EFFECTS OF SOIL INCORPORATED FABA BEAN AND SOYBEAN BIOMASS ON YIELDS OF SUBSEQUENT MAIZE IN WESTERN ETHIOPIA

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EXTENDED ABSTRACT

The decline of soil fertility is severe in western Ethiopia due to inappropriate cropping practices (monocropping, unbalanced nutrient application, continuous cultivation, removal of crop residues from the fields and suboptimal of fertilizer application). Hence, maize (*Zea mays*) productivity is low. The low productivity of maize can be reversed by use of biomass of faba beans and soybeans, popularly grown in the areas, in addition to use of nitrogen fertilizers. However, information on the effects of these practices farmers' fields in western Ethiopia is sparse. The overall goal of this research was to investigate the contribution of biologically fixed N_2 from precursor faba bean and soybean biomass together with nitrogen fertilizer on yields a subsequent maize crop in western Oromia. Field experiments were conducted on farmers' fields and on station in Oromia National Regional State, western Ethiopia. The on-farm trials were conducted on the Ultisols of Toke Kutaye district, representing the highland ecology. The on-station trials were conducted at Bako Agricultural Research Centre, which also represent mid altitude sub-humid agro-ecosystems. Soil characterization was conducted on four maize farmers' fields in Bako Tibe and Toke Kutaye districts of Western Ethiopia. The soybean (*Glycine max)* and faba bean (*Vicia faba)* precursor crops, without and with rhizobia inoculation, were grown at three sites in the 2013 cropping season. The soybean variety Didessa (medium maturity) and faba bean variety (Moti) were used. Rhizobia strains SB-12 and FB-1035 for soybean and faba bean, respectively, were used, at the rate of 10 g per kg of seed, and then pelleted with sugar to insure attachment of the inoculants with the seeds. In 2014, the faba bean and soybean precursor crops were incorporated into their respective soils, plots demarcated and experiments were laid out in randomized complete block design (RCBD) in a 2x2x3 factorial arrangement, with three replications. Two faba bean farmers' fields

and one soybean field were used. The factors were "without and with rhizobia inoculation", "two maize varieties", and "three N levels (0, 55 and 110 kg N ha^{-1})". The two maize varieties were Jibat and Wenchi for highland areas in Toke Kutaye cropped to faba bean. For the mid-altitude areas cropped to soybean, the site used was the Bako Agricultural Research Centre, and the maize varieties were BH-543 and BH-661. Soil types of the experimental sites were classified as Ultisols. The soil nutrient status was differed among the four maize farmers' fields indicating the importance of site and soil test based fertilizer recommendation for sustainable maize production. The pH of soil reaction is acidic. The mean grain yields and harvest index were significantly ($P<0.05$) higher for maize planted following faba bean precursor crop with the application of 55 and 110 kg N ha^{-1}. Significantly ($P<0.05$) higher mean grain yield maize was obtained from application half recommended nitrogen fertilizer following faba bean precursor crop. Higher agronomic efficiency, fertilizer N (recovery) use efficiency and nitrogen use efficiency of maize were obtained from 55 kg N ha^{-1} application as compared to 110 kg N ha^{-1}, which matched with higher grain yields of maize. Agronomic studies confirmed increased yields of maize following faba bean precursor crop without and with rhizobia inoculation and applying half recommended rate of nitrogen fertilizer (55 kg N ha^{-1}) in high altitude areas of western Ethiopia. The grain yields of maize were significantly ($P<0.05$) higher with the application of half (55 kg N ha^{-1}) and full (110 kg N ha^{-1}) recommended rate of nitrogen fertilizer following soybean precursor crop. Planting of maize following soybean precursor crop biomass with half-recommended nitrogen is recommended for increasing maize yields. Higher agronomic efficiency and fertilizer N (recovery) use efficiency were obtained with 55 kg N ha^{-1} fertilizer application. Production of BH-661 and BH-543 maize varieties following soybean precursor crop with half recommended (55 kg N ha^{-1}) rate improved mean grain yield and is recommended for maize in mid altitude areas of western Ethiopia. Therefore, fertilizer management practices following legumes precursor crop biomass incorporation that increase nitrogen use efficiency and improve yield of maize will likely be more effective and desirable options for the area. The results from this series of studies suggest possibilities for further research work on optimum nitrogen rate, interaction of soybean and faba bean precursor crop biomass incorporation with nitrogen rates in the production of maize in other areas of western Ethiopia.

DECLARATION

I, Tolera Abera Goshu, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

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ACRONYMS AND ABBREVATIONS

AEN	Nitrogen agronomic efficiency
AP	Available phosphorous
APPRC	Ambo Plant Protection Research Centre
BARC	Bako Agricultural Research Centre
BH	Bako Hybrid
BNF	Biological Nitrogen Fixation
CEC	Cation exchange capacity
CIMMYT	International Maize and Wheat Improvement Centre
CSA	Central statistical Authority
CV	Coefficient of variation
DF	Degree of freedom
EC	Electric conductivity
EIAR	Ethiopian Institute of Agricultural Research
ESSS	Ethiopian Soil Science Society
FAO	Food and Agricultural Organization
FB-1018	Faba bean strains
FNRE	Fertilizer N (recovery) use efficiency
Ha	hectare
IDRC	International Development Research Centre
K	Potassium
LSD	Least significant difference
MBARC	Meteorology of Bako Agricultural Research Centre
N	Nitrogen
Na	Sodium

Ndfsa	N derived from soil with total N difference method
NH_4-N	Ammonium nitrogen
NMSA	National Meteorological Service Agency
NO_3-N	Nitrate nitrogen
NS	Non-significant difference at 5 % probability level
NUE	Nitrogen use efficiency
^{O}C	Degree Celsius
OC	Organic carbon
OM	Organic matter
P	Phosphorus
PEN	Nitrogen physiological efficiency
RI	Rhizobia inoculum
RR	Recommended Rate
RUFORUM	Regional Universities Forum for Capacity Building in Agriculture
$S0_4$=S	Sulphur
SAS	Statistical Analysis software
SB-12	Soybean strain-12
SSA	Sub-Saharan Africa
SUA	Sokoine University of Agriculture
T	Ton
TNF	Total nutrient uptake from fertilized plots
TNU	Total nutrient uptake from unfertilized plots
TSP	Triple superphosphate

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 The Problem of Low Soil Fertility in Ethiopia

Land degradation, low soil fertility, limited and erratic rainfall with ever-increasing population pressure are common features of large parts of sub-Saharan Africa (Vesterager *et al*., 2008). Soil degradation is caused by unsustainable land uses and management practices, and climate extremes (FAO, 2015). The causes and effects of soil degradations are attributed to various social, economic and governance drivers' and its current rate of soil degradation threatens the capacity of future generations to meet their most basic needs. Approximately 50% of potentially arable land in Africa is currently under cultivation, of which 2000 million ha (23% of agricultural land) are already of low soil fertility, and the soil fertility of the remaining arable lands continues to decline due to mismanagement (FAO, 2003; UNEP, 2004).

According to FAO (2015) estimation, about 83% of rural people in Sub-Saharan Africa depend on the land for their livelihoods, but 40% of Africa's land resources is currently degraded. Furthermore, about 33% of soil are moderately to highly degrade due to erosion, nutrient depletion, acidification, salinization, compaction and chemical pollution (FAO, 2015). The decline in soil fertility is especially severe in tropical soils. Fertilizer-based green revolution has been attempted to improve crops yield at the beginning of the 1990s in some African countries, including Ethiopia (Ashworth, 2005; Quiñones *et al*., 1997; Takele, 1997). Although the fertilizer-based green revolution seemed successful in the first five years of its inception in Ethiopia, crop yields started to decline despite the continued fertilizer use (Belay, 2008). Cleemput *et al.* (2008) reported in many developing countries, continuous cultivation with inappropriate farming practices has resulted in severe depletion of nutrients and soil organic matter, seriously threatening agricultural production.

Inappropriate cropping systems, monocropping, nutrient mining, unbalanced nutrient application, removal of crop residues from the fields and inadequate re-supplies of nutrients have contributed to decline in crop yields (Nyamangara, 2001). Crop production is facing severe nutrient deficiencies driven by continuous production against a backdrop of little fertilizer use over the decades (Sanchez *et al.*, 1997). In sub-Saharan Africa, smallholder agricultural production has remained consistently low and food security is very low (Sanchez, 2002). Stoorvogel and Smaling (1990) reported, from a nutrient balance study in 38 sub-Saharan African countries and for 35 crops, negative soil nutrient balances for all three macro-nutrients (N, P, K), with mean annual losses of 22 kg N, 2.5 kg P and 15 kg K ha^{-1}. In Ethiopia, the nutrient balances were estimated to be -41 kg N, -6 kg P and -26 kg K ha^{-1} (Stoorvogel and Smaling, 1990). FAO (2015) reported currently much of the additional available land is not suitable for agriculture, sustainable management of the world's agricultural soils and sustainable production have therefore become imperative for reversing the trend of soil degradation and ensuring current and future global food security.

Cropping systems involving monoculture of cereals can cause reduction of yields and depletion of soil nitrogen. However, decreasing productivity can be alleviated by different methods such as the use of inorganic nitrogen fertilizers and use of legumes in a cropping system. Currently, the skyrocketed prices of synthetic fertilizer have made it difficult for smallholder farmers to use inorganic nitrogen for crop production. Furthermore, the crop takes up only a small fraction of this fertilizer (roughly 5% to 50%) (Carranca, 2012), but not all the nitrogen applied, since N could be lost by volatilization, gaseous plant emission, surface soil runoff, leaching and denitrification (Raun and Johnson, 1999). Of the total input in the form of nitrogen- and phosphorus fertilizers, only 15-20% is actually embedded in the food that reaches the consumers' plates, implying very large nutrient losses to the environment (Sutton *et al.*, 2013), while in Sub-Saharan Africa soil nutrient depletion (where extraction is higher than the input) is common (FAO, 2015). Consequently, the use of legumes in a cropping system for biological nitrogen fixation becomes an alternative source of nitrogen for crop production. Their nitrogen fixation ability of legumes can be improved by inoculation of seeds using appropriate rhizobia strains for each legume.

Furthermore, increased cereal nitrogen use efficiency must lead to the increased yields needed to feed a growing population that has to benefit from the promise of N_2-fixing legumes to subsequent cereal crops. The recently developed hybrid maize varieties in Ethiopia are highly productive and respond to high doses of N, but their N use efficiency has not been determined. More efficient use of water, reduced use of pesticides and overall improvements in soil health can lead to crop yield increases of 79% (FAO, 2015). Similarly, while many soybean and faba bean varieties are grown in western Ethiopia, their N_2-fixation capacity with and without rhizobia inoculation has not been tested. Therefore, knowing the N_2-fixation capacity of soybean and faba bean varieties and N-use efficiency of hybrid maize varieties are of paramount importance for increasing maize yields in the region.

1.2 Biological N_2-fixation

Legumes contribute to the maintenance and restoration of soil fertility by fixing N_2 from the atmosphere (Giller and Wilson, 1991). Furthermore, the use of leguminous green manures, crop rotation and intercropping are traditional, and the N derived from biological nitrogen fixation with a cropping system often promote significant increases in yields of subsequent grain or other crops. The input of fixed N from legumes may be a significant contributing factor in relation to sustaining productivity in smallholder systems (Sanginga, 2003). The N_2-fixing potential of soybean has been estimated at about 88-188 kg N ha^{-1} $year^{-1}$ (Giller, 2001), 41-50 kg ha^{-1} (Yusuf *et al*., 2006), and 31- 64 kg ha^{-1} $year^{-1}$ (Ali *et al*., 2002). On average, 50 to 60% of soybean N demand was met by biological N_2 fixation (Salvagiotti, 2008). Rennie and Kemp (1984) reported that bean fixed as much as 125 kg N ha^{-1}, but considerable differences existed among bean types and cultivars. The extent to which a N_2-fixing legume crop can benefit a subsequent crop depends on the quantity of N the legume fixed, which is incorporated into the soil, 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).

1.3 N-use efficiency

Nitrogen is an essential element and important constituent of many biomolecules in plants and lower N in soil is a limiting factor to high yields in a variety of agricultural systems (Zhang *et al*., 2010). Increased crop productivity has been associated with a 20-fold increase in the global use of N fertilizer during the past five decades (Glass, 2003) and this is expected to increase at least 3-fold more by 2050 (Good *et al*., 2004). Looking for varieties with efficient use of nitrogen is of paramount importance. N-use efficiency (NUE) is defined as grain production per unit of N applied to soil/available in the soil (Moll *et al.*, 1982). Grain NUE can be more thoroughly expressed as the product of N-uptake efficiency (N uptake per available unit of soil N) and N utilization efficiency (grain production per unit of absorbed N) (Coque and Gallais, 2007). Using the ^{15}N approach, Ma and Dwyer (1998) showed that a high ratio of the amount of ^{15}N recovered in grain or stover to the amount of fertilizer ^{15}N applied to the soil was primarily associated with greater N-uptake and improved dry matter production during the grain-filling period. Worldwide, nitrogen use efficiency (NUE) for cereal production is approximately 33% (Raun and Johnson, 1999). Identification of maize varieties with greater N use efficiency would make a great contribution to African smallholder farmers in increasing maize yields and production.

1.4 Importance of Inoculation on Nitrogen Fixation and Subsequent Maize Yields

Soybean and faba beans are legume plants, which have co-evolved with specific bacteria that have the ability to "fix" atmospheric nitrogen and make it available to the host plant. Nodules are formed on soybean and faba bean by the soybean-specific species like *Bradyrhizobia japonicum* and haricot bean-specific species *Rhizobium leguminosarum* bv. *viceae* (Loh and Stacey, 2003).

The soybean has been a recently introduced crop to Ethiopia, and use of appropriate rhizobia strains could help to increase the crop yields. Dobereiner and Campelo (1977) reported that inoculation of soybean is essential in new areas and in acid soils. They further stated that the selection of appropriate rhizobia strains is essential for new cultivars, and consideration must be given to the soil and climate into which the crop is being introduced. The soybean-brady rhizobia symbiosis can fix up to 300 kg N ha^{-1} per $year^{-1}$ under good conditions (Keyser and Li, 1992). Furthermore, LaRue and Patterson (1981) reported an average estimate of N_2-fixation by soybeans to be 75 kg N ha^{-1}, using adopted commercial cultivars and assuming that 50% of the N was from fixation.

Bezdicek *et al*. (1978) reported that soybeans were capable of fixing over 300 kg N ha^{-1} when the soil was low in available N and when effective strains of bradyrhizobia are supplied in high numbers.

The ability of a rhizobia strain to dominate the nodules of legume plants is dependent on environmental factors as well as on the genetic compatibility between the plant host and the rhizobia partner (Keyser and Li, 1992). Host plant selection of the competing strain may constitute an important factor that affects the ability of rhizobia to compete and nodulate successfully (George *et al*., 1992).

Faba bean cultivars do differ in their ability to fix N_2, and this may affect responses to inoculation or added N fertilizer (Beck and Duc, 1991). Mytton *et al.* (1977) reported that *Vicia faba* cultivars showed 73.8% of total variation in N_2 fixation due to host strain interactions. Low population of rhizobia was one of the factors for poor nodulation and N_2-fixation (Aynabeba *et al.,* 2001). Yield reduction of faba bean can be reversed through inoculation with adaptable, effective rhizobia, which lead to improved nodulation and yields (Kiros and Singh, 2006). Inoculation of cultivars increased grain yields in field experiments from 19 to 67% in soils containing high populations of native faba bean rhizobia (Rennie and Dubetz, 1986). Quantities of N fixed in faba bean vary greatly, and estimates of rates of fixation vary from 40 kg N ha^{-1} (Duc *et al.,* 1988), 93 kg N ha^{-1} (Brunner and Zapata, 1984) to 120 kg N ha^{-1} (Danso, 1992), and from 16 to 300 kg aboveground N per ha. 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 about 11 times more than the original soil N content (0.014%) from the plots where faba beans were grown (Fassile, 2010). Faba bean fixed 82 kg N ha^{-1} and provided 1.4 t ha^{-1}

faba bean grain yield, representing 35% to 69% increase due to the inoculation (Beck and Duc, 1991; Khosravi *et al*., 2001).

Inoculation of faba bean gave a higher total biological yield, grain yield and total nitrogen (Beck and Duc, 1991). Therefore, symbiotically effective rhizobia increase nodulation, N_2-fixation, growth and yields of their host plant (Kiros and Singh, 2006). Thus, there is a need for faba bean selection for increased nitrogen fixation under representative field conditions and involving improved inoculants. Walley *et al*. (2007) reported that a well-inoculated pulse crop could fix sufficient quantities of N to eliminate the need for N fertilizer inputs.

The input of fixed N from grain legumes may be a significant contributing factor in relation to sustaining productivity in smallholder systems (Sanginga, 2003). Faba bean can improve the economic value of a following crop by enhancing the yields (Lopez-Bellido *et al*., 1998). Wright (1990) also observed significant yield increases (12%) in the second cereal crop following faba bean as compared to N fertilized continuous cereals. Faba bean incorporated into a field remarkably increased subsequent maize yield, and yield of 8.32 Mg ha^{-1} for maize seed was possible under no fertilization (Beslemes *et al*., 2013). El-Gizawy (2009) found significantly higher mean grain yield of maize after faba bean, which might be due to the enriching of the soil with N and organic matter due to faba bean. Faba bean break crop enhanced the average yield in the subsequent barley and wheat crops by 21 and 12 %, respectively, 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 faba bean, soybean or field pea the requirement was only ca. 90 kg N ha^{-1}.

Muller and Sundman (1988) and Peoples *et al*. (2009) reported using ^{15}N-labeled residue that wheat, barley or cotton crop following faba bean might 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 in the soil (Nuruzzaman *et al*., 2005) and may indirectly make more phosphorus and potassium available for subsequent crops (KÖpke and Nemecek, 2010). The rotational benefit of faba bean in improving the P availability for subsequent crops is also considered to be closely related to the mineralization of its P-rich crop residues rather than to residual effects of root exudates on the P chemistry in the soil.

1.5 Total N Difference Method of Estimating N_2-fixation

Nitrogen fixation and N use efficiency can be determined using several methods that can be used to estimate field N_2-fixation. The total N difference methods are among the most common and widely used for estimating field nitrogen fixation by legumes. There are advantages and disadvantages associated with each method. The advantage of the difference method is that it is inexpensive, simple and does not require special techniques or equipment. The total N difference method is the simplest method used to estimate the amount of nitrogen fixed (Munroe and Davies, 1974). The total N fixed by a legume crop is derived by subtracting from the total N content of the legume from the N content of the non-fixing non-legume (derived solely from soil N). This would assume that leguminous (fixing) and non-leguminous (non-fixing, i.e. cereals) plant will have equal access to the soil N already available or mineralized under the influence of plants (Azam and Farooq, 2003). This method of calculating biologically fixed N does not account for the inherent differences in plant types in affecting the mineralization and availability of soil N. Rahman *et al.* (2009) found the estimate of plant N derived from N_2-fixation was higher when the N difference method was used as compared to other methods in broad bean and hairy vetch.

1.6 Justification for the Research Reported Herein

Low soil fertility stands as the most important bottleneck to crop productivity in the western parts of Ethiopia. Inappropriate farming practices have aggravated the situation. The contribution of legumes with rhizobia inoculation in cropping systems and NP fertilizer use can increase yields in the region. However, no study has been done on biological N_2-fixation by soybean or faba bean varieties due to rhizobia inoculation, and N-use efficiency of existing maize varieties has not been determined. Results of such studies will help farmers to save money, reduce the amounts of chemical fertilizers applied for crop production and environmental effects in the region.

Several research findings indicated the potential contribution of N_2-fixed by the inoculated faba bean and soybean in increasing yields of these legume crops. Furthermore, the crop residue inputs from biological nitrogen fixing plants often promote significant increases of yields of subsequent crops. However, the information on the contribution of legumes symbiotic N_2-fixation on farmer's fields in Ethiopia is sparse.

Besides, knowing the N-use efficiency of maize varieties is crucial for resource poor farmers to use efficient varieties to increase yields in the region. The quantity of N supplied from legume N_2-fixation to subsequent maize and N use efficiency of different maize based cropping systems are still unclear in Ethiopia. These issues are explored in the research reported herein.

1.7 Objectives of the Present Research

The overall objective of the study was to improve the N-use efficiency and yields of maize in western Ethiopia through incorporation of faba bean or soybean precursor crop biomass into the soil.

The specific objectives were to:

i. Characterize and classify the soils of the Toke Kutaye and Bako-Tibe.
ii. Determine effects of faba bean precursor crop biomass incorporated into the soil on maize response N, yields and nitrogen use efficiency in highland ecologies of Toke Kutaye, western Ethiopia.
iii. Determine effects of soybean precursor crop biomass incorporated into soil on maize response N, yields and nitrogen use efficiency in mid altitude maize growing ecologies at Bako Agricultural Research Centre, western Ethiopia.

1.8 Organization of this Dissertation

The study is organized into five chapters. The first chapter deals with review of different literature sources on the soil fertility status in Ethiopia. Different publications that investigated the soil fertility status, nitrogen management alternatives, biological nitrogen fixation and nitrogen use efficiency, the importance of rhizobia inoculation of nitrogen fixation and subsequent maize yields and methods of nitrogen fixation estimation were reviewed.

The second chapter deals with assessment of physical and chemical properties of the soils of the study area. The soil classification of the study sites was undertaken. The third chapter is the effects of faba bean precursor crop biomass incorporation into soil on nitrogen requirement and yields of subsequent highland maize. The use of faba bean precursor crop without and with rhizobia inoculation was studied. The fourth chapter is on effects of soybean precursor crop biomass incorporation on soil nitrogen requirement and yields of subsequent mid altitude maize varieties. The fifth chapter summarized all the results and gave recommendations for further research work for increasing maize yields in western Ethiopia.

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CHAPTER TWO

2.0 PEDOLOGICAL CHARACTERIZATION OF THE SOILS UNDER MAIZE PRODUCTION IN BAKO TIBE AND TOKE KUTAYE DISTRICTS OF WESTERN SHOWA, ETHIOPIA

Abstract

Maize farm fields were selected in two districts of western Showa, Ethiopia. Four representative maize fields were selected based on landforms and other physiographic attributes in humid highland and sub humid mid altitude areas of Toke Kutaye and Bako Tibe Districts. The objective was to characterize and classify the soils under maize production in Toke Kutaye and Bako Tibe Districts of western Showa, Ethiopia. Four soil profiles were opened and characterized. Pedons are formed under udic and perudic moisture and iso-thermic temperature regimes for both districts. The soils were very deep, well-drained reddish brown to dark reddish brown loamy sand to sandy clay loams, with thick reddish brown loamy sand top and sub soil for Bako Tibe and Toke Kutaye. Three pedons had clayey top and sub soils. The pH of surface soil ranged from 4.48-5.52 which was very strongly acidic to strongly acidic. The soil organic carbon contents of the topsoil and subsoil of the four pedons ranged from 2.07 to 2.69% and 0.35 to 2.85 %, which were rated as medium to high, but very low to high respectively. Both two highland pedons had CEC ranging from 20.06 to 54.17 $cmol_c$ kg^{-1}soil, which was rated as medium to very high, while in the two mid altitude pedons it ranged from 10.82 to 23.52 $cmol_c$ kg^{-1}soil CEC, which was low to medium. The total nitrogen levels ranged from 0.19 to 0.23% for topsoils, which was low to medium, and from 0.03 to 0.07 % for subsoils, which was very

low. According to USDA Soil Taxonomy, the four pedons were classified as *Typic Palehumults* (Acrisols and Alisols according to WRB). The four pedons were different in physicochemical properties, indicating the need to characterize soils to give site-specific fertilizer recommendations for maize production.

Keywords: Physico-chemical properties, fertility, pedons, maize

2.1 Introduction

Soil degradation and low rate of mineral fertilizer applications are a serious threat to food security in sub-Saharan Africa (Henao and Baanante, 1999). The major driving forces of land degradation include nutrient depletion, complete removal of crop residues, crop production with low levels of nutrient inputs and lack of adequate soil conservation practices in Ethiopia (Bojo and Cassels, 1995); longer cultivation (Wu *et al*., 2003). As a result, decline in soil fertility has a marked impact on plant growth and yield, grain quality, production costs and the increased risk of soil erosion. Conventional agriculture has certain limitations in terms of maintaining long-term soil fertility (Charpentier *et al*., 1999). A continental soil nutrient balance study in 38 sub-Saharan African countries for 35 crops reported negative soil nutrient balances for all three macro-nutrients (N, P, K) with mean annual losses of 22 kg N, 2.5 kg P and 15 kg K ha^{-1} (Stoorvogel and Smaling, 1990). The highest rate of nutrient depletion was observed in Ethiopia with aggregated national scale nutrient balances estimated to be -41kg N, -6kg P and -26kg K ha^{-1} (Stoorvogel and Smaling, 1990).

Inappropriate soil management practices such as low external inputs and internal nutrient cycles, and severe soil erosion contribute to soil and land degradation in Ethiopia. As a result, negative major plant nutrient balances are common problems in many parts of

Ethiopia (Elias *et al*., 1998). Different soil types exhibit varying characteristics due to differences in micro-morphological, morphological, physical, chemical and mineralogical properties (Ukut *et al*., 2014). Variations in soil forming factors and processes operating on different parent materials, under different climatic, topographic, and biological conditions over varying periods would cause these variations (Soil Survey Staff, 1993). Fagbami (1990) reported the diversity of soils as a major reason behind allocation of land to wrong uses. Overall, human population pressure, climate change and lack of land capability classification are the major causes of soil fertility depletion in Ethiopia regardless of variations among agroecosystems.

To maintain agricultural land at optimum level of fertility and productivity, great attention has been given to assess the physical and bio-chemical properties of the soil resources under different famers' fields. Soil characterization and classification could provide information for the understanding of the morphological, physical, chemical, mineralogical and microbiological properties of the soil (Ogunkunle, 1986). Esu (2005) reported soil characterization as a major building block for understanding the soil, classifying it and getting the best understanding of the environment. Furthermore, monitoring of nutrient status for assessing the degree of nutrient mining in an agro-ecosystem is very crucial. The change in soil nutrient stocks over time has to be measured in order to quantify the extent of nutrient mining and maintaining the cropping system for sustainable crop production. Soil properties that change with duration and intensity of weathering provide vital clue toward the pedogenesis of the studied soil (Bera *et al*., 2015). According to Giessen *et al*. (2009) characterization and/or evaluation of soil properties is a master key for describing and understanding the status and qualities of the major nutrients in soils. Assessing soil physico-chemical properties is used to understand the potential status of nutrients in soils under different land uses (Wondowosen and Sheleme, 2011). Soil characterization provides information that helps to understand the physical, chemical, mineralogical and microbiological properties of the soils we depend on to grow crops, sustain forests and grasslands as well as support homes and society structures (Ogunkunle, 2005). Furthermore, soil characterization data helps in the correct classification of the soil to serve as a basis for more detailed evaluation of the soil as well as gather preliminary information on nutrient, physical or other limitations needed to produce a capability class for crop production (Eswaran, 1977). This knowledge can ascertain whether the specified land use types are useful for a given production system and used to meet plants requirement for rapid growth and better crop production (Shishir and Sah, 2003).

A detailed study of the soil characteristics and classification will provide baseline information on the physical, chemical and mineralogical properties of the soil for crop production, land use planning and management. Owing to the fact that Bako Tibe and Toke Kutaye Districts are intensive maize producing districts and no site-specific soil characterization and classification have been done on the soils of the area. Despite their importance for agricultural cropping and especially for intensive maize production, limited information is available for soils of the area. Soil characterization and classification of the Bako Tibe and Toke Kutaye Districts are very important in providing the needed basic information on soils of the area. Thus, this study aims to characterize the soils of the area based on their morphological characteristics, physico-chemical properties and their classification according to the "*United States Department of Agriculture (USDA) Soil Taxonomy*" (SSS, 2014) and the "*FAO-World Reference Base for Soil Resources"* scheme of classification (IUSS Working Group WRB, 2015). The results emanating from the study will provide information on the soil fertility trends and will serve to guide activities related to the management of the existing land resources for sustainable agricultural production in western Ethiopia. Therefore, the objective this study was to characterize the soils under maize production in Bako Tibe and Toke Kutaye Districts of Western Showa, Ethiopia and to recommend management practices required for sustainable crop production.

2.2 Materials and Methods

2.2.1 Description of the study area

The soil characterization and classification study was conducted in Bako Tibe and Toke Kutaye Districts of West Showa zone of Oromia Regional National State, Ethiopia (Fig. 1). The study areas are located at Jato Dirki and Shakka in Bako Tibe with pedons designated as GTP-S01and TUP-S02, (opend from Gutu Tolera and Takele Uluma maize farm), and at Babichi and Kolba in Toke Kutaye with pedons named as SBP-S03 and GKP-S04, respectively (opend from Sisay Belete and Gutuma Kuma maize farm). The relevant site characteristics of the study areas are indicated in Table 2.1. The altitudes of the sites are 1727 and 1778 m.a.s.l. for Jato Dirki and Shakka in Bako Tibe; and 2322 and 2262 m.a.s.l. for Kolba and Babichi and in Toke Kutaye District. The soils are formed on flat plains with gradients ranging between 2.5 to 3; and 2 to 2.5%. The surface characteristics are moderate rill, inter-rill and sheet erosion. Soil profiles of all the study sites had well drained and slow run-off.

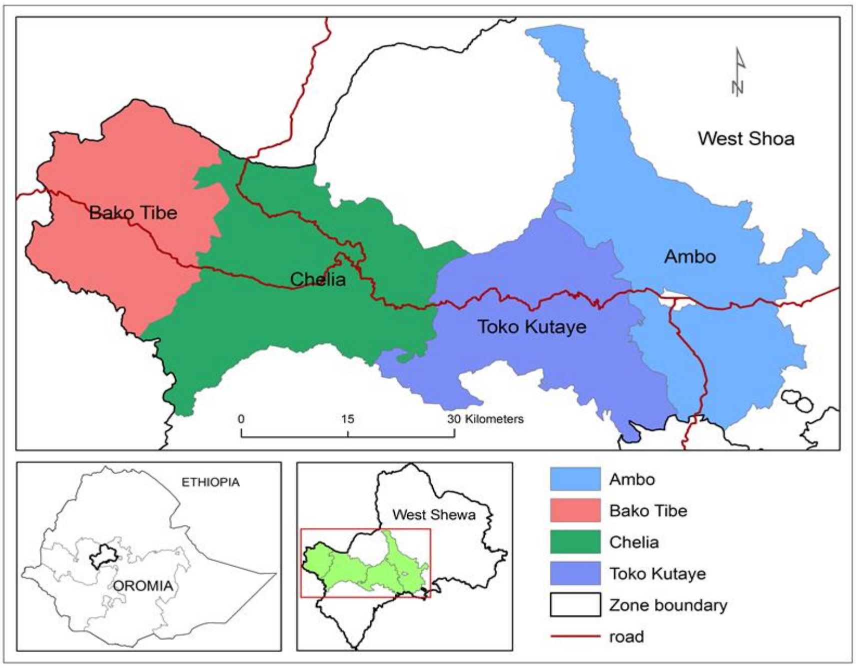

Figure 2.1: Study District in West Showa Zone of Oromia Region, Ethiopia

The nearby weather data for both districts are presented in Figures 2.2- 2.4. The long term weather station of Bako Agricultural Research Centre and National Meteorological Service Agency indicated that both study sites receive mean annual rainfall of 1265 and 1293 mm (MBARC, 2014 and NMSA, 2014b) for Bako Tibe and 1045 mm for Toke Kutaye (NMSA, 2014a) with unimodal distribution. Bako Tibe has warm humid climate with mean minimum, mean maximum and average air temperatures of 14, 28.5 and 21.2 ^{o}C for Bako; and 8.9, 13.2, 28 and 21^{o}C for Ilu-Gelan. However, Toke Kutaye has a cool humid climate with mean minimum, mean maximum and average air temperatures of 8.9, 27.4 and 18.1^{o}C, respectively.

Table 2.1: Site characteristics of the study sites

Pedon	Bako Tibe and Toke Kutaye	AEZ	Altitude *masl*	Land form	Slope %	Land use / Vegetation	SMR	STR
GTP-S01	N 9^{0}01'20 E 37^{0}13'29	Sub humid mid altitude	1730	flat	2.5	Agriculture (Maize, Tef, Sorghum, Hot pepper, Sweet potato, Haricot bean, Soybean, Mango, Sugarcane and Banana) Dominant vegetation includes (Cordia tree, Acacia spp, *Eucalyptus spp*, Croton, Ficus tree)	Udic	Isothermic
TUP-S02	N 8^{0}59'31" E 37^{0}21'53"		1778	flat	3		Udic	Isothermic
SBP-S03	N 8^{0}71'21 E 37^{0}42'	Humid highland	2322	flat	2	Agriculture (Tef, wheat, barley, maize, faba bean, field pea and Niger seed) Dominant vegetation includes (Acaia spp, *Eucalyptus spp and* Croton tree)	Perudic	Isothermic
GKP-S04	N 8^{0}9'8 E 37^{0}72'		2262	flat	2.5		Perudic	Isothermic

Masl = metres above sea level, AEZ=Agroecological zone, SMR= soil moisture regime, STR= soil temperature regime

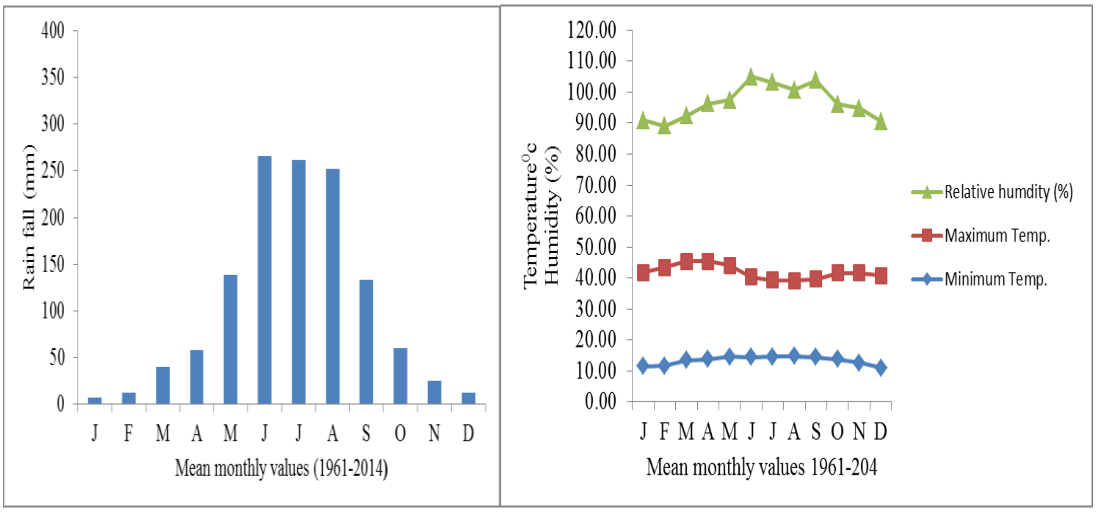

Figure 2.2: Mean monthly rainfall and temperature data for (GTP-S01) from 1961-2014

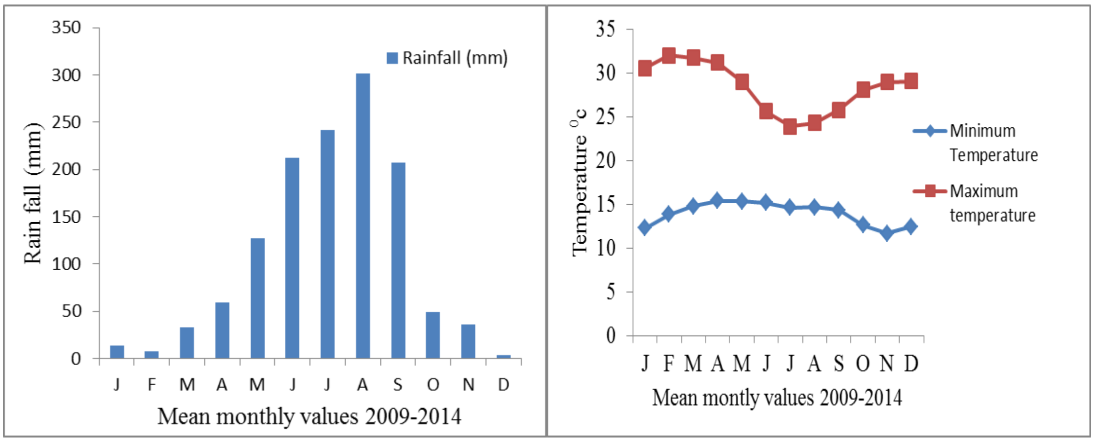

Figure 2.3:Mean monthly rainfall and temperature data for (TUP-S02) from 2009-2014

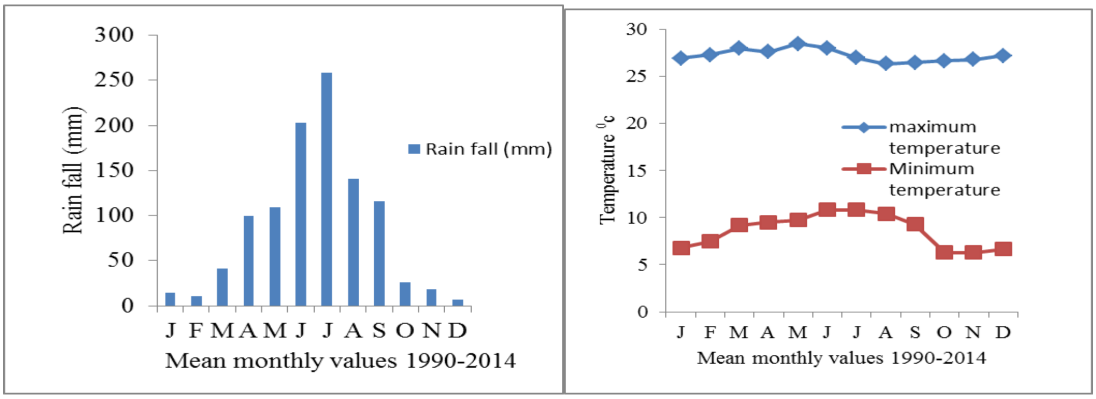

Figure 2.4: Mean monthly rainfall and temperature data for (SBP-S03 AND GKP-S04) from 1990-2014

2.2.2 Land characteristics, geo-referencing, profile description and soil sampling

The representative soil profile sites were selected randomly around major maize growing areas in mid altitude and highland ecologies based on landforms and other physiographic attributes. Data on landform, soil morphological characteristics, elevation, slope gradient, vegetation and land use or crops were collected from four observation sites that were selected to represent major landforms and soils of the selected maize fields. Four soil profiles, two from each district, were identified and opened for characterization. The opened soil profiles had 250 cm width, 150 cm length and 200 cm depth in the east to west direction using GPS compass. The soil profiles were studied, described and sampled according to FAO Guidelines for Soil Profile Description (FAO, 2006). The soil profiles were geo-referenced using Global Positioning System (GPS). The soil horizons were differentiated for each profile and soil samples collected from each horizon separately. The soil samples were air dried and passed through 2mm sieve for determination of most soil physical and chemical properties.

2.2.3 Morphological Characteristics

Soil color (dry and moist) was determined using the Munsell color chart (Munsell Color Company, 2009). Other soil morphological features including field texture, structure and consistence were determined using the FAO Guidelines for Soil description (FAO, 2006).

2.2.4 Soil physical analysis

Undisturbed soil samples were taken by 144cc core samplers with 66 and 42 mm diameter and height respectively and dried at 105^{o}C for 24 h for the measurement of bulk density. Bulk density was estimated by dividing the weight of the oven dried soil sample taken with core sampler to the volume of core sampler. Hydrometer method was used to determine the particle size distribution following the procedure FAO (1974).

2.2.5 Soil chemical analysis

Soil pH was measured potentiometrically using digital pH meter in the supernatant suspension of 1: 2.5H_2O, 0.01M $CaCl_2$, and 0.1M KCl as described by McLean (1982). Cation exchange capacity (CEC) of the soil and exchangeable bases were determined by saturating soil with neutral 1M NH_4OAc (ammonium acetate) and the adsorbed NH^{4+} displaced by using 1M KCl and then determined by Kjeldahl distillation method for estimation of CEC of soil (Polemio and Rhoades, 1977; Rhoades, 1982). The exchangeable bases (Ca^{2+}, Mg^{2+}, Na^+ and K^+) were determined by atomic absorption spectrophotometer (Anderson and Ingram, 1996). Percent base saturation was estimated from the sum of exchangeable bases as a percent of the CEC.

Exchangeable acidity was determined by saturating soil samples with potassium chloride solution and titrating with sodium hydroxide as described by Mclean (1965). Total nitrogen was determined following Kjeldahl procedure as described by Bremner and Mulvaney (1982). The available phosphorus was determined following Bray-II procedure as described by Bray and Kurtz (1945). Soil organic matter was determined following wet digestion methods as described by Walkley (1947) and FAO (1974).

2.2.6 Classification of soils

Field and soil physico-chemical laboratory analytical data were used for pedological characterization. The diagnostic epipedons and subsurface horizone were identified using the guidelines provides in the USDA Soil Taxonomy (SSS, 2006; 2014) and in the World Reference Base for Soil Resources (IUSS Working Group WRB, 2014; 2015). The soils were classified to the family level of the USDA Soil Taxonomy (SSS, 2014) and to tier-2 of the FAO World Reference Base for Soil Resources (IUSS Working Group WRB, 2014; 2015).

2.2.7 Statistical analysis

Pearson's simple correlation matrix was generated using Statistical Analysis Software 9.0 (SAS, 2004) to examine the relationship between different parameters.

2.3 Results and Discussions

2.3.1 Soil morphological characteristics

The data for selected morphological properties are presented in Table 2.2. The soil depths of the profiles varied from 160 to 200 cm. There was a slight variation between the two mid altitude pedons in the soil horizon while the pedons on the highland were similar. The diagnostic epipedons of the two pedons (GTP-S01 and SBP-S03) are mollic and ochric for (TUP-S02 and GKP-S04) respectively. The subsurface horizons (Bt) were argillic and well developed in all the different maize fields under udic and isothermic for mid altitude and highland. Many distinct clay cutans were observed in the subsoils indicating that eluviation-illuviation processes have been dominantly active. The four soil profiles are gently sloping, very deep, clayey, very strongly acid (GTP-S01), strongly acidic (TUP-S02), very strongly to extremely acid (SBP-S03) and medium to strongly acid (GKP-S04).

The color of moist surface soil was very dark red (2.5YR3/2) and dark red brown (2.5YR2.5/4) for all pedons (Table 2.2) for the mid altitude and highland. The topsoils (plough layers) had a slight color variation among the pedons (Table 2.2). They had the same hue (2.5YR) with varying value/chroma ranging 2.5/4 to 3/6 when moist. Most colors of the subsurface soil horizons were dark reddish brown having similar hue 2.5 YR and with varying value/chroma ranging from 2.5/4 to 5/8. The subsurface horizons had a dominant color of red in moist soil condition because of the presence of high concentration of hematite. Murphy (1959) and Wakene (2001) reported that redness is due to the presence of iron oxide in the subsurface horizons.

Table 2.2: Morphological characteristics of pedons in different maize fields of mid altitude and highland areas of Western Showa, Ethiopia

Pedon	Horizon	Depth (cm)	Texture	Soil colour		Structure	Consistence
				Moist	dry		
GTP-S01	Ap	0-29	C	db (2.5YR3/2)	r(2.5YR2.5/6)	SCSB	Hd,fr,SP
	BA	29 - 78.5	C	drb(2.5YR 3/4)	rb(2.5YR4/4)	MCSB	Hd,fr,SP
	Bt1	78.5 - 119	C	r(2.5YR4/8)	r(2.5YR4/8)	MCAB	Hd,fr,SP
	Bt2	119 -1 63	C	rb(2.5YR4/4)	r(2.5YR4/6)	WCSB	Hd,fr,SSP
	BC	163 - 200	C	dr(2.5YR3/6)	drb(2.5 YR3/4)	nd	nd
TUP-S02	Ap	0 - 20	C	dr(2.5YR3/6)	drb(2.5YR2.5/4)	SCSB	Hd,fr,SP
	Bt1	20 - 54	C	rb(2.5YR 4/4)	r(2.5YR4/6)	MCSB	Hd,fr,SP
	Bt2	54 - 89	C	drb(2.5YR3/4)	r(2.5YR5/6)	MCAB	Hd,fr,SP
	Bt3	89 -129	C	rb(2.5YR4/4)	r(2.5YR4/6)	WCSB	Hd,fr,SSP
	BC	129 - 200	C	r(2.5YR4/6)	r(2.5 YR4/8)	nd	nd
SBP-S03	Ap	0 - 26	C	db(2.5YR3/2)	r(2.5YR4/6)	SCSB	Hd,fr,SP
	BA	26 - 48	C	drb(2.5YR 2.5/4)	drb(2.5YR3/4)	MFSB	Hd,fr,SP
	Bt1	48 - 94	C	db(2.5YR3/2)	r(2.5YR4/8)	MCAB	Hd,fr,SP
	Bt2	94 -1 42	C	drb(2.5YR2.5/4)	r(2.5YR4/6)	WMSB	Hd,fr,SSP
	BC	142 - 200	C	drb(2.5YR3/4)	drb(2.5 YR3/4)	nd	nd
GKP-S04	Ap	0 - 20	C	drb(2.5YR2.5/4)	drb(2.5YR2.5/4)	SCSB	Hd,fr,SP
	BA	20 - 63	C	drb(2.5YR 3/4)	dr(2.5YR3/6)	WFSB	Hd,fr,SP
	Bt1	63 - 102	C	yr(5YR 5/8)	yr(5YR4/6)	MCAB	Hd,fr,SP
	Bt2	102 - 129	C	rb(5YR4/4)	rb(5YR5/4)	WMSB	Hd,fr,SSd
	BC	129 - 160	SCL	yr(5YR5/6)	rg(5 YR5/2)	nd	nd

C= clay, SCL= sand clay loam, WFSB = weak fine sub angular blocky, SCSB = strong coarse sub angular blocky, MCAB = moderate coarse angular blocky, WMSB = weak medium sub angular blocky, Fr =friable, Hd = hard, SP = sticky and plastic, Shd = slightly hard, SSP = slightly sticky and plastic, MMC = moderate medium crumb, nd= not determined

2.3.2 Soil physical properties

2.3.2.1 Soil structure

The structure of the soil was from weak to strong sub angular blocky for the four pedons (Table 2.2). Similar results were reported by Wakene (2001). Soil consistence was similar among the different pedons of different soil surface horizons. The soils were sticky and plastic when wet, and friable when moist for all horizons of studied pedons. Soil consistence is an inherent soil characteristic and a reflection of the particle size composition of the soil, high organic matter content changed stickiness and plasticity of surface soil layer.

2.3.2.2 Soil texture

Clay was the predominant texture throughout soil horizons (Tables 2.2-2.6). The silt to clay ratio of surface and subsurface soil profile in the maize farm fields was low which might be due to tillage practices in the topsoil and illuvation of clay minerals into the subsurface horizons. A similar result was reported by Achalu *et al*. (2012) stating that higher clay fraction and lower silt to clay ratio recorded in the cultivated land was attributed to the impacts of farming practices. The soil texture distributions varied among farms. The tillage practices could facilitate clay particle translocation within the different soil horizon.

2.3.2.3 Bulk density and moisture holding capacity

The bulk densities of the surface horizons ranged from 1.29 to 1.49 Mg/m^3 (Tables 2.3-2.6), whereas the bulk densities of sub surface horizons ranged from 1.30 to 1.55 Mg/m^3 (Tables 2.5-2.8). The higher soil bulk densities in the sub surface horizons than in the surface horizons can be attributed to the higher soil organic matter content in the latter (Gregorich *et al*., 1994; Wakene, 2001; Achalu *et al*., 2012). Soils having low or high bulk density, exhibit favourable and poor soil physical conditions, respectively (Hajabbasi *et al*., 1997; Patil and Prasad, 2004). The moisture holding capacity of the topsoils of studied maize fields ranged from 17.96 to 29.36% weight/weight (Tables 2.3-2.6). In subsoils, moisture holding capacities ranged from 10.77 to 33.88 % w/w (Tables 2.3-2.6). The soil moisture holding capacity decreased with increased soil depth. This can be attributed to the higher soil organic matter content in the topsoils than in the subsoils (Achalu *et al*., 2012).

Table 2.3: Important physico-chemical properties of soils at different horizons of GTP-S01 profile at Shaka, Bako Tibe district of West Showa, Ethiopia

Parameters	Soil depth (cm) and horizons				
	0-29(Ap)	29-78.5 (BA)	78.5 - 119 (Bt1)	119 -1 63(Bt2)	163-200 (BC)
pH(H_2O)	4.78	5.37	5.79	5.72	5.02
Organic carbon (%)	2.42	0.97	0.74	0.58	0.51
Organic matter (%)	4.17	1.67	1.28	1.00	0.88
CEC_{soil} ($cmol_c\ kg^{-1}$)	23.52	16.76	13.95	12.89	12.95
CEC_{clay} ($cmol_c\ kg^{-1}$)	38.40	19.43	15.72	14.13	17.56
Total N (%)	0.20	0.08	0.08	0.06	0.06
Available P ($mg\ kg^{-1}$)	52.67	7.24	4.94	4.12	28
C: N	12.10	12.13	9.25	9.67	8.50
EC µs/cm	44.5	47.1	53.0	73.6	70.8
Na ($cmol_c\ kg^{-1}$)	1.59	0.81	0.97	1.04	0.60
K ($cmol_c\ kg^{-1}$)	0.92	0.46	0.53	0.56	0.35
Mg ($cmol_c\ kg^{-1}$)	2.83	1.08	1.42	1.42	1.44
Ca ($cmol_c\ kg^{-1}$)	6.59	3.40	3.49	2.59	2.49
BS (%)	51	34	46	44	38
Clay (%)	61.25	86.25	88.75	91.25	73.75
Silt (%)	17.50	5.00	5.00	2.50	3.00
Sand (%)	21.25	8.75	6.25	6.25	23.0
Exc. Al^{3+} Acidity	0.23	0.14	0.17	0.14	0.21
pH (0.1MKCl)	3.45	4.97	4.26	4.20	4.60
pH (0.01$CaCl_2$. 6H_20)	4.52	5.00	5.56	5.55	4.91
Bulk density (Mg/m^3)	1.49	1.42	1.55	1.56	1.69
Moisture holding capacity (%)	17.96	25.27	12.00	11.43	18.29
Total sulfur	130.44	37.54	36.87	32.6	32.14

2.3.3 Soil chemical properties

2.3.3.1 Soil pH

The pH (H_2O) of topsoil ranged from 4.48 to 5.52 for the four pedons (Tables 2.3-2.6). The soil reaction of surface soils varied from very strongly acidic to strongly acidic (Jones 2003 and Truog, 1948) as cited by Landon (1991). The results were in agreement with the findings of Achalu *et al*. (2012), who analysed the soil properties of cultivated field in western Ethiopia.

The lower value of soil pH under the cultivated land might be due to the depletion of basic cations in crop harvest and due to its highest microbial oxidation that produces organic acids, which provide H ions to the soil solution that lower its soil pH value (Achalu *et al.*, 2012). Moreover, Frossard *et al.* (2000) reported that the acidic nature with low soil pH obtained from all the representative land uses, might be attributed to the fact that soils were derived from weathering of acidic igneous granites and leaching of basic cations such as K, Ca and Mg from the surface soil.

Table 2.4: Important physico-chemical properties of soils at different horizons of TUP-S02 profile at Jato Dirki, Bako Tibe District of West Showa, Ethiopia

Parameters	**Soil depth (cm) and horizons**				
	0-20(Ap)	**20-54(Bt1)**	**54 – 89(Bt2)**	**89 -129 (Bt3)**	**129-200 (BC)**
pH(H_2O)	4.56	4.66	5.57	4.69	5.2
Organic carbon (%)	2.69	1.40	1.17	0.97	0.58
Organic matter (%)	4.64	2.41	2.02	1.67	1.00
CEC_{soil} ($cmol_c$ kg^{-1})	18.55	16.44	17.00	12.63	10.82
CEC_{clay} ($cmol_c$ kg^{-1})	36.20	22.29	21.59	15.54	14.74
Total N (%)	0.23	0.12	0.09	0.08	0.07
Available P (mg kg^{-1})	50.2	0.69	0.47	0.39	2.67
C:N	11.70	11.67	13.00	12.13	8.29
EC µs/cm	114.3	76.0	52.6	52.5	46.5
Na ($cmol_c$ kg^{-1})	1.13	0.48	0.37	0.35	0.32
K ($cmol_c$ kg^{-1})	0.65	0.30	0.25	0.20	0.17
Mg ($cmol_c$ kg^{-1})	3.67	1.42	2.25	2..76	2.65
Ca ($cmol_c$ kg^{-1})	5.12	2.54	2.81	2.65	2.55
BS (%)	57	29	33	25	53
Clay (%)	51.25	73.75	78.75	81.25	78.75
Silt (%)	25.00	10.00	7.50	7.50	10.00
Sand (%)	23.75	16.25	13.75	11.25	11.25
Exch. Al^{3+} acidity	0.27	0.29	0.31	0.24	0.21
pH (0.1MKCl)	3.40	3.44	3.51	3.36	3.56
pH(0.01$CaCl_2$. 6H_20)	4.46	4.60	4.70	4.66	5.11
Bulk density(Mg/m^3)	1.29	1.30	1.43	1.46	1.35
Moisture holding capacity (%)	27.77	15.54	20.62	25.36	14.00
Total sulfur	151.00	56.31	42.85	42.67	23.13

2.3.3.2 Available phosphorus

The available phosphorus for surface soil ranged from 30.51 to 80.26 mg kg^{-1}which is high relative to the P content of mineral soils (FAO, 1990 and Olsen and Dean, 1961; and

Fassbender, 1980) as cited by Landon (1991). However, the sub surface horizons had soil with lower amounts of available phosphorus than surface horizons of all the pedons. Tolessa (2006) and Wakene (2001) reported similar results in Alfisols of western Ethiopia. Varying amounts of phosphorus were observed among soil profiles, which might be due to continuous cultivation for prolonged period. Tekalign and Haque (1987) and Dawit *et al*. (2002) reported that the availability of P in most soils of Ethiopia vary due to fixation, abundant crop harvest and erosion. Similarly, Paulos (1996) found variations in available P contents in soils, which are related to the intensity of soil disturbance, the degree of P-fixation with Fe and cations.

2.3.3.3 Cation exchange capacity of the soil

The CEC levels of the surface soils were 23.52 and 18.55 $cmol_c\ kg^{-1}$ for GTP-S01 and TUP-S02, respectively, with low sub surface CEC concentration. The CEC of the four surface pedons studied ranged from 18.55 $cmol_c\ kg^{-1}$ for TUP-S02 to 28.84 $cmol_c\ kg^{-1}$ for GKP-S04, which is regarded as low to high CEC based on (FAO, 1990; Barber and Rowell, 1972) as cited by Landon (1991). Similar results were reported by Achalu *et al*. (2012) suggesting that soil CEC is expected to increase through improvement of the soil OM content.

2.3.3.4 Total exchangeable bases and percent base saturation

The total exchangeable bases (sum of Mg, Ca, K and Na) and percent base saturation for surface soil ranged from 10.54 to 17.57 $cmol_c\ kg^{-1}$ and 51 to 61 %, respectively for the four maize fields (Tables 2.3 to 2.6). The base saturation for surface soil was rated as medium (FAO, 1990; and Barber and Rowell (1972) as cited by Landon, 1991). The studied soils had higher base saturation percentage (Tables 2.3 to 2.6). The percent base saturation for top soils for both mid altitude and highland was greater than 50%.

2.3.3.5 Organic carbon

The organic carbon contents of the surface soil ranged from 2.07 to 2.69%, indicating medium to high level of OC based on (FAO, 1990; Metson, 1961) as cited by Landon (1991) (Tables 2.3-2.6). This might be due to frequent cultivation, which has increased soil aeration through enhanced decomposition of SOM. The results were in agreement with Achalu *et al*. (2012). Similarly, studies conducted by Lal (1996); Mandiringana *et al.* (2005) and Michel *et al*. (2010) indicated lower percentage of soil OC content in cultivated land. The organic carbon levels decreased with increasing soil depth starting from surface horizon to subsurface horizon, which is in agreement with the results of Tolessa (2006) and Wakene (2001). This is because the surface soil is biologically the most active parts of soil system because of high population of soil fauna and flora and receives different organic residues continuously.

2.3.3.6 Total nitrogen

The total nitrogen contents of the surface soil ranged from 0.19 to 0.23% (Tables 2.3-2.6). The total N levels were rated as low to medium according to FAO (1990) and Metson (1961) as cited by Landon (1991). This might be due to continuous cultivation of the field that resulted to crop harvest and crop residue removal. Similarly, the lower total N in cultivated land was in agreement with the findings of Abbasi *et al*., 2007; Jaiyeoba, 2003; Heluf and Wakene (2006).

Table 2.1: Important physico-chemical properties of soils at different horizons of SBP-S03 profile at Babichi, Toke Kutaye District of West Showa, Ethiopia

Parameters	Soil depth (cm) and horizons				
	0-26 (Ap)	26-48 (BA)	48 – 94 (Bt1)	94 -142 (Bt2)	142-200 (BC)
pH(H_2O)	4.48	4.72	4.84	5.32	5.32
Organic carbon (%)	2.07	1.44	2.85	0.66	0.39
Organic matter (%)	3.57	2.48	4.91	1.14	0.67
CEC_{soil} ($cmol_c\ kg^{-1}$)	20.06	23.28	23.17	22.32	24.35
CEC_{clay} ($cmol_c\ kg^{-1}$)	35.66	31.57	29.42	27.47	30.91
Total N (%)	0.19	0.13	0.1	0.08	0.04
Available P ($mg\ kg^{-1}$)	80.26	11.04	7.52	6.27	25.32
C:N	10.89	11.08	28.50	8.25	9.75
EC µs/cm	54.4	52.6	71.4	52.4	53.4
Na ($cmol_c\ kg^{-1}$)	1.75	1.73	2.50	2.75	2.75
K ($cmol_c\ kg^{-1}$)	1.01	0.95	1.18	1.78	1.48
Mg ($cmol_c\ kg^{-1}$)	1.75	1.25	1.08	1.08	1.07
Ca ($cmol_c\ kg^{-1}$)	6.03	3.04	2.15	2.05	2.11
BS (%)	53	30	30	34	30
Clay (%)	56.25	73.75	78.75	81.25	78.75
Silt (%)	27.50	17.50	10.00	10.00	5.00
Sand (%)	16.25	8.75	11.25	8.75	16.25
Exc. Al^{3+} Acidity	0.41	0.33	0.29	0.22	0.15
pH (0.1MKCl)	3.26	3.41	3.53	3.77	3.98
pH(0.01$CaCl_2$. $6H_20$)	4.37	4.61	4.68	5.27	5.09
Bulk density (Mg/m^3)	1.42	1.52	1.42	1.49	1.46
Moisture holding capacity (%)	29.02	10.77	12.15	13.44	12.44
Total sulfur	123.91	60.99	54.33	43.47	13.21

The low N fertility could be attributed to continuous monocropping (Wakene *et al*., 2004). Total nitrogen contents decreased with depth from surface soil through all sub surface horizons (Tables 2.3-2.6). The results were in agreement with those of Tolessa (2006) and Wakene (2001). The total N was of medium range (FAO, 1990) and Metson (1961) as cited by Landon (1991) and the soil has a good potential for agricultural crop production.

Table 2.2: Important physico-chemical properties of soils at different horizons of GKP-S04 profile at Koleba, Toke Kutaye District of West Showa, Ethiopia

Parameters	Soil depth (cm) and horizons				
	0-20 (Ap)	**20-63 (BA)**	**63 – 102 (Bt1)**	**102 -1 29 (Bt2)**	**129-1 60 (BC)**
pH(H_2O)	5.52	5.48	5.62	5.69	5.83
Organic carbon (%)	2.49	1.36	0.86	0.70	0.35
Organic matter (%)	4.29	2.34	1.48	1.21	0.60
CEC_{soil} ($cmol_c$ kg^{-1})	28.84	29.91	29.18	34.08	54.17
CEC_{clay} ($cmol_c$ kg^{-1})	43.53	39.23	38.27	49.57	164.15
Total N (%)	0.21	0.11	0.08	0.06	0.03
Available P (mg kg^{-1})	30.51	4.20	2.86	2.38	16.22
C:N	11.86	12.36	10.75	11.67	11.67
EC µs/cm	93.0	84.2	69.7	166.7	86.3
Na ($cmol_c$ kg^{-1})	4.75	4.25	2	1.25	1.5
K ($cmol_c$ kg^{-1})	1.07	2.07	1.18	0.44	0.59
Mg ($cmol_c$ kg^{-1})	4.92	2.25	3.67	4.25	4.78
Ca ($cmol_c$ kg^{-1})	6.83	4.29	5.59	6.17	6.57
BS (%)	61	43	43	36	25
Clay (%)	66.25	76.25	76.25	68.75	33
Silt (%)	17.50	15.00	5.00	15.00	20.75
Sand (%)	16.25	8.75	18.75	16.25	46.25
Ex.Al^{3+} acidity	0.12	0.17	0.15	0.11	0.30
pH (0.1MKCl)	4.10	4.03	4.06	4.08	4.12
pH(0.01$CaCL_2$. $6H_20$)	5.45	5.42	5.43	5.57	5.72
Bulk density (Mg/m^3)	1.38	1.45	1.46	1.42	1.30
Moisture holding capacity (%)	29.36	28.48	21.12	22.54	33.86
Total sulfur	136.96	51.6	43.47	27.85	9.91

2.3.3.7 C:N ratio

The C: N ratios of the surface soil ranged from 10.89-12.10:1 (Tables 2.3- 2.6), found in medium range, which is good quality (Msanya *et al*., 2000). The C:N ratios of the subsurface soil ranged from 8.29 - 28.50:1 and were rated as low to very high (Tables 2.3-2.6), showing good to poor quality (Msanya *et al*., 2000; and Landon, 1991). C:N ratio is the traditional guide to the nature of the organic matter present in the soil (Brady and Weil, 2002). The C:N ratio of the surface soil was in narrow range. Similarly, Achalu *et al*. (2012) found cultivated land recorded narrow C:N ratio. This might be due to different tillage practices applied during land preparation, which enhance decomposition process in the soil system. Aeration during tillage and increased temperature that enhances mineralization rates of OC than organic nitrogen could probably be the causes for the lower level of C:N ratio in cultivated land (Achalu *et al*., 2012). Abbasi *et al*. (2007) found narrow C:N ratio in soil of cultivated land might be due to higher microbial activity and more CO_2 evolution and its loss to the atmosphere in the top (0 - 20 cm) soil layer which resulted to the narrow C:N ratio. Soil management practices are necessary for improving the narrow range of C:N ratio. Haney *et al.* (2012) reported introducing management schemes to improve the C:N ratio and increase microbial activity should result in increased soil fertility/soil biology and highly productive and sustainable systems. Therefore, it is important to sustain to restore intensively cultivated lands through best management practices, for instances improving soil properties by managing using crop rotation, composting, returning crop residues to the fields and cultivating no more than necessary and adding organic materials are very crucial

2.3.4 Classification of the studied soils

On the basis of soil morphological and laboratory analytical data, the diagnostic horizons and other diagnostic features (Table 2.7), classification of the soils of the study area is as presented in Table 2.8. The diagnostic epipedons of the two pedons (GTP-S01 and SBP-S03) were mollic and ochric for (TUP-S02 and GKP-S04) according to USDA Soil Taxonomy (SSS, 2014) (Table 2.7). The diagnostic subsurface horizons of the four soil profiles were argillic USDA Soil Taxonomy (SSS, 2014) (Table 2.7). While according to

WRB IUSS Working Group WRB (2015), the diagnostic horizons of surface epipedons and subsurface horizons of the four pedons were mollic and argic horizon, respectively. The soil names (taxa) are presented in Table 2.8. The soil order of Western Showa zone (from Toke Kutaye to Bako-Tibe) was Ultisols according to USDA Soil Taxonomy (SSS, 1993; 2014). According to WRB for Soil Resources (IUSS Working Group WRB,2007; 2015), the tier-1 soil names were respectively Acrisols (GTP-S01 and TUP-S02) and Alisols (SBP-S03 and GKP-S04) (Table 2.8). In contrary, formly it was Alfisols according to USDA Soil Taxonomy (SSS, 2014), corresponding to Nitisols with Soil Resources (IUSS Working Group WRB, 2015).

Table 2.3: Summary of the morphological and diagnostic features of surface epipedons and subsurface horizons Bako-Tibe and Toke Kutaye Districts, Western Showa, Ethiopia

Pedon No.	Diagnostic horizons, and other features: USDA Soil Taxonomy (SSS, 2014)		Diagnostic horizons, properties and materials: IUSS Working Group WRB (2015)
GTP-S01	Mollic epipedon, argillic horizon	Gently sloping, very deep, clayey, very strongly acid, udic SMR, isothermic STR	Mollic horizon, argic horizon
TUP-S02	Ochric epipedon, argillic horizon	Gently sloping, very deep, clayey, strongly acid, udic SMR, isothermic STR	Mollic horizon, argic horizon
SBP-S03	Mollic epipedon, argillic horizon	Gently sloping, very deep, clayey, very strongly to extremely acid, perudic SMR, isothermic STR	Mollic horizon, argic horizon
GKP-S04	Ochric epipedon, argillic horizon	Gently sloping, very deep, clayey, medium to strongly acid, perudic SMR, isothermic STR	Mollic horizon, argic horizon

Table 2.4: Details classification of the studied soils

USDA Soil Taxonomy (SSS, 2014)						World Reference Base for Soil Resources [IUSS Working Group WRB (2015)]			
Pedon No.	**Order**	**Suborder**	**Greatgroup**	**Subgroup**	**Family**	**Reference Soil Group – Tier 1**	**Principal Qualifiers**	**Supplementary Qualifiers**	**Tier-2 soil name**
GTP-S01	Ultisols	Humults	Palehumults	Typic Palehumults	*Gently sloping, very deep, clayey, very strongly acid, udic, isothermic, Typic Palehumults*	Acrisols	*Haplic*	*Clayic, Cutanic, Humic, Profondic*	*Haplic Acrisols (Clayic, Cutanic, Humic, Profondic)*
TUP-S02	Ultisols	Humults	Palehumults	Typic Palehumults	*Gently sloping, very deep, clayey, strongly acid, udic, isothermic, Typic Palehumults*	Acrisols	Haplic	Clayic, Cutanic, Humic, Profondic	*Haplic Acrisols (Clayic, Cutanic, Humic, Profondic)*
SBP-S03	Ultisols	Humults	Palehumults	Typic Palehumults	*Gently sloping, very deep, clayey, very strongly to extremely acid, perudic, isothermic, Typic Palehumults*	Alisols	*Rhodic, Haplic*	*Clayic, Cutanic, Humic, Profondic*	*Haplic Rhodic Alisols (Clayic, Cutanic, Humic, Profondic)*
GKP-S04	Ultisols	Humults	Palehumults	Typic Palehumults	*Gently sloping, very deep, clayey, medium to strongly acid, perudic, isothermic, Typic Palehumults*	Alisols	*Haplic*	*Clayic, Cutanic, Humic, Profondic*	*Haplic Alisols (Clayic, Cutanic, Humic, Profondic)*

2.3.5 The relationships between soil nutrients of topsoils

Soil pH had non-significant negative association with total nitrogen and available phosphorous concentration of the soil (Table 2.9), indicating that as pH decreases, the amounts nitrogen and phosphorous increases in the soil. Significantly, higher and positive correlation coefficients were observed between organic carbon with total nitrogen (0.96) and base saturation percentage (0.98) (Table 2.9). This indicated that the higher the organic carbon concentration the higher would be the total nitrogen and base saturation percentage and vice versa. There were significantly positive association with correlation coefficients between total nitrogen and base saturation percentage (0.91). Significantly ($P<0.05$), perfect positive association was obtained between total nitrogen and total sulfur concentration (Table 2.9). The relationship among available phosphorous and total sulfur concentration of the soil was significant and positive with correlation coefficients of 0.86. Magnesium had significantly positive association with calcium with correlation coefficients of 0.88 (Table 2.9), indicating that soils with higher levels of Mg will also have higher levels of Ca concentration and vice-versa. In conclusion, some soil physicochemical properties had positive and negative relationship with other properties of the soil.

Table 2.5: Pearson`s correlation coefficients (r) among selected soil physico-chemical properties of the surface soil of Bako Tibe and Toke Kutaye Districts of Western Showa, Ethiopia

	$pH(H_2O)$	OC	CEC	TN	TP	K	Mg	Ca	PBS	Ts
$pH(H_2O)$		-0.60	-0.41	-0.78	-0.87	0.16	0.086	-0.011	-0.48	-0.77
OC			0.22	0.96*	0.72	0.51	-0.53	-0.71	0.98*	0.95
CEC				-0.096	0.41	-0.92	0.30	0.48	-0.32	-0.075
TN					0.83	0.38	-0.39	-0.52	0.91*	0.99**
TP						-0.19	0.025	-0.091	0.68	0.86*
K							-0.61	-0.73	0.54	0.33
Mg								0.88*	-0.43	-0.29
Ca									-0.70	-0.45
PBS										0.92
Ts										

pH (H_2O) = soil pH, OC=organic carbon, CEC=Cation exchange capacity, TN=Total nitrogen, TP= Total phosphorous, K= potassium, Mg= Magnesium, ca=Calcium, PBS= Percent base saturation, and Ts= Total sulfur.

2.4 Conclusions and Recommendations

Results of the study showed that soils of Bako Tibe and Toke Kutaye Districts of Western Showa, Ethiopia, are Ultisols. The surface soils contained higher organic carbon, total nitrogen and available phosphorous. The CEC of the surface soils were 23.52 and 18.55 cmolc kg^{-1} in Bako Tibe district maize farms field, decreasing as depth increases; whereas the CEC were 20.06 and 28.84 cmolc kg^{-1} for Toke Kutaye maize farmer's field increased with increasing soil depth. Significantly ($P = 0.05$) positive association was observed between total nitrogen and total sulfur concentration. The soil physico-chemical characteristics differed between and among pedons in the highland and mid altitude agroecology. Soil fertility variations were observed among four pedons of maize farmers' field based on nutrient concentrations. The total N and available P status of the soils were found to vary from low to medium and low to adequate range. There is a need for a more targeted approach soil fertility intervention that differentiates between maize farm field in highland and mid altitude of western Ethiopia. Soil test-based and integrated soil fertility management is recommended for sustainable maize production in highland and mid altitude areas of Western Ethiopia.

2.5 References

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CHAPTER THREE

3.0 EFFECTS OF SOIL INCORPORATED FABA BEAN PRECURSOR CROP BIOMASS ON YIELDS OF SUBSEQUENT HIGHLAND MAIZE IN TOKE KUTAYE DISTRICT, WESTERN ETHIOPIA

Abstract

The study was conducted to assess effects of faba bean precursor crop biomass incorporation into soil on N requirement, N use efficiency and performance of subsequent maize varieties. The experiment was laid out in 2 x 2 x 3 factorial arrangement with randomized complete block design in three replications. Two types of faba bean field (with and without rhizobia inoculation) as factor A, the two maize varieties (Wenchi and Jibat) factor B and three levels of nitrogen (0, 55, 110 kg N ha^{-1}) were used as factor C. The grain yield and harvest index of maize (8115 and 5132 kg ha^{-1} and 30.58 and 34.67%) significantly ($P<0.05$) affected by application of nitrogen fertilizer following faba bean precursor crop biomass in highland areas of both farms. Maize varieties used in this study showed significant ($P<0.05$) differences in thousand seed weight and harvest index, indicating the inherent genetic variation between the two varieties. Higher agronomic efficiency and fertilizer N (recovery) use efficiency (49.28 Kg grain kg N applied^{-1} and 501%) was obtained with 55 kg N ha^{-1} indicating greater losses of N from the system and points to the need adjust the time of fertilizer application with the period of high crop demand without excess or deficiency**.** Higher grain yield of maize (7718 and 8115 kg ha^{-1}) was obtained from application of half and full recommended rate of nitrogen fertilizer following faba bean precursor crop. Therefore, planting maize varieties with application of nitrogen fertilizer following faba bean precursor crop is recommended for increasing yields of the maize varieties.

Key words: precursor crop, faba bean, rhizobia inoculation, fertilizer, varieties

3.1 Introduction

Cropping systems involving monoculture of cereals can cause reduction of yields and depletion of soil nitrogen. These can be alleviated by different methods such as use of inorganic nitrogen and use of legumes in cropping system. Currently high prices of synthetic fertilizer have made it difficult for smallholder farmers to use inorganic nitrogen for crop production. Moreover, crops do not use all the nitrogen applied (Carranca, 2012). Each year soil nitrogen is lost, along with the money paid for it, due to volatilization, gaseous plant emission, surface soil runoff, leaching and denitrification (Canfield *et al*., 2010; Raun and Johnson, 1999). Consequently, the use of legumes in a cropping system for biological nitrogen fixation becomes an alternative source of nitrogen for crop production. Jensen *et al*. (2012) and Peoples *et al*. (2009) reported that the symbiotic relationship between legumes and rhizobia represents the most important nitrogen-fixation association in the world, with an annual global 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 commonly used in agricultural systems as a source of N for subsequent crops and for maintaining soil N levels (Glasener *et al*., 2002). 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 (Rahman *et al*., 2009). 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 the following crops and may moderate NO_3-N 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 from biological N_2-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 contributed to total biological yield, grain yield and total nitrogen (Beck and Duc, 1991). Therefore, symbiotically effective rhizobia increase nodulation, N_2-fixation, growth and yields of their host plant (Kiros and Singh, 2006). Walley *et al*. (2007) reported that a well-inoculated pulse crop could 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 that 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, 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 N difference method and ^{15}N natural abundance method (Rahman *et al*., 2009). Lo´pez-Bellido *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} 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 precursor crop and affordable fertilizer rate is essential for increasing maize yields in the region. Identification of suitable precursor crop with optimum fertilizer was more reliable and usually maximize maize grain yield. Therefore, the objective was to determine effects of faba bean precursor crop biomass incorporation into soil on yields and nitrogen use efficiency of subsequent maize varieties in Toke Kutaye, western Ethiopia.

3.2 Materials and Methods

3.2.1. Description of the study area

The experiments were conducted during the 2013 and 2014 cropping seasons on two farmers' fields in the humid highlands of Toke Kutaye in Oromia National Regional State, western Ethiopia. The two farm field are Gadisa Beksisa (as Farm1) and Sisay Belete (as Farm 2). The area lies between $8^{o}9'8''$ and $8^{0}71^{'}21''$N and $37^{O}72'$ and $37^{0}42'$ E and located at the 2,262 and 2,322 meter above sea level, with mean annual rainfall of 1,045 mm (NMSA, 2014). It has a cool humid climate with the mean minimum, mean maximum, and average air temperatures of 8.9, 27.4 and 18.1^{o}C, respectively.

3.2.2 Soil sampling and analysis

The soil sample was collected at the depth of 0-20 cm with auger before application of the treatment (2013), and after harvesting of the precursor crop while the field was prepared for maize planting in 2014. The determination of soil particle size distribution was carried out using the hydrometer method (Dewis and Freitas, 1984; FAO, 1974). The soil pH was measured using a digital pH meter in 1:2.5 soil to solution ratio with H_2O (McLean, 1982). Exchangeable bases were extracted with 1 M ammonium acetate at pH7. The Ca and Mg in the extract were measured by atomic absorption spectrophotometer while Na and K were determined by flame photometry (Van Reeuwijk, 1992). Cation exchange capacity of the soil (CEC) and exchangeable bases were determined by saturating soil with neutral 1M NH4OAc (ammonium acetate) and the adsorbed NH_4^+were displaced by using 1M KCl and then determined by the Kjeldahl distillation method for estimation of the CEC of the soil (Polemio and Rhoades, 1977; Rhoades, 1982). The percent base saturation was calculated from the sum of exchangeable bases as a percent of the CEC of the soil. The exchangeable acidity was determined by extracting the soil samples with M KCl solution and titrating with sodium hydroxide as described by McLean (1965). The organic carbon was determined following wet digestion methods as described by Walkley (1947) and Nelson and Sommers (1982) whereas the Kjeldahl procedure was used for the determination of total N as described by Bremner and Mulvaney (1982). The available P was determined 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 (Keeney and Nelson, 1982).

3.2.3 Experimental field

The experiment was conducted in 2013 and 2014 cropping season. The faba bean (variety Moti) was planted with and without rhizobia inoculation in the preceding cropping season as precursor crop. The rhizobia strain (FB-1035 which was released by Land and Water Resources Research Process of Holetta Agricultural Research Centre) was used for the inoculation. For the precursor crop (Faba bean), recommended seed rate of 200 kg ha^{-1} and rhizobia strain of 10 g per kg seed were used for the plots receiving rhizobia. The total area is 52 m x 16.5 m and divided in to two (26m x 16.5 m). Half of the quantities of seeds of faba bean variety were inoculated with rhizobia strains, while the remaining half was not inoculated. Maize without fertilizer was planted as non-fixer control.

The spacing was 40 x 5 cm and 75 x 25 cm between rows for faba bean and maize. The faba bean inoculated with rhizobia is pelleted with sugar to insure attachment of the inoculants with seed. Uninoculated and inoculated seeds of faba bean were planted on oxen-ploughed fields of 26m x 16.5m each with total area of 52 m x 16.5 m. Faba bean tissue and seed samples were collected at 50% flowering and at the harvesting stage. The tissue samples were dried in an oven at 70^{o}C for 24 hours. The collected tissue samples were chopped, dried, and ground for analysis. The seed samples were also ground for analysis. The plant tissues were subjected to wet digestion. The N content of the plant tissue was determined by Kjeldahl procedure as described by Nelson and Sommers (1982). The total nutrient uptake was calculated as the sum of grain nutrient uptake and biomass nutrient uptake. Total N concentration (percentage total N in dry matter) of the whole plant was used to calculate grain nutrient uptake and biomass nutrient uptake by multiplying the N concentration by dry biomass per hectare of faba bean. The total nitrogen fixation of faba bean 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, maize). The seed yield biomass and biological N_2-fixation of faba bean precursor crop is indicated in Table 3.1. The biomass of each plot was chopped, uniformly distributed and incorporated into the soil after harvesting and threshing faba bean in 2013. The faba bean precursor crop biomass incorporated fields were delineated and divided into different plots used for maize in 2014 cropping season.

Table 3.1: Yields and biological N_2-fixation of faba bean and soybean on the study sites in Toke Kutaye, western Ethiopia in 2013 cropping seasons

Farms	Faba bean	Seed yield (kg ha^{-1})	Dry biomass (kg ha^{-1})	Ndfa (kg ha^{-1})
Farm 1	With rhizobia inoculation	1258	15 000	254.34
	Without rhizobia inoculation	1058	14 750	192.0
Farm 2	With rhizobia inoculation	1563	22 000	514.59
	Without rhizobia inoculation	1791	22 750	542.7

Ndfa= Nitrogen derived from the soil with total N difference method

In the second year (2014 cropping season), two maize varieties were sown with three levels of nitrogen. Twelve treatment combinations were imposed with the main crop (maize). The maize hybrid (Wenchi and Jibat) were planted with three levels of nitrogen fertilizers onto plots of faba bean precursor crop biomass with and without rhizobia inoculation. The experiment was laid out in 2 x 2 x 3 factorial arrangement in randomized complete block design in three replications in 2014. The two types of faba bean field (with and without rhizobia inoculation) were used as factor A, the two maize varieties (Wenchi and Jibat) were used as factor B while the three levels of nitrogen (0, 55, 110 kg N ha^{-1}) were used as factor C, resulting in 12 treatment combinations.

The total gross plot size used for each experimental unit was 5.1 x 4.5 m with 3 x 5.1m net plot sizes. The spaces between rows and plant stands were 75 cm and 25 cm, respectively. The seed rate for maize was 25 kg ha^{-1} and planted following the recommended planting date of the study site. The full dose phosphorus fertilizer, 20 kg P ha^{-1} was applied in the form of triple superphosphate at planting, while nitrogen was applied in in two splits; half at planting and the remaining half at 30 to 40 days after planting in the form of urea. All other agronomic management practices were applied as per the recommendations for the varieties.

3.2.4 Plant parameters recorded

The grain yield, thousand seed weight, dry biomass and harvest index of maize varieties were recorded at physiological maturity. The grain yield was harvested from a net plot area of 15.3m^2 (3 m x 5.1m). The harvested grain yield was adjusted to 12.5% moisture level (Birru, 1979; Nelson *et al.*, 1985).

3.2.5 Plant tissue sampling and analysis

The maize tissue samples were taken from the leaves and stalks at 50% tasseling and from grain at harvesting. The maize tissues and grains were subjected to wet digestion (Jones and Case, 1990). The N content of the plant tissue was determined by a Kjeldahl procedure, whereas the P content was determined colorimeterically according to Murphy and Riley (1962).

3.2.6 Determination of N uptake and use efficiencies

The total N uptake was obtained by dividing the N concentration in the tissue to total dry biomass weight (kg ha^{-1}) of maize, whereas N agronomic efficiency (NAE) was obtained by dividing the grain yield to the applied N as presented in equation 1 (Wu *et al*, 2011; Cleemput *et al.* 2008).

$$NAE(kg\ grain/kgN) = \frac{Y_N - Y_0}{F_N} \text{ ----------------------------- (1)}$$

where Y_N and Y_0 are the grain yield with and without N applied, respectively; and F_N is the amount of N fertilizer applied.

The N use efficiency (UEN) (equation 2) is the total amount of N absorbed (including that present in the roots, often disregarded) per kg of applied N:

$$UEN(kgN/kgN) = \frac{U_N - U_0}{F_N} \text{ --------------------------------------- (2)}$$

The nitrogen physiological efficiency was calculated as total dry matter or grain yield produced per unit of N absorbed. N utilization efficiency was calculated as (Haegele, 2012) (equation 3):

$$PEN(kg\,grain/kgN = \frac{Y_N - Y_0}{U_N - U_0}$$ ----------------------------------- (3)

Apparent fertilizer N use (recovery) efficiency (ANRE) (equation 4) is the amount of fertilizer N taken up by the plant per kg of N applied as fertilizer, which was calculated as described by Azizian and Sepaskhah (2014), Cleemput *et al*. (2008), Craswell and Godwin (1984):

% fertilizer nutrient recovery (ANRE) = $\frac{(TNF)-(TNU)}{R} X100$ ----------------- (4)

Then, N harvest index (NHI) at maturity was calculated (equation 5) (Jones *et al*., 1990) and N accumulation (kg N ha^{-1}) in the shoots or grains was calculated (Seleiman *et al*., 2013; Xu *et al*. 2006) as follows:

$$N\,harvest\,index = \frac{Grain\,N\,accumulation\ (kg\,ha^{-1})}{Total\,N\,accumulation\,(kg\,ha^{-1})}$$ ----------------------------- (5)

Where, the total N accumulation includes all N that accumulated in the leaves, stem, shank, cobs and husk organs (equation 6) in addition to the grain (equation 7).

$$Shoot\,N\,accumulation\,(kg\,ha^{-1}) = \frac{shoot\,N\,content\ (g\,kg^{-1}) \times shoot\,DM\,(kg\,ha^{-1})}{1000}$$ -- (6)

$$Grain\,N\,accumulation\,(kg\,ha^{-1}) = \frac{grain\,N\,content\ (g\,kg^{-1}) \times grain\,DM\,(kg\,ha^{-1})}{1000}$$ - (7)

3.2.7 Statistical analysis

Agronomic data analysed for variance using statistical packages and procedures of Statistical Analysis System Computer Software (SAS, 2004). The mean separation was done using least significance difference (LSD) procedure at 5 % probability level (Steel and Torrie, 1980).

3.3 Results and Discussion

3.3.1 Physical and chemical properties of the experimental soil

The soil analysis results of the two farms before planting of faba bean and the main crop (maize) are indicated in Table 3.2. The texture of the soil was clay and clay loam. The soil pH in H_2O ranged from 4.36 to 5.77 for Farm 1 and Farm 2, which were found in very strongly acidic to moderately acidic (Jones and Truog, 1948) as cited by Landon (1991). Faba bean planting without and with rhizobia inoculation improved the soil pH of the two farms. Similarly, Tolera *et al.* (2009) observed that crop rotation and the N-P amendment significantly increased soil pH.

Total N ranged from 0.17 to 0.25% in Farm 1 and 0.16 to 0.23% in Farm 2. The total N concentrations for the two farms were in the low to medium range (Bruce and Rayment, 1982; FAO, 1990; Metson (1961) as cited by Landon (1991). The total nitrogen concentration of Farm 2 was increased by 37.5 and 43.75% without and with rhizobia inoculation, respectively. This could attributed 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 soil in wheat-lentil rotation was reported by Campbell *et al*. (1992); and in maize haricot bean rotation by Tolera *et al*. (2009). The increase in total N following faba bean helps to reduce the amount of N required to optimize maize yield.

The soil NO_3-N concentration ranged from 46.2 to 71.4 mg kg^{-1} in Farm1, and found to be high; and 2.43 to 64.4 mg kg^{-1} for Farm 2, which is low to high range (FAO, 2006; and Bashour, 2002). Planting of faba bean improved the amounts of NO_3-N by 20.43 and

20.89 %; without rhizobia inoculation; and by 54.55 and 25.50 % with rhizobia inoculation for Farm 1 and Farm2 as compared to the soil $N0_3$-N level before planting. This implies that the use of faba bean with and without rhizobia inoculation contributed for biological nitrogen fixation, which retained the fixed N fertilizer in the field for use by the next season crop. The soil NH_4-N concentration was 19.6 to 40.6 mg kg^{-1} for Farm 1, which fall in high; and 2.92 to 39.2 mg kg^{-1} in Farm 2, considered to be optimum (Marx *et al*., 1999). Horneck *et al*. (2011) and Marx *et al*. (1999) reported ammonium-nitrogen concentrations of 2-10 ppm are typical. 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 because of a relatively inefficient recovery of soil mineral N compared to other crops (Turpin *et al*., 2002). The concentrations of NO_3-N and NH_4-N in the soil were higher in faba bean fields planted with and without rhizobia inoculation. Planting faba bean in cropping sequence without rhizobia inoculation where a farm had history of faba bean production and with rhizobia inoculation in new areas is the key in solving the soil N fertility status for maize production.

Table 3.2: Some soil physical and chemical properties before main crop (maize) at Toke Kutaye districts, western Ethiopia

Soil parameters	Farm 1			Farm 2		
	Before faba Bean,2013	Faba bean + 0 RI,2014	Faba bean + 10 g RI kg seed $^{-1}$, 2014	Before faba Bean, 2013	Faba bean + 0RI , 2014	Faba bean + 10 g RI kg seed^{-1}, 2014
pH (H_2O)	4.4	5.57	5.77	4.36	5.05	5.66
AP (mg kg^{-1})	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 (cmol kg^{-1})	18.5	25.93	27.78	19.44	23.85	25.57
k (cmol kg^{-1})	0.28	0.7	0.84	0.14	1.41	1.46
Exc. acidity (cmol kg^{-1})	0.35	0.18	0.15	0.42	0.23	0.18
$N0_3$-N (mg kg^{-1})	55.64	71.4	46.2	2.43	64.4	53.2
NH_4-N (mg kg^{-1})	23.43	40.6	19.6	2.92	39.2	21
Sand (%)	18.75	24	22	26.25	12.5	10
Silt (%)	30	28	35	12.50	27.5	27.5
Clay (%)	51.25	44	42	61.25	60	62.5
Texture	clay loam	clay loam	clay loam	Clay	Clay	Clay

0RI= Faba bean precursor crop without rhizobia inoculation
10g RI= Faba bean precursor crop with rhizobia inoculation at 10 g kg seed $^{-1}$

The available P ranged from 5.43 to 8.21 and 4.97 to 6.69 mg kg^{-1} for Farm 1 and Farm 2, which was in the low to medium range (FAO, 1990; Olsen and Dean, 1961; Fassbender, 1980) as cited by Landon (1991). This relatively low P can be attributed to the high phosphorous fixing capacity of the acid soil. In Farm 1, planting of faba bean with rhizobia inoculation improved the available P by 51.20 and 72.48% as compared to before planting and planting of faba bean without rhizobia inoculation. In Farm 2, planting faba bean with and without rhizobia inoculation reduced the amount of available P by 25.41 and 25.71%.

The organic carbon contents of the soil ranged from 1.91 to 2.57 and 2.46 to 2.57% in Farm 1 and Farm 2, respectively (Table 3.2), which are in the low to medium range (FAO, 1990; Metson (1961) as cited by Landon (1991). The exchangeable K contents of the soil ranged from 0.28 to 0.84 and 0.14 to 1.46 cmol kg^{-1} (Table 3.2), which is in the low to medium and low to high range, respectively. The CEC of the soil ranged from 18.5 to 27.78 and 19.44 to 25.57 cmol kg^{-1} of soil (Table 3.2), which is in the medium to high range (FAO, 1990; Barber and Rowell (1972) as cited by 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.

3.3.2 Effects of prior inoculation of soil incorporated faba bean biomass on yield and yield components of subsequent maize

Mean grain and biomass yields, thousand seed weight and harvest index of maize are indicated in Table 3.3. The mean grain and biomass yields, thousand seed weight and harvest index of maize were not significantly ($P<0.05$) affected by faba bean precursor crop biomass incorporated into soil (Table 3.3), regardless of whether the precursor faba bean crop had been inoculated with rhizobia or not. This observation was made in both Farm 1 and Farm 2. This implies that rhizobia inoculation of faba bean did not significantly ($P<0.05$) improve N_2-fixation and growth faba bean (Table 3.1). Thus, the soils, due to their long history of growing faba bean, contained effective indigenous rhizobia, which could not be outcompeted by the introduced rhizobia.

McKenzie *et al*. (2001) found that rhizobial inoculation of field pea increased yield on land with no history of legumes, with yield increased by an average of 19%. Non-response to added inoculant was due to the presence of indigenous rhizobia (Kutcher *et al*., 2002; Abebe and Tolera, 2014; Tolera and Zerihun, 2014). Therefore, most soils with long history of faba bean cultivation contain large populations of indigenous rhizobia for faba bean and inoculation is usually not required (Murinda and Saxena, 1985; Jensen, 1987; Jensen *et al*. 2010; Patriquin, 1986). Due to high numbers of indigenous rhizobia, the number of rhizobia introduced may not have been able to out-compete indigenous rhizobia (Mungai and Karubiu, 2012).

The result was in agreement with Chemining'wa *et al*. (2007) in western Kenya using six legumes. Assefa *et al*. (2010) found the native rhizobia strains of the Wollo region to be more competitive than the two exotic rhizobia strains. Thus, legumes cultivation in the farm history may be necessary to help the build-up of rhizobia in soil (Raposeiras *et al*., 2006). Therefore, more studies on indigenous faba bean rhizobia from soils of Toke Kutaye, western Ethiopia, need to be undertaken to confirm what was presently observed in the two farms.

The biomass yield, thousand seed weight and harvest index of maize varieties were not significantly ($P<0.05$) different between inoculated and non-inoculated faba bean precursor crop biomass incorporation into soil in Farm 1 and Farm 2 (Table 3.1). This might again be due to failure of introduced rhizobia to out-compete local rhizobia in the soil during faba bean precursor crop growth.

3.3.3 Effects of maize varieties on yield and yield components of subsequent maize crop following incorporation of faba bean biomass

The mean grain yields of maize were not significant ($P<0.05$) differences between varieties of maize both in Farm 1 and Farm 2 following faba bean precursor crop biomass incorporation (Table 3.3). However, some yield components varied significantly ($P<0.05$) between varieties in the farms (Table 3.3).

Table 3.3: Effects of faba bean biomass, maize varieties and nitrogen rates on yield and yield components of subsequent maize in Toke Kutaye, western Ethiopia in 2014 cropping season

Treatment	Farm 1						Farm 2					
	Grain yield (kg ha^{-1})	Biomass yield (kg ha^{-1})		1000 seed weight (g)	Harvesting index (%)		Grain yield (kg ha^{-1})	Biomass yield (kg ha^{-1})	1000 seed weight (g)		Harvesting index (%)	
Biomass of faba bean no inoculated with rhizobia	6988	31826		393	23.34		4585	14722	372		31.36	
Biomass of inoculated faba bean	7523	33822		384	22.81		4272	14204	375		30.05	
LSD (5%)	1138^{Ns}	5398^{Ns}		24 ^{Ns}	4.0437 ^{Ns}		456^{NS}	1376^{Ns}	24^{NS}		2.7069^{Ns}	
Maize Variety												
Wenchi	7351	29733b		390	25.91a		4607	14135	354b		32.59a	
Jibat	7161	35915a		387	20.25b		4249	14790	394a		28.82b	
LSD (5%)	1138^{Ns}	5398		24^{Ns}	4.0437		455^{NS}	1376^{Ns}	24		2.7069	
Mineral N rates (kg ha^{-1})		Wenchi	Jibat		Wenchi	Jibat			Wenchi	Jibat	Wenchi	Jibat
0	5934b	29270	33558	367b	20.72b	17.51b	3804b	13045b	329	391	29.15b	29.38
55	7718a	33190	38704	397a	26.42ab	18.20b	4349b	14127b	370	385	34.67a	27.00
110	8115a	26739	35484	401a	30.58a	25.04a	5132a	16217a	361	404	33.94a	30.08
LSD (5%)	1393	10414^{NS}	9977^{NS}	28.97	8.3137	6.0047	558	1685	42Ns	46^{Ns}	3.5132	6Ns
CV (%)	22.99	28.08	22.27	8.93	25.73	23.77	15.10	15.95	9.52	9.33	8.64	15.34

NS=non-significant difference between means in the same column at 5% probability level.
Numbers followed by same letter in the same column are not significantly different at 5% probability level.

In other studies on-station and on-farm, grain yields of Wenchi and Jibat maize varieties were also equal (Gudeta *et al*., 2012) as observed in the current study. Therefore, in terms of grain yields, within each form, Wenchi and Jibat maize varieties can be equally recommended in highland areas of the Toke Kutaye district and other similar agroecologies. However, a general observation is that mean grain yield, dry biomass and harvest index of maize varieties seemed to vary between farms, although the two farms did not seem to vary much in their soil properties.

Harvest indices of maize were significantly ($P<0.05$) different between the two maize varieties in Farm 1 and Farm 2 (Table 3.3). In both farms Wenchi maize variety gave higher ($P<0.05$) harvest index as compared Jibat variety. Similarly, harvest indices of maize varied between varieties of maize (Eivazi and Habibi, 2013). Harvest index gives an indication of the efficiency of the distribution of photosynthesis to the harvestable organs of the plant (Khademi and Malakotti, 1998). The higher the index the greater the yield of the harvestable economic product.

3.3.4 Effects of faba bean biomass + nitrogen fertilizer rates on yield and yield components of subsequent maize

Nitrogen fertilizer was significantly ($P<0.05$) increased the grain yield of maize varieties following incorporation of faba bean precursor crop biomass (Table 3.3). Significantly ($P<0.05$) higher mean grain yields of maize were realized from maize planted with application of full recommended nitrogen fertilizer rate in addition to faba bean biomass in Farm 2 (Table 3.3). Similarly, El-Gizawy (2009) found that nitrogen fertilizer significantly affected the mean grain yield of maize and that the higher N rate 120 kg N ha^{-1} was more effective in increasing grain yield of maize. In Farm 1, there was no significant ($P<0.05$)

difference in grain yields between 55 and 110 kg N ha^{-1}. This implies that there was, overall, better utilization of the higher N rate in Farm 2 than in Farm 1, implying a real difference in the fertility of this soil contrary to the trend shown by the analytical data (Table 3.2). It is therefore seen that the N rate for maximizing grain yields will differ between different farms/soils. Ear yield, a component of yield in maize generally increased with an increasing rate of N fertilizer (Turgut *et al.*, 2005). Similar results were also previously reported by others (Gungula *et al*. 2005; Habtamu, 2015; Kidist, 2013).

The results of this study indicate that application of some amount of nitrogen fertilizer may be necessary in addition to legume biomass for maximizing maize yields in the region. This is because mineralization of N from biomass may not alone provide enough N to increase yields. Therefore, there is need for improvement in the current fertilizer N management practices and that fertilizer rates will be ‘site-specific’ to improve maize yield and nutrient use efficiency of maize varieties.

Nitrogen fertilizer application on Farm 2 significantly ($P<0.05$) increased mean biomass yield of Jibat maize variety but the increase was non-significant in Farm 1 (Table 3.3). Likewise, total dry matter maize was reported to increase with increasing nitrogen fertilizer application (Eivazi and Habibi, 2013). Higher mean biomass yield was observed for maize varieties from application of full recommended nitrogen fertilizer as compared to the treatment without and with half rate of nitrogen fertilizer application in Farm 2. Similarly, Beslemes *et al*. (2013) found maize planted following faba beans green manure with maximum rate of inorganic fertilization application gave higher total biomass production (19.66 Mg ha^{-1}) as compared to the control. Higher biomass production levels might be the result of increase in N-mineralization from biomass as well as enhanced fertilizer recovery fraction (10-15%) (Beslemes *et al*., 2013). Similarly, Habatamu (2015) and Kidist (2013) found that biomass yield of maize were significantly increased with the application of N fertilizer. However, therefore, dry biomass production of different maize varieties can vary following faba bean precursor crop biomass combined with nitrogen fertilizer application.

Thousand seed weight of (Jibat maize variety) in Farm 1 was significantly ($P<0.05$) affected by application N fertilizer following faba bean precursor crop biomass incorporation in soil but non-significant for Farm 2 (Table 3.3). In Farm 1, the higher thousand seed weight of 401g obtained with application of full recommended nitrogen fertilizer was however, non-significantly different from that under half recommended nitrogen fertilizer following faba bean precursor crop biomass.

Application of nitrogen fertilizer rates significantly ($P<0.05$) increased mean harvest index of both maize varieties on Farm 1 (Table 3.3). In Farm 2, application of nitrogen fertilizer significantly ($P<0.05$) affected harvest index of only Wenchi variety but was non-significant for Jibat variety. In a different study, harvest index of maize varieties were similarly significantly increased with increasing levels of nitrogen fertilizer application (Eivazi and Habibi, 2013; Habtamu, 2015; Lawrence, 2008), although in some cases harvest index of maize decreased as rates of N were increased (Kidist, 2013; Abdo, 2009).

3.3.5 Effects of prior inoculation of soil incorporated faba bean biomass on total nitrogen uptake of subsequent maize

Results of total nitrogen uptake by the maize varieties are reported in Table 3.4. Total nitrogen uptake by the maize varieties was not significantly ($P<0.05$) affected by faba bean precursor crop biomass incorporated into soil in both Farm 1 and Farm 2. Higher mean total nitrogen uptake was obtained from Farm 1 as compared to Farm 2. This indicates the two farms were different and heterogeneous in nitrogen status due to different nature of soil in the two farms. El-Gizawy (2009) observed higher grain N uptake in maize planted after faba bean as compared to maize planted after wheat. Pulses biomass was observed to increase total nitrogen uptake by 72% in wheat (Wright, 1990). The lack of significant difference due to inoculation implies that faba bean precursor crop biomass without and with rhizobia inoculation field could be equally useful for subsequent maize production in the highlands of Toke Kutaye.

3.3.6 Effects of maize varieties on total nitrogen uptake of subsequent maize crop following incorporation of faba bean biomass

The total nitrogen uptake of maize varieties was not significantly ($P<0.05$) different between varieties of maize both in Farm 1 and Farm 2 upon faba bean precursor crop biomass incorporation (Table 3.4). This may explain the lack of significant differences in the grain yields of the two varieties (Table 3.3).

3.3.7 Effects of faba bean biomass + nitrogen fertilizer rates on total nitrogen uptake of subsequent maize

The mean total nitrogen uptake of maize varieties were significantly ($P<0.05$) affected by application nitrogen fertilizer rates (Table 3.4). Higher total nitrogen uptake of maize was obtained from application 55 kg N ha^{-1} in Farm 1 but with 110 kg N ha^{-1} for Farm 2. Similarly, Beslemes *et al.* (2013) reported significant differences ($P<0.05$ and $P<0.01$) on total N uptake of maize with increased N fertilization levels. Maize that received 120 kg N ha^{-1} in addition to faba bean biomass also had higher grain N uptake (El-Gizawy, 2009).

Increased N uptake with application of nitrogen as compared to without fertilizer indicates better improvement soil N status (and organic matter) following precursor crop biomass, leading to enhanced nitrogen uptake by maize.

Table 3.4: Effects faba bean biomass, maize varieties and nitrogen rate on nitrogen uptake of subsequent maize in Toke Kutaye, western Ethiopia in 2014 cropping season

Treatment	Total nitrogen uptake (kg ha $^{-1}$)	
	Farm 1	Farm 2
Biomass of faba bean not inoculated with rhizobia	698	436
Biomass of inoculated faba bean	824	408
LSD (5%)	128^{Ns}	33.61^{Ns}
Maize Variety		
Wenchi	698	414
Jibat	824	429
LSD (5%)	128^{Ns}	33.61^{Ns}
Mineral N rate (kg ha^{-1})		
0	655b	329c
55	815a	438b
110	813a	498a
LSD (5%)	157.27	41.167
CV (%)	24.41	11.53

NS=non-significant difference between means in the same column at 5% probability level.
Numbers followed by same letter in the same column are not significantly different at 5% probability level.

3.3.8 Effects of prior inoculation of soil incorporated faba bean biomass on nitrogen agronomic efficiency and nitrogen use efficiency of subsequent maize

The nitrogen agronomic efficiency of the two maize varieties varied among farms, maize varieties and precursor crop biomass without/with rhizobia (Table 3.5). Higher ($P<0.05$) nitrogen agronomic efficiency of maize was observed from maize planted following faba bean precursor crop biomass without rhizobia inoculation as compared to with inoculation in Farm 1. This indicates faba bean precursor crop without rhizobia gave higher biological N_2-fixation due to effective native rhizobia.

The nitrogen use efficiency of maize varieties was higher (P<0.05) following faba bean precursor crop with rhizobia inoculation as compared without rhizobia in Farm 1 but the opposite was observed in Farm 2. This indicates that Farm 1 and Farm 2 had differences in soil N fertility status (Table 3.2).

3.3.9 Effects of maize varieties on nitrogen agronomic efficiency and nitrogen use efficiency of subsequent maize crop following incorporation of faba bean biomass

Maize varieties showed significant (P<0.0) difference in nitrogen agronomic efficiency following faba bean precursor biomass in Farm 2, with significantly higher nitrogen agronomic efficiency achieved from Wenchi maize variety as compared to Jibat (Table 3.5). The result obtained match with better grain yield of Wenchi maize variety from Farm indicated in Table 3.3. Therefore, use of Wenchi maize variety should be recommended for producers in the area.

Maize varieties showed significant (P<0.05) difference in nitrogen use efficiency in both farms following faba bean precursor crop. Jibat had higher mean nitrogen use efficiency following faba bean precursor crop with rhizobia inoculation in Farm1, which entails matching of higher grain yield of Jibat maize variety as indicated in Table 3.3. In Farm 2, Wenchi maize variety had better nitrogen use efficiency following faba bean precursor crop without rhizobia inoculated fields. However, these were not translated into grain yield differences (Table 3.3). Even though not significantly different in grain yield, the result obtained matched with higher nitrogen use efficiency of maize varieties in both farms.

3.3.10 Effects of faba bean biomass + nitrogen fertilizer rates on agronomic efficiency and nitrogen use efficiency of subsequent maize

The application of nitrogen fertilizer rates significantly ($P<0.05$) affected nitrogen agronomic efficiency of Wenchi maize variety following faba bean precursor crop biomass in Farm 1 but for both (Wenchi and Jibat varieties) in Farm 2 (Table 3.5).

In both farms higher mean nitrogen agronomic efficiency of (42.85 and 19.40 kg grain kg N applied^{-1}) were obtained for Wenchi variety with application 55 kg N ha^{-1} as compared to 110 kg N ha^{-1}. Similarly, Amanullah and Alkas (2009) reported NAE was 28 kg (kg N)$^{-1}$ at an application rate of 60 kg N ha^{-1} but decreased to 23 and 19 kg (kg N)$^{-1}$ at application rates of 120 and 180 kg N ha^{-1}, respectively.

The application of nitrogen fertilizer significantly ($P<0.05$) affected nitrogen use efficiency of the maize varieties. Significantly higher nitrogen use efficiency was gained from Jibat and Wenchi variety planted with 55 kg N ha^{-1} (as compared to 110 kg N ha^{-1}) following incorporation of faba bean precursor crop biomass in Farm 1 and farm 2, respectively.This implies that both maize varieties (Wenchi and Jibat) were efficient in using N under the lower mineral nitrogen input system, which could be affordable by resource poor smallholder farmers in the area. Goodroad and Jellum (1988) found higher nitrogen use efficiency was obtained when nutrient concentration was near the critical level, and this was true in the present situation whereby the total N levels in the present study sites were rated as being low to medium. The result agrees with results of Ortiz-Monasterio *et al*. (1997) and Woldeyesus *et al*. (2004) who reported that N uptake efficiency was higher at lower rates of N application, but drastically decreased with further increases in the rate of the N.

Table 3.5: Effects of faba bean biomass, maize varieties and nitrogen rates on nitrogen agronomic efficiency and N use efficiency of subsequent maize in Toke-Kutaye, western Ethiopia in 2014 cropping season

Treatment	Farm 1				Farm 2			
	Agronomic efficiency (Kg grain kg N applied^{-1})		Nitrogen use efficiency (Kg N uptake kg N applied^{-1})		Agronomic efficiency (kg grain kg N applied^{-1})		Nitrogen use efficiency (kg N uptake /kg N applied)	
Biomass of faba bean not inoculated with rhizobia	43a		2.62b		16.33		2.37a	
Biomass of inoculated faba bean	27b		5.32a		14.94		1.47b	
LSD (5%)	3.73		0.2864		1.948^{Ns}		0.4922	
Maize Variety								
Wenchi	30.81b		3.74b		15.03a		2.32a	
Jibat	39.63a		4.20a		12.79b		1.51b	
LSD (5%)	3.73		0.2864		1.948		0.4922	
CV (%)	14.81		18.23		17.41		19.35	
Mineral N rate (kg ha^{-1})	Wenchi	Jibat	Wenchi	Jibat	Wenchi	Jibat	Wenchi	Jibat
55	42.85a	49.28	4.86	5.01a	19.40a	14.09b	3.01a	1.55
110	18.76b	29.99	2.63	3.39b	10.66b	10.50a	1.61b	1.48
LSD (5%)	15.216	23·34^{Ns}	2.30^{Ns}	0.71	3.4588	3.32	1.052	0.72^{Ns}
CV (%)	17.36	21.60	15.55	21.02	17.29	12.94	14.07	15.85

NS=non-significant difference between means in the same column at 5% probability level.
Numbers followed by same letter in the same column are not significantly different at 5% probability level.

3.3.11 Effects of prior inoculation of soil incorporated faba bean biomass on N physiological efficiency and fertilizer N (recovery) use efficiency of subsequent maize

Higher nitrogen physiological efficiency of 30.19 and 17.49 kg grain kg N uptake^{-1} were achieved from of maize planted following incorporation of faba bean precursor crop without prior rhizobia inoculation in Farm 1 and Farm 2 (Table 3.6). This indicates the presence competitive indigenous rhizobia strains in the soil. The result did not match with grain yield variation following faba bean precursor crop biomass incorporation in Table 3.3.

Higher fertilizer N (recovery) use efficiency of 103 and 61% maize varieties were obtained from Farm 1 and Farm 2 following incorporation faba bean precursor crop biomass with rhizobia inoculation and without, respectively (Table 3.6). Miller and Heitchel (1995) reported that N recovery following green manure crops might vary due to the amount of N fixed, mass of plant material incorporated, rate of decomposition and immobilization of legume N in the soil.

N fertilizer recovery efficiency (REN) was significantly after legumes than after natural fallow or maize (Yusuf *et al*., 2009) to the tune of 34 and 20% greater than that of maize following maize and fallow, respectively (Yusuf *et al*., 2009). The N recovery fraction was enhanced by 10-15% after faba bean cover cropping, for sandy and clayey soil (Beslemes *et al*., 2013). Ladd (1981) showed 23 and 4% recovery of N in wheat following incorporation of medic residues the first and second year, respectively. Maize plants were observed to recover only 17-25% of the N from alfalfa residues (Harris and Hesterman

1987) implying the need for supplemental mineral N. In contrary, Carsky *et al*. (1999) reported lower REN values in maize following soybean genotype than maize following natural fallow. Cassman *et al*. (2002) stated that when soil-N content is increasing, the amount of sequestered N contributes to higher nitrogen use efficiency (NUE) of the cropping system, and the amount of sequestered N derived from applied N contributes to higher N fertilizer recovery efficiency.

3.3.12 Effects of maize varieties on N physiological efficiency and fertilizer N (recovery) use efficiency of subsequent maize crop following incorporation of faba bean biomass

The maize varieties used showed significant ($P<0.05$) difference in nitrogen physiological efficiency (Table 3.6) The mean nitrogen physiological efficiency of 21.89 kg grain kg N uptake^{-1} were attained from Jibat maize variety in Farm 1 following faba bean precursor crop. Wenchi maize variety had higher maize nitrogen physiological efficiency of 17.23 kg grain kg N uptake^{-1} in Farm 2 following faba bean precursor crops. Likewise, Eivazi and Habibi (2013) found variation in nitrogen physiological efficiency between single cross maize varieties, which is true for three way crosses of Wenchi, and Jibat hybrid maize varieties currently used for the study.

The maize varieties showed significant ($P<0.05$) difference with fertilizer N (recovery) use efficiency in both farms. Jibat maize variety had higher fertilizer N (recovery) use efficiency in Farm 1 but Wenchi maize variety had higher efficiency in Farm 2 following faba bean precursor crop biomass. This implies both maize varieties had different fertilizer N (recovery) use efficiency in different locations. The variation in fertilizer N (recovery) use efficiency of maize varieties was also reported Eivazi and Habibi (2013).

Table 3.6: Effects of faba bean biomass, maize varieties and nitrogen rates on nitrogen physiological efficiency and Fertilize N (recovery) use efficiency of subsequent maize in Toke Kutaye, western Ethiopia in 2014 cropping season

Treatment	Farm 1				Farm 2			
	Nitrogen physiological efficiency (kg grain/kg N uptake^{-1})		Fertilize N (recovery) use efficiency (%)		Nitrogen physiological efficiency (kg grain/kg N uptake^{-1})		Fertilize N (recovery) use efficiency (%)	
Biomass of faba bean not inoculated with rhizobia	30.19b		262b		17.49a		237a	
Biomass of inoculated faba bean	9.8b		532a		12.86b		147b	
LSD (5%)	3.016		40.45		3.3737		14.58	
Maize Variety								
Wenchi	14.15b		374b		17.23a		231a	
Jibat	21.89a		420a		13.12b		152b	
LSD (5%)	3.016		40.45		3.3737		14.58	
CV (%)	28.30		21.28		22.30		9.89	
Mineral N rate (kg ha^{-1})	Wenchi	Jibat	Wenchi	Jibat	Wenchi	Jibat	Wenchi	Jibat
55	12.08	13.70	501a	486	7.29	13.10b	301a	157
110	31.08	14.60	339b	339	7.21	22.06a	161b	147
LSD (5%)	64.42^{Ns}	12^{Ns}	158	324^{Ns}	2.15^{Ns}	6.47	47.16	96.6^{Ns}
CV (%)	24.96	22.36	22.14	25.04	22.38	24.47	15.91	23.71

NS=non-significant difference between means in the same column at 5% probability level.
Numbers followed by same letter in the same column are not significantly different at 5% probability level.

3.3.13 Effects of faba bean biomass + nitrogen fertilizer rates on N physiological efficiency and fertilizer N (recovery) use efficiency of subsequent maize

The nitrogen physiological efficiency of both maize varieties not significantly ($P<0.05$) affected by nitrogen fertilizer rates in Farm 1. In Farm 2 Jibat variety significantly ($P<0.05$) had higher nitrogen physiological efficiency at the higher nitrogen fertilizer rate (following faba bean precursor crop). Similarly Beslemes *et al*. (2013) found significant differences for faba bean green manure management and N fertilization on the N physiological efficiency of maize. The N physiological efficiency of maize following legumes increased significantly with increasing nitrogen rates **(**Yusuf, *et al*., 2009)**.** Higher mean nitrogen physiological efficiency attained by variety Jibat in Farm 2 with application 110 kg N ha^{-1} as compared 55 kg N ha^{-1} implies increasing N uptake as N supply increases and it suggests that higher grain yield could be achieved at higher N rate (Yusuf, *et al*., 2009). In contrary Barbieri *et al*. (2008) reported that physiological efficiency of maize decreased with increasing rates of nitrogen fertilizer application. Jibat variety had better nitrogen physiological efficiency, and can be recommended to resource poor smallholder farmers for increased maize yields. Further research will be needed to improve the nitrogen physiological efficiency by matching application rate and timing with plant demands.

The nitrogen fertilizer rate at 55 kg N ha^{-1} significantly ($P<0.05$) on fertilizer N (recovery) use efficiency of Wenchi variety in both farms, but the increase was non-significant for Jibat. This corresponds to the higher grain yield of maize indicated in Table 3.3, which match higher grain yield with higher fertilizer nitrogen recovery efficiency. The N recovery gradually decreased with increase N as was also observed by others (El-Gizawy, 2005; 2009; Berenger *et al*. 2009). This implies the response to fertilization was very poor, but analysis of grain yield and N uptake showed significant differences between all fertilizer rates (Yusuf *et al*., 2009). Therefore, the wide adoption of Wenchi maize variety following faba bean precursor crop is desirable for increased maize yields under smallholder farms in the region.

3.3.14 Effects of soil incorporated faba bean biomass on shoot and grain N accumulation and N harvest index of subsequent maize

Mean results of shoot N accumulation, grain N accumulation and N harvest index of maize varieties are indicated in Table 3.7. Shoot N accumulation of maize varieties was significantly ($P<0.05$) affected by the use of faba bean precursor crop with and without rhizobia inoculation in both farms (Table 3.7). This might be due to differences the fertility status and historic management practices applied to the two farms.

The grain N accumulation and N harvest index of maize varieties were not significantly ($P<0.05$) affected by inoculation of faba bean precursor crop. This implies that the local rhizobia strains were as efficient as the introduced strain. Thus, much emphasis should be given to characterize the local rhizobia for further use for faba bean production.

3.3.15 Effects of maize varieties on shoot and grain N accumulation and N harvest index of subsequent maize crop following incorporation of faba bean biomass

The maize varieties showed significant ($P<0.05$) difference in mean shoot N accumulation in Farm 1 and Farm 2 following incorporation of faba bean precursor crop. Wenchi variety gave higher shoot N accumulation as compared to Jibat maize variety in both farms had been planted with faba bean precursor crop. The shoot N content of maize was varied between hybrid maize varieties (Uribelarrea *et al*., 2009).

Table 3.7: Effects of faba bean biomass, maize varieties and nitrogen rates on shoot and grain N accumulation, and N harvest index of maize in Toke Kutaye, western Ethiopia in 2014 cropping season

Treatment	Farm 1					Farm 2				
	Shoot N accumulation (kg ha^{-1})		Grain N accumulation (kg ha^{-1})	N Harvesting index (%)		Shoot N accumulation (kg ha^{-1})		Grain N accumulation (kg ha^{-1})	N Harvesting index (%)	
Biomass of faba bean not inoculated with rhizobia	6.31b		8.86	0.59		5.20a		6.03	0.53	
Biomass of inoculated faba bean	6.64a		9.67	0.59		5.05b		5.98	0.54	
LSD (5%)	0.003		1.384^{Ns}	0.044^{Ns}		0.0032		0.51^{Ns}	0.0225^{Ns}	
Maize variety										
Wenchi	7.32a		9.02	0.55b		5.59a		5.90	0.52b	
Jibat	5.63b		9.52	0.63a		4.66b		6.11	0.56a	
LSD (5%)	0.003		1.384^{Ns}	0.044		0.0032		0.51^{Ns}	0.0225	
Mineral N rate (kg ha^{-1})	Wenchi	Jibat		Wenchi	Jibat	Wenchi	Jibat		Wenchi	Jibat
0	5.58b	4.53b	7.00b	0.54	0.62	3.64c	4.79	4.76c	0.55a	0.51b
55	8.02ab	4.82b	9.82a	0.58	0.65	6.95a	4.54	5.95b	0.48b	0.55b
110	8.31a	7.54a	10.98a	0.53	0.61	6.19b	4.66	7.30a	0.52ab	0.63a
LSD (5%)	2.6394	2.070	1.6954	0.101^{Ns}	0.116^{Ns}	0.5546	0.75^{Ns}	0.6243	0.0528	0.0636
CV (%)	18.92	24.49	21.61	14.67	14.79	7.95	12.92	12.28	8.18	9.10

NS=non-significant difference between means in the same column at 5% probability level.
Numbers followed by same letter in the same column are not significantly different at 5% probability level.

The grain N accumulation of maize varieties was not significantly ($P<0.05$) different between maize varieties used following faba bean precursor crop biomass. In contrary to this result, Uribelarrea *et al*. (2009) reported different hybrid maize varieties exhibited variation grain N concentration.

The maize varieties used significantly ($P<0.05$) varied with N harvest index of maize following faba bean precursor crop in both farms. There variation N harvest index between farms, maize varieties, precursor crop and application of nitrogen rates. This implies that different sites will vary in this characteristic.

3.3.16 Effects of faba bean biomass + nitrogen fertilizer rates on shoot and grain N accumulation and N harvest index of subsequent maize

Application of nitrogen fertilizer rates significantly ($P<0.05$) affected shoot N accumulation of both maize varieties in Farm 1 and Wenchi maize variety in Farm 2. Similarly, Moser (2004) found that shoot N concentration increased as the rate of N application increased in tropical maize varieties. Increase of nitrogen rates showed significant difference for shoot N accumulation of maize varieties (Uribelarrea *et al*. (2009). Similarly, nitrogen fertilizer application rates significantly influenced shoot N yield and increased with increases in N rate (Kidist, 2013; Muurinen, 2007; Woldeyesus *et al*., 2004).

In Farms 1 and 2, the mean grain N accumulation of maize varieties increased significantly ($P<0.05$) as the rates of nitrogen fertilizer increased from 0 to 110 kg N ha^{-1}, indicating direct influence of nitrogen application on seed development due to its role in amino acid and nucleic acid synthesis, both of which contain nitrogen. Maize planted after faba bean that received 120 kg N ha^{-1} also gave higher grain N uptake (El-Gizawy, 2009). Likewise, variation due to nitrogen application rate was observed for grain N concentration (Uribelarrea *et al*. (2009). Therefore, application of recommended nitrogen fertilizer could increase grain N accumulation of maize varieties.

The application of nitrogen fertilizer rates following faba bean precursor crop significantly ($P<0.05$) increased N harvest index of both maize varieties in Farm 2 but non-significant ($P<0.05$) for Farm 1. Kidist (2013) also found that nitrogen fertilizer application rates significantly influenced nitrogen harvest index.

3.4 Conclusions and Recommendations

The soil nutrient concentrations were improved by planting of faba bean precursor crop without or with rhizobia inoculation. Planting maize varieties following faba bean precursor crop biomass with nitrogen fertilizer application improved grain, biomass yield and other yield components; therefore this combined approach is useful in increasing yields. The two farms, being different and heterogeneous in nitrogen status, may sometimes respond differently to treatments. Application of 55 kg N ha^{-1} may be what is required and not higher rates. Production of Wenchi and Jibat varieties of maize with 55 kg N ha^{-1} of N application following faba bean precursor crop biomass is recommended for highland areas of Toke Kutaye and similar agroecologies.

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CHAPTER FOUR

4.0 EFFECTS OF SOIL INCORPORATED SOYBEAN PRECURSOR CROP BIOMASS ON YIELDS OF SUBSEQUENT MAIZE IN MID-ALTITUDE AREA OF WESTERN ETHIOPIA

Abstract

Maintaining soil fertility using legumes precursor crop and minimum nitrogen fertilizer use is paramount for sustaining maize production. A study was conducted at Bako Agricultural Research Center to assess the effects of soybean precursor crop biomass and nitrogen fertilizer rates on subsequent maize grain yield and nitrogen use efficiency. The experiment was laid out in 2 x 2 x 3 factorial arrangement in randomized complete block design with three replications. The soybean precursor crop with two fields (without and with rhizobia), two maize varieties (BH-543 and BH-661) and three levels of nitrogen (0, 55, and 110 kg N ha^{-1}). The application of nitrogen fertilizer following soybean precursor crop biomass incorporation significantly ($P<0.05$) affected the mean grain yield and harvest index of maize. The higher grain yield of maize (7600 kg ha^{-1}) was produced from maize planted with the application of half and full recommended rate of nitrogen fertilizer. The agronomic efficiency and fertilizer N (recovery) use efficiency of maize varieties (9.72 kg grain kg N applied^{-1} and 194%) were higher with application of 55 kg N ha^{-1} following soybean precursor crop indicating loss of nitrogen when applied in higher dose and need a desirable nitrogen fertilizer management practices to improve crop yield and nutrient use efficiency. Therefore, planting of maize following soybean precursor crop biomass with half recommended nitrogen fertilizer was recommended for increasing maize yields.

Key words: Nitrogen fixation, rhizobia, soil nitrogen

4.1 Introduction

Soil fertility depletion is considered as the major threats to food security in Ethiopia. Conventional agriculture (continuous cropping with low inputs) has certain limitations in terms of maintaining long-term soil fertility (Charpentier *et al*., 1999). Wu *et al.* (2003) reported that 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 N and P fertilizers and intensive mechanized tillage practice lead to increased 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.

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 globally 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*. (2009a) 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. Maize rotated annually with soybean and first year corn after five year of consecutive soybean yielded 12% more than continuously grown corn (Pedersen and Lauer, 2002). Crookston *et al*. (1991) reported a 5% yield advantage for first-year corn after several years of soybean as compared with corn rotated annually with soybean. First year corn after 5-year soybean and annually rotated corn produced the highest yield averaging 9, 12, and 10 Mg ha^{-1} 3 years (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 an important management consideration 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*. (2009b) found that soybean rotation resulted in significant increase in total N uptake as compared to continuous maize. The 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*., 2009b). Information is scanty on the combination of soybean precursor crop biomass with nitrogen rates on corn grain yields and nitrogen efficiency of maize varieties. Peterson and Varvel (1989) found that corn grown in a four year 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 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 biological nitrogen fixation by soybean with and without rhizobia inoculation and determining its effects of nitrogen requirement of subsequent maize are potential for increased maize production. The objective this study was to determine the effects of soybean precursor crop biomass on yields and nitrogen use efficiency of subsequent maize varieties at Bako, western Ethiopia.

4.2 Materials and Methods

4.2.1 Description of the study site

A crop rotation experiment with soybean was conducted from 2013 to 2014 cropping seasons at Bako Agricultural Research Centre (BARC), situated in East Wollega Zone of the Oromia National Regional State (Fig 4.1). The Centre is located at $9^{o}6'$N latitude and $37^{o}09'$E longitude and at an altitude of the 1650 meter above sea level (Fig 4.1). The long-term (1961- 2014) mean annual rainfall at BARC is 1265 mm, with unimodal distribution. It has a warm humid climate with the mean minimum, mean maximum and average air temperatures of 13.4, 28.49 and $20.95^{o}{}_{C}$, respectively (MBARC, 2014). Sixty percent of the soil (1400 ha) of Bako Research Centre, is reddish brown in colour clay and loam in texture (Wakene, 2001) and of the Ultisols type (SSS, 2014). The relative humidity ranges from 46 to 65 %.

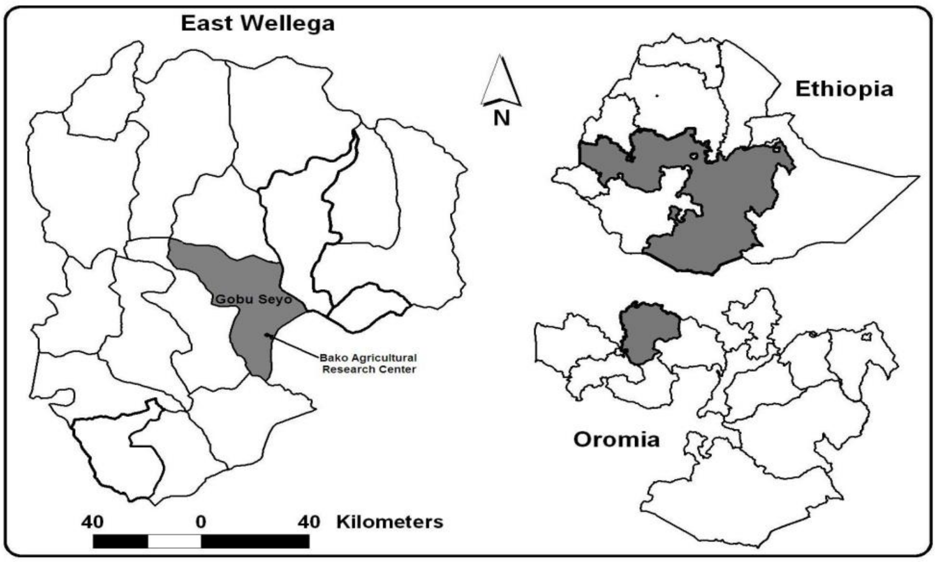

Figure 4.1: Aerial map of the study area located in East Wollega Zone of Oromia National Regional State, Ethiopia

4.2.2 Soil sampling and analysis

Soil samples were collected at the depth 0 - 20 cm with auger before the application of the treatments (2013) and before the maize planting in 2014. The soil samples were processed and analysed following standard procedures. The determination of soil particle size distribution was carried out using the hydrometer method (Dewis and Freitas, 1984, FAO, 1974). Soil pH was measured using digital pH meter in 1:2.5 soil to solution ratio with H_2O (Mclean, 1982), whereas the exchangeable bases were extracted with 1M ammonium acetate at pH 7. Calcium and Mg in the extract were measured by atomic absorption spectrophotometer while Na and K were determined by flame photometry (Van Reeuwijk, 2002). Cation exchange capacity of the soil (CEC) and exchangeable bases were determined by saturating soil with neutral 1M NH_4OAc (ammonium acetate) and the adsorbed $NH4^+$ions were displaced by using 1M KCl and then determined by the Kjeldahl distillation method for estimation of CEC of the soil (Polemio and Rhoades, 1977; Rhoades, 1982). The per cent base saturation was calculated from the sum of exchangeable bases as a per cent of the CEC of the soil. The exchangeable acidity was determined by extracting the soil samples with M KCl solution and titrating with sodium hydroxide as described by McLean (1965). The organic carbon was determined following wet digestion methods as described by Walkley (1947) and Nelson and Sommers (1982) whereas the Kjeldahl procedure was used for the determination of total N as described by Bremner and Mulvaney (1982). The available P was determined 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 (Keeney and Nelson, 1982).

4.2.3 Field experiments

During the 2013 cropping season, the trial field was divided into two and planted to soybean without and with rhizobia inoculation of the seed. One soybean variety (Didessa from medium maturity set) without and with rhizobia was used with one control (i.e. maize (Variety BH-543) as non-fixer, without fertilizer application) was planted in 2013 cropping season. The rhizobia strain (SB-12) was used to inoculate the soybean seed receiving inoculation. In 2013 cropping season, precursor crop soybean (*Glycine max*) without and with rhizobia inoculation and continuous maize without fertilizer were planted. The seed rate used was 70 kg ha^{-1}. The spacing was 60 x10 cm and 75 x 30cm between rows for soybean and maize. The soybean receiving rhizobia inoculation was pelleted with sugar to insure attachment of the inoculants with seed. Uninoculated and inoculated seeds of faba bean and soybean were planted on oxen-ploughed fields of 26m x 16.5m each with total area of 52m x 16.5m.

Soybean tissue and seed samples were collected at 50% flowering and at the harvesting stage. The tissue samples were dried in an oven at $70^{o}{}_{C}$ for 24 hours. The collected tissue samples were chopped, dried, and ground for analysis. The seed samples were also ground for analysis. The plant tissues were subjected to wet digestion. The N content of the plant tissue was determined by Kjeldahl procedure as described by Bremner and Mulvaney (1982). The total nutrient uptake was calculated as the sum of grain nutrient uptake and biomass nutrient uptake. Total N concentration (percentage total N in dry matter) of the whole plant was used to calculate grain nutrient uptake and biomass nutrient uptake by multiplying the N concentration by dry biomass per hectare of faba bean. The total nitrogen fixation of 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, maize). The seed yield, biomass and biological N_2-fixation of faba bean precursor crop are indicated in Table 4.1. The biomass of each plot was chopped, uniformly distributed and incorporated into the soil after harvesting and threshing soybean in 2013. The soybean precursor crop biomass incorporated fields were delineated and divided into different plots used for maize in 2014 cropping season.

Table 4.1: Yields and biological N_2-fixation of soybean on the study site in BARC, western Ethiopia in 2013 cropping seasons

Soybean	**Seed yield (kg ha^{-1})**	**Biomass yield (kg ha^{-1})**	**Ndfa (kg ha^{-1})**
With rhizobia inoculation	2520	5600	111.1
Without rhizobia inoculation	2940	6400	198.3

Ndfa= Nitrogen derived from the soil with total N difference method

During the 2014 cropping season maize (main crop) hybrid (BH-543 and BH-661) were planted on each soybean field with three levels of fertilizer (0, 55, and 110 kg N ha^{-1}). The experiment was laid out in 2 x 2 x 3 factorial arrangement in randomized complete block design with three replications. The soybean precursor crop with two fields (without and with rhizobia) was used as factor A, two maize varieties (BH-543 and BH-661) as factor B and three levels of nitrogen (0, 55, and 110 kg N ha^{-1}) as factor C.

The total gross plot size was 5.1 x 4.5 m with 3 x 5.1m net plots. The spaces between rows and plants within a row were 75 cm and 30 cm, respectively. The seed rate used for maize was 25 kg ha^{-1}. Sowing dates followed recommended dates of planting within May, when the rainfall was well established. Full dose of phosphorus (20 kg P ha^{-1}) (as TSP) was applied at planting, while nitrogen (as urea) was applied in spilt doses, half at planting and the remaining half at 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 relevant crop growth stages.

4.2.4 Plant parameters recorded

Crop parameters recorded include grain yield, thousand seed weight, dry biomass and harvest index after maturity of maize. 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; Nelson *et al.,* 1985) and converted to grain yield as kilogram per hectare.

4.2.5 Plant tissue sampling and analysis

Plant biomass (dry tissue at 50% flowering, and grain at harvesting) was sampled during the 2013 evaluation for soybean and during 2014 for maize. The collected plant tissue and grain samples were prepared following standard procedures and analysed at Holleta and Debre Zeit Agricultural Research Centre Soil and Plant Analysis Laboratory using standard procedures for different selected nutrients. 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 colorimeterically according to Murphy and Riley (1962).

4.2.6 Plant N uptake and use efficiencies

The total N uptake was obtained by dividing the N concentration in the tissue to total dry biomass weight (kg ha^{-1}) of maize, whereas N agronomic efficiency (NAE) was obtained by dividing the grain yield to the applied N as presented in equation 1 (Wu *et al*, 2011; Cleemput *et al.* 2008).

$$NAE(kg\ grain/kgN) = \frac{Y_N - Y_0}{F_N}$$ -- (1)

Where Y_N and Y_0 are the grain yield with and without N applied, respectively; and F_N 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, calculated as (equation 2):

$$UEN(kgN / kgN = \frac{U_N - U_0}{F_N}$$ -- (2)

Nitrogen physiological efficiency was calculated as total dry matter or grain yield produced per unit of N absorbed. N utilization efficiency was calculated (equation 3) as described by Haegele (2012):

$$PEN(kg\,grain/kgN = \frac{Y_N - Y_0}{U_N - U_0}$$ ------------------------------------ (3)

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; this was calculated (equation 4) as described by Azizian and Sepaskhah (2014) and Cleemput *et al*. (2008):

% fertilizer nutrient recovery (ANRE) = $\frac{(TNF)-(TNU)}{R} X100$ ----------------- (4)

Then, N harvest index (NHI) (equation 5) 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:

$$N\ harvest\ index = \frac{Grain\ N\ accumulation\ (kg\ ha^{-1})}{Total\ N\ accumulation\ (kg\ ha^{-1})}$$ --------------------------- (5)

where, the total N accumulation includes all N that accumulated in leaves, stem, shank, cobs and husk organs (equation 6) in addition to the grain (equation 7).

$$Shoot\,N\,accumulation\,(kg\,ha^{-1}) = \frac{shoot\,N\,content\;(g\,kg^{-1}) \times shoot\,DM\,(kg\,ha^{-1})}{1000} \text{ -- (6)}$$

$$Grain\,N\,accumulation\,(kg\,ha^{-1}) = \frac{grain\,N\,content\;(g\,kg^{-1}) \times grain\,DM\,(kg\,ha^{-1})}{1000} \text{ -- (7)}$$

4.2.7 Statistical analysis

Analysis variance the data were carried out using statistical packages and procedures of Statistical Analysis System computer software (SAS, 2004). Mean separation was done using least significance difference (LSD) procedure at 5% probability level (Steel and Torrie, 1980).

4.3 Results and Discussion

4.3.1 Chemical and physical properties of soil in the experimental site

Analytical results of selected physicochemical properties of the soil are indicated in Table 4.2. The texture of the soil was clay. The soil pH in H_2O ranged from 4.43 to 4.65 (very strongly acidic) according to Truog (1948) as cited by Landon (1991). This might be due to continuous monocropping with application of (110 kg N ha^{-1}) urea fertilizer for hybrid maize production, which led to acidity of the soil. Similar results were reported by Wakene (2001) and Wakene *et al*. (2004).

The organic carbon and organic matter concentrations were in the medium range according to FAO (1990) and Metson (1961) as cited by Landon (1991). The total N concentration of the soils are 0.21% before soybean planting, and 0.16 and 0.18% after soybean planting without and with rhizobia inoculation, which is in the low range according to FAO (1990) and Metson (1961) as cited by Landon (1991).

Table 4.2: Some physico-chemical properties soil of farmer's field before planting maize at BARC, western Ethiopia in 2013 and 2014 cropping seasons

Soil parameters	Before soybean 2013	Soybean +0 RI 2014	Soybean + 10 g RI kg seed $^{-1}$ 2014
pH (H_2O)	4.54	4.65	4.43
Available P(mg kg^{-1})	10.87	3.83	15.79
Total N (%)	0.21	0.16	0.18
OC (%)	2.46	2.14	2.18
OM (%)	4.23	3.68	3.75
CEC (cmol kg^{-1})	21.72	13.65	11.25
K (cmol kg^{-1})	1.13	0.19	0.12
Exc. acidity (cmol kg^{-1})	0.18	0.28	0.5
$N0_3$-N (ppm)	44.01	37.8	46.2
NH_4-N (ppm)	17.6	11.2	15.4
Texture	Clay	Clay	Clay

RI= rhizobia inoculation,
0RI= Soybean precursor crop without rhizobia inoculation,
soybean +10RI= Soybean precursor crop with rhizobia inoculation at 10 g kg^{-1} seed

The $N0_3$-N and NH_4-N concentrations of the soil were found to be medium to high, and high to very high, respectively (Bashour, 2002; FAO, 2006), sometimes excessive (Marx *et al*., 1999). This implies biological nitrogen fixation of soybean could be limited since N is amply available. The available phosphorous content of the soil was 10.87 mg kg^{-1} before soybean planting. It increased to 3.87 after soybean planting without rhizobia and 15.79 mg kg^{-1} after soybean planting with rhizobia inoculation, respectively, which is within low and medium range (FAO, 1990; Olsen and Dean, 1961; Fassbinder, 1980 as cited by Landon 1991). Planting of soybean with rhizobia, inoculation improved the total phosphorous concentration of the soil. Tropical soils contain considerable reserves of P that are fixed in unavailable or less liable forms due to high P fixing 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 by its strongly acidic nature. In agreement with this result, Wakene (2001) reported considerable fixation of available P by Al and Fe in the Alfisol of the same region. The CEC of the soil ranged from 11.25 to 21.72 cmol kg^{-1}, which was in the low to medium range (FAO, 1990; Barber and Rowell, 1972) as cited by Landon (1991). The soil is deficient in K.

4.3.2 Effects of prior inoculation of soil incorporated soybean biomass on yield and yield components of subsequent maize

The grain and biomass yields, thousand seed weight and harvest index of maize varieties are indicated in Table 4.3. Incorporation soybean biomass did not significantly ($P<0.05$) influence grain yield, biomass yield, thousand seed weight, and harvest index of the maize varieties (Table 4.3), whether the soybean precursor crop biomass was inoculated with rhizobia or not. This implies that there are effective indigenous soybean rhizobia in these soils. Therefore, the soybean field without prior rhizobia-inoculated soybean (biomass) is still promising for subsequent maize production in the region upon incorporation of the soybean biomass should be carried out to identify indigenous rhizobia.

Introduced strains may sometimes disappear completely from the soil without repeated inoculation. Therefore, studies should be done to determine the effects of the introduced rhizobia vis-à-vis the indigenous ones. This will determine whether or not continued inoculation is required in these fields. However, inoculation of seeds with relevant strains of rhizobia before sowing may be required in areas where soybean are to be grown for the first time on the land.

4.3.3 Effects of maize varieties on yield and yield components of subsequent maize crop following incorporation of soybean biomass

BH-661 maize variety gave significant ($P<0.05$) higher mean grain and dry biomass yields as compared to BH-543 variety, indicating that BH-661 had more grain and biological yield potential as compared to BH-543 (Table 4.3). Similar results were reported by Uribelarrea *et al*. (2009) where by dry biomass and grain yield variation were observed between different hybrid maize varieties. This implies that varieties differ in their ability to absorb and store nutrients in their tissues as well as differing photosynthesis rates (Uribelarrea *et al*., 2004).

The thousand seed weight and harvest index of the maize varieties were not significantly ($P<0.05$) different (Table 4.3). However, in other studies harvest index of maize had significant differences between varieties (Eivazi and Habibi, 2013).

4.3.4 Effects of soybean biomass + nitrogen fertilizer rates on yield and yield components of subsequent maize

Nitrogen fertilizer at 110 kg N ha^{-1} resulted significantly ($P<0.05$) higher mean grain yield of 7600 kg ha^{-1} for BH-661 maize variety, but there was non-significant difference for BH-543 variety (Table 4.3). This indicates the need for optimum nitrogen fertilizer in one maize variety in addition to soybean biomass incorporation. Similarly, other research findings were similar to this result (Eivazi and Habibi, 2013; Moser, 2004; Nemati and Sharifi, 2012; Stanger and Lauer, 2008; Riedell *et al*., 2009; Uribelarrea *et al*., 2009; Zhao *et al*., 2013). Lack of significant effect of N fertilizer, as in the case of the BH-543 variety has also been reported in other maize varieties (Bundy and Carter, 1988; Lawrence *et al*. 2008; Sanjeev and Bangarwa, 1997; Thanki *et al*. 1988; Yusuf *et al*. 2009a).

Table 4.3: Effects of soybean biomass, maize varieties and nitrogen rates on yield and yield components of subsequent maize at BARC, in 2014 cropping season

Treatment	Grain yield (kg ha^{-1})		Biomass yield (kg ha^{-1})		Thousand seed weight (g)	Harvesting index (%)
Biomass of soybean not inoculated with rhizobia	6750		17643		386	39.58
Biomass of inoculated soybean	7104		16431		395	44.21
LSD (5 %)	501.71^{Ns}		1941.7^{Ns}		20.726^{Ns}	5.5737^{Ns}
Maize Varieties						
BH-543	6590b		15894b		394	43.49
BH-661	7264a		18180a		387	40.30
LSD (5 %)	501.71		1941.7		20.726^{Ns}	5.57^{Ns}
Mineral N rate (kg N ha^{-1})	BH-543	BH-661	BH-543	BH-661		
0	6133	6840b	16652	18236	382	37.12b
55	6690	7352ab	15218	18548	394	43.22ab
110	6947	7600a	15812	17757	396	45.34a
LSD (5 %)	1275^{Ns}	568.32	3659 ^{Ns}	3434^{Ns}	25.4^{Ns}	6.8263
CV (%)	15.51	6.27	18.46	15.14	7.79	19.51

NS=non-significant difference between means in the same column at 5% probability level.
Numbers followed by same letter in the same column are not significantly different at 5% probability level.
BH= Bako hybrid maize

The biomass yield and thousand seed weight of maize varieties were not significantly ($P<0.05$) affected by application of nitrogen fertilizer following soybean biomass incorporation (Table 4.3). In contrary, previous results report total dry matter of maize varieties were different with nitrogen fertilizer and increased with increasing nitrogen fertilizer application (Barbieri *et al*., 2008; Eivazi and Habibi, 2013; Ma *et al*., 2003; Samira *et al*., 1998; Torbert *et al*., 2001).

The harvest index of the maize varieties were significantly ($P<0.05$) higher upon application of the full recommended nitrogen fertilizer rate (110 Kg N ha^{-1}) as compared to without fertilize (following soybean precursor crop biomass) (Table 4.3). This implies harvest index of maize was improved with application of nitrogen fertilizer in addition to soybean biomass incorporation (Table 4.3). Similar results have been reported by Eivazi and Habibi (2013); Nemati and Sharifi (2012); Lawrence (2008); and Zeidan *et al*. (2006) in that harvest index of maize varieties were significantly affected by nitrogen rates and increased with increasing levels of nitrogen fertilizer application.

4.3.5 Effects of prior inoculation of soil incorporated soybean biomass on total nitrogen uptake of subsequent maize

The total nitrogen uptake by maize is indicated in Table 4.4. The maize varieties were not significantly ($P<0.05$) different in total nitrogen uptake following incorporation of non-inoculated or inoculated soybean biomass, indicating the presence effective local rhizobia strain in the soil which improved N status of the soil to the same extent as introduced rhizobia.

4.3.6 Effects of maize varieties on total nitrogen uptake of subsequent maize crop following incorporation of soybean biomass

The total nitrogen uptake of maize was not significantly ($P<0.05$) different between maize varieties following soybean biomass incorporation. Similarly Adesoji *et al.* (2015) found maize variety effect was not significant on shoot N uptake of maize following soybean. The two varieties of maize are, thus, similar in nitrogen uptake since the nitrogen fertilizer rate recommended for both hybrid maize varieties is also equal. Adesoji *et al*. (2015) found similarity exhibited by maize varieties in the nutrient uptake, an indication that both varieties were similar in accumulation of nitrogen.

Table 4.4: Effects of soybean biomass, maize varieties and nitrogen rates on nitrogen uptake of subsequent maize at BARC, western Ethiopia in 2014 cropping season

Treatment	Nitrogen uptake (kg ha $^{-1}$)
Biomass of soybean not inoculated with rhizobia	619
Biomass of inoculated soybean	558
LSD (5%)	78.204^{Ns}
Maize Variety	
BH-543	565
BH-661	612
LSD (5%)	78.20^{Ns}
Mineral Nitrogen rate (kg ha^{-1})	
0	584
55	596
110	586
LSD (5%)	95.78^{Ns}
CV (%)	19.22

NS=non-significant difference between means in the same column at 5% probability level.
Numbers followed by same letter in the same column are not significantly different at 5% probability level.
BH= Bako hybrid maize

4.3.7 Effects of soybean biomass + nitrogen fertilizer rates on total nitrogen uptake of subsequent maize

The maize varieties did not significantly ($P<0.05$) differ in total nitrogen uptake with application of nitrogenous fertilizer in addition to soybean biomass incorporation (Table 4.4). In contrary, in other studies, application of nitrogen fertilizer following legumes significantly affected the total uptake of nitrogen of maize (Adesoji *et al*., 2015; Hussaini *et al*., 2008; Rutkowska *et al*., 2014; Yusuf *et al*., 2009a) and that higher N uptake matched with the higher grain yield achieved at higher N rate.

4.3.8 Effects of prior inoculation of soil incorporated soybean biomass on nitrogen agronomic efficiency and nitrogen use efficiency of subsequent maize

Results of nitrogen agronomic efficiency and nitrogen use efficiency of maize are indicated in Table 4.5. Nitrogen agronomic efficiency of the maize varieties was not significantly ($P<0.05$) different in maize planted following soybean precursor crop biomass with rhizobia inoculation as compared to without rhizobia inoculation, and this led to non-significant difference on maize yields (Table 4.3). In contrary, Yusuf *et al*. (2009a) reported N agronomic efficiency of maize was significantly affected by crop rotation and that yields of maize following legumes were on average 14 and 12% greater than those of maize following maize and fallow, respectively and the N agronomic efficiency values of maize matched well with the grain yields.

The nitrogen use efficiency of maize varieties were significantly ($P<0.05$) higher in maize following soybean biomass that was inoculated with rhizobia as compared to without rhizobia inoculation (Table 4.5). Similarly, nitrogen use efficiency of maize differed significantly among rotation systems with NUE of 35% higher in maize-alfalfa rotation, and 25% higher in maize-soybean rotation than in continuous maize monoculture (Ma *et al*., 2003). The result is also in agreement with Ma and Dwyer (1998) and Singer and Cox (1998) who reported that NUE was greater in maize following legume crops than from continuous maize monoculture.

4.3.9 Effects of maize varieties on nitrogen agronomic efficiency and nitrogen use efficiency of subsequent maize crop following incorporation of soybean biomass

The maize varieties were not significantly ($P<0.05$) different in terms of nitrogen agronomic efficiency and nitrogen use efficiency following soybean biomass incorporation (Table 4.5). In contrary, Eivazi and Habibi (2013) found significant difference for nitrogen agronomic efficiency and nitrogen use efficiency between different maize varieties due to variation among maize varieties used. Thus, results from one set of maize varieties may not always be similar with those of a different set of varieties.

Table 4.5: Effects of soybean biomass, maize varieties and nitrogen rates on nitrogen agronomic efficiency and nitrogen use efficiency of subsequent maize at BARC, western Ethiopia in 2014 cropping season

Treatment	Nitrogen agronomic efficiency (kg grain kg N applied^{-1})	Nitrogen use efficiency (kg N uptake kg N applied^{-1})
Biomass of soybean not inoculated with rhizobia	8.0	1.12b
Biomass of inoculated soybean	8.9	1.80a
LSD (5%)	0.94^{Ns}	0.459
Maize Variety		
BH-543	8.77	1.21
BH-661	8.10	1.42
LSD (5%)	0.94^{Ns}	0.459^{Ns}
Mineral Nitrogen rate (kg ha^{-1})		
55	9.72a	1.86a
110	7.16b	0.69b
LSD (5%)	0.94	0.459
CV (%)	12.74	23.83

NS=non-significant difference between means in the same column at 5% probability level.
Numbers followed by same letter in the same column are not significantly different at 5% probability level.
BH= Bako hybrid maize

4.3.10 Effects of soybean biomass + nitrogen fertilizer rates on nitrogen agronomic efficiency and nitrogen use efficiency of subsequent maize

The application nitrogen fertilizer at 55 kg N ha^{-1} gave significantly ($P<0.05$) higher nitrogen agronomic efficiency of maize varieties following soybean biomass incorporation (Table 4.5). The result explains the higher grain yield of maize with application of 55 kg N ha^{-1} as indicated in Table 4.3. Similarly, in other studies, the nitrogen agronomic efficiency of maize varieties was significantly improved with 110 kg N ha^{-1} application as compared to higher rates (Kalinova *et al*., 2014). The result of the present finding corresponds to results by others (Eivazi and Habibi, 2013; Rutkowska *et al*., 2014). Thus, planting maize following soybean precursor crop with 55 kg N ha^{-1} increased agronomic efficiency and higher yields and is recommended for maize production in this area.

The application of nitrogen fertilizer resulted in significantly ($P<0.05$) higher N use efficiency of maize varieties with 55 kg N ha^{-1} as compared to application of 110 kg N ha^{-1} (Table 4.5). The results support the higher grain yields of maize variety BH-661 at 55 kg N ha^{-1} application (Table 4.3) due to higher N use efficiency maize varieties. Similar result was reported by Rahimizadeh *et al*. (2010) on wheat and Eivazi and Habibi (2013) on maize varieties. The poor performance at high N rates might be due to poor N uptake and low NUE due to excessive N losses (Sowers *et al*., 1994). To increase N fertilizer use efficiency is to supply nitrogen when it is needed by the crop (Keeney, 1982). Therefore, use of higher rates of fertilizer should be evaluated by matching application rate and timing with plant N demand is to improve N use efficiency (Ferguson *et al*., 2002; Nemati and Sharifi, 2012).

4.3.11 Effects of prior inoculation of soil incorporated soybean biomass on physiological efficiency and fertilizer N (recovery) use efficiency of subsequent maize

Results of nitrogen physiological efficiency and fertilizer N (recovery) use efficiency of maize are indicated in Table 4.6. The nitrogen physiological efficiency of the maize varieties was not significantly ($P<0.05$) different when sown with soybean biomass without and with prior inoculation with rhizobia (Table 4.6). The nitrogen physiological efficiency of maize varieties may justify the non-significant grain yield difference of maize indicated in Table 4.3. In contrary, Ma *et al*. (2003) reported significant variations in nitrogen physiological efficiency maize varieties in maize-legume rotations as compared to continuous maize.

Similarly, fertilizer N (recovery) use efficiency of maize not significantly ($P<0.05$) influenced following soybean biomass that had been inoculated with rhizobia as compared to following soybean not inoculated with rhizobia (Table 4.6). This result also matches with the non-difference in maize grain yields in Table 4.3. Similarly, soybean residues in Nebraska had minimal effects on fertilizer N recovery (Maskina *et al*., 1993). In contrary, Yusuf *et al*. (2009a) reported that N fertilizer recovery efficiency was significantly influenced by crop rotation.

4.3.12 Effects of maize varieties on physiological efficiency and fertilizer N (recovery) use efficiency of subsequent maize crop following incorporation of soybean biomass

The nitrogen physiological efficiency of BH-543 maize variety was not significantly ($P<0.05$) different as compared to BH-661 maize variety following soybean biomass incorporation (Table 4.6). Similar result was reported by Ma *et al*. (2003) who found no difference in nitrogen physiological efficiency between maize hybrids. In contrary, Moser (2004) reported difference between tropical maize varieties.

Similar trends were also observed in terms of N fertilizer (recovery) use efficiency between the varieties, which also explains the absence of significant yield variation between the maize varieties used in Table 4.3.

4.3.13 Effects of soybean biomass + nitrogen fertilizer rates on physiological efficiency and fertilizer N (recovery) use efficiency of subsequent maize

The maize varieties overall did not differ significantly ($P<0.05$) in their nitrogen physiological efficiency at 110 kg N ha^{-1} as compared to 55 kg N ha^{-1} (Table 4.6) although in one maize variety (BH-661) grain yields were increased significantly (P,0.05) at 55 kg N ha^{-1} in addition to soybean biomass (Table 4.3). This implies better N uptake and utilization at 55 kg N ha^{-1} and that this was the optimum N rate in combination with soybean biomass. Therefore, based on this finding the current fertilizer N rate and management practice (biomass incorporation) are optimal for maize production in the area.

Table 4.6: Effects of soybean biomass, maize varieties and nitrogen rates on nitrogen physiological efficiency and fertilizer N (recovery) use efficiency of subsequent maize at BARC, western Ethiopia in 2014 cropping season

Treatment	Nitrogen physiological efficiency (kg grain kg N uptake^{-1})	Fertilizer N (recovery) use efficiency (%)
Biomass of soybean not inoculated with rhizobia	8.68	112
Biomass of inoculated soybean	12.59	152
LSD (5%)	10.69^{Ns}	106^{Ns}
Maize Variety		
BH-543	11.50	142
BH-661	9.76	121
LSD (5%)	10.69^{Ns}	106^{Ns}
Mineral N rate (kg ha^{-1})		
55	6.60	194a
110	14.67	69b
LSD (5%)	10.69^{Ns}	106
CV (%)	14.86	21.62

NS=non-significant difference between means in the same column at 5% probability level.
Numbers followed by same letter in the same column are not significantly different at 5% probability level.
BH= Bako hybrid maize

The fertilizer N (recovery) use efficiency of the maize varieties was significantly ($P<0.05$) higher with 55 kg N ha^{-1} as compared to 110 kg N ha^{-1} following soybean biomass incorporation into soil (Table 4.6) explaining the higher maize yield of variety BH-661 (Table 4.3). The fertilizer N (recovery) use efficiency of maize decrease as N rates increased is in agreement with findings of others (Barbieri *et al*., 2008; Cassman *et al*., 1993; Dobermann *et al*., 2000; Guillard *et al*., 1995; Moser, 2004; Peng and Cassman, 1998; Yusuf, *et al*., 2009a, 2009b). The decreases of N fertilizer recovery efficiency at higher N rate may be due to greater losses of N from the system as suggested by Huggins and Pan (2003). Therefore, there is need for improvement in the current fertilizer N management practice for maize production in mid altitude areas of western Ethiopia, especially when higher N rates are adopted.

4.3.14 Effects of prior inoculation of soil incorporated soybean biomass on shoot and grain N accumulation and N harvest index of subsequent maize

The shoot N accumulation, grain N accumulation and N harvest index of the maize varieties are indicted in Table 4.7. The shoot N accumulation of maize varieties were significantly ($P<0.05$) higher for maize varieties planted following incorporation of soybean biomass that was not inoculated with as compared to with rhizobia inoculation. This implies that the indigenous rhizobia strains in soil were effective in biological N_2-fixation of soybean, which contributed to increase in shoot N accumulation of maize. Similarly, Adesoji *et al*. (2015) reported that incorporation of mucuna, lablab and soybean significantly increased uptake of N shoot of maize as compared with incorporation of weedy fallow which might be attributed to the increases in the quantity of fixed N derived from the decomposition of the incorporated green manure crops (Adesoji *et al*., 2013).

The grain N accumulation of maize varieties were not significantly ($P<0.05$) affected by soybean biomass incorporation into soil (Table 4.7). The grain N accumulation of maize varieties was similar for soybean biomass incorporation without and with prior rhizobia inoculation. In contrast to this result, Maskina *et al*. (1993) and Adesoji *et al*. (2015) reported higher grain N accumulation of maize in maize following soybean rotation that was attributed to the enhanced growth of maize plants, which in turn enhanced the uptake of the nutrient.

The N harvest indexes of the maize varieties were not significantly (P<0.05) affected by soybean precursor crop biomass incorporation (Table 4.7), and both maize varieties had almost equal N harvest indexes.

Table 4.7: Effects of soybean biomass, maize varieties and nitrogen rates on shoot N accumulation, grain N accumulation and N harvest index of maize at BARC, western Ethiopia in 2014 cropping season

Treatment variables	**Shoot N accumulation ($kg\ ha^{-1}$)**		**Grain N accumulation ($kg\ ha^{-1}$)**	**N harvest index (%)**
Biomass of soybean not inoculated with rhizobia	13.93a		9.51	0.50
Biomass of inoculated soybean	12.43b		9.80	0.55
LSD (5%)	0.0237		0.613^{Ns}	0.062^{Ns}
Maize Variety				
BH-543	12.11b		9.57	0.51
BH-661	14.25a		9.73	0.54
LSD (5%)	0.0237		0.613^{Ns}	0.062^{Ns}
Mineral N rate ($kg\ ha^{-1}$)	BH-543	BH-661		
0	10.62b	10.72c	8.86b	0.49
55	12.30ab	14.17b	10.14a	0.53
110	13.42a	17.85a	9.96a	0.55
LSD (5%)	2.0973	2.9345	0.7503	0.0757^{Ns}
CV (%)	13.88	16.51	9.18	17.01

NS=non-significant difference between means in the same column at 5% probability level.
Numbers followed by same letter in the same column are not significantly different at 5% probability level.
BH= Bako hybrid maize

4.3.15 Effects of maize varieties on shoot and grain N accumulation and N harvest index of subsequent maize crop following incorporation of soybean biomass

The maize varieties used showed significant (P<0.05) difference in shoot N accumulation following soybean biomass incorporation (Table 4.7). BH-661 maize varieties gave significantly (P<0.05) higher shoot N accumulation as compared BH-543 maize variety following soybean biomass incorporation. Similar findings were reported by Moser (2004) and Uribelarrea *et al*. (2009) who found differences in shoot N concentration of hybrid maize varieties as was true for the Bako hybrid used for this study. This implies that there is variation between the two Bako maize hybrids.

The grain N accumulation and N harvest index of maize varieties was not significantly (P<0.05) different between the maize varieties used following soybean biomass incorporation (Table 4.7). This indicates both varieties had similar habit in storing N in the seed. Adesoji *et al*. (2015) also reported similar results.

4.3.16 Effects of soybean biomass + nitrogen fertilizer rates on shoot and grain N accumulation and N harvest index of subsequent maize

The shoot N accumulation of BH-543 and BH-661 maize varieties were significantly (P<0.05) increased with the increase of nitrogen fertilizer rates following soybean biomass incorporation. A similar result was reported by Uribelarrea *et al*. (2009). Variation due to N fertilizer rate was observed for shoot N concentration, and increased as the rate of N application increased (Moser, 2004; Adesoji *et al*. 2015).

The grain N accumulation of maize varieties significantly (P<0.05) increased with the application of nitrogen fertilizer following soybean biomass incorporation. Similarly, El-Gizawy (2009), Riedell *et al.* (2009) and Adesoji *et al*. (2015) reported that grain N uptake markedly increased with the increase in N rates.

The N harvest indexes of the maize varieties were not increased significantly (P<0.05) with application of nitrogen rates. Similar results were observed from studies in Wisconsin (Oberle and Keeney, 1990).

4.4 Conclusions and Recommendations

Soybean precursor crop biomass, without or with prior rhizobia inoculation, integrated with nitrogen fertilizer, have potential to increase hybrid maize productivity through better efficiency in utilization of nutrient inputs. The result soil analysis indicated that most of the nutrient concentrations were below the critical levels and would require better management practices for increasing maize yields. Application of nitrogen fertilizer to maize following soil incorporated soybean precursor crop biomass improved grain yield and harvest index of the maize varieties. Soybean precursor crop biomass provide N, and this reduces the amount of nitrogen fertilizer for maximizing maize yields to the tune of up to half of the recommended N rate. Incorporated soybean precursor crop biomass with rhizobia inoculation and half nitrogen fertilizer application also improved N utilization by maize varieties. Application 55 kg N ha^{-1} to maize following soybean precursor crop biomass was agronomically optimum, and is recommended for maize production in Bako area and other areas with similar agroecology.

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CHAPTER FIVE

5.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The results of these studies show that improved grain yield, thousand seed weight, dry biomass and harvest index were obtained from maize planted following soil incorporated faba bean precursor crop biomass with application of half and full recommended nitrogen fertilizer indicating that application of nitrogen fertilizer was very crucial for increase maize yields in addition to faba bean precursor crop biomass incorporation. Higher grain yield of maize obtained from application half recommended nitrogen fertilizer following soil incorporated faba bean precursor crop biomass show that faba bean biomass contributed for nitrogen status improvement soil although some nitrogen fertilizer is still required for subsequent maize. Half of the recommended N rate that is 55 kg N ha^{-1} is all that is needed. Inoculation with rhizobia was not necessary in these areas with long history of faba bean cultivation.

Higher grain yield and biomass of maize were harvested from BH-661 variety, but not the other variety (BH-543) planted following soil incorporated soybean precursor crop biomass, indicating variations of maize varieties in yielding potential following soybean. Improved grain yield of maize was produced from maize planted with application of half and full recommended rate of nitrogen fertilizer following soil incorporated soybean precursor crop biomass, showing importance of additional nitrogen application in the cropping sequence. Higher agronomic efficiency, N use efficiency, nitrogen physiological efficiency and fertilizer N (recovery) use efficiency with 55 kg N ha^{-1} fertilizer application were responsible for increasing the maize yields. Faba bean and soybean inoculation with both locally available native as well as introduced rhizobia strains both resulted in higher nitrogen fixation indicating that for these areas inoculation may not be necessary. Higher yields of maize was produced following faba bean or soybean precursor crop biomass incorporation into soil, with half recommended (55 kg N ha^{-1}) nitrogen application in addition, will reduce the N fertilizer burden for farmers in these areas.

5.2 Recommendations

From the results of the present research, the following recommendations area given:

i. Planting of maize following soil incorporated soybean precursor crop biomass with and without rhizobia with half-recommended nitrogen fertilizer application or soybean precursor crop without rhizobia with full-recommended nitrogen fertilizer application is recommended for increased maize yields.

ii. Jibat and Wenchi; and BH-543 and BH-661 maize varieties were appropriate for nitrogen use efficiency and recommended for increased maize yields in highland and mid-altitude areas of Western Ethiopia, respectively.

iii. Conduct further research promotion and scale up work using recommended varieties and nitrogen in the cropping systems in Toke Kutaye and Bako-Tibe districts of western Ethiopia and other areas with similar agroecology.

iv. The results show the importance site-specific fertilizer recommendation to improve maize yield and nitrogen use efficiency indices in western Ethiopia. Thus, additional studies are recommended to get site-specific recommendations.

APPENDICES

Appendix 1: Mean square of growth and yields of maize due to faba bean precursor crop, varieties and nitrogen rate around Toke Kutaye, western Ethiopia

Source of variation	DF	Mean square							
		Farm 1				Farm 2			
		Grain yield (kg ha^{-1})	Dry biomass (Kg ha^{-1})	Thousand seed weight (g)	Harvest index (%)	Grain yield (kg ha^{-1})	Dry biomass (Kg ha^{-1})	Thousand seed weight (g)	Harvest index (%)
Replication	2	9553430.10	38363824.9	975.35441	198.5939236	53316.38	3682965.00	1430.66116	5.3134176
Rhizobia inoculation (RI)	1	2573984.31	35869399.7	776.45982	2.5452007	880809.06	2416365.26	59.60428	15.4011452
Varieties (V)	1	323137.15	343985309.5 *	45.43787	287.5145370*	1152645.83	3866064.10	14156.55768*	127.7895037*
Nitrogen (N)	2	16190746.58*	88038138.2	4051.28285 *	232.0503746*	5351309.37*	31202216.86*	1601.16060	22.7372528
RI X V	1	36997.93	45466961.9	1125.81084	53.2619898	2393203.80	16660269.55	1926.89226	6.3882149
RI X N	2	2057277.03	19376028.2	533.40079	57.7262133	272548.80	6977979.74	443.12035	6.4480072
V X N	2	3159448.25	15906451.0	564.87111	18.8789580	1510045.44	10189294.48	1693.82606	46.7907894
RI X VXN	2	6834685.74	141888509.2	5176.23488	15.7759639	241763.88	2340534.98	606.87493	12.7135430
Error	22	2573531.5	64465001	965.19789	35.556253	296691.63	606.87493	1313.30556	14.4951116
CV (%)		22.11	24.46	7.99	25.84	12.30	11.65	9.71	12.40

*= Significant at 5% probability level

Appendix 2: Mean square of combined growth and yields of maize due to faba bean rhizobia inoculation, maize varieties and nitrogen rate around Toke Kutaye, western Ethiopia

Source of variation	DF	Mean square			
		Grain yield (kg ha^{-1})	Thousand seed weight (g)	Dry biomass (kg ha^{-1})	Harvest index (%)
Replication	2	7264739.4	1909.18237	16035259	139.350275
Rhizobia inoculation (RI)	1	221678.0	202.90341	803879	18.028476
Farm (FM)	1	143902656.7*	4188.97680*	6805555556*	1923.726661*
Varieties (V)	1	1348188.7	6298.97294*	321220129*	928.967318*
Nitrogen (N)	2	19135053.4*	5352.76500*	74234698	177.784435
FM X RI	1	3233115.4	633.16069	57354617	42.278437
FM X V	1	127594.3	7903.02262	68999255	42.239618
FM X N	2	2407002.5	299.67845	62919055	109.684032
RI X V	1	1512663.6	2999.21142	43474257	15.484340
RI X N	2	1648086.6	339.03316	20377825	45.271173
V X N	2	4460471.9	1152.68830	29005091	8.619361
RI X VXN	2	2252781.3	4615.16087	66174223	62.805627
FM X RI X VXN	7	1763771.0	839.48332	28346451	46.133648
Error	46	2995450.8	1111.3205	38832130	68.132526
CV (%)		21.54	8.75	24.24	19.37

*= Significant at 5% probability level

Appendix 3: Mean square of nitrogen use efficiencies of maize due to faba bean precursor crop, varieties and nitrogen rate around Toke Kutaye, western Ethiopia

Source of variation	DF	Mean square							
		Farm 1				**Farm 2**			
		AEN (kg grain kg N^{-1})	NUE (kg N uptake kg N^{-1})	PEN (kg grain kg N uptake^{-1})	FNRE %	AEN (kg grain kg N^{-1})	NUE (kg N uptake kg N^{-1})	PEN (kg grain kg N uptake^{-1})	FNRE %
Replication	2	21.269933	0.14702498	13.535179	28.8253	6.4194107	0.08409149	12.976173	567.42847
Rhizobia inoculation (RI)	1	1464.110696*	17.8809319*	4848.0184*	135996.18*	1.4155510	2.47869701*	263.50840*	38680.344*
Varieties (V)	1	79.134960	10.3114801*	5656.8403*	48027.225*	121.0335006*	3.90707589*	223.98189*	71143.423*
Nitrogen (N)	1	648.174001*	14.7412199*	7023.7052*	128116.76*	11.8356185	3.14269731*	2623.1781*	4766.2695*
RI X V	1	1.097305	6.85047348	2365.28857	15853.3762	3.9131272	0.00189545	433.951422	7831.43580
RI X N	1	0.055234	0.00025573	3798.87165	11110.2156	70.1771198	0.45552624	2685.06950	666.99519
V X N	1	1197.912471	2.64588339	4358.66085	47849.5325	322.9870263	2.58165897	2638.84023	53903.5780
RI X VXN	1	367.001387	0.22384528	8211.35900	4889.8886	8.0648736	0.06510726	2474.60610	2797.63305
Error	14	0.00613270	0.10697259	11.86466	2134.1875	4.9495555	0.31603198	14.84549	277.1319
CV (%)		14.81	18.23	28.30	21.29	17.41	29.35	22.30	9.89

AEN= Nitrogen agronomic efficiency, NUE=Nitrogen use efficiency, PEP= Nitrogen physiological efficiency, FNRE= Fertilizer nitrogen recovery use efficiency and *= Significant at 5% probability level

Appendix 4: Mean square of total nitrogen uptake, shoot and grain N accumulation and N harvest index of maize due to faba bean precursor crop, varieties and nitrogen rate around Toke Kutaye, western Ethiopia

Source of variation	DF	Mean square							
		Farm 1				Farm 2			
		TNU (Kg ha^{-1})	SNA (Kg ha^{-1})	GNA (Kg ha^{-1})	NHA (%)	TNU (Kg ha^{-1})	SNA (Kg ha^{-1})	GNA (Kg ha^{-1})	NHA (%)
Replication	2	20782.6112	0.00145638	15.3686774	0.01207130	2216.3590	0.00303900	0.06774630	0.00034579
Rhizobia inoculation (RI)	1	141639.5685*	0.97923016*	5.8009525	0.00001236	7002.6997	0.20716612*	0.02237168	0.00095749
Varieties (V)	1	141689.4249*	25.7014077*	2.2598508	0.05277065*	1839.7558	7.76953135*	0.40885154	0.01657779*
Nitrogen (N)	2	101029.7648*	24.7146895*	50.414607*	0.00478326	88699.525*	7.76427830*	19.29593881	0.01222137*
RI X V	1	2112.5539	52.88931614	0.0023345	0.07864573	20275.5884	0.86309593	4.28657686	0.01896964
RI X N	2	23197.3734	11.86853523	6.4646434	0.02040590	14737.2034	0.39250032	0.62003586	0.00141743
V X N	2	38677.9939	5.56612189	8.9987015	0.00015566	10997.0505	10.31492469	2.71412933	0.01783205
RI X VXN	2	196166.3788	8.21545046	13.5609305	0.00016680	24462.4382	2.71969194	0.74528946	0.00640152
Error	22	34506.070	20782.6112	4.0098136	0.00410452	2364.2498	0.00002189	0.54379934	0.00105745
CV (%)		24.41	0.067	21.61	10.89	11.53	0.091	12.28	6.03

*= Significant at 5% probability level, TNU=Total nitrogen uptake, SHA= Shoot N accumulation, GNA= Grain N accumulation and NHA= Nitrogen harvest index

Appendix 5: Mean square of growth and yields of maize due to soybean rhizobia inoculation, maize varieties and nitrogen rate at Bako Agricultural Research Centre, western Ethiopia

Source of variation	DF	Mean square			
		Grain yield (kg ha^{-1})	Thousand seed weight (g)	Dry biomass (kg ha^{-1})	Harvest index (%)
Replication	2	3015593.457	615.140615	60735142.9	135.0066896
Rhizobia inoculation (RI)	1	1130653.190	834.164423	20516811.5	193.1268682
Varieties (V)	1	4089704.388*	404.967710	56547404.2*	91.1515473
Nitrogen (N)	2	1938546.896*	640.269943	3755322.2	218.3831120
RI X V	1	6860741.683*	37.035918	4435631.9	120.7521220
RI X N	2	63567.293	1348.792298	5847216.7	19.9131190
V X N	2	2627.069	845.656298	2820001.1	19.0166427
RI X VXN	2	222961.758	17.714297	136054.4	32.4496568
Error	22	375765.59	1015.48214	11644395.6	76.130936
CV (%)		8.85	8.16	19.89	20.83

*= Significant at 5% probability level

Appendix 6: Mean square of nitrogen use efficiencies of maize due to soybean precursor crop, varieties and nitrogen rate around Toke Kutaye, western Ethiopia

Source of variation	DF	Mean square			
		Nitrogen agronomic efficiency (g) (kg grain kg N applied^{-1})	nitrogen use efficiency (kg ha^{-1}) (kg N uptake kg N applied^{-1})	Nitrogen physiological efficiency (%) (kg grain kg N uptake^{-1})	N fertilize recovery efficiency (%)
Replication	2	1.63733577	0.49257361	7.157755	12687.40799
Rhizobia inoculation (RI)	1	4.88658454*	8.88225563*	190.232091*	8776.29899
Varieties (V)	1	2.68595510	1.14406633	2977.379298*	21955.29468
Nitrogen (N)	1	39.39583158*	10.47320316*	3639.064685*	2462.11479
RI X V	1	31.01750032	24.08493688	26.847272	184.71149
RI X N	1	11.84502393	1.32296590	1.685281	23.32806
V X N	1	0.16722030	2.78474991	4308.928777	3194.86261
RI X VXN	1	0.80881936	0.18265688	236.235024	8060.75244
Error	14	1.1560145	0.27473604	10.27504	21767.5526
CV (%)		12.74	23.83	19.16	26.76

*= Significant at 5% probability level

Appendix 7: Mean square of total nitrogen uptake, shoot and grain N accumulation and N harvest index of maize due to soybean precursor crop, varieties and nitrogen rate around Toke Kutaye, western Ethiopia

Source of variation	DF	Mean square			
		Total nitrogen uptake (Kg ha^{-1})	Shoot N accumulation (Kg ha^{-1})	Grain N accumulation (Kg ha^{-1})	Nitrogen harvest index (%)
Replication	2	66445.0331	0.0079489	5.72647572	0.00613270
Rhizobia inoculation (RI)	1	32743.5840	20.3224110*	0.75713202	0.02114165
Varieties (V)	1	20317.0557	41.0572929*	0.25109453	0.01249405
Nitrogen (N)	2	511.8316	74.0434870*	5.72377105*	0.00992438
RI X V	1	5368.8666	7.2258542	13.65566089	0.03803732
RI X N	2	20461.4197	39.0854837	0.16903330	0.00397210
V X N	2	1902.9416	14.2256107	1.35667538	0.00012262
RI X VXN	2	1792.4954	1.4860781	1.74630806	0.00828377
Error	22	12797.9235	0.0011745	0.78532081	0.00798616
CV (%)		19.22	0.26	9.18	17.01

*= Significant at 5% probability level

Appendix 8: 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 (ºc)												**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

Appendix 9: Rainfall, temperature and relative humidity data for the Bako Agricultural Research Centre

Year						**Rainfall (mm)**							
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Total**
1961-1 999	13.07	17.16	56.86	65.51	150.19	208.22	237.32	228.97	150.50	72.67	18.61	10.87	1214.26
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	1445.50
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	1354.20
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	1040.90
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	1395.10
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	1161.30
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	1258.20
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	1365.10
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	1287.40
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	1527.60
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	1035.80
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	1338.00
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	1425.30
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	889.29
2013	13	0.1	38	4	149.3	287.8	342	300.9	139.8	113.1	44.6	0	1432.60
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	1067.10
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	1265.63
					Temperature (°c)								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

Appendix 10: Rainfall and temperature data for the Ilu-Gelan site as obtained from nearby weather stations

Years	**Rainfall (mm)**												
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Total**
2009	14.3	28.1	35.0	95.3	32.9	181.0	230.8	296.5	253.1	168.6	3.5	1.8	1340.9
2010	39.9	5.2	27.2	41.3	271.6	194.3	265.4	285.6	174.6	0.0	12.4	0.0	1317.5
2011	1.5	0.0	34.9	72.9	188.4	250.2	198.3	385.3	196.4	19.0	116.4	14.9	1478.2
2012	11.0	0.0	42.9	31.5	79.7	211.4	331.4	283.5	237.6	70.0	51.3	1.3	1351.6
2013	10.0	6.2	28.0	56.2	80.0	223.1	203.1	275.7	198.4	20.0	25.0	3.3	1129.0
2014	6.0	4.0	31.0	57.0	113.0	215.0	219.0	279.7	185.6	16.0	11.0	2.1	1139.4
Mean	13.8	7.3	33.2	59.0	127.6	212.5	241.3	301.1	207.6	48.9	36.6	3.9	1292.8
	Temperature (ºc)												**Mean**
Minimum	12.3	13.8	14.8	15.4	15.3	15.2	14.6	14.7	14.3	12.6	11.7	12.5	14.0
Maximum	30.5	32.0	31.7	31.2	29.0	25.6	23.9	24.3	25.8	28.0	28.9	29.1	28.5
Mean	21.4	22.9	23.2	23.3	22.2	20.4	19.3	19.5	20.0	20.3	20.3	20.8	21.2