kg ha$^{-1}$ obtained from farm 1 and farm 2 planted following faba bean precursor crop without and with rhizobium inoculated fields. Jibat variety was gave higher mean grain N accumulation as compared to Wenchi in farm 1. The mean grain N accumulation of maize varieties were increased as the rates of nitrogen fertilizer increased from 0 to 110 kg N ha-1 indicating direct influence nitrogen application on seed due to its role in amino acid and nucleic acid chemical composition of nitrogen. Maize after faba bean and receiving 120 kg N ha-1 was gave higher grain N uptake (El-Gizawy, 2009). Therefore application of recommended nitrogen fertilizer could increase grain N accumulation of maize varieties. The N harvest index of maize varieties were varied between farms, maize varieties, precursor crop and application of nitrogen rates. Higher mean N harvest index was harvested from maize varieties planted following faba bean precursor crop without rhizobium inoculation as compared to with rhizobium inoculation fields. In farm 2 higher N harvest index was achieved from maize varieties planted following faba bean precursor crop with rhizobium inoculation as compared to without rhizobium. Equivalent mean N harvest index of maize was obtained following faba bean without and with inoculation fields.

## 4. Conclusion

The result soil analysis indicates most of the nutrient concentrations were improved with planting of Faba bean precursor crop without and with rhizobium inoculation. Some soil nutrients are below the critical level and was requires better management practices for sustainable maize productions. Wenchi and Jibat maize varieties were gave varied growth parameters between two farms and with application of different rates of nitrogen fertilizer following Faba bean precursor crop indicting variation in soil fertility status of the two farms. Harvest index of maize was significantly influenced by maize varieties indicating variation the differences in two varieties. Application of nitrogen fertilizer was significantly affected mean grain yield of maize varieties. Interaction rhizobium inoculation with maize varieties and nitrogen fertilizer were significantly affected mean grain yield, dry biomass and harvest index of maize varieties. The mean nitrogen uptake of maize varieties following Faba bean precursor crop without and with rhizobium inoculation were varied between farms, maize varieties and applied nitrogen fertilizer indicating variation of all the variables. The two farms were different and heterogeneous in nitrogen status due to Faba bean planting and/or nature of soil in the two farms. Considerably higher mean agronomic efficiency advantage of 60.27 % was achieved from maize planted following faba bean with rhizobium inoculation. The mean agronomic efficiency was ranged from 13 to 56 and 16 to 778 when planted following faba bean precursor crop without and with rhizobium inoculation. Significantly higher mean agronomic efficiency and nitrogen uptake efficiency of both maize varieties were obtained from lower rates of N application as compared to the higher rates used. Maize varieties planted following faba bean precursor crop with rhizobium inoculation were had higher nitrogen use efficiency with lower rates of nitrogen as compared to 55 and 110 kg N $ha^{-1}$ application. Jibat variety had better nitrogen use efficiency and recommended for sustainable maize production in smallholder farmers. The fertilizer N (recovery) use efficiency was decreased as the rates of nitrogen fertilizer increased. Wenchi and Jibat maize varieties were better in fertilizer N (recovery) use efficiency. The shoot N accumulation, grain N accumulation and harvest index of maize varieties were varied between farms and Faba bean precursor crop. Agronomic analyses confirmed production of maize varieties following faba bean precursor crop without and with rhizobium inoculation and applying half recommended nitrogen fertilizer were recommended for sustainable maize production in high altitude areas of Toke Kutaye, western Ethiopia.

**Acknowledgements**

The authors thank Regional University Fund for Capacity Building for funding the experiment. I am very grateful to Ambo Plant Protection Research Center for providing me all necessary equipment's and logistics during the research work. All the technical and field assistants of Land and Water Resources Research Process are also acknowledged for unreserved effort during executing the experiment. Holleta and Debre Zeit Agricultural Research Center, Soil and Plant Analysis Laboratory are acknowledged for their provision of laboratory service for soil. I want to thank farmers at Bako Tibe for providing me their land for field research work.

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**Table 12. Long term rainfall and temperature data for the Toke Kutaye sites as obtained from nearby weather stations.**

| Year | Rainfall (mm) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | J | F | M | A | M | J | J | A | S | O | N | D | Total |
| 1990-2008 | 38.5 | 17.46 | 49.7 | 89.35 | 93 | 155.45 | 247.4 | 172 | 96.4 | 46.45 | 11.2 | 13.9 | 1031 |
| 2009 | 55.6 | 49.2 | 58.7 | 139.2 | 62.9 | 142.8 | 292.4 | 102.2 | 112.0 | 27.2 | 13.0 | 16.0 | 1071 |
| 2010 | 0.0 | 0.0 | 68.6 | 110.2 | 154.5 | 285.8 | 175.4 | 109.4 | 115.1 | 0.0 | 34.3 | 9.6 | 1063 |
| 2011 | 7.1 | 9.9 | 44.4 | 93.0 | 123.1 | 270.3 | 306.1 | 218.5 | 118.6 | 3.6 | 18.6 | 0.0 | 1213 |
| 2012 | 0.0 | 0.0 | 0.0 | 8.6 | 0.0 | 241.0 | 318.4 | 148.7 | 117.2 | 4.6 | 20.0 | 0.0 | 859 |
| 2013 | 0.0 | 0.3 | 37.0 | 160.3 | 176.8 | 141.8 | 225.6 | 87.5 | 128.7 | 77.2 | 17.2 | 4.0 | 1056 |
| 2014 | 0 | 0.2 | 27.0 | 99.5 | 152.0 | 185.0 | 245.6 | 147.0 | 125.0 | 22.0 | 15.0 | 3.0 | 1021 |
| Mean | 14.5 | 11.0 | 40.8 | 100.0 | 108.9 | 203.2 | 258.7 | 140.8 | 116.1 | 25.9 | 18.5 | 6.6 | 1045 |
| | **Temperature (0c)** | | | | | | | | | | | | Mean |
| Minimum | 6.8 | 7.4 | 9.2 | 9.5 | 9.7 | 10.8 | 10.8 | 10.4 | 9.3 | 6.3 | 6.3 | 6.7 | 8.9 |
| Maximum | 26.9 | 27.3 | 27.9 | 27.6 | 28.5 | 28.0 | 27.0 | 26.3 | 26.5 | 26.6 | 26.8 | 27.2 | 27.4 |
| Mean | 16.9 | 17.4 | 18.6 | 18.6 | 19.1 | 19.4 | 18.9 | 18.4 | 17.9 | 16.5 | 16.5 | 16.9 | 18.1 |