SOIL CHARACTERIZATION, EFFECTS OF NITROGEN SOURCES, TILLAGE METHODS AND CROPPING SYSTEMS ON SOIL PROPERTIES AND MAIZE (*Zea mays* L.) IN THE CENTRAL RIFT VALLY OF ETHIOPIA

PhD DISSERTATION

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SOIL CHARACTERIZATION, EFFECTS OF NITROGEN SOURCES, TILLAGE METHODS AND CROPPING SYSTEMS ON SOIL PROPERTIES AND MAIZE (*Zea mays* L.) IN THE CENTRAL RIFT VALLY OF ETHIOPIA

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This is to certify that the dissertation entitled "Soil Characterization, Effects of Nitrogen Sources, Tillage Methods and Cropping Systems on Soil Properties and Maize (*Zea mays* L.) in the Central Rift Valley of Ethiopia", submitted in partial fulfillment of the requirement for the degree of **Doctor of Philosophy** in School of Plant and Horticultural Sciences with specialization in **Soil Science**, the Graduate Program of the School of Plant and Horticultural Sciences, and has been carried out by **Ashenafi Nigussie** ID.No Ph. D./soil/002/10, under our supervision. Therefore, we recommended that the student has fulfilled the requirement and, hence hereby he can submit the dissertation to the school.

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Final approval and acceptance of the dissertation is contigent upon the submission of the final copy of the dissertation of the School of Graduate Studies (SGS) through the School Graduate Committee (SGS) of the candidate's School.

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DEDICATION

This dissertation is dedicated to my wonderful wife, Mrs. Etalemahu Muleta, and our lovely children, who supported me throughout my PhD work.

STATEMENT OF THE AUTHOR

I declare that this dissertation submitted in partial fulfillment of the requirements for the Degre of Doctor of Philosophy (PhD) in Soil Science at Hawassa University and is deposited at the University Library to be made available to borrowers under the rules of the library. I declare that this dissertation is not submitted to any other institutions any where for the award of any academic degree, diploma or certificate. Brief quotations from this dissertation are allowable without special permission provided that accurate acknowledgment of the source is made. Request for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the Dean of the School of Graduate Studies of the college when in their judgment the proposed use of the materials is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

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LIST OF ABBREVIATIONS AND ACRONYMS

AAS	Atomic Absorption Spectrophotometer
AE	Agronomic Efficiency
ANRE	Apparent Nitrogen Recovery Efficiency
BD	Bulk Density
BH	Bako Hybrid
CRD	Completely Randomized Design
CS	Cropping System
CSA	Central Statistical Agency
CT	Conventional Tillage
CV	Coefficient of Variation
ESP	Exchangeable Sodium Percentage
GCPs	Ground Control Points
GDP	Gross Domestic Product
GIS	Geographical Information System
GLM	General Linear Model
GPS	Global Positioning System
ha	Hectare
HNMSA	Hawassa National Meteorological Service Agency
LSD	Least Significant Difference
m.a.s.l	Meter Above Sea Level
MT	Minimum Tillage
MCS	Monocropping System

NDVI	Normalized Difference Vegetative Index
NUE	Nutrient Use Efficiency
OC	Organic Carbon
PCA	Principal Component Analysis
PE	Physiological Efficiency
RCBD	Randomized Complet Block Design
RCS	Rotation Cropping System
RF	Rainfall
SAS	Statistical Analysis System
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SSA	Sub-Sahara África
TM	Tillage Methods
TN	Total Nitrogen
TNS	Total Nitrogen Stock
USDA	United State Department of Agriculture
WRB	World Reference Book

Organization of the Thesis

The thesis is divided into seven chapters. The first chapter is an overview and description of the study area. The second chapter deals with soil characterization and identification. The third chapter, which was published in the Journal of Applied and Environmental Soil Science, is a greenhouse experiment. The thesis's fourth, fifth, and sixth chapters are field experiments, and their manuscripts have been written and submitted to various publications. The summary, conclusion and recommendation drawn from the entire study are presented in the seventh chapter of the thesis.

The following manuscripts are prepared from this study:

I. Nigussie A., Haile W., Agegnehu G., and Kiflu A., 2021. Characterization and Identification of the Soil Types under Maize production in the Central Rift Valley of Ethiopia **(Manuscript prepared).**

II. Nigussie A., Haile W., Agegnehu G., and Kiflu A., 2021. Growth, Nitrogen uptake of Maize (*Zea mays* L.) and Soil Chemical properties, Responses to Compost, Nitrogen rates and their mixture on different textured soils: Pot experiment**.** Published in Applied and Environmental Soil Science. **https://doi.org/10.1155/2021/9931763.**

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Soil Characterization, Effects of Nitrogen Sources, Tillage Methods and Cropping Systems on Soil Properties and Maize (*Zea mays* L.) in the Central Rift Valley of Ethiopia

GENERAL ABSTRACT

Declining soil fertility is one of the major challenges to crop production and productivity in Ethiopia. Thus, addressing this challenge through developing new techniques and application of integrated soil management practices tailored to a particular crop and location is vital to improve crop productivity and production. Given this, studies were conducted in two districts of the central rift valley of Ethiopia with objectives: (1) To characterize and identify the soils of the study areas (2) To evaluate the effects of compost, inorganic nitrogen fertilizer and their mixture on soil properties, growth, and nitrogen uptake of maize, and (3) To assess the combined effects of tillage methods, cropping system and nitrogen fertilization on selected soil chemical properties, maize performance; and organic carbon and total nitrogen stocks. Two pedons, one from each, site were excavated and characterized with respect to morphological, physical and chemical properties. Pot trials were executed using a factorial combinations of five compost rates (0, 5, 10, 15, and 20 t ha^{-1}) and four inorganic nitrogen fertilizer rates (0, 46, 92, and 138 kg N ha^{-1}), laid out as a completely randomized design with three replications. Field study was carried out using three-factors arranged as split-split plot arrangement in randomized complete block design with three replications. The tillage methods were used as the main plot, cropping system as a subplot, and four levels of nitrogen fertilization as the sub-sub plot. Maize variety BH 546 was used as a test crop. The results of soil characterization showed great differences in their morphological, physical, and chemical properties within and among the profiles. Accordingly, the soil of the Dore Bafeno site was classified as Cambisol (Loamic, Aric, Humic), whereas, the Bati Dubano site was classified as Someric Phaeozems (Pantoclayic, Aric). The analysis of variance showed that the combined application of compost and inorganic N fertilizer significantly improved soil chemical properties, plant growth, and nitrogen uptake, compared to the unfertilized or separate addition of compost and/or inorganic N fertilizer. Similarly, different soil management practices were significantly affecting grain yield, N-uptake

and selected soil chemical properties. In both soils, the conventional tillage and haricot bean-maize rotation system increased the yield and yield components, and N-uptake in contrast to the minimum and maize monocropping, respectively. *However, tillage methods differed in their effects on soil organic carbon and total nitrogen stocks, which were improved through MT compared to CT. Therefore, a CT plus haricot bean-maize rotation system with the addition of sole inorganic N at 92 kg ha^{-1} and integrated 46 kg N ha^{-1} + 10 t compost ha^{-1} should be recommended, to achieve better yield and yield components as well as N-use efficiency, for Cambisols in Hawassa Zuria and Phaeozems in Meskan study sites, respectively. Nevertheless, to ensure sustainable maize production in the studied soils, we recommended that the integrated application of 4*6 kg N ha^{-1} *+ 10 t ha^{-1} compost along with MT and legume-based crop rotation, which can enhance soil properties, and in the long run will improve yield, and N-uptake as well as utilization efficiency. This is because the field study was carried out only for two consecutive years and generated short-term results. Therefore, a longer-term study should be carried out at similar soils/sites to assess the long-term effects of tillage practices, cropping systems, and nitrogen fertilization on soil properties, and yield and yield components as well as nitrogen utilization efficiency.*

Keywords: Crop rotation system, declining soil fertility, grain yield, N-use efficiency, soil characterization, tillage methods, yield components.

CHAPTER ONE

General Introduction and Description of the Study Areas

1. GENERAL INTRODUCTION AND DESCRIPTION OF THE STUDY AREAS

1.1 Introduction

Land degradation, limited and erratic rainfall with ever-increasing population pressure are common features of large parts of Sub-Saharan Africa (Sanchez, 2002; Farouque and Tekeya, 2008). Land degradation includes all processes that diminish the capacity of land resources to perform essential functions and services in ecosystems (Hurni et al., 2010). The causes and effects of soil degradations have been attributed to various social, economic, and governance drivers and the current rate of soil degradation threatens the capacity of future generations to meet their most basic needs. About 50% of potentially arable land in Africa is currently under cultivation, of which 2000 million ha (23% of agricultural land) are already low in soil fertility and the remaining arable land is under continuous soil fertility decline due to mismanagement (FAO, 2003; UNEP, 2004).

Declining soil fertility and the concomitant food insecurity problems are the major challenges facing Sub-Saharan Africa (SSA), with about 23% of the population being malnourished and over 35 million people anticipated to be food insecure by 2050 (Lal et al., 2015; FAO and ECA, 2018). According to FAO (2015) estimation, about 83% of rural people in Sub-Saharan Africa depend on the land for their livelihoods, but two-thirds of the land are considered unsuitable for agriculture compared to one-third for South America and 40% for Asia (Vlek et al., 2008). Furthermore, about 33% of soils are moderate to highly degraded, which is due to erosion, nutrient depletion, acidification, salinization, compaction, and chemical pollution (FAO, 2015). The decline in soil fertility is especially severe in tropical soils. Farouque and Tekeya (2008)

stated that widespread land degradation and low soil fertility are the major biophysical root causes of declining per-capital food production in Sub-Saharan Africa.

In Ethiopia, depletion of soil fertility and extensive soil degradation are the major constraints limiting crop productivity and natural resource conservation (Zeleke et al., 2010; Agegnehu et al., 2017). According to CSA (2019) estimation, over 80% of the Ethiopian population depends on land for their livelihoods and nourishment, but 31% of the land resources are currently degraded (Spielman et al., 2009; Zeleke et al., 2010). Similarly, Wakene et al. (2007) stated that low soil fertility is one of the major problems in resource-poor farmers in Ethiopia. Therefore, customizing the farming systems, which might be robust to improve soil fertility and health, are a very indispensable approach for addressing these challenges.

Agriculture remains vital for the Ethiopian economy and livelihoods, which contribute to 35.5% of the gross domestic product (GDP), and the sector typically, generates about 80% of employment (CSA, 2020). However, agriculture is mainly characterized by low productivity, principally caused by low soil fertility and the absence of efficient, sustainable and, site-specific soil fertility management practices (Abush et al., 2011). The country has about 51.3 million hectares of arable land; out of which, only about 12.4 million hectares, just over 20 percent, are currently being cultivated (CSA, 2019). Over the past decade, cereals productions have been more than double. Nevertheless, the food security problem remains a critical issue for many households and the country as a whole.

Maize or corn (*Zea mays* L.) is one of the world's main cereals, ranking second in production after wheat (FAO, 2019). It is cultivated on nearly 238 million hectares in about 173 countries having a wider diversity of soil, climate, and management practices (FAO, 2019). Ethiopia is

the seventh maize-producing country in Africa. Maize is the second in area coverage next t tef (*Eragrostis tef*), with total land areas of 10,478,217 ha being under cereals, of which maize covered about 17.68% (2,274,305.93 ha) (CSA, 2019). Despite the large area under maize production, its current national average yield is about 4.2 t ha^{-1} (CSA, 2019), which is far below the world's average yield of 5.8 t ha^{-1} (FAO, 2019). Although numerous factors contribute to wide yield gaps, low external input, particularly N, poor soil fertility, low water-holding capacity of the soil, and poor soil infiltration problems are among the major factors paid for low maize productivity (Chimdi et al., 2012; Teklewold et al., 2013; Mourice et al., 2015). Moreover, frequent tillage and monoculture practices and the complete removal of crop residues are also the governing factors for low productivity (Kassie et al., 2013).

Soil is the major reservoir of organic carbon, which plays a crucial role in the global carbon cycle. Moreover, it provides food, fodder, and fuel for meeting basic human and animal needs. The concentration of organic carbon (OC) is an indicator of soil health and quality (Waring et al., 2014). Soil is part of a dynamic and diverse production system with physical, chemical, and biological attributes (Sanchez et al., 2003). The dynamic quality is a function of the prevailing soil management practices (Gajri et al., 2002). Hence, maintenance of soil health is essential for sustained productivity of food, the decomposition of wastes, sequestration of carbon, and the exchange of gases.

Soil management practices have impacts on the long-term use of soil resources by influencing soil quality, stability, and resilience. In the past several decades, agricultural practices such as intensive tillage, continuous cropping systems, and low level of inputs application resulted in soil fertility degradation (Kimetu et al., 2008; Vanlauwe et al., 2010). According to Cleemput

et al. (2008), in many developing countries, continuous cultivation with unsuitable farming practices resulted in severe depletion of soil organic matter, putting agricultural production at risk. Moreover, in the advent of climate change (CC) where rainfall patterns are reduced and temperatures are raised, appropriate use of climate-smart agriculture technologies could improve crop productivity among smallholder farmers (FAO, 2010). Therefore, holistic management of arable soils is the key to dealing with the most complex, dynamic, and interrelated soil properties, as well as maintaining sustainable agricultural production systems.

Tillage is the most universally used agricultural practice and has been considered as a 'Farmer's technology' for at least 10,000 years (Lal et al., 2007). It is an important soil management practice that influences the soil's physical, chemical, and biological properties and can be a major factor in determining final crop yield (Lal and Stewart, 2013). It provides various benefits to farmers (Tangyuan et al., 2009), and can contribute up to 20% of yield reduction (Khurshid et al., 2006). Similarly, Ozpinar and Cay (2009) and Pekrun et al. (2003) proved that adopting different tillage systems have effects on plant nutrient dynamics and the distribution of macro- and micronutrients in topsoil. However, tillage can degrade soil quality by mechanically destroying the soil aggregates and exposing the inherent SOM to further microbial attack. Studies made by other authors also emphasized the effects of different tillage systems on maize grain yield and its components (Wang et al., 2015; Wasaya et al., 2017). Therefore, adopting an appropriate tillage method is vital to overcome edaphic constraints, since inconvenient tillage practice may cause a variety of undesirable outcomes (Lal, 1998).

Conventional tillage (CT) is a type of tillage practice commonly used by the majority of farmers around the globe and has been associated with improved soil aeration, good seedbed

preparation, and weed control (Wang et al., 2015). However, CT has the potential to reduce inherent soil organic matter content due to enhanced decomposition rate and hence, negatively affect long-term crop productivity, nutrient uptake, and soil health (Zuber et al., 2015). Previous studies also indicated that OM decomposition rates increased due to repeated tillage (Rusinamhodzi et al., 2011; Panettieri et al., 2013). Gao et al. (2016b) and Peng et al. (2016) stated that soil fertility declined due to frequent CT practice. Therefore, problems associated with conventional tillage can be managed through conservation tillage practices such as no-till or minimum tillage, which are less destructive than the traditional conventional tillage (Zhanga et al., 2015).

Minimum tillage is a type of conservation tillage practice, which is defined as any practice that minimizes soil water loss, and maintains a 30% surface cover with cash or cover crop residues. Compared to traditional tillage that is a conventional method, minimum tillage can significantly improve soil structure, decrease soil erosion, and nutrient leaching, retain soil moisture, overcome soil compaction, and enhance soil microbial activity (Plaza et al., 2013). Various studies depicted that operating reduced tillage improved the soil's physical (López-Garrido et al., 2012; Plaza et al., 2013), chemical, and biological properties (Bronick and Hobbs, 2005). Reicosky and Archer (2009) reported that larger amounts of CO_2 were released into the atmosphere as the result of tillage, which in turn, reduced the soil carbon content.

Nowadays, conservation tillage such as minimum and/or zero tillage has entered widespread use in most farmers around the globe, due to their advantages in reducing soil erosion, conserving soil moisture, improving soil OM, and reducing labor, fuel, and machinery costs (López-Garrido et al., 2012; Plaza et al., 2013). However, at the transitional time, yield and

nutrient availability, particularly N, is usually lower in minimum or zero tillage than the conventional method (Pittelkow et al., 2015).

Soil fertility often changes in response to cropping systems and management practices (Zeleke et al., 2010). This can be alleviating by different methods such as the use of legume crops in cropping systems and integrated organic and inorganic nutrient sources among the others. A cropping system has an enormous effect on soil physicochemical properties and thereby crop production and productivity (Rahman and Ranamukhaarachchi, 2003). Unsuitable cropping practices, such as monocropping, imbalanced nutrient application, complete removal of crop residue and insufficient nutrient re-supplies, have had negative impacts on soil fertility and crop productivity (Nyamangara, 2001). To amend this situation, cropping sequence in defined patterns based on scientific knowledge is extremely important (Fisseha and Tewodros, 2014).

According to Cleemput et al. (2008), prolonged cultivation combined with ineffective farming practices resulted in substantial loss of nutrients and soil organic matter, posing a serious danger to agricultural production. Wakene (2001) also reported that continuous monocropping with heavy applications of NP fertilizers and intensive mechanized tillage practice leads to increased soil acidity, degradation of organic carbon, and leaching of the exchangeable bases. However, a continuous cropping system under conservation tillage practice is recognized to improve the SOM content (Awale et al., 2013) notably by enhancing carbon accumulation in soil aggregates.

Crop rotation is a systematic strategy that provides the preservation of natural resources while also allowing effective nutrient consumption (Feizabadi and Koocheki, 2012). Crop rotation is currently a hot topic among agricultural experts due to its effects on nitrogen efficiency and its availability to plants (Fisseha and Tewodros, 2014). Owing to legume-based crop rotation, the

cost of mineral N fertilizer for grain crops might be decreased by 4 to 71% (Fustec et al., 2010). Similarly, Coulter et al. (2011) and Fustec et al. (2010) found that legume-based cropping sequence affects soil quality and availability of nutrients and thereby yield of successive crops. Berzsenyi et al. (2000) also found that under the same conditions, the grain yield obtained by the rotation system was higher than monocropping. Therefore, incorporating legumes into the cropping system are both environmentally and economically beneficial (Fustec et al., 2010; Hirel et al., 2011).

Nitrogen (N) is a universally deficient element in almost all the agricultural soils and cropping systems of the world (Mohan et al., 2015). Approximately half of the world's population relies on nitrogenous fertilizers for food, either directly or indirectly. The availability of nitrogen applied as a fertilizer to a crop is determined not only by the rate but also by the nature of the nitrogen fertilizer, soil types and management practices, cropping systems, soil temperature, and amount of precipitation during the growing season (Przulj and Momcilovic, 2001).

Among cereals, maize requires an adequate amount of nutrients, particularly N, for optimum growth and yield (Agba et al., 2005). Nitrogen application is the second precondition for successful maize production. Limited nitrogen could exert a substantial effect on maize crop yield and yield components (Kogbe and Adediran, 2003). Previous studies indicated that maize grain yield significantly increased by about 43-68%, due to N application (Ogola et al., 2002). Similarly, N management can significantly improve soil quality (Habtegebrial et al., 2007). Therefore, nitrogen management in the maize cultivation system is one of the major concerns to boost yield and improve soil quality (Blumenthal et al., 2008; Bilalis et al., 2009; Baral and Abhikari, 2015).

Limited application of inorganic N fertilizers, on the one hand, resulted in yield loss (López-Bellido et al., 2014; Meena et al., 2014). Excessive application, on the other hand, is uneconomical, dangerous to the environment, and potentially harmful to crops (Guo et al., 2010). To counter this phenomenon, the integrated use of organic and inorganic N sources is a good framework to improve grain yield, N uptake, and reduce N losses. Several studies indicated that integrated nutrient management improves grain yield and nutrient use efficiency over a single application of either organic or inorganic inputs (Amoah et al., 2012; Zelalem, 2014). Generally, evidence from research reports suggested that combined application of half the recommended rate of NP fertilizer with 50% of the recommended dose of compost can be the best alternative fertility management measure instead of either single inorganic or organic fertilizer application (Agegnehu et al., 2014; Solomon and Jafer, 2015).

Sustainable agriculture production requires balanced and judicious management practices that are also efficient, eco-friendly, and environmentally sound. To ensure sustainable production, sound management of cropping systems are required including knowledge of the physical, chemical, and biological state of the soils and crops during the growing season (Benton, 2003). However, in the absence of reliable soil fertility information, agricultural land use, and in particular crop production has negatively led to crop yields, with the next land degradation. Therefore, for decision-making, knowledge of the kinds and properties of soils, through distinctive measurement is fundamental in aspects of crop production and different land-uses.

In Ethiopia, per capita, food production is declining and not keeping pace with population growth. These are attributed to soil fertility depletion and widespread soil degradation (Zeleke et al., 2010; Agegnehu et al., 2016). The major driving forces of land degradation in Ethiopia

include nutrient depletion, complete removal of crop residues, limited application of appropriate types and rates of fertilizers, and unsuitable land management practices such as inadequate soil conservation practices and longer cultivation (Agegnehu et al., 2016; Zelleke et al., 2010). In addition, soil disturbance through conventional tillage has been reported as, among others, the cause of land degradation (Wu et al., 2011) which have effects on physical, chemical, and biological soil degradation (Thierfelder and Wall, 2009).

Hawassa Zuria and Meskan are among maize-producing districts in the central rift valley of Ethiopia, where inappropriate soil management practices such as conventional tillage along with continuous monocropping, low external inputs, and severe soil erosion are the core causes of low soil fertility and agricultural productivity. Hence, choosing a suitable tillage method, cropping system and nitrogen fertilizer rate can boost soil productivity while also decreasing environmental pollution by increasing nitrogen usage efficiency and carbon sequestration. In the study areas, however, no attempt was made to assess the combined impacts of tillage methods, cropping systems, and nitrogen fertilization on selected soil properties, maize productivity, and nitrogen use efficiency. Therefore, the present study was initiated with the following general and specific objectives.

1.1.1 General objective

The overall objective of this study was to characterize and identify the soils of the study areas and assess the combined effects of tillage methods, cropping systems and nitrogen fertilization on soil properties including organic carbon and total nitrogen stocks, maize productivity and nitrogen use efficiency in different soil types.

1.1.2 Specific objectives

1. To characterize the morphological, physical and chemical properties and identify the soil types of the study areas.
2. To determine integrated organic and inorganic nitrogen rates on soil properties and nitrogen concentration in maize.
3. To evaluate the effects of tillage methods, cropping system and nitrogen fertilization on selected soil chemical properties, maize performance; and organic carbon and total nitrogen stocks.

1.1.3 Hypothesis

I. Soils of the study areas are different and have different morphological, physical and chemicals properties as a function of different soil forming factors.

II. Integrated applications of organic and inorganic nitrogen fertilizers have positive effects on soil selected properties, growth, yield, and nitrogen concentration in maize.

III. Application of integrated nitrogen fertilizers along with legume-based crop rotation system and minimum tillage method will improve soil chemical properties including OC and TN stocks, yield, and yield components as well as nitrogen uptake and use efficiency by maize.

1.2 Materials and Methods

1.2.1 Description of the study areas

The study was conducted in two districts of the Central Rift Valley of Ethiopia. The study areas specifically were Dore Bafeno kebele in Hawassa Zuria district and Bati Dubeno in Meskan district (Fig. 1.1). The experimental sites were selected purposively based on their potential for maize production under conventional tillage and monocropping system as well as on their difference in soil fertility status. The major crops grown in the study areas include maize (*Zea mays* L.), sorghum (*Sorghum bicolor*), haricot-bean (*Phaseolus vulgaris*), millet (*Eleusine coracana*) and hot pepper (*Capsicum frutescens* L.). According to the Hawassa Zuria and Meskan Districts Office of Agriculture reports (unpublished), farmers in the study areas usually use blanket recommendations of Urea and NPS inorganic fertilizers as sources of N and P. At both sites, maize was the preceding crop with conventional tillage and monocropping practices.

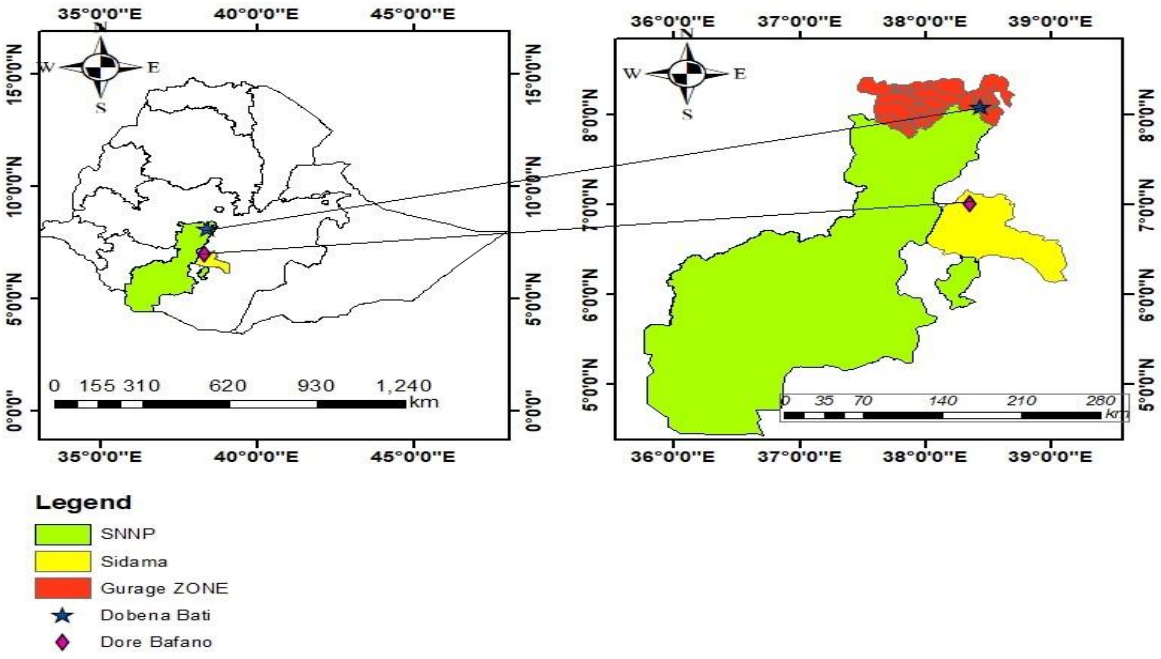

Figure 1.1. Map showing the location of the study sites.

1.2.1.1 Hawassa Zuria Site

Hawassa Zuria district is located between the geographical coordinates of 6° 52' 52.06" to 7° 09' 20.67" N Latitude and 38° 59' 03.6" to 38° 23' 05.2" E Longitude. The long-term weather station of Hawassa National Meteorological Service Agency (HNMSA) indicated that the district receives a mean annual rainfall of 957 mm with the principal rainfall season extending from April to September (HNMSA, 2019). The mean annual temperature is 20.5 °C with a mean minimum and maximum temperatures of 13.4°C and 27.6°C, respectively (Fig. 1.2). The specific study site of the intervention area is called Dore Bafeno kebele. It is found at approximately 27 and 287 km southwest of Hawassa town and south of Addis Ababa, respectively, and geographically located at 07° 1' 0.83" N Latitude and 38° 22' 26" E Longitude with an altitude of 1713 m a.s.l.

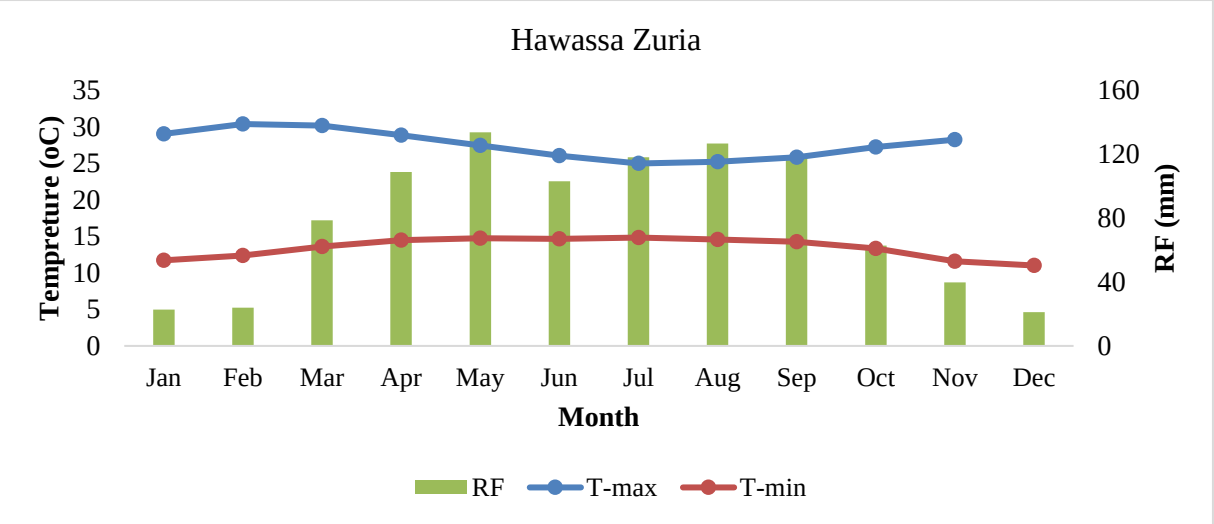

Figure 1.2. Annual rainfall and average monthly maximum and minimum temperature of Hawassa Zuria (1999-2018). RF: Rainfall; T-min and T-max: minimum and maximum temperatures, respectively.

1.2.1.2 Meskan Site

Meskan district is located between the geographical coordinates of 7° 99' to 8° 28' N Latitude and 38° 26' to 38° 58' E Longitude. The long-term weather station of Hawassa National Meteorological Service Agency indicated that the district received a mean annual rainfall of 989 mm (HNMSA, 2019) with the unimodal distribution extending from April to September. The mean annual temperature is 18.8 °C with a mean annual minimum and maximum temperatures of 11 and 26.7 °C, respectively (Fig. 1.3). The specific study site is called Bati Dubeno is found 155 and 135 km northwest of Hawassa city and south of Addis Ababa, respectively, and geographic located at 08° 05' 33" N Latitude and 38° 26' 75" E Longitude with an altitude of 1841 m a.s.l. Crop cultivation is mainly relied on rain-fed along with irrigation practices during the dry period.

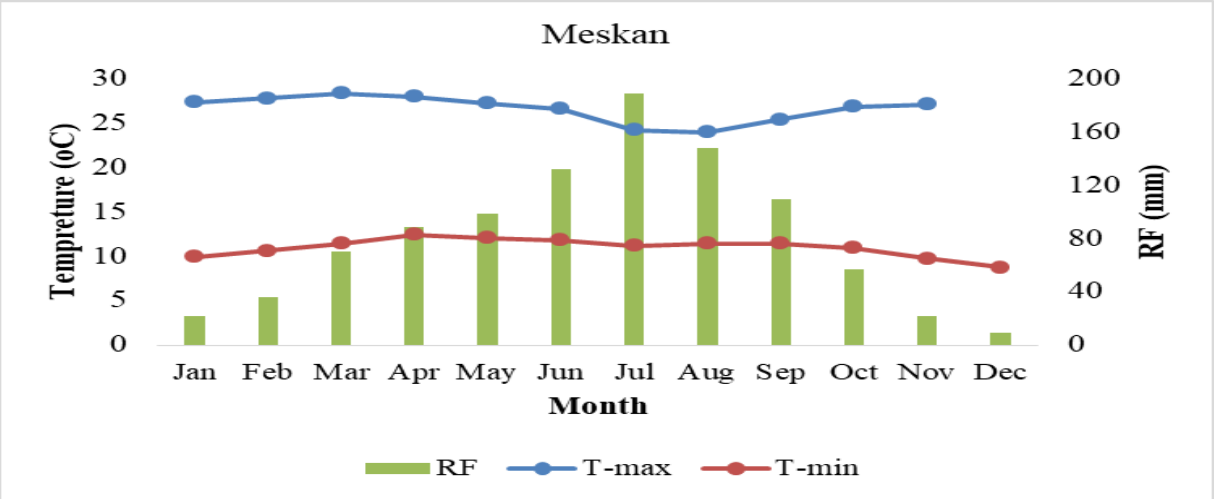

Figure 1.3. Annual rainfall and average monthly maximum and minimum temperature of Meskan (1999-2018). RF: Rainfall; T-min and T-max: minimum and maximum temperatures, respectively.

1.2.2 Soil profile description

One representative profile was selected at each study site in the main maize growing areas. Before digging the pits, an auger inspection was performed to determine typical profiles at each location. A pedon of 2 x 1.5 x 2 m was excavated by hand digging at each site. The pedon sites have flat topography and hence are assumed to have predominantly one soil type at each site. The representative pedons were described *in situ* following the Guidelines for Field Soil Descriptions (FAO, 2006). The soil profiles were geo-referenced with the use of the Global Positioning System (GPS). Soil samples were collected from the entire areas of the identified horizons for physicochemical analyses.

1.2.3 Greenhouse and field experimental procedures and designs

1.2.3.1 Greenhouse experimental procedure and design

A greenhouse experiment was conducted at Awada Agricultural Research Sub-Center to evaluate the effects of compost, inorganic nitrogen fertilizer, and their mixture on maize growth, yield and nitrogen uptake and soil properties; and to determine optimum integrated organic and inorganic N-rates for each soil type of the study areas. Bulk surface soils (0-20 cm) were also collected from the Mr. Anchamo`s maize farm of Dore Bafeno kebele in Hawassa Zuria District and Mr. Nasri`s maize farm of Bati Dubeno in Meskan district. Prior to seed sowing, three sub-samples were taken from each soil type for soil physicochemical analyses. Maize variety of "BH 546" was used as a test crop. The trials comprised factorial combinations of five levels of compost (0, 5, 10, 15, and 20 t ha^{-1}) and four rates of inorganic nitrogen fertilizer (0, 46, 92, and 138 kg N ha^{-1}) treatments and laid out in a completely randomized design (CRD) with three

replications. The compost rates were based on the respective inorganic N equivalence of 0, 25, 50, 75, and 100% and applied 10 days before seed sowing.

1.2.3.2 Field experimental procedure and design

Two tillage methods (TM) were evaluated: conventional tillage (CT) and minimum tillage (MT). The two tillage practices were combined with two cropping systems (CS): haricot bean-maize rotation (RCS) and maize monocropping (MCS), and four levels of nitrogen fertilization (NF) were used as treatment factors. Treatments were arranged in a split-split plot arrangement, assigning tillage methods to main plots, cropping systems to sub-plots, and nitrogen fertilization treatments to sub-sub-plots, with three replicates; making total of 48 sub-sub-plots for each experimental site. Details of treatment combinations are summarized in Table 1.1.

Table 1.1. Arrangement of experimental treatments

Treatment No.	Tillage methods (TM)	Cropping systems (CS)	Nitrogen fertilization (NF)	Treatment combinations
1	MT	RCS	N1	MT + RCS + N1
2	MT	RCS	N2	MT + RCS + N2
3	MT	RCS	N3	MT + RCS + N3
4	MT	RCS	N4	MT + RCS + N4
5	MT	MCS	N1	MT + MCS + N1
6	MT	MCS	N2	MT + MCS + N2
7	MT	MCS	N3	MT + MCS + N3
8	MT	MCS	N4	MT + MCS + N4
9	CT	RCS	N1	CT + RCS + N1
10	CT	RCS	N2	CT + RCS + N2
11	CT	RCS	N3	CT + RCS + N3
12	CT	RCS	N4	CT + RCS + N4
13	CT	MCS	N1	CT + MCS + N1
14	CT	MCS	N2	CT + MCS + N2
15	CT	MCS	N3	CT + MCS + N3
16	CT	MCS	N4	CT + MCS + N4

Prior to seed sowing, the experimental plots assigned for conventional tillage were plowed three times using an ox-drawn local Maresha. Plots intended for minimum tillage, on the other hand, were plowed once during seeding with an ox-drawn local Maresha. Moreover, minimum tillage plots received one application of Roundup (Glyphosate) herbicide (3 liters per hectare) to control weeds before seed emergence. In this study, the hybrid maize variety of "BH 546" and haricot bean variety of "Hawassa Dume" were used as test crops. Maize and haricot bean were sown at a space of 80 × 25 cm and 40 × 10 cm, respectively. Each main, sub-plot and sub-sub plot had an area of 15 x 9 m = 135 m^2, 15 x 4 m = 60 m^2 and 4.8 m x 3 m 14.4 m^2, respectively, and the total experimental area was 31.5 x 30 m= 945 m^2.

During the 2019 cropping season, urea fertilizer was applied at the rate of 92 kg N ha^{-1} in split form. Half at sowing time and the remaining half at the vegetative growth stages of six leaves (V6) of the maize, in all plots except the sole bean, which is in bean-maize rotation treatment, assuming the bean benefited from its N_2 fixation. As required, recommended agro-technical measures were performed evenly in all experimental units. Furthermore, 30% of the crop residues were retained after harvesting in minimum tilled plots.

During the 2020 cropping season, the experiment was laid out in a 2 x 2 x 4 a split-split plot arrangement, with three replications. Each main plot (conventional and minimum tillage methods) had eight treatment combinations, i.e., two cropping systems with four nitrogen fertilization treatments. According to the treatment, ten days before sowing, compost was applied on the surface of the soil, based on inorganic N-equivalency. In the case of conventionally tilled plots, applied compost was incorporated (0-20 cm depth) following the application on the top of the soil using ox-drawn local Maresha. On the minimum tilled plots,

the compost was evenly distributed on the surface of the soil and the incorporation was made during sowing since in the minimum tillage method we proposed to till the soil once which is during seed sowing using ox-drawn local Maresha. In both seasons, the recommended rate (46 kg P_2O_5 ha^{-1}) phosphorus fertilizer was applied to all plots at sowing as triple superphosphate (TSP), in a band in the row. All other agronomic and plant protection operations were kept uniform for all treatments according to local recommendations to avoid the effect of other factors.

1.2.4. Soil sampling and preparation

For soil characterization and classification study, both disturbed and undisturbed soil samples were collected from the entire area of every identified horizon. For the greenhouse experiment, three sub-samples were taken from each soil type to analyze the initial soil fertility status. After the pot trial, soil samples were collected from each pot and soil type, then the collected samples were combined as per treatments, after manual homogenization, representative composite sub-samples per treatment and site were prepared for analysis. In the case of field experiments, both disturbed and undisturbed soil samples were collected twise from the surface (0–20 cm) and subsurface (20-40 cm) soil depths. Before the implementation of the treatments, representative three sub-samples were collected from the above-identified soil depths per each experimental site, during March 2019, to know the initial fertility status of the experimental sites. After crop harvest, one core and three random soil samples per sub-sub plots were collected from 0-20 and 20-40 cm soil depths at each experimental location, following the standard soil sampling procedure. After manual homogenization, representative composite sub-samples per experimental unit and site were prepared for physicochemical analyses. Accordingly, a total of

192 soil samples (16 treatment combinations × 3 replication x 2 sites × 2 soil depths) were collected.

The collected soil samples were air-dried at room temperature (22^0C) and sieved with 2-mm mesh wire for the analysis of soil pH, texture, available P, exchangeable bases, CEC, and available micronutrients. However, a 0.5 mm sieve was used for the analysis of OC and TN. The soil parameters were analyzed in the soil testing laboratory in the College of agriculture at Hawassa University, Kulumsa agricultural Research Center and Southern Nations Nationalities, and Peoples Regional Bureau of Agriculture.

1.2.5. Soil analysis

1.2.5.1 Analysis of soil physical properties

Soil bulk density

Undisturbed soil samples were collected by core samplers having a coring cylinder of about 5 cm long and 5 cm diameter. The cylinder was pressed into the soil horizontally for profiles and vertically for field experiment soil sampling until the end of the cylinder was flush with the soil surface inside the core. Then, the cylinder was carefully removed after excavating around the core, and then the samples were trimmed flush at the ends of the cylinder. The collected samples were oven-dried at 105°C for 24 h; and then the soil dry weight was measured using a sensitive balance. Finally, the bulk density of the soil was calculated by dividing the dry weight of the sample by the volume of the cylinder (Blake and Hartge, 1986).

Particle size distribution

The particle size distribution (percentage of sand, silt, and clay) was determined using the modified sedimentation hydrometer method procedure of FAO (1974) and the soil texture was determined using the USDA textural triangle. A 50 g air-dried soil (< 2 mm) sample was weighed into a one-liter plastic bottle and 100 ml of water with dispersing agent was added. Then, the mixture was shaken on an end-to-end shaker for 3 hr. The soil and the solution were transferred into the cup of a mixer by washing the bottle and stirred with a mechanical stirrer for 5 minutes. Finally, the suspension was transferred to a cylinder, and hydrometer readings were taken at 40 seconds and 2 hr. The temperature was recorded, and the temperature correction factor was taken into account for the calculation of the three particles size fractions.

1.2.5.2 Analyses of soil chemical properties

Soil pH and electrical conductivity

The pH (pH-H_2O) of the soil was measured potentiometrically in the supernatant suspension of a 1:2.5 soil to water solution ratio using a pH meter as outlined by Sahilemedihin and Taye (2000). First, ten g of air-dried soil (< 2 mm) was weighed into 100 ml of the beaker and 25 ml of distilled water was added. Then, the samples were transferred to an automatic stirrer and stirred for 30 minutes. The solution was permitted for 1 h to stagnate the solution and the pH was measured in the upper part of the suspension using a glass electrode pH meter. The electrical conductivity (EC) of the soils was determined in a 1: 5 soils to water solution ratio and the reading for the EC was taken by inserting the conductivity meter cell into the solutions as described by Sahilemedihin and Taye (2000).

Soil organic carbon, total nitrogen and available phosphorus

The soil organic carbon was analyzed following the wet oxidation method of Walkley and Black (1934). A 2 g of soil sample was weighed and transferred to a 500 ml Erlenmeyer flask. A 10 ml 1 N $K_2Cr_2O_7$ solution was added with a pipette to both samples and blank. A 20 ml conc. H_2SO_4 was added with a measuring cylinder and the flask was swirled for 30 minutes. Then, 200 ml distilled water was added and allowed to cool and 10 ml concentrated orthophosphoric acid was added. An indicator, 0.5 ml of barium diphenylamine sulphonate, was added just before titration. Both samples and blanks were titrated with 0.5 N ferrous sulfate solution until the color changed to purple or blue, then ferrous sulfate solution was added drop by drop until the color flashes changed to green and then continue to a light green endpoint. Finally, the amounts of ferrus sulphate used for titration were taken to calculate the soil organic carbon using the following equation:

$$\%OC = N \times \frac{V1 - V2}{S} * 0.39 * mcf$$

Where:

N= normality of ferrous sulfate solution (from blank titration)

V1= ml ferrous sulfate solution used for blank.

V2= ml ferrous sulfate solution used for sample.

S= weight of air-died soil samples in gram

$$0.39 = 3 \times 0.001 \times 100 \times 1.3 \ (3 = equivalent\ weight\ of\ C$$

mcf = moisture correction factor.

The total nitrogen content of the soil was determined by the wet acid Kjeldahl method (Van Reeuwijk, 1992). One g air-dried soil sample was weighed and transferred into a digestion tube. Then two g of catalyst mixture and few boiling stones were added and mixed with the soil. Then, 7 ml of conc. H_2SO_4 was added to the mixture and digested for 3 hours in a block digester pre-heated to 300 ^{0}C. The samples were then cooled and 50 ml of distilled water was added and cooled again. The acid digest was transferred into the macro-Kjeldahl flasks and rinsed with distilled water. A 20 ml boric acid solution was measured and two drops of indicator solution were added to the sample. After that, 75 ml of 40 percent NaOH was poured and fitted with 250 ml Kjeldhal distillation flasks and the distillation process started through heating the flasks, and 80 ml of distillate was collected. The receiver flask solution was titrated from green to a pink endpoint with 0.1 N H_2SO_4. Finally, the burette volume was recorded.

$$\%TN = \frac{a-b}{S} * N * 0.014 * 100 * mcf$$

Where:

a= ml of H_2SO_4 required for titration of sample

b= ml of H_2SO_4 required for titration of blank

S= weight of air-died soil samples in gram

N= Normality of H_2SO_4 (0.1 N)

mcf = moisture correction factor.

The available phosphorous content of the soil was determined using 0.5 M sodium bicarbonate extraction solution (pH=8.5) following the method of Olsen (Olsen et al., 1954). Five grams of soil samples were shaken with 100 ml, of 0.5 M sodium bicarbonate extracting solution for 30

minutes on orbital shaker. The solution was then filtered through Whatman no. 42 filter paper. Three ml of the filtrate was mixed with 3 ml of mixed reagent and left for 1 h for the blue color to develop. The analysis was made by molybdate ascorbic acid blue method of Murphy and Riley (1962) procedure. This procedure involves, after extraction the sample 5 ml aliquot of the extractant, it was diluted in 20 ml distilled water. Then, 2 ml aliquot was taken from this diluted sample and placed in a test tube. Subsequently, 8 ml of the ascorbic acid working solution or reagents was added to the test tube containing 2 ml of the diluted sample. After 10 minutes for complete the blue color development, the absorbance was measured using spectrophotometer at 880 nm. The absorbance measured for the samples was converted to concentration using the standard curve. After measuring absorbance, the calibration curve was plotted for absorbance against P concentration of standards of known concentration with a range of 0.5 to 5 ppm P in solution.

Cation exchange capacity and exchangeable bases

The cation exchange capacity of the soil (CEC) was determined by saturating the soil with neutral 1M NH_4OAc (ammonium acetate) at pH 7 as outlined by Sahlemedhin and Taye (2000). Five grams of air-dried soil was weighed into a 250 ml beaker and 100 ml of 1 M- NH_4OAc (pH 7) solution was added and stirred rapidly with a stirring rod and allowed to stand overnight. Then, the suspension was transferred to a filter funnel placed on a 250 ml volumetric flask and filtered. Afterward, the remaining soil was washed with 100 ml of 1 M-ammonium acetate into the funnel to a volume of 200 ml. For the determination of CEC, 250 ml plastic bottles were placed under the filter funnel and the soil was washed on the filter with 25 ml ethanol 3 times. The soil was saturated with sodium by washing with successive 20 mL aliquots of sodium

chloride (NaCl) 5 times and the filtrate was collected into 250 ml plastic bottles for the determination of CEC by distillation method. The leachate was transferred to a 500 ml Kjeldahl flask and the plastic bottles were washed with 25 ml of distilled water. Fifteen ml of 0.20 N H_2SO_4 was poured into the distillate receiver of a 250 ml Erlenmeyer flask and the distillation tip was dipped into the Kjeldahl flask and connected immediately to the distillation apparatus. Lastly, the distillate receiver was removed from the distiller, the condenser tip was rinsed, and the distillate was back titrated with 0.1 N NaOH using methyl red as an indicator until the color changed from purple to yellow.

Exchangeable bases (Ca^{2+} and Mg^{2+}) in the ammonium acetate leachate were measured using atomic absorption spectrophotometer (AAS) following the techniques outlined by Sahlemedhin and Taye (2000). A 0.5 ml of the ammonium acetate leachate was pipetted into a test tube and 4.5 ml of distilled water was added. Five ml of 0.5% La suppressant solution was mixed and homogenized. Finally, the Ca and Mg contents were measured by AAS at 422.7 and 285.2 nm wavelengths, respectively. Exchangeable K^+ and Na^+ in the leachate were measured using a flame photometer at wavelengths of 768 and 598 nm, for K and Na, respectively. Finally, percent base saturation was calculated using the following equation:

$$PBS = \frac{(\mathrm{Ca} + \mathrm{Mg} + \mathrm{K} + \mathrm{Na})}{CEC} * 100$$

Available micronutrients

The available micronutrients (Fe, Mn, Zn, and Cu) were determined following Lindsay and Norvell (1978) procedure. A 20 g of soil samples and 40 ml diethylene triaminepentaacetic acid (DTPA) were added to a 100 ml polythene bottle and then the bottle was shaken for 2 h at a

speed of 150 rpm at 20 ^{o}C. It was filtered through Whatman no.42 filter paper. The solution was filtered, and 10 ml of the sample extract was mixed with 0.1% lanthanum solution and homogenized. The micronutrients extracted with this method were measured by AAS at 248.3, 279.5, 324.7, and 213.9 nm wavelengths for Fe, Mn, Cu, and Zn, respectively.

1.2.6 Preparation and analysis of compost

The compost was prepared at the Wondo Genet Agriculture Research Center botanical backyard using locally available composting materials such as green leaves, farmyard manure, fresh and dry cow dungs, and animal feed remains from dairy cattle, and wood ash. Three representative compost sub-samples were collected. The collected compost was dried at room temperature 22^{0}C and ground to a fine powder for the determinations of pH, EC, OC, TN, Avail-P, and C: N ratio at the soil and plant analysis laboratory of Southern Agricultural Research Center, Ethiopia. The pH was determined in a sample: water ratio of 1:5 using a pH meter. The moisture content was determined as described by Hesse (1972). The organic C and total N contents were determined Walkley and Black method (Walkley and Black, 1934) and Kjedahl method (Jackson, 1958), respectively.

1.2.7 Growth, yield, and yield components measurements

For the greenhouse trial, maize plant height was measured at fifty-two days after sowing with the aid of a meter rod from the soil surface to the top of the plant and their mean was used for computation. The number of leaves per plant (NLPP) was counted 52 days after sowing. Normalized Difference Vegetation Index (NDVI) value was measured using a Green Seeker ^{TM} Handheld Optical Sensor Unit (NTech Industries, Inc., USA) on 4, 5, and 6 weeks after sowing,

and their means were used for computation. Stem girth was measured at 52 days after sowing, using a digital caliper. The aboveground parts of the plant were harvested at 52 days after sowing at the soil level and their fresh weights were weighed using an electronic sensitive balance. Similarly, the root parts were carefully separated and cleaned using water and weighed. Air-dried shoots and roots parts of the plants were separately oven-dried at 65 ^{0}C to constant weight and measured using an electronic sensitive balance.

In the field experiments, the plant parameters such as NDVI, plant height, aboveground biomass, grain yield and thousand-seed weight collected. The NDVI was measured from the central two rows at the vegetative growth stages of six (V6) and eight (V8) leaves using a Green Seeker ^{TM} Handheld Optical Sensor Unit (NTech Industries, Inc., USA) following the method used by Verhulst et al. (2010b) and their means were taken for computation. Plant height was measured (in cm) from ground level to the base of the tassel of five randomly selected plants per plot using a measuring stick just before physiological maturity and the averages were taken for computation. Sun-dried, aboveground biomass was measured at physiological maturity of maize from a net plot area of 4 m^2 of which 250 gm samples were taken from each plot and then oven-dried at 70 ^{0}C until a constant weight was attained. The grain yield was harvested from a net plot area of 4 m^2 (1.25 m x 3.2 m) by excluding the border rows. The harvested grain yield was adjusted to a 12.5% moisture level (Nelson et al., 1985) and it was converted into hectare bases. Thousand-kernel weight was counted using an electronic seed counter from the bulk of threshed seeds and weighed using a sensitive balance from each plot at harvest and was adjusted to a 12.5% moisture content. The harvest index was calculated using the following formula: - as the ratio of grain yield at 12.5% moisture to aboveground dry biomass and multiplied by 100.

1.2.8 Plant analysis

For the greenhouse trial, air-dried shoot parts of the plants were oven-dried at 70 ^{0}C to constant weight. After oven drying, samples were taken from each experimental unit and milled to bypass via a 0.5 mm sieve, and the tissue nitrogen concentration was determined by the Kjeldahl procedure after wet digestion using H_2SO_4/H_2O_2 (Nelson and Sommers, 1982). For the field experiemnts, twenty grams of grain and stover samples were taken from each experimental unit and site. The grains and stover samples were grounded in stainless steel Wiley Mill and passed through a 0.5 mm sieve for laboratory analysis of N contents. The nitrogen content in grain and stover was analyzed using the Kjeldahl procedure after wet digestion by H_2SO_4/H_2O_2 (Nelson and Sommers, 1982). The grain and stover nitrogen uptake were computed by multiplying N-content with the respective grain and stover yield (kg ha^{-1}), respectively. The total N-uptake was calculated by adding the N-uptake in grain and N-uptake in stover (kg ha^{-1}).

1.2.9 Statistical analysis

Prior to the analysis of variance (ANOVA), the assumption of normality was checked using Shapiro-Wilk normality test, then the collected data were exposed to the analysis of variance following the general linear model procedure (PROC GLM) of the SAS 9.3 software package (SAS, 2014). The following model was used for the greenhouse experiment to compute the general variability of the trait:

$$Y_{ijk} = {}_{u} + R_i + C_j + N_k + CN_{(jk)} + e_{ijk}$$

Where Tijk is total observation, μ = grand mean, Ri is the effect of the ith replication, Cj is the effect of the jth compost level, Nk is the effect of the kth nitrogen rate, CN is the interaction, and eijk are the differences due to random error.

The following model was used for the field experiment to compute the general variability of the trait:

$$Yijkl = \mu + Ri + Aj + R(A)ij + Bk + ABjk + R(AB)ijk + Cl + ACjl + BCkl + ABCjkl + \varepsilon ijkl$$

Where Y_{ijk} is the observed value, μ = grand mean, R_i is the effect of the i^{th} replicate, A_j is the effect of the j^{th} tillage method, B_k is the effect of the k^{th} cropping system, C_l is the effect of the l^{th} nitrogen fertilization, AB, AC and BC are the two-way interaction effects, ABC_{jkl} is the three-way interaction effect and $R(A)_{ij}$, $R(AB)_{ijk}$ and e_{ijk} are the variations due to random error for the main, sub and sub-sub plots, respectively. At a probability level of $P \leq 0.05$, differences between treatments means were separated using the protected Fisher's least significant difference (LSD) (Steel and Torrie, 1980). The LSD differences for the main factors and interaction effects comparisons were calculated using the appropriate standard error terms. Pearson correlation coefficient (r) was performed using SAS software 9.3 software package (SAS Institute, 2014). All graphs were designed using Origin2021 procedures.

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CHAPTER TWO

Characterization and Identification of the Soil Types under Maize Production in the Central Rift Valley of Ethiopia

2. CHARACTERIZATION AND IDENTIFICATION OF THE SOILS TYPES UNDER MAIZE PRODUCTION IN THE CENTRAL RIFT VALLEY OF ETHIOPIA

Abstract

Providing up-to-date soil information to the beneficiaries is indispensable in tackling specific and local problems of agriculture. Proper characterization and identification of the experimental soil are required for transfer of crop research results to other similar sites. However, the soil resources studied so far in Hawassa Zuria, and Meskan districts were shallow and could not be applicable for site-specific soil management practices. Therefore, this study was conducted to characterize and identify the soils in terms of their morphological, physical, and chemical properties. Purposively field of maize was selected from two districts. One pit from each location was opened and the profiles were described in situ. Soil samples were collected from each identified genetic horizon. The studied soils had considerable heterogeneity in morphological, physicochemical properties within and among the profiles. The pH of the surface soils was moderately acidic (6.18) and neutral (6.94) in Dore Bafeno and Bati Dubeno pedons, respectively. The organic carbon contents in pedons ranged from low to high. The total nitrogen and available phosphorus contents of the surface soils of the two pedons ranged from 0.24 to 0.36% and 4.5-23.6 mg kg^{-1}, respectively. The cation exchange capacity of the soils in Dore Bafeno pedon varied from 22 to 32-cmolc kg^{-1}, while in Bati Dubano pedon ranged from 56 to 66-cmolc kg^{-1}. In both pedons, PBS was greater than 50 and had an increasing tendency with depth. The soil of Dore Bafeno Pedon had a Mollic epipedon and a Cambic subsurface horizon, and this soil was classified as Cambisols (Loamic, Aric, Humic). However, Bati Dubano pedon had a Mollic surface horizon and a PBS (> 50) throughout the profile and classified as Someric Phaeozems (Pantoclayic, Aric). The significant variations in the physicochemical properties of the studied soils, indicating site-specific soil management is required for each soil in order to maintain and improve soil organic matter and essential plant nutrients.

Keywords: Horizon, morphological, physicochemical properties, profile, soil fertility

2.1 Introduction

Agriculture is the mainstay of Ethiopia's economic system, which accounts for 35.5% of the gross domestic product (GDP) and over 80% of employment (CSA, 2020). However, the sector has been characterized by low productivity, specifically due to low soil fertility and the absence of site-specific balanced fertilization and applicable soil management practices, among others. Agricultural intensification requires information on the soil resources in terms of their potential and constraints. Former and existing soil management practices tended to reinforce the physical, chemical, and biological degradation of the soils, causing reduced soil productiveness (Zingore et al., 2015). As indicated by Benton (2003), sound management of cropping systems requests information on the physicochemical and biological properties of soils in the course of the growing season. However, the acquirement of this information is difficult due to the limited data on characteristics of soils and the excessive stage of variants in soil properties.

Soil characterization is a scientific way of collecting soil facts that allow recognizing the physical, chemical, and mineralogical properties of the soils that alleviate the unfavorable outcomes of soil variety and resource precision agriculture (Verma and Jayakumar, 2012; Sharu et al., 2013). According to Esu (2005) and Giessen et al. (2009), soil characterization is critical for describing and understanding the status and quality of soils. Characterizing the soil can function as an indicator of the soil potential to provide secure and nutritious food, enhance human and animal health, and overcome degradation (Schoenholtza et al., 2000).

Moreover, soil characterization records allow the ideal classification of the soil to serve as a basis for a more detailed assessment of the soil in addition to accumulating preliminary facts on nutrient, physical or other limitations for crop production (Sharu et al., 2013). However, in the

absence of reliable soil fertility information, agricultural land use, and in particular crop production has negatively led to crop yields, with the next land degradation. Therefore, for decision-making, knowledge of the kinds and properties of soils throught distinctive measurement is fundamental in aspects of crop production and different land-use types.

Providing up-to-to-date and location-specific soil information to the beneficiaries based on precise soil studies at the farm level is indispensable in tackling specific and local problems of the agriculture sector (Hailu et al., 2015). Furthermore, Wang et al. (2001) showed the importance of location specific soil analysis in the evaluation of the nutrient status of a given semi-natural and cultivated ecosystems. Different soil types have varying traits in micro-and macro-morphological, physical, chemical, and mineralogical properties (Ukut et al., 2014). Even though the knowledge of the kinds and properties of soils is important, soil resources studies so far were not detailed and could not be applicable for site-specific soil management practices. Moreover, Hawassa Zuria and Meskan areas are intensive maize-producing districts in the central rift valley of Ethiopia, but site-specific soil characterization and classifications were not done. Hence, this study was executed to characterize the soils in terms of their morphological, physical, and chemical properties, and classify them following the World Reference Base for Soil Resources (IUSS, 2015).

2.2 Materials and Methods

2.2.1 Description of the study sites

Soil characterization and identification of the soil types were conducted at Dore Bafeno in Hawassa Zuria district, and Bati Dubeno of Meskan district, in the Central Rift Valley of Ethiopia (Table 2.1). Prior to the study, an investigation survey was carried out within the selected study sites to identifying the major information including soils, topography, vegetation, land use and land management and socioeconomic condition. Detailed descriptions of the study sites are indicated under section 1.2.1.

Table 2.1 Site characteristics of the studied soils

Pedon/Site name	Geographic Position	Altitude (m.a.s.l)	Slope %	Drainage	Erosion		PM	Land use/vegetation
					At site	sounding		
Dore Bafeno	07° 1' 0.83" N 38° 22' 26" E	1723	2%	W	N	N	IR (IP4)	Maize, haricot bean, millet and sugarcane
Bati Dubano	08° 05' 33" N 38° 26' 75" E	1841	2%	W	N	N	IR (IB)	Maize, haricot bean, millet, and other cereal crops

PM: parent material; W: well surface dranage; N: none IR: igneous rock; IP4: ignimrite; IB: basic igneous (basalt type).

2.2.2 Soil profile description and sampling

One representative profile was selected at each study site in the main maize growing areas. Before digging the pits, an auger inspection was performed to determine typical profiles at each location. A pedon of 2 x 1.5 x 2 m was opened to study the soil type at each study site. The representative soil profile of each site was described *in situ* following the Guidelines for Field

Soil Descriptions (FAO, 2006). For each pedon, a recently excavated profile was used for the morphological description and soil sampling. The soil profiles were geo-referenced with the use of the Global Positioning System (GPS).

Soil color (dry and wet) notation was determined using the Munsell color chart (Munsell Color Company, 2009). Soil structure was described in terms of the sequence: grade, size, and type (shape) of aggregates, whereas consistency was identified at dry, moist, and wet moisture conditions. The horizon boundaries were described in terms of depth, distinctness, and topography. Both disturbed and undisturbed soil samples were collected from the entire areas of every identified horizon for analyses of the selected physicochemical properties. The soil samples collected from every recognized horizon were air-dried and passed through 2 mm sieve for the analysis of soil pH, texture, avail-P, exchangeable bases, and CEC; however, a 0.5 mm sieve size was used for determinations of organic carbon and total nitrogen.

2.2.3 Analysis of soil physical properties

Undisturbed soil samples were collected by core samplers and dried at 105°C for 24 h for the determination of bulk density, which was estimated by dividing the oven-dried soil sample taken with a core sampler by the volume of the core sampler (Blake and Hartge, 1986). Particle size distribution (percentage of sand, silt, and clay) was determined using the Hydrometer method following the procedure of FAO (1974) and the soil texture was determined using the USDA textural triangle.

2.2.4 Analysis of soil chemical properties

The pH (pH-H_2O) and electrical conductivity of the soils were determined in 1: 2.5 soils to water solution ratio using a pH and conductivity meter as outlined by Sahilemedihin and Taye (2000), respectively. Organic carbon was determined using the wet oxidation method (Walkley and Black, 1934) whereby the carbon was oxidized with potassium dichromate in sulfuric acid solution. Total nitrogen content was determined following the Kjeldahl procedure as described by Van Reeuwijk (1992), while available P was extracted using the sodium bicarbonate (pH 8.5) following the procedure described by Olsen et al. (1954) and the amount was measured by a spectrophotometer.

The cation exchange capacity of the soil (CEC) was determined by saturating the soil with neutral 1M NH_4OAc (ammonium acetate) at pH 7 and the adsorbed NH_4^+ were displaced by using 1M KCl and then determined by Kjeldahl distillation method for estimation of CEC of the soil (Sahilemedihin and Taye, 2000). Exchangeable bases were determined after leaching the soil with ammonium acetate; Ca^{2+} and Mg^{2+} in the leachate were analyzed by atomic absorption spectrophotometer (AAS), whereas, exchangeable K^+ and Na^+ were measured using a flame photometer. Percent base saturation was estimated from the sum of exchangeable bases as a percent of the CEC of the soil. Available micronutrients (Fe, Mn, Zn, and Cu) contents of the soils were determined by extracting with diethylene triamine pentaacetic acid (DTPA) method (Lindsay and Norvell, 1978) and the contents in the extract were determined by AAS.

2.2.5 Identification of the soil types

Based on the field morphological characteristics and laboratory analytical data, the soil types of the study areas were identified according to the World Reference Base for Soil Resources (IUSS Working Group, 2015)

2.2.6 Statistical analysis

Pearson's simple correlation matrix was generated using Statistical Analysis Software 9.3 (SAS, 2014) to examine the relationship between different soil parameters.

2.3 Results and Discussion

2.3.1 Morphological properties of the experimental soils

Soil morphological properties are vital tools for soil classification purposes than those of physical and chemical properties in view that they are located under natural and undisturbed conditions (Sharma, 2006). According to USDA (2010) soil depth class, the soil pedons were very deep (> 190 cm) and are not restricted by the parent materials and/or groundwater (Table 2.2). Four genetic horizons: Ap, Bw1, Bw2, and BC horizon sequences were identified at Dore Bafeno site (Table 2.2). Whereas, five: Ap, A1, Bk1, Bk2, and Btkg horizon sequence, were identified at Bati Dubano site.

The soil color (moist) in the pedon at Dore Bafeno site varied from very dark grey (2.5Y3/2), black (2.5Y2.5/1), dark olive-brown (2.5Y3/3), to olive-brown (2.5Y4/4). The color of the horizons had the same hue (2.5Y) with varying value and chroma, which ranged from 2.5/1 to 4/4 (Table 2.2). According to Sharma et al. (2006), values greater than three indicate low organic

matter while chroma greater than two suggests a deeper water table in the soils. On the other hand, the profile at Bati Dubano indicated soil color (moist) changing from black 10YR/2/1 to glayic Glay1/2.5/N (Table 2.2). The soils of the horizons had similar hue, values and chroma, except for the Btkg horizon. The last horizon (Btkg) showed a strong gleying color indicating either iron has been reduced under stagnant saturated conditions and is preserved in the soil (reduced matrix) or removed (redox depletion). The soil color variations observed among and within the pedons suggest the differences in OM contents, parent material, and drainage conditions (Nahusenay et al., 2014; Alem et al., 2015). In both pedons, there was no mottling (red, yellow, or brown splotches) in all horizons suggesting that the soil pores have not been filled with water for prolonged periods (Sharma et al., 2006).

In both pedons, the surface horizon had a weak, fine to coarse granular structure that changed from weak to moderate, fine to strong, and subangular blocky down the profile (Table 2.2). This result is in agreement with Yitbarek et al. (2016) and Kebede et al. (2017) who found granular soil structure in the surface horizons that changed to angular and subangular blocky structures in the subsurface horizons. In the pedon at Dore Bafeno site, except the bottom horizon (BC), the others possessed slightly sticky and slightly plastic consistency when wet and very friable, loosely, and very firm when moist (Table 2.2). The surface horizon of Dore Bafeno pedon had a very friable and slightly sticky/slightly plastic consistency, which might be due to the higher OM contents of the surface than those of subsurface layers. Mulugeta and Sheleme (2010) indicated that the surface layers had a friable consistency compared to the subsurface. In pedon of Bati Dubano, however, both the surface and subsurface layers had a friable and slightly sticky/slightly plastic consistency when moist and wet, respectively. These indicate that the soils have a high OM content and biological activities exist throughout the designated strata.

Moreover, the friable consistency proves the workability of the soil at the appropriate moisture content (Ashenafi et al., 2010).

Table 2.2 Selected Morphological properties of soil pedons

Horizons	Depth (cm)	Color Moist	Structure	Consistency moist	Consistency wet	BOU	Root abundance and size	$CaCO_3$ by 10% HCl
Dore Bafeno								
Ap	0-40	2.5Y/3/1	WE, F, GR	VFR	SST, SPL	C, S	F, F	N
Bw1	40-80	2.5Y/2.5/1	MO, F, SAB	LO	SST, SPL	C, S	VF, VF	N
Bw2	80-130	2.5Y/3/3	WE, F, SAB	LO	SST, SPL	G, S	N	N
BC	130-200+	2.5Y/4/4	MO, C, CR	VF	NS, NPL	-	N	N
Bati Dubano								
Ap	0-20	10YR/2/1	WE, C, GR	FR	SST, SPL	A, S	C, F	N
A1	20-40	10YR/2/1	ST, M, SAR	FR	SST, SPL	A, S	F, VF	N
Bk1	40-100	10YR/2/1	WE, F, SAR	FR	SST, SPL	C, S	VF, VF	SL
Bk2	100-140	10YR/2/1	WE, F, SAR	FR	SST, SPL	G, S	VF, VF	MO
Btkg	140-200+	Gley1/2.5/N	WE, F, GR	VFR	SST, SPL	-	N	ST

The description and abbreviations in the table are the following guidelines for field soil description (FAO, 2006). WE, week; MO, moderate; ST, strong; F, fine; C, coarse; M, medium; GR, granular; SAB, subangular blocky; CR, FR, friable; Lo, loose; VFR, very friable; VF, very firm; SST, slightly sticky; NS, non-sticky; SPL, slightly plastic; NPL, non-plastic; BOU, boundary; C, clear; S, smooth; G, gradual; D, diffuse; N, non; SL, slight; MO, moderate; ST, strong (for $CaCO_3$ by HCL).

Horizon boundaries provide facts on the dominant soil-forming processes that have made the soil. The distinctness of the boundaries of the soil horizons at Dore Bafeno was clear and gradual with smooth topography, whereas at Bati Dubeno the boundaries were abrupt, clear, and gradual distinctness with smooth topography (Table 2.2). The variations in horizon boundaries among the soil pedons indicate that the soils formed in different soil-forming processes. The root distribution at Dore Bafeno pedon varied from few in the surface layer to very few in Bw1 horizon, no root was observed in the third and fourth horizons. Whereas at Bati Dubano, the

root distribution varied among horizons as common, few, and very few at Ap, A1, and Bk1 and Bk2 horizons. In Dore Bafeno, no effervescence was observed by application of 10% HCl, indicating the absence of calcium carbonate. However, in Bati Dubano, effervescence was observed at Bk1, Bk2, and Btkg horizons. This result was also supported via soil analytical results of calcium carbonate equivalency through the titration technique (Table 2.2).

2.3.2 Selected soil physical properties

Bulk density

Soils with a high bulk density exhibit poor physical soil condition, whereas low soil bulk density shows favorable condition for agriculture (Patil and Prasad, 2004). The results of the present study showed inconsistent bulk density values across soil depth in both pedons (Table 2.3). The surface horizon at Dore Bafeno pedon had a bulk density of 0.94 gm cm^{-3} (Table 2.3), while the values in the subsurface horizons ranged from 0.98 to 1.09 gm cm^{-3}. In general, low bulk density values were recorded across the identified horizons, which is below the normal range for mineral soils (1.3-1.4 gm cm^{-3}) as indicated by Bohn et al. (2001). This low bulk density could be attributed to the parent material of the soil at this site, which is pumice and rich organic matter content (Hazelton and Murphy, 2007). Similarly, Akiro et al. (2014) reported that most Andisols show a low bulk density of 0.9 gm cm^{-3} or less than that of mineral soils. The surface soil had lower bulk density value than the subsoils, owing to the presence of higher organic matter on the surface soil. This result was fully supported by different scholars, Wakene (2001); Achalu et al. (2012); Mesfin (2020) who reported that the surface soils had lower bulk density compared with their subsurface counterparts.

Likewise, the soils of the Bati Dubano pedon generally showed low bulk density; whereby the lowest (0.99 gm cm^{-3}) and the highest (1.12 gm cm^{-3}) values were recorded on the surface horizons Ap and A1 horizons, respectively (Table 2.3). Lower bulk density in the surface (Ap) horizon could be due to the higher OM content at the surface (Celik, 2005). In natural soils, bulk density has an increasing tendency with soil depth, due to changes in OM content, porosity, and compaction (Chaudhari et al., 2013). However, in the present study, the soil bulk density decreased with profile depth from A1 to Btkg horizons, possibly due to clay separate increment along with soil depth.

Soil texture

Soil texture is the most stable physical property, which influences other soil properties like soil structure, soil moisture regime, permeability, consistency, workability, root penetrability, and the fertility of the soil (Landon, 2014). In the soils of Dore Bafeno pedon, sand, silt, and clay particles varied from 34 to 42, 32 to 40, and 24 to 30%, respectively. According to Hazelton and Murphy (2007), who rated all sand, silt, and clay contents of the soil into high (>40%), moderate (25-40%), and low (10-25%), respectively. Thus, the sand, silt, and clay contents of the soils ranged between moderate to high, moderate, and low to moderate, respectively (Table 2.3). Whereas, the soils of the Bati Dubano pedon contained 16 to 28% sand, 24 to 34% silt, and 46 to 48% clay fractions, which could be rated as low to moderate, moderate, and high, respectively (Table 2.3).

Loam was the main textural class throughout the genetic horizon of the Dore Bafeno pedon. Clay increment by 4% was found just below the overlying horizon (Ap), which is not adequate to characterize it as an argic horizon since argic horizon has an 8% clay increment within 2.5

cm soil (Soil Survey Staff, 2003). At Bati Dubano pedon, clay was the dominant textural class throughout the genetic horizons, and clay separates showed an increasing trend with profile depth (Table 2.3). The increase in clay content of the subsoil horizons could be due to the weathering of primary minerals and secondary clay synthesis (Buol et al., 2011). The soils in Bati Dubano pedon had higher clay content as compared with that of Dore Bafeno, which might be due to the fine-grained basaltic nature parent materials at Bati Dubano site.

Silt to clay ratio is an index used to evaluate the rate of weathering potential and determine the relative degree of soil development. In the soils of Dore Bafeno Pedon, the silt to clay ratio was varied from 1.07 to 1.58, which is more than one, indicating the soils are comparatively young with a high degree of weathering potential. This might be due to the parent materials, which are mainly composed of volcanic rocks, with alkaline lavas, ashes, and ignimbrites (Meron, 2007). This result agrees with the finding of Girma and Endalkachew (2013), Alemayehu et al. (2016), and Mesfin (2020), which indicated silt to clay ratio of 1.1 to 2.0 in the Ziway and Hawassa area soils. Moreover, the surface soil had moderately higher silt to clay ratio than that of the subsurface layers, which is probably because of tillage practices in the topsoil and illuviation of clay minerals into the subsoils.

In Bati Dubano Pedon, however, the silt to clay ratio was below one, which varied from 0.45 to 0.71; this could be due to the presence of high clay content. Previous research report (Buol et al., 2011) indicated that higher clay content confirms a complete alteration of weatherable minerals into secondary clays and oxides. Additionally, the variation in particle-size distribution among the horizons of the profiles shows the distinction in the material from which the horizons have been formed (FAO, 2006).

Table 2.3 Selected physical properties of soils in the pedons

Profile horizon	Depth (cm)	Bulk density	Particle size distribution			Silt: Clay	Textural class
		(g cm^{-3})	Sand (%)	Silt (%)	Clay (%)		
Dore Bafeno							
Ap	0-40	0.94	34	40	26	1.54	Loam
Bw1	40-80	1.09	38	32	30	1.07	Clay loam
Bw2	80-130	1.02	42	32	26	1.23	Loam
BC	130-200+	0.98	38	38	24	1.58	Loam
Bati Dubano							
Ap	0-20	0.99	22	32	46	0.70	Clay
A1	20-40	1.12	20	32	48	0.67	Clay
Bk1	40-100	1.07	28	24	48	0.50	Clay
Bk2	100-140	1.03	20	30	50	0.60	Clay
Btkg	140-200+	1.02	16	26	58	0.45	Clay

2.3.3 Selected soil chemical properties

The analytical results revealed that the pH (H_2O) of the soils in Dore Bafeno pedon varied from slightly acid (6.18) in the surface horizon to moderately alkaline (7.91) in the subsurface horizon (Table 2.4). Whereas in Bati Dubano pedon the soil pH ranged from 6.94 in the surface horizon to 8.38 in the lower horizons, which is neutral to moderately alkaline according to Benton (2003), and Tekalign (1991). In both pedons, the soil pH increased gradually with soil depth, the lowest value being in the surface layers, and this might be due to the removal of basic cations from the overlying horizon by leaching and crop uptake.

The EC data the surface horizons of the two pedons revealed very low electrical conductivity in general, ranging between 0.03 to 0.06 dS m^{-1}, indicating that the soils are nonsaline (FAO,

2006). However, the sub-surface horizons of the Bati Dubano pedon had higher EC, ranging between 0.06 to 0.09 dS m^{-1}, which might be due to the results of basic cation leaching and parent material. Similarly, the calcium carbonate content in the subsurface horizons of the Bati Dubano pedon ranged from 1 to 5% and exhibited an increasing trend with soil depth (Table 2.4). This may be either the impact of the parent material or the result of neo-formation (secondary carbonate). This result is in covenant with Ozsoy and Aksoy's (2007), who reported that calcium carbonate content increased with depth. The soil pH values also confirmed the accumulation of a basic (calcic) character (pH 8–8.7) due to the dominance of $CaCO_3$ (FAO, 2014).

According to the rating of Tekalign (1991), the OC contents in Dore Bafeno pedon ranged from low to medium, whereas in Bati Dubano pedon the values varied from low to high (Table 2.4). The OC contents in the surface soils of Dore Bafeno and Bati Dubano pedons were 2.61 and 4.10%, respectively. Medium and high OC contents at the surface horizons could be attributed to the accumulation of more organic materials. Considering the depth of the pedon, OC showed a decreasing pattern (Table 4). Various findings showed that the surface soils had higher OC than the subsoils (Abay et al., 2015; Alemayehu et al., 2016). In this study, the experimental soils had variable organic carbon content, suggesting that the need for site-specific soil management options. In agreement with this result, OC content in soils had a variable distribution in different areas of the country (Ashenafi et al., 2010; Daniel and Tefera, 2016).

The total nitrogen (TN) concentration in the surface soils of the two pedons ranged from 0.24 to 0.36% (Table 2.4). According to London (2014) rating, TN content of the surface soils is in the medium range, which might be due to nitrogen removal through crop harvest and continuous

cultivation. Soils having low to medium TN require external N containing inputs for sustainable production, as N is dynamic and prone to leaching, volatilization, and crop uptake. Moreover, the TN distribution within the studied pedons accompanied a comparable pattern to that of OC, implying that OM was the major source for TN. This results in agreement with the findings of Mulugeta and Sheleme (2010); Alemayehu et al. (2016) which reported that the TN concentration decreased with increasing profile depth. Therefore, enhancing and/or keeping OM contents of the soil through addition of organic residues is essential for sustainable soil productivity including ecosystem services.

The C: N ratio was varied from 10.89 to 13.5:1 in Dore Bafeno pedon and from 10.75 to 13.37:1 in Bati Dubano pedon, and categorized in a medium range, indicating good quality for mineral soils (Msanya et al., 2000) (Table 2.4). As indicated by Assen and Yilma (2010), the C: N ratio of about 10:1 is ideal and comparatively better for OM decomposition and serves as an index of improved N availability to plants. The surface horizon in Bati Dubano pedon had a relatively wider C: N ratio than that of Dore Bafeno pedon, which might be due to the variation in soil texture, since clay textured soils have a wider C: N ratio. Organic matter decomposition rate was low in clay-textured soils, which seems to be a major mechanism of soil organic matter preservation (Christensen, 2001).

Table 2.4 Soil reaction, electrical conductivity, organic carbon, total nitrogen, C: N ratio, available P, and calcium carbonate equivalent of the soils in the pedons.

Horizon	Depth (cm)	pH-H_2O	EC (dS m^{-1})	$CaCO_3$ (%)	OC %	TN %	C: N	Avail. p (mg kg^{-1})
Dore Bafeno								
Ap	0-40	6.18	0.03	0.00	2.61	0.24	10.89	4.36
Bw1	40-80	6.99	0.03	0.22	2.11	0.18	13.22	3.73
Bw2	80-130	7.25	0.03	0.38	1.87	0.17	12.65	3.10
BC	130-200+	7.91	0.04	0.46	1.76	0.13	13.54	2.94
Bati Dubano								
Ap	0-20	6.94	0.06	0.00	4.10	0.36	11.38	23.16
A1	20-40	7.13	0.08	1.00	3.71	0.29	12.79	6.86
Bk1	40-100	7.75	0.09	4.00	2.54	0.19	13.37	3.57
Bk2	100-140	7.77	0.08	4.20	0.98	0.09	10.89	3.57
Btkg	140-200+	8.38	0.09	5.00	1.72	0.16	10.75	0.16

The available phosphorus content of the soils in pedons ranged from 0.16 to 23.16 mg kg^{-1} (Table 2.4), which could be categorized from very low to very high (Benton, 2003). According to Havlin et al. (1999), P-Olsen between 12 to 18 mg kg^{-1} is considered as sufficient for crop production. Thus, the available P contents in the surface horizons of Dore Bafeno and Bati Dubano pedons were low (4.36) and very high (23.16 mg kg^{-1}), respectively. The low and insufficient available P in Dore Bafeno pedon could be due to the high phosphorus fixation power of Andisols. The surface soil in Bati Dubano pedon, however, had very high available P, which could be due to the neutral pH of the soil, as neutral pH has low P fixation power. Moreover, the carry over effects of continuous inorganic P fertilizer application for vegetable production (onion and tomato) might have also contributed to the high available phosphorus as

was also reported by Dinku et al. (2014). Alemayehu et al. (2016) also reported a similar finding. Additionally, available P values declined with increasing profile depth, which might be attributed to decrease in soil OM and an increase in clay content. Mulugeta and Shelem (2010) also stated that available P decreased with depth in soils of Kindo Koye site. In general, the available phosphorus content varied in most Ethiopian soils, mainly due to the difference in soil properties, the intensity of soil disturbance, abundant crop harvest, and erosion (Dawit et al., (2002).

The cation exchange capacity (CEC) can help to decide the suitable fertilizer packages and the amount of nutrients needed to correct imbalances. Hazelton and Murphy's (2007) rated CEC of the soils < 6, 6-12, 12-25, 25-40, and >40 $cmol_c\ kg^{-1}$ soil as very low, low, medium, high, and very high, respectively. Thus, the overall CEC values of the soils in the present study ranged from 22 to 62 $cmol_c\ kg^{-1}$, which could be rated as medium to very high. High and very high CEC values indicate the soils have a greater ability to hold cations and require higher rates of fertilizer as compared to those with lower CEC (Hamza, 2008). The CEC of soils in the Dore Bafeno pedon ranged from 22 to 32 $cmol_c\ kg^{-1}$and had an increasing trend with soil depth: from the surface horizon (Ap) to the second horizon (Bw1), due to increase in clay content. However, the CEC values decreased with further profile depth suggesting decrease in OM content and andic properties with depth. On the other hand, the CEC values of the Bati Dubano pedon ranged between 56 to 66 $cmol_c\ kg^{-1}$ without a regular trend with soil depth (Table 2.5). The high CEC values might be due to the high clay and OM contents. A similar result was reported by Benton (2003) indicating the CEC value is closely related to the soil texture; i.e., sandy soils have CECs ranging from 1 to 8; loamy sands, 9 to 12; sandy or silty loam, 13 to 20; loam, 21 to 28; clay loam, 29 to 40; and clay soils >40 $cmol_c kg^{-1}$, respectively.

Exchangeable Ca^{2+} levels vary among and inside pedons with a general tendency of increasing with soil depth (Table 2.5). Its content in the soils of Dore Bafeno and Bati Dubano pedons varied from 10.22 to 49.9 $cmol_c\ kg^{-1}$ and could be rated as medium to very high (FAO, 2006). In both pedons, the subsurface horizons contained higher exchangeable Ca^{2+} than the surface horizon, which could be due to leaching from the overlying horizons. Other authors, Ashenafi et al. (2010), Nahusenay et al. (2014) also indicated that the exchangeable Ca^{2+} accumulation increased with profile depth. However, the exchangeable Mg^{2+} ranged from low to medium and very high in Dore Bafeno and Bati Dubano pedons, respectively (Table 2.5). Relatively the highest exchangeable Mg^{2+} contents were recorded in Bw2 horizon of Dore Bafeno pedon and Bk2gt horizon of Bati Dubano pedon, but Mg^{2+} content had an irregular trend with soil depth.

In accordance with the EthioSIS (2014) rating, the potassium contents of the soils >2.3, 1.5-2.3, 0.51-1.5, 0.2-0.5, and <0.2 are classified as very high, high, optimum, low, and very low, respectively. Thus, the soils of the two pedons contained optimum to high exchangeable K^+ that could be sufficient for crop production. This result supports the common belief that Ethiopian soils contain sufficient K for crop production. The exchangeable Na^+ in the soils of Dore Bafeno and Bati Dubano pedons were high and medium, respectively (FAO, 2006), and showed an increasing pattern with profile depth. Generally, the contents of exchangeable bases increased with increasing soil depth, possibly due to leaching.

The order of exchangeable cations in fertile agricultural soils is $Ca^{2+} > Mg^{2+} > K^+ > Na^+$ as described by Bohn et al. (2001) and any deviations from this order may create an ion-imbalance problem for plants. Thus, the result of the present study revealed that the exchangeable Ca^{2+} dominates the exchange complex, but there were different orders of exchangeable cations. In

Dore Bafeno pedon, the order was K^+, Na^+, and Mg^{2+} followed Ca^{2+}. In Bati Dubano pedon however the order was Ca^{2+} followed by Mg^{2+}, K^+, and Na^+, which could be considered as suitable cation distribution for plant growth in accordance with FAO (2006b).

Agricultural soils having a percent base saturation (PBS) > 50 are considered as more fertile and favorable for crop production, however, soils with less than 50 are reflected as less promising (FAO, 2006). In both pedons, PBS was greater than 50 and had an increasing tendency with depth, which is probably due to leaching of bases from the overlying layers and subsequent accumulation in the subsurface horizons (Table 2.5). It varied from 55.89 to 69.5% in Dore Bafeno pedon and 73.66 to 105.5% in Bati Dubano pedon and rated as moderate to very high (Hazelton and Murphy, 2007). The B_{k2} horizon in Bati Dubano pedon had a PBS greater than 100 (Table 2.5), which might be due to solubility of calcium carbonate that contributes calcium during ammonium acetate leachate at pH 7. Similar research finding reported by Sekhar et al. (2014) who described that larger PBS observed due to high exchangeable Ca^{2+} ions occupying the soil exchange sites.

It is critical to know a soil's Ca: Mg ratio in order to assess the potential impact of calcium on Magnesium (Mg) and Phosphorus (P) uptake by plant roots. The analytical result of the soils in the surface horizon indicated that the Ca: Mg ratios were 27.79 and 5.89 for pedon 1 and 2, respectively, which are greater than 5:1. Thus, calcium may reduce the availability of both Mg and P (Landon, 2014). On the contrary, Engdawork (2015) suggested that the Ca: Mg ratio in most cases was above 3:1, representing the balance between the two mineral elements.

Potassium (K) availability depends on not only amount of exchangeable K^+ contents of the soil but also influenced by the relative amounts of other cations (Ca and Mg). The analytical result

of the soils in the surface horizon indicated that the K: Mg ratios were 5.19 and 0.12 for pedon 1 and 2, respectively (Table 2.5). The surface horizon of the second pedon had K: Mg ratio of 0.12: 1, which is lower than the treshhold value of 0.7:1 (Loide, 2004). Thus, Mg may reduce the availability of K (Laekemariam et al., 2016).

Table 2.5 Exchangeable bases, cation exchange capacity (CEC), percent base saturation (PBS), K: Mg, and Ca: Mg ratio of the soils in the pedons

Horizons	**Depth (cm)**	**Exchangeable bases and CEC ($cmol_c\ kg^{-1}$)**					**PBS**	**K: Mg**	**Ca: Mg**
		Ca	**Mg**	**K**	**Na**	**CEC**			
Dore Bafeno									
Ap	0-40	10.22	0.37	1.92	1.66	22	64.42	5.19	27.79
Bw1	40-80	13.10	0.70	2.33	1.75	32	55.89	3.33	18.66
Bw2	80-130	14.64	1.52	2.95	2.27	31	68.95	1.94	9.63
BC	130-200+	10.33	0.27	2.74	2.65	23	69.51	10.14	38.44
Bati Dubano									
Ap	0-20	37.29	6.95	0.86	0.56	62	73.66	0.12	5.90
A1	20-40	44.89	6.95	1.34	0.96	66	82.02	0.19	6.46
Bk1	40-100	49.90	6.46	1.07	0.73	62	93.82	0.16	7.72
Bk2	100-140	48.59	8.88	0.97	0.62	56	105.5	0.11	5.47
Btkg	140-200+	45.40	9.51	0.76	0.33	57	98.23	0.08	4.77

Currently, micronutrient deficiencies emerged as a new tricky to crop production in Ethiopia. Micronutrient deficiencies mainly Zn and Cu were widespread in different parts of the country (Yifru and Sofia, 2017). The results of this study showed that the available micronutrients such as Fe, Cu, and Zn were very low in the surface layers of both pedons, which are insufficient for crop production (Benton, 2003). Conversely, the surface layer of the two pedons contained an

adequate amount available Mn and considered as enough for crop production. Generally, in Dore Bafeno pedon, the available Fe and Zn distribution decreased consistently with profile depth, the maximum values were found in the surface than the subsurface layers. While Cu and Mn showed inconsistent trends along with profile depth. Therefore, the two experimental soils require application of fertilizers containing Fe, Cu, and Zn for better crop production.

Table 2.6 Micronutrient contents of the soils in the profiles of the study areas

Horizon	Depth (cm)	Available micronutrient ($mg\ kg^{-1}$)			
		Fe	Cu	Zn	Mn
Dore Bafeno					
Ap	0-40	1.83	0.17	0.70	1.03
Bw1	40-80	1.16	0.12	0.63	3.09
Bw2	80-130	0.31	0.18	0.39	1.55
BC	130-200+	0.25	0.05	0.36	0.42
Bati Dubano					
Ap	0-20	0.45	0.32	0.56	1.07
A1	20-40	0.69	0.20	0.18	0.44
Bk1	40-100	0.75	0.34	0.17	0.10
Bk2	100-140	0.57	0.25	0.15	0.27
Btkg	140-200+	0.31	0.75	0.21	0.13

2.3.4 Identification of the soil types

The soils of the study sites were identified according to World Reference Base Legend (IUSS Working Group, 2015) classification system based on the morphological, physical and chemical characteristics of the soils observed in the field and the results obtained from laboratory analyses. Soils of Dore Bafeno pedon had a texture of loam or finer, a clay increment up to 4%

observed just below the overlying horizon, which is not enough to represent it as an argic horizon. The profile had granular and subangular blocky structures at the surface and subsurface horizons, respectively. Moreover, the surface horizon is particularly characterized by way of a quite thick profile depth, very dark grey colored with a Munsell color value of ≤ 3 moist, and chroma of ≤ 3 moist, a high percent base saturation (> 50), and a medium content of organic carbon. These characteristics demonstrate a Mollic diagnostic epipedon. However, most of the subsurface horizons showed evidence of pedogenetic alteration, structural development and removal of carbonates or gypsum, absence of rock structure in over 50 % of the volume of the fine earth fraction and have a thickness > 15 cm. These properties qualify for Cambic horizon. Therefore, the soils is classified as **Cambisols** according WRB soil classification system (IUSS Working Group, 2015). Moreover, the profile had loamy and clay loam textural classes in a layers ≥ 30 cm thick, with the surface soils ploughed to a depth of ≥ 20 and OM content greater than 1% throughout the profile. These properties were suitable for clayic, aric and humic supplemental qualifiers, respectively. Therefore, the soil is classified as **Cambisol (Loamic, Aric, Humic).**

The surface horizon in Bati Dubano pedon is characterized by black colored with a Munsell color value of ≤ 3 moist, and chroma of ≤ 3 moist, weak, coarse, granular structure; friable consistency; clay textural class; low bulk density; neutral soil reaction; and ≥ 0.6% soil OC content, very high CEC, thickness ≥ 20 cm and a base saturation (> 50%) throughout the profile. These properties qualify for Mollic horizon. Thus, considering the morphological and analytical properties of the surface and subsurface horizons, the soils of the Bati Dubano site is classified as **Phaeozems** according WRB soil classification system (IUSS Working Group, 2015). The profile had mollic horizon < 20 cm thick to be classified as **Someric** principal qualifier.

Moreover, the profile had a textural class of clay throughout the profile and the surface soils ploughed to a depth of ≥ 20, these properties suitable for Pantoclayic and aric supplemental qualifier, respectively. Therefore, the soil is classified as **Someric Phaeozems (Pantoclayic, Aric).**

2.3.5 Pearson`s correlation coefficient analysis

Pearson`s correlation coefficient (r) was conducted to explore the magnitude and direction of the relationships among selected chemical properties of the soils in the pedons along its profile depths. In both pedons, soil reaction (pH) positively and significantly correlated to calcium carbonate concentration, suggesting that dawn ward movement of basic cations partcicularly Ca. Similarly, soil OC positively and significantly correlated with soil TN in both peofiles, suggesting that the OM was the major source for TN. In line with this result, Meysner et al. (2006) showed that as much as 93 to 97% of the total N in soils is closely associated with OC. Therefore, it may be imperative to maintain and increase the level of soil organic matter in the management of total nitrogen.

Table 2.7 Pearson`s correlation coefficient (r) between selected soil chemical properties of the two pedons Hawassa and Meskan districts of Southern Ethiopia. Upper right side for pedon 1 and lower left side for pedon 2

	pH	**EC**	**$CaCO_3$**	**OC**	**TN**	**Av. P**	**PBS**
pH	1	0.77	**0.97***	**-0.98***	**-0.99****	**-0.96***	0.43
EC	-0.03	1	0.64	-0.86	-0.73	-0.59	0.51
$CaCO_3$	**0.96****	0.21	1	-0.94	**-0.97***	**-1.0****	0.50
OC	-0.82	-0.18	**-0.91***	1	**0.95***	0.92	-0.59
TN	-0.81	-0.34	**-0.92***	**0.98****	1	**0.95***	-0.35
Av. P	-0.82	-0.42	-0.86	0.75	0.83	1	-0.50
PBS	0.83	0.32	**0.93***	**-0.98****	**-0.99*****	-0.83	1

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$; ns, not significant

2.4 Conclusion

In conclusion, two soil types were identified based on their morphological, physical and chemical characteristics observed in the field and the results obtained from laboratory analyses. The soil of Dore Bafeno pedon had a Mollic epipedon and a Cambic subsurface horizon, and this soil was classified as **Cambisol (Loamic, Aric, Humic).** However, Bati Dubano pedon had a Mollic surface horizon and a PBS (> 50) throughout the profile and classified as **Someric Phaeozems (Pantoclayic, Aric)**. The significant variations in the physicochemical properties of the studied soils, indicating site-specific soil management needs of each soil type to maintain soil organic matter and essential plant nutrients.

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CHAPTER THREE

Growth, Nitrogen Uptake of Maize (*Zea mays L.*) and Soil Chemical Properties, Responses to Compost, Nitrogen rates and their Mixture on Different soils

3. GROWTH, NITROGEN UPTAKE OF MAIZE (*Zea mays* L.) AND SOIL CHEMICAL PROPERTIES, RESPONSES TO COMPOST, NITROGEN RATES AND THEIR MIXTURE ON DIFFERENT SOILS

Abstract

Integrated nutrient management, that primarily involves the combined application of organic and inorganic nutrient sources, is one the simplest approach to handle declining soil fertility challenges and increase crop productivity and production. In view of this fact, a pot experiment was conducted to evaluate the effects of compost, inorganic nitrogen fertilizer and their mixture on soil properties, growth, and nitrogen uptake of maize on Cambisols and Phaeozems soil types at Awada Agricultural Research Sub-Center. Treatments comprised factorial combinations of five compost rates (0, 5, 10, 15, and 20 t ha^{-1}) and four rates of inorganic nitrogen fertilizer (0, 46, 92, and 138 kg N ha^{-1}), laid out as a completely randomized design with three replications. Results showed that both the main and interaction effects of compost and mineral N fertilizer rates significantly affected the selected soil chemical properties and yield, and nitrogen concentration of maize. There were significant associations between plant parameters and soil nitrogen contents. The addition of 92 kg ha^{-1} N + 10 t ha^{-1} compost and 46 kg ha^{-1} N + 10 t ha^{-1} compost were the best treatments for Cambisols and Phaeozems soil types of the study areas, which improved shoot dry matter by 179.5 and 284.5%, compared to the unfertilized pot, respectively. From the results of this experiment, we concluded that the integrated application of compost and mineral nitrogen fertilizer enhanced soil chemical properties and thus improved nitrogen uptake and sustainable production of maize in the study areas.

Keywords: Crop growth, maize shoot, soil properties, soil nitrogen, soil productivity.

3.1 Introduction

Soil is the most prominent natural resource that provides important ecological services for human beings, such as regulation of nutrient and water cycling, carbon sequestration, and preservation of biodiversity (Greiner et al., 2017). During the current past, the exploitation of natural resources is increased due to global population stress, particularly in arid and semiarid regions and thus become threatened for the sustainable farming system (Abbasi and Khizar, 2012). Widespread land degradation and low soil fertility are the major biophysical root causes of declining per-capita food production in Sub-Saharan Africa (Farouque and Tekeya, 2008). In the tropics, soil fertility management become a major concern of smallholder farmers to sustain their agricultural production (FAO, 2001). Thus, adopting context-specific soil management practices is crucial for sustainable agricultural productivities and environmental quality.

In Ethiopia, over 80% of the population depends on land for their livelihoods and nourishment (CSA, 2016), but 31% of their land resources are currently degraded (Spielman et al., 2009). In resource-limited farmers, soil fertility degradation has been the bottleneck to sustainable agricultural productivity (Negassa et al., 2004). According to Gelaw et al. (2014), loss of soil organic matter due to topsoil erosion along with poor physicochemical properties is the prominent causes for the deterioration of soil fertility and productivity. Balanced and careful use of external inputs together with eco-friendly and environmentally sounds soil management practices are essential issues for sustainable agriculture production (Kumar et al., 2015). Lal (2015) indicated that the implementation of improved soil management practices could affect the sustainable use of soil resources through their impacts on soil quality, stability, and resilience

to climate change. Therefore, restoring soil fertility through fertilizer application is essential to improve and maintain crop yields over a period.

Nitrogen (N) is a universally deficient element in almost all the agricultural soils and cropping systems of the world (Mohan et al., 2015). Among cereals, maize required an adequate amount of nutrients particularly N for optimum growth and yield (Agba and Long, 2005). Limited nitrogen could exert a substantial effect on maize crop yield and yield components as the plant would remain small and rapidly turn yellow (Kogbe and Adediran, 2003). Previous studies indicated that maize grain yield significantly increased by about 43-68%, due to N (Ogola et al., 2002). Therefore, nitrogen management in the maize cultivation system is one of the major concerns, as it is the most yield-limiting element (Blumenthal et al., 2008; Baral and Abhikari, 2015).

In modern agriculture, intensive cultivation through extreme use of chemical fertilizers considered as a means to boost crop yields and thus demonstrated as a convenient soil management option than the use of organic inputs. However, extreme use of chemical fertilizers brought several soil fertility problems, including soil acidity (Sheng et al., 2016), soil structure and quality deterioration, and low nitrogen use efficiency (Feng and Zhu, 2017). The destructive effects of chemical fertilizers, together with unaffordable price expenses, have led to use of organic inputs as a source of nutrients (Hepperly et al., 2009). Organic inputs like farm yard manure (FYM), compost, or manure can contribute to the organic components of the soil, thereby improving friability, water-holding capacity, and cation exchange capacity of the soil. Amending soils with organic fertilizers have positive effects on the soil productivity and quality (Agegnehu and Amede, 2017; Zhao et al., 2016). Fereidooni et al. (2013) observed that the

addition of organic inputs improved the soil physical properties, which leads to a better environment for root development, water retention, nutrient exchange and soil health. Hence, the usage of locally available organic resources in agricultural soil is crucial to improve and sustain crop productivity.

However, the use of organic inputs individually as a substitute for inorganic fertilizer is not sufficient to increase crop yields and satisfy the food needs of humankind since organic fertilizers are of a slow-release nature and will not fully deliver the required quantities of nutrients via plants (Fereidooni et al., 2013). Hence, the integrated application of organic and inorganic fertilizer inputs is the most convenient nutrient management method to increase nutrient synchrony and decreases losses of nutrients through leaching (Kramer et al., 2002). The combined application of organic and inorganic fertilizer inputs is important to improve soil fertility, crop productivity, nutrient use efficiency, and protect soil health (Agegnehu and Amede, 2017). Earlier studies also proved that the positive effect of the integrated application of organic and inorganic N sources, in supporting higher growth and yield of maize (Amoah et al., 2012; Solomon and Jafer, 2015). Several fields and greenhouse studies showed that sustainable crop yields are possible with combined application of organic and inorganic inputs (Adamu et al., 2015; Agegnehu et al., 2015; Abdulrahman et al., 2016). Furthermore, the cost of inorganic fertilizers has been decreased by 25% (Bokhtiar and Sakurai, 2005) and 50% (Kiani et al., 2005) when integrated organic and inorganic inputs are applied. Therefore, the combined use of organic and synthetic fertilizers has considerable importance as to take corrective measures in soil fertility improvement, sustainable crop productivity, and economic viability.

Although studies at the separate impacts of organic and synthetic fertilizer inputs on crop growth, yield, and soil characteristics were undertaken, facts at the combined consequences of compost and inorganic nitrogen fertilizer on soil properties, growth, and yield and nitrogen uptake of maize in the study areas are generally inadequate. In addition to these, maize is an intensively cultivated cereal crop in Hawassa Zuria, and Meskan districts, however, site-specific soil and crop response to integrated organic and inorganic fertilizer input studies not yet properly executed. Therefore, a pot study was conducted to evaluate the effects of compost, inorganic nitrogen fertilizer, and their mixture on maize growth, yield and nitrogen uptake and soil properties; and to determine optimum integrated organic and inorganic N-rates for each soil type of the area. We hypothesized that the application of integrated organic and inorganic nitrogen fertilizer will improve soil properties, growth, yield, and yield components.

3.2 Materials and Methods

3.2.1 Characterization of the experimental soil and compost

Bulk surface soils (0-20 cm) were collected from two farmer fields (Anchamo maize farm in Hawassa Zuria District, 07° 1' 0.83" N and 38° 22' 26" E; and Nasri maize farm in Meskan District, 08° 05' 33" N and 38° 26' 75" E; in Southern Ethiopia. The experimental soils are loam and clay textured for Hawassa Zuria and Meskan, respectively. Earlier to planting, three sub-samples were taken from each soil type for physicochemical analysis. The collected soil samples were air-dried and sieved with 2-mm sieve; however, a 0.5 mm sieve was used for the determinations of organic carbon and total nitrogen.

The compost was prepared at the Wondo Genet Agriculture Research Center botanical backyard using locally available composting materials such as green leaves, farmyard manure, fresh and dry cow dungs, and animal feed remains from dairy cattle, and wood ash. A homogenized mixture of composting materials was composted in pits of 2 m × 1.5 m wide by 1.5 m deep. The composting materials were placed in alternate layers, starting with a maize stover material at the bottom layer. All recommended management practices were operated as required until the materials were ready for use. Three representative compost subsamples were taken to analyses pH, EC, OC, TN, Avail-P, and C: N ratio. The samples were air-dried, ground, and sieved through a 2 mm sieve, whereas a 0.5 mm sieve was used for determinations of OC and TN. The selected chemical properties of the compost used in this study are presented in Table 3.1.

The particle size was determined by hydrometer method using one percent sodium hexameter phosphate as a dispersing agent and the textural class was determined using the USDA textural

triangle (Sahilemedihin and Taye, 2000). The pH (H_2O) was determined in a 1: 2.5 soil to water ratio using a pH meter whiles the electrical conductivity was determined in a 1: 5 soils to water ratio using a conductivity meter as outlined by Sertsu and Bekele (Sahilemedihin and Taye, 2000). Soil Organic carbon (OC) was determined following the Walkley and Black wet oxidation method (Walkley and Black, 1934), soil total nitrogen by the Kjeldahl method (Van Reeuwijk, 1992). Available phosphorus (Avail-P) inside the soil was determined using the sodium bicarbonate solution extraction (pH 8.5) method and the quantity was measured using a spectrophotometer at 880 nm as defined by way of Olsen et al. (1954), cation exchange capacity (CEC) by saturating the soil with a neutral 1M NH_4OAc (ammonium acetate) method at pH 7 (Van Reeuwijk 1992). The selected soil physicochemical properties before treatment application are presented in Table 3.1.

Table 3.1 Selected physico-chemical properties of the soils and compost prior to treatment application

Soil properties	**Units**	**Soil**				**Compost**
		Hawassa Zuria site (Cambisols)		**Meskan site (Phaeozems)**		
		Mean	**SD**	**Mean**	**SD**	
Physical properties						
Sand	%	41.30	± 1.15	16.00	± 2.00	-
Silt	%	33.40	± 1.15	36.00	± 3.46	-
Clay	%	25.30	± 1.15	48.00	± 2.00	-
Textural class	-	Loam		Clay		-
Chemical properties						
pH	-	5.91	± 0.08	6.80	± 0.44	6.79
EC	dS/m	0.03	± 0.00	0.06	± 0.01	0.09
OC	%	2.55	± 0.14	3.98	± 0.45	14.80
TN	%	0.26	± 0.01	0.35	± 0.03	1.21
C: N	-	9.80	± 0.44	11.45	± 1.91	12.23
Avail-P	mg kg^{-1}	4.36	± 0.16	22.69	± 3.01	77.1
CEC	$cmol_c$ kg^{-1}	21.47	± 1.29	62.00	± 2.65	-

3.2.2 Experimental procedure

A greenhouse experiment was conducted at Awada Agricultural Research Sub-Center in Sidama Zone, Southern Ethiopia, from October 1 to November 22/2019. The plastic pot used for this trial had a 23 cm upper and 19.2 cm lower diameter, a depth of 19.5 cm, and a total volume of proximately 6833.5 cm^3 and perforated at the bottom for drainage outlets. Two kg of air-dried soil was placed in each pot after being screened through a 6 mm sieve. The treatments comprised factorial combinations of five levels of compost (0, 5, 10, 15, and 20 t ha^{-1}) and four rates of inorganic nitrogen fertilizer (0, 46, 92, and 138 kg N ha^{-1}), laid out in a completely randomized design (CRD) with three replications. The organic rates (compost) were based on the respective inorganic N equivalence of 0, 25, 50, 75, and 100%; the aim was to reach a fertilization rate equivalent in N to those applied to the pots that received mineral fertilization.

The soil moisture within the pots was kept close to field capacity until seed sowing i.e., for 10 days to allow the organic amendment to mix properly with the soil. Four maize (*Zea mays* L.) seeds of var. Bako hybrid (BH-546) were sown per a pot at a depth of 3 cm. The entire quantity of phosphorus fertilizer (triple superphosphate) was applied uniformly to all pots except the control at the rate of 20 kg P ha^{-1}. The calculated dose of nitrogen containing fertilizer (Urea) was applied at sowing as per treatment. Thinning of the crop was done about eight days after sowing leaving two plants per pot to maintain a uniform plant stand in all experimental units. Crop was irrigated carefully considering the field capability of each soil type with the aid of the given formula: Field capacity multiplied by the amount of soil in the pot. Other crop management practices were made uniformly on all pots to keep away from the competition of

weeds and keep free from insects, pests, and disease attacks. Moreover, the visual observation was used to identify any ordinary signs and symptoms.

3.2.3 Data collection

At the end of the experiment, soil samples were collected from each pot, then the samples were combined as per treatments, making a bulk sample, after manual homogenization, representative composite sub-samples per treatment and site were prepared for selected chemical analysis.

3.2.4 Measuring plant growth parameters and nitrogen content

Plant height was measured at fifty-two days after sowing with the aid of a meter rod from the soil surface to the top of the plant and their mean was used for computation. The number of leaves per plant (NLPP) was counted at 52 days after sowing. Normalized difference vegetative index (NDVI) value was measured using a Green Seeker ^{TM} Handheld Optical Sensor Unit (NTech Industries, Inc., USA) on weeks 4, 5, and 6 after sowing, and their means were used for computation. Stem girth was measured 52 days after sowing, using a digital caliper. The aboveground parts of the plant were harvested 52 days after sowing at the soil level and their fresh weights were taken using an electronic sensitive balance. Similarly, the root parts were carefully separated and cleaned using water and weighed. Air-dried shoots and roots parts of the plants were oven-dried independently at 65 ^{0}C to constant weight and measured using an electronic sensitive balance. After oven drying, the shoot samples were milled to bypass via a 0.5 mm sieve, and the tissue nitrogen concentration was determined by the Kjeldahl procedure after wet digestion using H_2SO_4/H_2O_2. The TN concentration/uptake was calculated by multiplying the nitrogen concentration in the tissue with the total shoot dry weight (kg pot $^{-1}$) of maize, as presented in the equation below (Wu et al., 2011).

$$Total\ nitrogen\ content\ (mg/pot) = \left\{nitrogen\ concentration\ in\ tissue\left(\frac{mg}{kg}\right) * Shoot\ dry\ matter\ yield\ \left(\frac{Kg}{pot}\right)\right\}$$

3.2.5 Statistical analysis

Prior to the analysis of variance (ANOVA), the assumption of normality was checked using Shapiro-Wilk normality test, then the collected data was exposed to the analysis of variance following the general linear model procedure (PROC GLM) of SAS 9.3 software package (SAS, 2014). The following model was used to compute the general variability of the trait:

$$Y_{ijk} = \mu + R_i + C_j + N_k + CN_{(jk)} + e_{ijk}$$

Where Tijk is total observation, μ = grand mean, Ri is the effect of the ith replication, Cj is the effect of the jth compost level, Nk is the effect of the kth nitrogen rate, CN is the interaction, and eijk are the differences due to random error. Differences among treatments were separated with the protected least significant difference (LSD) at $P \leq 0.05$ probability level. The principal component analysis (PCA) was executed using SAS PRINCOMP procedure. Pearson correlation coefficient (r) was performed using SAS software 9.3 (SAS, 2014). All graphs were designed using Sigma Plot 14.0 procedures.

3.3 Results and Discussion

3.3.1 Soil properties before treatment application

The initial physicochemical properties of the soils at Hawassa Zuria showed that sand separate dominates the experimental soil (41.3%) followed by silt (33.4%) and clay (25.3%) rated as high and moderate according to Hazelton and Murphy (2007) and classified as loam in texture. While in Meskan soil, clay particles (48%) dominated the mineral fraction followed by silt (35%) and sand (17%) rated as high, moderate, and low, respectively, and classified as clay in texture. According to Benton (2003), the soil pH (H_2O) was (5.9) at Hawassa Zuria and 6.8 at Meskan, which are moderately acidic and neutral, respectively. Organic carbon contents were 2.55 and 3.98% for Hawassa Zuria and Meskan soils, respectively, and rated as medium and high respectively (Landon, 2014). The higher carbon contents may contribute to the greater total soil nitrogen at the Meskan site as compared to Hawassa Zuria soil. The available phosphorus content of the soils was 4.36 and 22.69 mg kg^{-1} in Hawassa Zuria and Meskan, respectively, and rated as low and extremely high (Havlin, 1999). Generally, the soil analysis results prior to treatment application indicated that the nitrogen content of the soils was in medium range. Hence, medium soil total nitrogen levels indicate that the experimental soils require the addition of external nitrogen-containing inputs to restore and maintain their fertility status.

3.3.2. Effects of compost and nitrogen fertilizer rates on selected soil chemical properties

In both soil types, after harvest, soil reaction in water (pH), soil organic carbon, total nitrogen, and avail- P significantly responded to the treatments (Table 3.2; Figs. 3.1 and 3.2). Soil reaction in water (pH) was significantly increased from 5.8 to 6.4 in Hawassa Zuria soil and 6.9 to 7.3

in Meskan soil due to the treatments, with the highest being from the application of 15 t ha^{-1} compost and 92 kg ha^{-1} N + 15 t ha^{-1} compost for Hawassa Zuria and Meskan soils, respectively. In contrast, the unfertilized (control) treatment yielded the lowest value (Table 3.2). In Hawassa Zuria and Meskan soils, the addition of compost at the rate of 15 t ha^{-1} improved the soil reaction (pH) by 10.3 and 5.8% respectively compared to the control treatment, suggesting basic cations added to the soil solution through the decomposition of compost. This shows that the application of compost had a positive effect on improving the soil reaction as compared with synthetic nitrogen fertilizer. Previous research has proven that the addition of animal manure has the capacity to preserve and raise soil reaction (pH) (Dhillon et al., 2018).

Likewise, the integrated use of compost and inorganic nitrogen fertilizer had a significant effect on soil organic carbon (Fig. 3.1 and 3.2). In both soil types, the maximum soil OC was achieved from the addition of 20 t ha^{-1} compost and 138 kg ha^{-1} inorganic N, while the minimum OC was obtained from the control treatment (Fig. 3.1 and 3.2). The results of the current study revealed that OC content of the soils was significantly improved with the addition of compost. This could be due to the properties of compost, which act as the storehouse of diverse plant nutrients and increased microbial biomass carbon. Dhillon et al. (2018) made a comparable remark and stated that organic inputs were influential in improving and sustaining soil OC as compared to inorganic N sources. Hafidi et al. (2012) described that the sole use of manure or in mixture with mineral fertilizer resulted in higher soil organic carbon content than the sole application of mineral fertilizers.

In both soil types, the addition of compost and inorganic nitrogen fertilizer also significantly improved the total nitrogen content (Fig 3.1 and 3.2). The highest soil TN 0.29% and 0.44% for

Hawassa Zuria and Meskan soil were recorded with the integrated addition of the highest rate of inorganic N and compost, suggesting additional N released from compost through decomposition and mineralization process. Preusch et al. (2002) reported that composts affected soil N mineralization because of the presence of strong N compounds found in it. However, the lowest soil TN (0.2%) was obtained from 20 t ha^{-1} compost, which is statistically at par with the control (Fig. 3.1a). The reason for this could be the immobilization of N released from compost for a short time by soil microorganisms with the absence of inorganic N as a substrate for them, which is similar to the outcomes of an earlier study (Agegnehu et al., 2015). Likewise, Yan et al. (2007) stated that inorganic N fertilizer influences most soil biological processes, which is vital in mineralization and nutrient transformation. In general, compost addition positively affects the accessibility of inherent or applied nutrients as compared with the unfertilized (control) and application of inorganic N fertilizer only.

In both soil types, the separate and combined addition of compost and inorganic nitrogen treatments showed significant influences on the available phosphorus contents of the soils. In Hawassa Zuria soil, the available phosphorus was low and ranged from 2.57 to 5.23 mg kg^{-1} (Table 3.2). Whereas in Meskan soil available phosphorus was very high and fluctuated from 17.36 to 29.59 mg kg^{1}, where the soil pH was neutral, the neutral pH has low P fixation power. In the current study, the addition of inorganic N fertilizer along with 10, 15, and 20 t ha^{-1} compost rates significantly improved soil avail-P, suggesting additional P supplemented with compost through decomposition and mineralization process. This argument is consistent with the findings of Sarwar et al. (2008) who described that combined application of compost and NPK mineral fertilizers significantly improved soil avail-P. In Hawassa Zuria soil with the absence of inorganic nitrogen, available soil P concentration showed a decreasing trend despite

using equal amount of P on all experimental units. The reason for this could be immobilization of P by soil microorganisms with the absence of inorganic N as a substrate for them; moreover, phosphorus immobilization is great in soils having amorphous Fe and Al hydroxides and allophane, which is the typical property of Andisols.

Table 3.2 Interaction effects of different compost and inorganic nitrogen rates on soil pH, and available soil P after crop harvest

N (kg ha ^{1})	Hawassa Zuria soil					Meskan Soil				
	Compost rates (t ha ^{1})									
	0	5	10	15	20	0	5	10	15	20
	soil pH									
0	5.80^{e}	5.90^{de}	5.90^{de}	6.40^{a}	6.20^{b}	6.90^{d}	6.90^{d}	7.00^{cd}	7.10^{bc}	7.00^{cd}
46	5.90^{de}	6.00^{cd}	6.00^{cd}	6.20^{b}	6.00^{cd}	7.10^{bc}	7.10^{bc}	7.10^{bc}	7.20^{ab}	7.20^{ab}
92	6.00^{cd}	6.00^{cd}	6.00^{cd}	6.10^{bc}	6.20^{b}	7.10^{bc}	7.00^{cd}	7.10^{bc}	7.30^{a}	7.20^{ab}
138	6.10^{bc}	5.90^{de}	5.90^{de}	6.10^{bc}	6.10^{bc}	7.20^{ab}	7.10^{bc}	7.10^{bc}	7.20^{ab}	7.10^{bc}
LSD (0.05)			**0.135**					**0.13**		
	Avail- P (mg kg^{-1})									
0	3.26^{k}	2.72^{l}	3.36^{j}	2.57^{m}	2.67^{l}	17.36^{i}	17.70^{hi}	19.33^{g}	18.96^{gh}	18.81^{g}
46	3.56^{i}	3.66^{h}	4.50^{d}	5.23^{a}	4.77^{c}	18.80^{gh}	20.30^{fg}	22.12^{def}	23.66^{bcd}	21.48^{ef}
92	3.76^{g}	4.30^{e}	4.85^{b}	4.90^{b}	4.70^{c}	18.90^{gh}	21.40^{ef}	24.00^{bcd}	24.35^{bc}	28.81^{a}
138	3.51^{i}	4.04^{f}	4.04^{f}	4.85^{b}	4.73^{c}	18.70^{gh}	22.50^{cde}	21.43^{ef}	29.58^{a}	25.09^{b}
LSD (0.05)			**0.066**					**2.06**		

Within the columns, means followed by the same letter(s) are not significantly different at $P \leq 0.05$ (LSD).

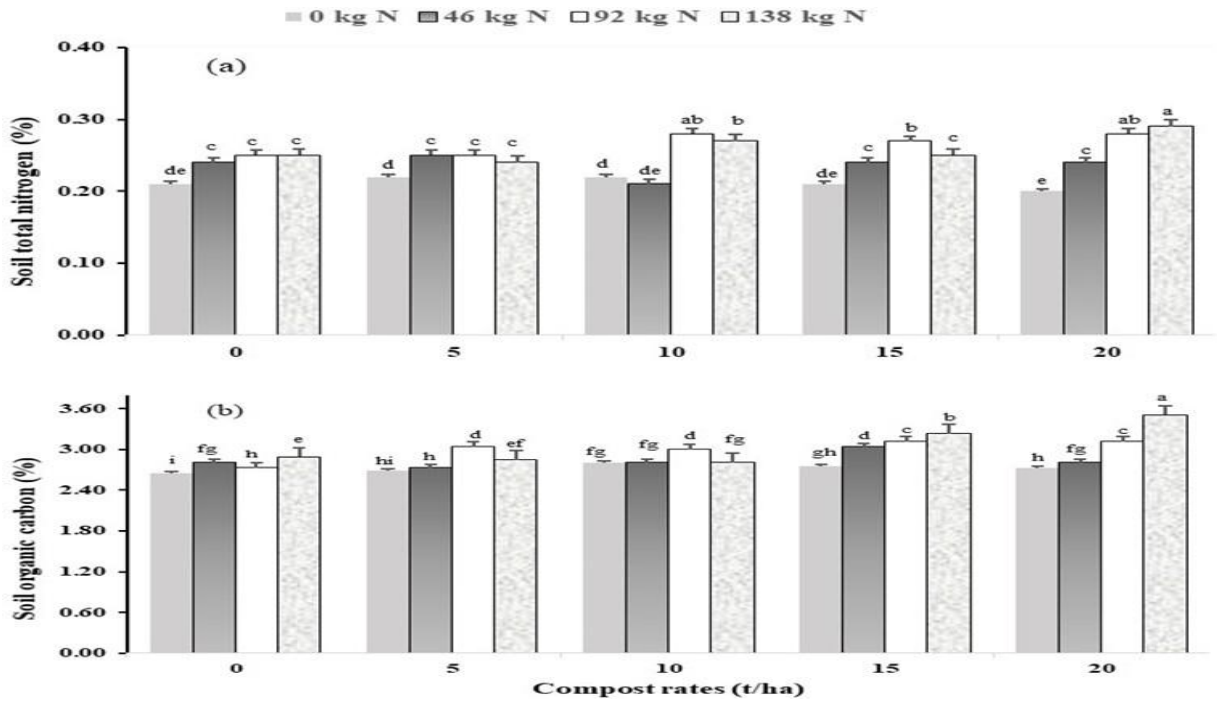

Figure 3.1. Effects of inorganic nitrogen and compost rates on soil total nitrogen (a) and organic carbon (b) after crop harvest in Hawassa Zuria soil. Different letters imply significanct difference between treatments at P≤ 0.05 (LSD).

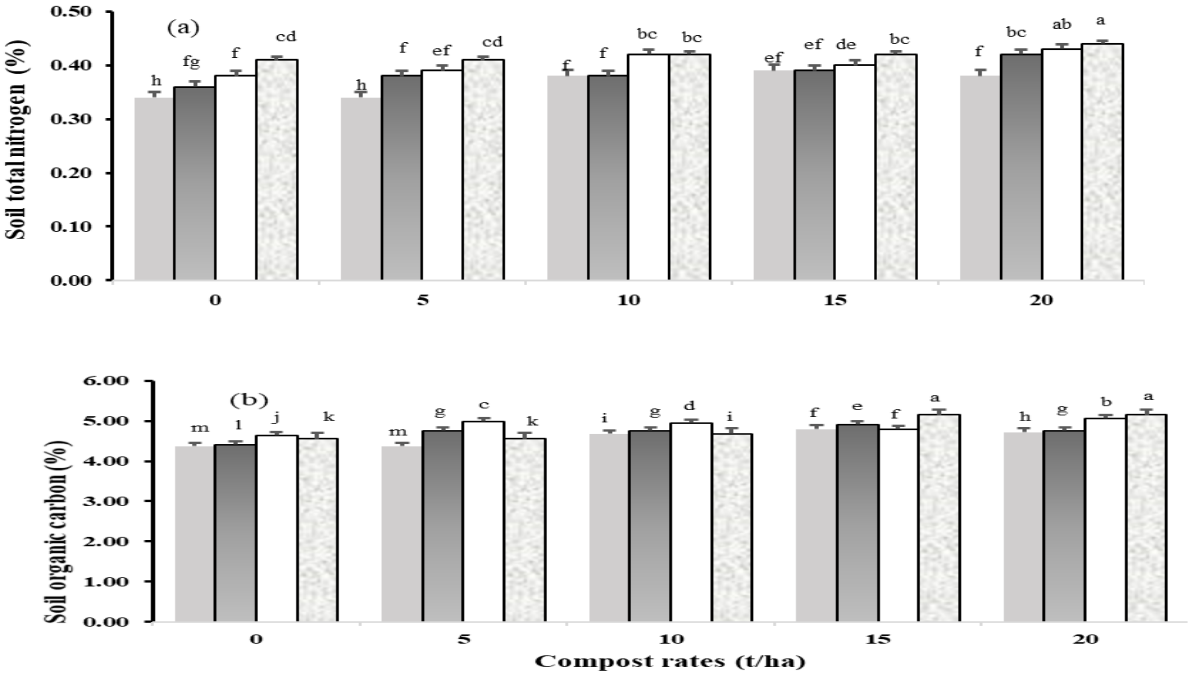

Figure 3.2. Effects of inorganic nitrogen and compost rates on soil total nitrogen (a) and organic carbon (b) after crop harvest in Meskan soil. Different letters imply significanct difference between treatments at P≤ 0.05 (LSD).

3.3.3 Effects of compost and inorganic nitrogen rates on maize growth

The result of this analysis shows that the main and interaction effects of inorganic N fertilizer and compost significantly affected maize plant height (Table 3.3). In Hawassa Zuria soil, the tallest plant height (76.8 cm) of maize was obtained from the combined application of 138 kg ha^{-1} N and 10 t ha^{-1} compost, which is statistically comparable with 138 kg ha^{-1} N + 10 t compost ha^{-1} and 92 kg ha^{-1} N + 15 t compost ha^{-1}. Whereas in Meskan soil the tallest plant height, (73.67 cm) was achieved from the integrated application of 46 kg ha^{-1} N and 10 t ha^{-1} compost followed by 92 kg ha^{-1} N and 10 t ha^{-1} compost. However, the unfertilized pot (control) gave the shortest plant height of maize in both soil types. The addition of 138 kg ha^{-1} N and 10 t ha^{-1} compost and 46 kg ha^{-1} N and 10 t ha^{-1} compost increased maize plant height by 51.2 and 46.4% above the control in Hawassa Zuria and Meskan soils, respectively, which could be due to enhanced nutrient availability and uptake. This is consistent with the findings of Agegnehu et al. (2015), who suggest that the combined use of biochar, compost, and inorganic fertilizer significantly improved maize plant height compared to the individual application. Shisanya et al. (2009) also reported similar observations in their experiment.

In both soil types, nitrogen levels by compost interaction significantly increased number of leaves per plant. The maximum number of leaves per plant was recorded from the incorporated use of 138 kg ha^{-1} N and 10 t ha^{-1} compost and 92 kg ha^{-1} N and 5 t ha^{-1} compost at Hawassa Zuria and Meskan soils, respectively (Table 3.3). However, the minimum number of leaves per plant was recorded from the unfertilized pot in both soil types (Table 3.3). This could be because nitrogen encouraged vegetative growth in maize. This result agrees with the findings of Adamu

et al. (2015) who stated that integrated use of compost and N fertilizer produced maximum leaf numbers per plant.

Table 3.3 Interaction effects of different inorganic nitrogen and compost rates on plant height and number of leaves per plant

N (kg ha^{-1})	Hawassa Zuria soil					Meskan Soil				
	Compost rates (t ha^{-1})									
	0	5	10	15	20	0	5	10	15	20
	Plant height (cm)									
0	50.8^{i}	59.50^{h}	67.7^{cde}	68.3^{cde}	69.5^{cd}	50.3^{i}	60.7^{efg}	61.5^{efg}	50.8^{i}	56.0^{h}
46	68.3^{cde}	61.4^{gh}	71.8^{bc}	64.0^{efg}	69.5^{cd}	59.0^{gh}	62.8^{ef}	73.7^{a}	63.7^{de}	68.7^{bc}
92	67.5^{cde}	70.5^{cd}	71.7^{bc}	75.2^{ab}	69.2^{cd}	68.3^{bc}	69.5^{bc}	71.8^{ab}	66.8^{cd}	68.0^{c}
138	67.7^{cde}	76.7^{a}	76.8^{a}	66.7^{def}	63.0^{fgh}	68.7^{bc}	59.0^{gf}	59.5^{fgh}	58.1^{gh}	61.3^{efg}
LSD (0.05)			**4.39**					**3.59**		
CV (%)			**3.92**					**3.45**		
	Number of leaves per plant									
0	7.2^{c}	7.5^{c}	7.17^{c}	7.67^{bc}	7.67^{bc}	7.67^{d}	8.33^{abc}	8.00^{bcd}	8.17^{abcd}	8.33^{abc}
46	7.8^{abc}	7.5^{c}	7.50^{c}	7.17^{c}	7.50^{c}	8.50^{ab}	7.83^{cd}	8.33^{abc}	8.33^{abc}	7.83^{cd}
92	7.3^{c}	7.8^{abc}	7.67^{bc}	8.00^{abc}	7.83^{abc}	8.50^{ab}	8.67^{a}	8.33^{abc}	8.33^{abc}	8.17^{abcd}
138	7.8^{abc}	8.7^{ab}	8.83^{a}	8.17^{abc}	7.67^{bc}	8.50^{ab}	8.50^{ab}	8.33^{abc}	7.67^{d}	8.17^{abcd}
LSD (0.05)			**1.03**					**0.59**		
CV (%)			**8.10**					**4.39**		

Means followed by the same letter(s) within a column are not significantly different at $P \leq 0.05$ (LSD).

The results of this study showed that nitrogen and compost application at different rates had a significant effect ($p < 0.05$) on the mean normalized difference vegetative index (NDVI). The maximum NDVI values 0.74 in Hawassa soil and 0.76 in Meskan soil were obtained from 138 kg ha^{-1} N +10 t ha^{-1} compost and 92 kg ha^{-1} N + 10 t ha^{-1} compost, respectively (Table 3.4). However, the minimum NDVI value was recorded in the control treatment (Table 3.4). The addition of 138 kg ha^{-1} N +10 t ha^{-1} compost for Hawassa Zuria soil and 92 kg ha^{-1} N + 10 t ha^{-1} compost for Meskan soil improved NDVI value by 29 and 25%, as compared to the control treatment. In the current study, the integrated use of compost and inorganic N fertilizer increased NDVI values in general, possibly nitrogen availability in the soil and uptake by plant enhanced

due to compost amendment. Similar results reported by Alchanatis et al. (2005) on maize leaf reflectance (near 550 nm wavelength) described there is a strong association between NDVI and soil nitrogen contents. Based on the results, we make the following observation: the effect of inorganic N rates on NDVI was more than the compost, when inorganic N increased from zero- to 138 kg ha^{-1} N the mean NDVI also consistently improved. However, the change owing to the application of compost rates was minimal and inconsistent (Table 3.4).

Analysis of variance revealed that stem girth was differed significantly among the fertilizer treatments in both soil types. The maximum stem girth of 1.61 cm was gained from the combined application of 138 kg ha^{-1} N + 10 t ha^{-1} compost in Hawassa soil, which is statistically at par with 92 kg ha^{-1} N + 10 t ha^{-1} compost and 92 kg ha^{-1} N + 15 t ha^{-1}, respectively. Whereas in Meskan soil, the addition of 92 kg ha^{-1} N + 10 t ha^{-1} compost produced wider stem girth, which is statistically at par with 92 kg ha^{-1} N + 5 t ha^{-1} compost. Both soil types, however, the narrower stem girth was produced from the unfertilized pot (control). Adamu et al. (2015) reported similar results in their experiments, which suggest that the integrated use of organic and inorganic nitrogen sources is prominent to plant growth, yield, and yield components.

Table 3.4 Interaction effects of different inorganic nitrogen and compost rates on normalized difference vegetative index and stem girth

N (kg ha ^{1})	Hawassa Zuria soil					Meskan Soil				
	Compost rates (t ha ^{1})									
	0	5	10	15	20	0	5	10	15	20
	NDVI									
0	0.57^{i}	0.63^{fgh}	0.62^{gh}	0.63^{efg}	0.66^{cde}	0.59^{i}	0.67^{ef}	0.66^{efg}	0.63^{h}	0.64^{gh}
46	0.68^{bc}	0.68^{bc}	0.60^{h}	0.66^{cde}	0.60^{h}	0.65^{fgh}	0.67^{ef}	0.67^{ef}	0.71^{bc}	0.67^{ef}
92	0.65^{cdef}	0.65^{defg}	0.70^{b}	0.68^{bc}	0.64^{defg}	0.72^{bc}	0.7^{bc1}	0.76^{a}	0.74^{a}	0.68^{de}
138	0.67^{cd}	0.71^{b}	0.74^{a}	0.67^{cd}	0.64^{efg}	0.68^{de}	0.70^{cd}	0.72^{abc}	0.70^{cd}	0.71^{c}
LSD (0.05)	**0.03**					**0.02**				
CV (%)	**2.64**					**2.07**				
	Stem girth diameter (cm)									
0	1.04^{f}	1.2d^{ef}	1.13^{ef}	1.28^{cde}	1.44^{abc}	1.11^{i}	1.21^{fghi}	1.30^{defg}	1.21^{fghi}	1.14^{hi}
46	1.42^{abc}	1.50^{ab}	1.27^{cde}	1.21^{def}	1.36^{bcd}	1.3^{defg}	1.37^{cde}	1.38^{cde}	1.37^{cde}	1.08^{i}
92	1.29^{cde}	1.45^{abc}	1.40^{bc}	1.45^{abc}	1.3^{bcde}	1.3^{efgh}	1.57^{ab}	1.62^{a}	1.17^{ghi}	1.17^{ghi}
138	1.31^{cde}	1.42^{abc}	1.61^{a}	1.44^{abc}	1.41^{bc}	1.3^{efgh}	1.37^{cde}	1.32^{def}	1.51^{abc}	1.44^{bcd}
LSD (0.05)	**0.19**					**0.15**				
CV (%)	**8.50**					**6.89**				

Means followed by the same letter(s) within a column are not significantly different at $P \leq 0.05$ (LSD) test.

The main and interaction effects of nitrogen and compost rates significantly affected shoot and root dry weights (Table 3.5), but the magnitude of the effects was not usually analogous. The maximum shoot dry weight of maize in Hawassa soil was achieved at the integrated application of 138 kg ha^{-1} N + 10 t ha^{-1} compost, which is statistically similar with 92 kg ha^{-1} N + 10 t ha^{-1} compost, while the unfertilized treatment gave the minimum value. The shoot dry biomass obtained from 138 kg ha^{-1} N + 10 t ha^{-1} compost and 92 kg ha^{-1} N + 10 t ha^{-1} compost treatments, respectively, were 1.85 and 1.79 times that of the unfertilized treatment (Table 3.5). In Meskan soil, the addition of 92 kg ha^{-1} N + 10 t ha^{-1} compost treatment produced superior shoot dry weight, which is statistically at par with 46 kg ha^{-1} N + 10 t ha^{-1} compost. In this soil, the shoot dry biomass produced from the addition of 92 kg ha^{-1} N + 10 t ha^{-1} compost and 46 kg ha^{-1} N + 10 t ha^{-1} compost treatments, respectively, were 2.85 and 2.73 times that of the control (Table 3.5). The increase in shoot dry biomass from the integrated treatments could be ascribed to

enhanced root development and nutrient uptake caused by compost application along with inorganic nitrogen. Various researchers reported similar results (eg., Agegnehu et al., 2015) which stated that the combined application of inorganic and organic nutrient sources produced significantly greater biomass as compared with sole application of inorganic or organic nutrient sources.

Similarly, application of different fertilizer treatments significantly affected root dry biomass, where the maximum root dry weight values obtained from 138 kg ha^{-1} N + 15 t ha^{-1} compost and 92 kg ha^{-1} N + 10 t ha^{-1} compost treatments in Hawassa Zuria and Meskan soils, respectively (Table 3.5). In this trial, the greater shoot and root dry biomass obtained from the combined use of compost and inorganic nitrogen fertilizer might be due to the positive effect of compost in improving soil physical properties, slowing mineralization, and nutrient release, and thus increasing the efficiency of inorganic fertilizer. Previous studies also suggested that the combined use of compost and inorganic nitrogen fertilizer could be a better option for soil fertility improvement and subsequently yield and yield components (Agegnehu et al., 2015; Solomon and Jafer, 2015).

Table 3.5 Effects of different nitrogen levels and compost rates on the shoot dry weights, root dry weights and relative shoot dry matter.

Treatments	Hawassa Zuria soil			Meskan Soil		
	RDW (g/pot)	**ASDW (g/pot)**	**RSDM (100%)**	**RDW (g/pot)**	**ASDW (g/pot)**	**RSDM (100%)**
Control	6.70^{cdefgh}	14.65^{j}	100.00	5.90^{j}	10.88^{i}	100
$N_0 + Com_5$	7.64^{abcd}	15.94^{ij}	108.78	7.16^{fghi}	16.76^{h}	154.04
$N_0 + Com_{10}$	5.99^{fghi}	15.02^{j}	102.50	6.69^{hij}	17.38^{gh}	159.77
$N_0 + Com_{15}$	7.55^{abcde}	16.54^{hij}	112.92	7.21^{fghi}	19.94^{fg}	183.24
$N_0 + Com_{20}$	6.79^{cdef}	18.06^{fghig}	123.30	6.05^{j}	22.61^{ef}	207.81
$N_{46} + Com_0$	5.71^{ghi}	18.25^{efghig}	124.57	7.32^{fgh}	25.06^{cde}	230.30
$N_{46} + Com_5$	6.37^{defgh}	19.77^{efghig}	134.97	9.25^{ab}	26.10^{bcd}	239.92
$N_{46} + Com_{10}$	6.44^{defgh}	18.21^{efghig}	124.32	6.73^{hijk}	29.74^{a}	273.32
$N_{46} + Com_{15}$	5.62^{ghi}	17.46^{ghij}	119.20	8.28^{cde}	28.75^{ab}	264.25
$N_{46} + Com_{20}$	5.20^{i}	22.35^{bcdef}	152.56	6.31^{ij}	24.14^{de}	221.90
$N_{92} + Com_0$	7.06^{bcdef}	21.09^{cdefg}	143.98	8.74^{bcd}	28.83^{ab}	264.98
$N_{92} + Com_5$	7.15^{bcdef}	22.65^{bcde}	154.61	7.87^{def}	30.61^{a}	281.34
$N_{92} + Com_{10}$	6.68^{cdefgh}	26.29^{ab}	179.48	9.78^{a}	30.95^{a}	284.47
$N_{92} + Com_{15}$	7.79^{abc}	24.21^{abcd}	165.28	6.69^{hij}	28.08^{abc}	258.12
$N_{92} + Com_{20}$	6.09^{fghi}	20.76^{cdefgh}	141.73	9.02^{abc}	24.14^{de}	221.88
$N_{138} + Com_0$	7.03^{bcde}	24.25^{abc}	165.51	8.82^{bc}	22.69^{ef}	208.52
$N_{138} + Com_5$	8.02^{ab}	24.46^{abc}	166.99	9.36^{ab}	28.52^{ab}	262.13
$N_{138} + Com_{10}$	8.08^{ab}	27.15^{a}	185.32	8.78^{bcd}	24.18^{de}	222.22
$N_{138} + Com_{15}$	8.38^{a}	25.81^{ab}	176.18	7.70^{ef}	23.65^{de}	217.40
$N_{138} + Com_{20}$	5.53^{hi}	22.64^{bcde}	154.54	7.62^{efg}	22.59^{ef}	207.63
LSD (0.05)	**1.21**	**4.44**	**-**	**0.92**	**3.07**	**-**
CV (%)	**10.79**	**12.93**	**-**	**7.15**	**7.65**	**-**

RDW= root dry weight; ASDW= absolute shoot dry weight; RSDM= relative shoot dry matter. Means followed by the same letter(s) are not significantly different at P <0.05 according to LSD test.

3.3.4 Effects of different nitrogen levels and compost rates on maize seedlings nitrogen concentration and uptake

In both soil types, the main and interaction effects of nitrogen fertilizer and compost (Fig. 3.3a and 3.4a) significantly influenced nitrogen concentration through maize vegetation. In Hawassa Zuria soil, plant N concentration progressively increased with the increase in nitrogen and compost rates. A consistent increasing trend was observed in plant N concentration with N rates increased from 0 to138 kg ha^{-1} and compost rates from zero to 20 t ha^{-1}. However, these phenomena did not appear in Meskan soil, possibly due to initial soil TN dissimilarity between

the two experimental soils (Table 3.1). In Meskan soil, plant N concentration significantly increased with the increasing applied mineral nitrogen from 0 to 46 kg N ha^{-1} and compost rates from zero to 15 t ha^{-1} compost (Fig. 3.4a). The high plant nitrogen concentration implies that higher nitrogen existed in the soil solution and available to the plants. In Hawassa Zuria soil, the combined addition of 138 kg ha^{-1} N + 10 t ha^{-1} compost caused the maximum mean plant N concentration of 3.36%, which is statistically similar with 138 kg ha^{-1} N + 5 t ha^{-1} compost treatment. Whereas, in Meskan soil, the combined addition of 46 kg ha^{-1} N + 20 t ha^{-1} compost produced the maximum mean plant N concentration of 2.47%, followed by 46 kg ha^{-1} N + 15 t ha^{-1} compost and 92 kg ha^{-1} N + 15 t ha^{-1} compost (Fig. 3.4a). In contrast, the lowest plant nitrogen concentrations of 0.73 and 0.67% were recorded from the control treatment in Hawassa Zuria and sole 20 t ha^{-1} compost in Meskan soil respectively, which were statistically like the unfertilized pot. Hence, plant N concentration increased by ~360% and 247% due to the addition of 138 kg ha^{-1} N + 10 t ha^{-1} compost and 46 kg ha^{-1} N + 20 t ha^{-1} compost as compared to the control in Hawassa Zuria and Meskan soils, respectively. Agegnehu et al. (2015) showed that organic amendments such as compost and biochar with inorganic fertilizer considerably increased plant total N and NO_3-N concentration relative to the control.

Similarly, the main and interaction effects of inorganic nitrogen and compost rates in both soil types (Fig. 3.3b and 3.4b) significantly affected nitrogen uptake by maize plants. In Hawassa soil, the highest mean N uptake of 912.2 mg pot^{-1} was attained from the addition of 138 kg ha^{-1} N + 10 t ha^{-1} compost, with the N uptake increment of 88.3% over the control (unfertilized) treatment. While in Meskan soil, the integrated use of 46 kg ha^{-1} N + 20 t ha^{-1} compost produced a maximum mean N uptake of 465.9 mg pot^{-1}, with the N uptake increment of 81.8% over the unfertilized treatment. However, the lowest nitrogen uptake value was observed in control and

sole 20 t ha^{-1} compost in Hawassa Zuria and Meskan soil, respectively. In both soil types, combined use of mineral N with compost significantly improved nitrogen uptake but there were different responses to the applied fertilizer treatments. This is consistent with the findings of Abedi et al. (2010), which suggested that the integrated use of organic and inorganic inputs considerably improved nutrient and water uptake, solely either organic or inorganic amendment since organic inputs potentially enhance soil physical properties and root development. Vanlauwe et al. (2011) reported that the combined use of compost and inorganic fertilizer resulted in the highest AE of N.

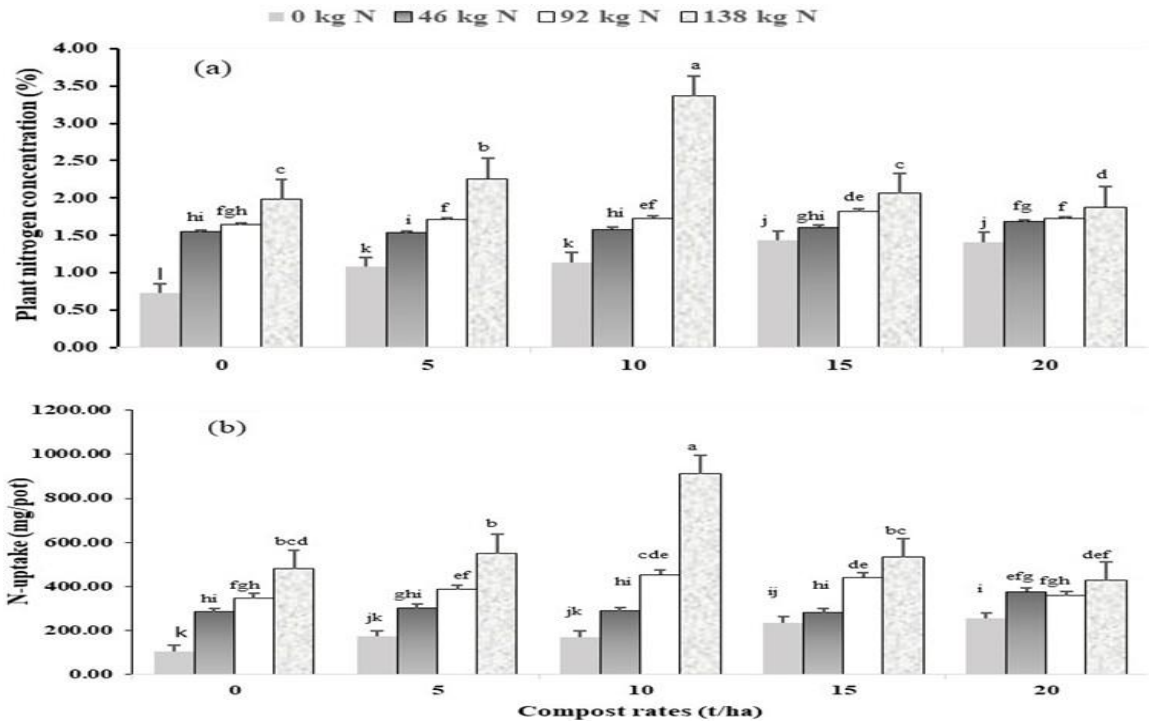

Figure 3.3. Effect of nitrogen and compost rates on nitrogen concentration (a) and N-uptake (b) of maize growth in Hawassa Zuria soil. Different letters indicate significance between treatments at $p \leq 0.05$ according to LSD test.

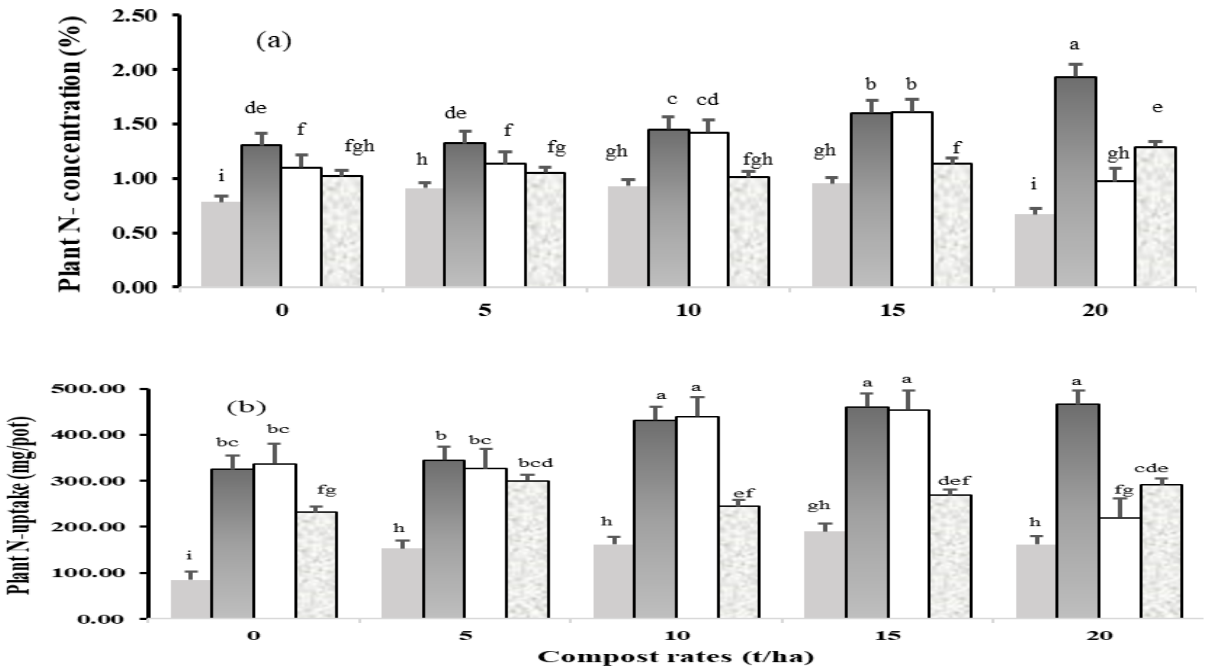

Figure 3.4. Effect of nitrogen and compost rates on nitrogen concentration (a) and N-uptake (b) of maize growth in Meskan soil. Different letters indicate significance between treatments at $p \leq 0.05$ according to LSD test.

Analysis of the data depicted that the first two principal components (PC1 and PC2) accounted 80 and 69% of the total disparity of the treatments in Hawassa Zuria and Meskan soils, respectively, of which PC1 contributed 68% for Hawassa Zuria and 52% for Meskan site (Table 3.6). In this study, except root dry weight for Hawassa Zuria soil and leaf number per plant for Meskan soil, in the first eigenvector, other parameters independently contributed comparable effects to the treatment's total variation. It ranged from 0.306–0.381 and 0.273–0.427 in Hawassa Zuria and Meskan soils, respectively, suggesting that the first principal component provided a realistic summary of the data and described most of the deviation in the entire dataset. The maximum values, 0.381 and 0.427, were recorded from the plant N-uptake and shoot dry weight characters in Hawassa Zuria and Meskan soils, respectively, indicating that these variables influenced the grouping more than those with lower values do.

The variables such as stem girth, shoot dry weight, plant, and soil N-content had positive loadings on second eigenvector, but plant height, leaf number per plant, NDVI, and root dry biomass showed negative loadings in Hawassa soil (Table 3.6). Whereas in Meskan soil, negative loadings showed on the variables plant height, nitrogen concentration, and nitrogen uptake but the remaining characters have positive loading (Table 3.6). Therefore, the cumulative effects of several characters should dictate the variation among treatments into different clusters than an individual variance. Similarly, Agegnehu et al. (2015) compared the conventional business as a usual fertilizer treatment with different soil fertility treatments containing organic and inorganic sources, using PCA to determine optimum soil amendments.

Table 3.6 Eigenvalue, percentage, cumulative variances, and eigenvectors of first four principal components (PC1–4) for nine characters in twenty treatments

Parameters	**Hawassa Zuria soil**				**Meskan soil**			
	PC1	**PC2**	**PC3**	**PC4**	**PC1**	**PC2**	**PC3**	**PC4**
Eigenvalue	6.14	1.08	0.52	0.50	4.68	1.51	1.07	0.64
% Variance	68.00	12.00	6.00	6.00	52.00	17.00	12.00	07.00
Cumulative	68.00	80.00	86.00	92.00	52.00	69.00	81.00	88.00
Characters	**Eigenvectors**							
PHT	0.306	0.096	0.016	0.850	0.364	-0.144	0.219	0.170
LNPP	0.366	0.181	-0.171	0.009	0.207	0.370	0.673	0.258
NDVI	0.352	0.168	0.194	-0.254	0.404	0.134	-0.088	0.132
SG	0.333	-0.004	-0.429	-0.416	0.281	0.329	-0.195	-0.757
SDW	0.359	-0.327	0.078	-0.079	0.427	0.027	0.183	-0.065
RDW	0.158	0.860	0.145	-0.091	0.281	0.472	-0.223	0.045
Plant N-content	0.376	-0.120	-0.254	0.106	0.304	-0.581	-0.041	-0.097
Soil N-content	0.312	-0.207	0.790	-0.118	0.273	0.054	-0.602	0.528
Plant N-uptake	0.381	-0.163	-0.181	0.009	0.393	-0.390	0.083	-0.141

3.3.5 Pearson`s correlation coefficient analysis

In both soil types, significant associations were detected among plant growth parameters, plant and soil nitrogen contents ($p \leq 0.05$). In Hawassa Zuria soil, the normalized difference vegetative index (NDVI) was positively significantly correlated with maize plant height, leaves number per plant, stem girth, shoot weight, plant nitrogen concentration, and soil nitrogen content, with r= 0.60, 0.74, 0.73, 0.66, 0.76, and 0.69, respectively (Table 3.7). Whereas in Meskan soil, plant height, stem girth, shoot and root dry weights, plant nitrogen concentration and soil total nitrogen content were positively significantly associated with NDVI of the leaves with r= 0.61, 0.55, 0.74, 0.58, 0.45, 0.59, and 0.63, respectively. The red NDVI r = value for shoot dry weight is similar with the values for maize yield (r = 0.7–0.8) (Teal et al., 2006), and (r = 0.65) Inman et al. (2005).

Pearson correlation coefficient of shoot dry weight under different fertilizer treatments was positively significantly correlated with maize plant height, leaves number per plant, mean NDVI, stem girth, plant nitrogen concentration, soil nitrogen content, and nitrogen uptake (r = 0.61, 0.73, 0.69, 0.74, 0.82, 0.78 and 0.89), respectively in Hawassa Zuria soil. Similarly, in Meskan soil shoot dry weight was positively significantly associated with maize plant height, leaves number per plant, mean NDVI, root dry weight, plant nitrogen content, and nitrogen uptake with r = 0.69, 0.54, 0.74, 0.53, 0.55 and 0.82, respectively (Table 3.7). The observations are consistent with the findings of Agegnehu et al. (2015) which indicated that shoot and root dry weight were significantly correlated with plant growth parameters, chlorophyll content, plant nitrogen concentration, and nitrogen uptake.

Table 3.7 Correlation coefficients among soil and plant parameters of maize grown on the two soils from Hawassa and Meskan districts of Southern Ethiopia. Upper right side for Meskan soil and lower left side for Hawassa Zuria soil

Characters	PHT	LNPP	NDVI	SG	SDW	RDW	NC (%)	Soil TN (%)	N-uptake
PHT	1	0.38^{ns}	0.61^{**}	0.32^{ns}	0.69^{**}	0.34^{ns}	0.56^{**}	0.34^{ns}	0.69^{**}
LNPP	0.67^{**}	1	0.42^{ns}	0.22^{ns}	0.54^{*}	0.33^{ns}	-0.04^{ns}	0.01^{ns}	0.21^{ns}
NDVI	0.60^{*}	0.74^{**}	1	0.55^{*}	0.74**	0.58^{**}	0.45^{*}	0.59^{**}	0.63^{**}
SG	0.53^{*}	0.73^{**}	0.73^{**}	1	0.55^{*}	0.53^{*}	0.15^{ns}	0.31^{ns}	0.35^{ns}
SDW	0.61^{*}	0.73^{**}	0.69^{**}	0.74^{**}	1	0.53^{*}	0.55^{*}	0.43^{ns}	0.82^{***}
RDW	0.33^{ns}	0.51^{*}	0.47^{*}	0.29^{ns}	0.09^{ns}	1	0.04^{ns}	0.45^{*}	0.25^{ns}
NC (%)	0.69^{**}	0.85^{***}	0.76^{***}	0.73^{**}	0.82^{***}	0.24^{ns}	1	0.32^{ns}	0.92^{***}
Soil TN (%)	0.52^{*}	0.61^{*}	0.69^{**}	0.51^{*}	0.78***	0.18^{ns}	0.63^{**}	1	0.36^{ns}
N-uptake	0.69^{**}	0.85^{***}	0.76^{***}	0.73^{**}	0.82^{***}	0.24^{ns}	0.99^{***}	0.63*	1

PHT= plant height; LNPP= leaf number per plant; NDVI= normalized difference vegetative index; SDW= shoot dry weight; SG= stem girth; RDW= root dry weight; NC= nitrogen concentration; Soil TN= soil total nitrogen and N-uptake= nitrogen uptake. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$; ns, not significant

3.4 Conclusion

Our results evidently demonstrated that the combined application of compost and inorganic N fertilizer significantly improved soil organic carbon and total nitrogen contents. Moreover, the integrated use of compost and mineral N fertilizer significantly enhanced plant growth and nitrogen uptake compared to the unfertilized or separate addition of compost and inorganic N fertilizer. In Hawassa Zuria (Cambisols), the treatment 138 kg ha^{-1} N + 10 t ha^{-1} compost was superior to other treatments but statistically similar with 92 kg ha^{-1} N + 10 t ha^{-1} compost. Similarly, plant nitrogen concentration and uptake were significantly improved; the highest was achieved at the application 138 kg ha^{-1} N + 10 t ha^{-1}. In Meskan (Phaeozems), the addition of 92 kg ha^{-1} N + 10 t ha^{-1} compost treatment produced superior shoot dry biomass and nitrogen uptake, which is statistically at par with 46 kg ha^{-1} N + 10 t ha^{-1} compost. From the results of the current study, it could be concluded that the combined application of 92 kg ha^{-1} N + 10 t ha^{-1} compost and 46 kg ha^{-1} N + 10 t ha^{-1} were the best treatments for Cambisols in Hawassa Zuria and Phaeozems in Meskan sites, respectively, which improved shoot dry matter by 179.5 and 284.5%, compared to the unfertilized pot, respectively. However, additional research is required under field situations to ascertain the advantages and effects of these amendments on soil fertility, crop yield, and economic returns to farmers.

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CHAPTER FOUR

Soil chemical properties, and Yield and Yield Components of Maize (*Zea mays* L.) as Influenced by Tillage, Cropping Systems and Nitrogen Fertilization

4. SOIL CHEMICAL PROPERTIES, AND YIELD AND YIELD COMPONENTS OF MAIZE (*ZEA MAYS* L.) AS INFLUENCED BY TILLAGE, CROPPING SYSTEMS AND NITROGEN FERTILIZATION

Abstract

*Although numerous factors contribute to wide yield gaps, low external inputs, particularly N, and poor cropping practices such as soil tillage and monocropping are among the major factors affecting low maize production. In view of this, field experiments were implemented on two sites with Cambisols and Phaeozems soil types in two consecutive years to evaluate the impacts of tillage, cropping systems, and N-fertilization on the yield and yield components of maize and selected soil properties. A three-factor experiment was arranged as a split-split plot arrangement randomized complete block design with three replications. The minimum tillage (**MT**) and conventional tillage (**CT**) were used as the main plot, haricot bean-maize rotation, and maize monocropping as a subplot, and four levels of nitrogen fertilization (Control, 20 t ha^{-1} compost, 46 kg N ha^{-1} + 10 t ha^{-1} compost, and 92 kg N ha^{-1}) as the sub-sub plot. Analysis of variance showed that soil management practices were significantly affecting yield and yield components and soil properties. In both soils, conventional tillage and haricot bean-maize rotation system increased the grain yield and yield components in contrast to the minimum and monocropping, respectively. Similarly, nitrogen fertilization clearly affected the yield and yield components and selected soil properties. However, tillage methods differed in their effects on soil chemical properties; soil organic carbon and total nitrogen concentrations were improved through MT compared to CT. Therefore, a CT plus haricot bean-maize rotation system with the addition of sole 92 kg N ha^{-1} and integrated 46 kg N ha^{-1} + 10 t compost ha^{-1} could be recommended for Cambisols in Hawassa Zuria and Phaeozems in Meskan sites, respectively. However, in order to ensure sustainable maize production in the investigated soils, an integrated N-treatment with MT and a rotation system should be recommended, which could improve soil properties.*

Keywords: Compost, cropping systems, fertilization, grain yield, maize, tillage

4.1 Introduction

Maize or corn (*Zea mays* L.) is one of the world's leading cereals, ranking second in production after wheat (FAO, 2019). Ethiopia is the seventh maize-producing country in Africa. It is the second in area coverage next to tef (*Eragrostis tef* (Zucc.), with a total land area of 10,478,217 ha being under cereals, of which maize covered about 17.68% (2,274,305.93 ha) (CSA, 2019). Despite the large area under maize production, its current national average yield is about 4.2 t ha^{-1} (CSA, 2019), which is far below the world's average yield of 5.8 t ha^{-1} (FAO, 2019). Although numerous factors contribute to wide yield gaps, low external inputs, particularly N, poor soil fertility, reduced water-holding capacity of the soil, and poor soil infiltration problems are among the major factors paid for low maize productivity (Chimdi et al., 2012; Teklewold et al., 2013; Mourice et al., 2015). Moreover, frequent tillage, monocropping, and complete removal of crop residues are also the governing factors for low productivity (Kassie et al., 2013). Thus, managing appropriate soil tillage and cropping system along with the optimal nutrient supply for different soils are prerequisites for improving maize productivity.

Tilling soil is the most universally used agricultural practice and has been considered as a 'Farmer's technology' for at least 10,000 years (Lal et al., 2007). Tillage is an important soil management practice for successful crop production. It provides various benefits to farmers (Tangyuan et al., 2009), which also negatively affect soil resources and the environment (Gupta et al., 2002). It contributes up to 20% of yield reduction (Khurshid et al., 2006) and affects N dynamics in the soil by influencing organic matter (OM) decomposition, soil aeration, compaction, rooting pattern and microbial activity (Keshavarz et al., 2016; Wasaya et al., 2017). Similarly, Ozpinar and Cay (2009) and Pekrun et al. (2003) proved that adopting different tillage

systems has effects on plant nutrient dynamics and the distribution of macro- and micronutrients in topsoil. Studies made by other authors also emphasized the impacts of different tillage practices on maize grain yield and its components (Wang et al., 2015; Wasaya et al., 2017).

Conventional tillage (CT) is a frequently used tillage method, which primarily improves the soil's physical properties (Wang et al., 2015). However, CT has the potential to reduce soil organic matter due to enhanced decomposition rate and hence, negatively affect long-term crop productivity, nutrient uptake, and soil health (Zuber et al., 2015). Previous study also confirmed that organic matter mineralization is enhanced through conventional tillage (Panettieri et al., 2013; Rusinamhodzi et al., 2011). Similarly, Gao et al. (2016b) and Peng et al. (2016) reported that soil fertility can be declined due to frequent CT practices. However, soil loosening by tilling also improves grain yield (Wasaya et al., 2017a) and biomass production (Wasaya et al., 2012) by improving water infiltration rate and root proliferation (Wang et al., 2015). Therefore, problems associated with conventional tillage can be managed by no-till or reduced tillage practices, which are less destructive than the traditional ones (Zhanga et al., 2015).

Reduced tillage practice is a type of conservation tillage, defined as any practice that minimizes soil water loss, and maintains a 30% surface cover with cash or cover crop residues. Nowadays, conservation tillage systems such as "minimum" and "zero tillage" have entered widespread use in most farmers around the globe, due to their benefits in minimizing soil erosion, preserving soil moisture, improving soil organic matter, and reducing labor, fuel, and machinery costs (López-Garrido et al., 2012; Plaza et al., 2013). Various studies depicted that operating reduced tillage improved the soil's physical (López-Garrido et al., 2012; Plaza et al., 2013), chemical, and biological properties (Bronick and Hobbs, 2005). However, at the transitional time, yield,

nutrient bioavailability, particularly N, is commonly lower in minimum or zero tillage than the conventional method (Pittelkow et al., 2015).

Cropping systems refers to the type and sequence of practices and crops grown over space and time. It has immense effects on soil's physical and biochemical properties, and consequently, crop productivity (Rahman and Ranamukhaarachchi, 2003). A study made by Jahiruddin and Satter (2010) indicated that the change in soil fertility was observed due to cropping systems. Similarly, Cleemput et al. (2008) reported that continuous cultivation along with poor farming practices resulted in severe depletion of soil nutrients and organic matter, which seriously threatens agricultural production and productivity.

Crop rotation is a systematic approach that allows preserving the existing natural resources and their efficient utilization (Feizabadi and Koocheki, 2012). Presently, agricultural researchers have given great emphasis to crop rotation due to its effects on N efficiency and nitrogen availability to the plant (Fisseha Negash and Tewodros Mulualem, 2014). An earlier study proved that the cost of mineral nitrogen fertilizer requirements of grain crops could be reduced by 4 to 71% due to legume-based crop rotation (Fustec et al., 2010). A legume-based rotation system can improve the yield of succeeding grain crops and have the potential to minimize N-losses compared to monocropping (Coulter et al., 2011). In most cases, the yield produced from monoculture crops is lower compared to a rotation under the same condition (Berzsenyi et al., 2000). Therefore, the presence of legumes in the cropping system is an environmentally beneficial and economically sound approach (Fustec et al., 2010; Hirel et al., 2011).

The nutrient application, mainly of nitrogen, is the second precondition for effective maize production. Nitrogen (N) is a generally deficient element in all agricultural soils and cropping

systems of the world (Mohan et al., 2015). Therefore, nitrogen management in maize cultivation is critical to increasing productivity and nutritional quality. Previous studies revealed that soil fertility was significantly improved due to N management (Habtegebrial et al., 2007). On the one hand, limited use of inorganic N fertilizers led to yield reduction (López-Bellido et al., 2014; Meena et al., 2014). On the other hand, excess application is uneconomical, environmentally unsafe and potentially harmful to crops (Guo et al., 2010). To reverse this phenomenon, an integrated nutrient management approach is a good framework to ascertain sustainable agricultural production.

In the study area, however, there is scarce information about the effects of tillage, cropping systems, and nitrogen fertilization and their interaction on the yield and yield components of maize as well as soil chemical properties. Therefore, the present study was conducted to evaluate the effects of different soil management practices on the selected soil chemical properties, and yield and yield components of maize grown in the central rift valley of Ethiopia; and to determine the optimal soil management practice for each soil of the study area. We hypothesized that application of integrated organic and inorganic nitrogen fertilizer along with crop rotation and minimum tillage practice will improve growth, yield, and yield components of maize as well as soil chemical properties.

4.2 Materials and Methods

4.2.1 Description of the experimental sites

The field experiments were conducted for two consecutive years (2019 and 2020) in Hawassa Zuria and Meskan districts of the Central rift valley of Ethiopia. Detail descriptions of the study sites are indicated under section 1.5.1. The experimental site at Hawassa is mainly characterized by a semi-arid climate with a long-term average annual rainfall of 958 mm, of which 81% falls during the growing season (April to October), and an annual mean temperature of 21 ◦C. The main cropping seasons (2019 and 2020) received an average annual rainfall of 1176 mm, and the average maximum and minimum air temperatures were 14.2 and 27.8 ^{0}C, respectively (Fig. 4.1). While the Meskan site received a long-term annual rainfall of 987 mm, of which 84% falls from April to October. During the experimentation, the trial site received an average annual rainfall of 1338 mm, and the average maximum and minimum air temperatures were 9.6 and 31.2 °C, respectively (Fig. 4.1). The soil types for the field trial were Cambisols for Hawassa Zuria and Phaeozems for Meskan, according to the WRB soil classification system (IUSS Working Group, 2015).

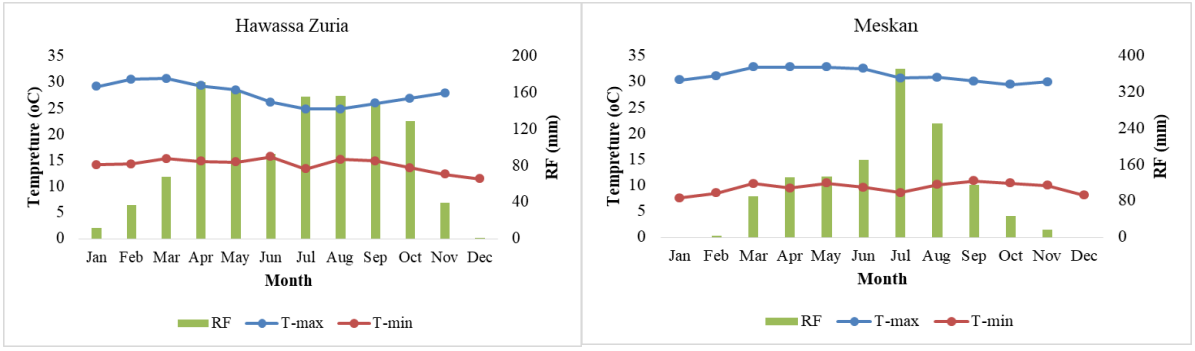

Figure 4.1. Annual rainfall and average monthly maximum and minimum temperature of Hawassa Zuria and Meskan sites (2019-2020). RF: Rainfall; T-min: minimum tempreture; T-max: maximum temperatures.

4.2.2 Characterization of the experimental soils and compost

Before the imposition of the treatments, 12 random sutface (0-20 cm) soil samples were collected in March 2019 to measure the baseline soil parameters at each experimental location, following the standard laboratory procedure. The collected 12 samples were combined and made into bulk samples for each location; after manual homogenization, three composite sub-samples per site were prepared for physicochemical analysis. The samples were air-dried at room temperature, ground, and sieved through 2 mm. However, a 0.5 mm mesh wire was used for the determinations of organic carbon (OC) and total nitrogen (TN).

Particle size distribution (percentage of sand, silt, and clay) was determined using the hydrometer method as described by FAO (1974). The pH (pH-H_2O) of the soils was determined at 1: 2.5 soils to water solution ratio using a pH meter as described by Sahelemidehin and Taye (2000); organic carbon content was determined following the Walkley and Black wet oxidation method (Walkley and Black, 1934). Soil total nitrogen content was determined following the Kjeldahl procedure as described by Van Reeuwijk (1992). Available P in the soil was analyzed using the Olsen sodium bicarbonate (pH 8.5) extraction method and the amount was determined using a spectrophotometer as described by Olsen et al. (1954); exchangeable cations and CEC using the ammonium acetate method (Sahelemidehin and Taye, 2000). The soil laboratory analysis was executed in the College of Agriculture at Hawassa University. Selected soil physicochemical characteristics at the start of the experiment are shown in Table 4.1.

The compost was prepared at the Wondo Genet botanical backyard using locally available composting materials such as green leaves, farmyard manure, fresh and dry cow dung, and animal feed leftovers from dairy cattle, bedding materials, and wood ash. A homogenized

mixture of the materials was composted in pits of 2 m × 1.5 m wide by 1.5 m deep following the standard procedure as described by EIAR (2009). The materials are placed in alternating layers, with a straw material constituting the bottom layer. According to the requirements, all recommended management practices were operated until the materials were ready for use. Three representative compost subsamples were taken to analyze pH, EC, OC, TN, Avail-P, and C: N ratio. The collected samples were air-dried, ground and sieved through a 2 mm sieve, whereas a 0.5 mm sieve was used for determinations of OC and TN. The selected chemical characteristics of the compost used in this study are shown in Table 4.1.

Table 4.1 Some physicochemical properties of the composite surface soils (0-20 cm) and compost prior to treatment application

Soil properties	Units	Soils of experimental locations		Compost
		Cambisols	Phaeozems	
Physical properties				
Sand	%	42.0	16.0	-
Silt	%	32.0	36.0	-
Clay	%	26.0	48.0	-
Textural class	-	Loam	Clay	-
Chemical properties				
pH	-	5.86	6.57	6.79
EC	ds/m	0.03	0.06	0.09
OC	%	2.42	4.10	14.80
TN	%	0.26	0.37	1.21
C: N	-	9.31	11.10	12.23
Avail-P	mg kg^{-1}	4.52	23.74	-
CEC	$cmol_c$ kg^{-1}	20.00	62.00	-
Exchangeable Ca	$cmol_c$ kg^{-1}	8.27	39.33	
Exchangeable Mg	$cmol_c$ kg^{-1}	0.34	7.67	
Exchangeable K	$cmol_c$ kg^{-1}	2.03	2.20	
Exchangeable Na	$cmol_c$ kg^{-1}	1.85	1.01	
Ca: Mg		24.32	5.12	
K: Mg		5.97	0.29	

4.2.3 Treatment and experimental design

Two tillage methods (TM) were evaluated: conventional tillage (CT) and minimum tillage (MT). The two tillage practices were combined with two cropping systems (CS): haricot bean-

maize rotation (RCS) and maize monocropping (MCS). In addition, four levels of nitrogen fertilization (NF) (0, 20 t compost ha^{-1}, 46 kg N ha^{-1} + 10 t compost ha^{-1}, and 92 kg N ha^{-1}) were combined with tillage practices and cropping systems. Treatments were arranged as Split-split plot arrangement randomized as an RCBD (randomized complete block design), with tillage methods as the main plots, cropping systems as sub-plots, and nitrogen fertilization treatments as sub-sub-plots, with three replicates; making 48 sub-sub-plots for each experimental site.

4.2.4 Experimental procedures and management practices

During the 2019 main cropping season, tillage practices as the main and cropping systems as subplots were arranged in a randomized complete block design with three replications. Three times and single ox-draw local plowing was used as conventional and minimum tillage practices, respectively. Moreover, minimum tillage plots received one application of roundup (glyphosate) herbicide 3 liters per hectare to control weeds before seed emergence.

A recently released hybrid maize variety "BH 546" and haricot bean variety "Hawassa Dume" which are well adapted to the agro-ecologies of the study areas were planted following optimum sowing time. The two-component crops were sown simultaneously in rows at a rate of two seeds per hill to ensure germination and after which the seedlings were thinned to a single plant per hill. Maize and haricot beans were sown at a space of 80 × 25 cm and 40 × 10 cm, respectively. Each main and sub-plot had an area of 15 x 9 m = 135 m^2 and 15 x 4 m = 60 m^2, respectively, and the total experimental area was 31.5 x 30 m= 945 m^2.

Phosphorus fertilizer was applied to all plots at sowing as triple superphosphate (TSP) at the recommended rate (20 kg P ha^{1}), in a band in the row. To minimize losses and increase the

efficiency of N, Urea fertilizer was applied at the rate of 92 kg N ha^{-1} in split form: half at sowing time and the remaining half at the vegetative growth stages of six leaves (V6) of the maize, to all plots except the sole bean, which is in bean-maize rotation treatment, assuming the bean benefited from its N fixation. Other recommended agronomic practices were operated uniformly in all experimental units as per recommendation. Furthermore, thirty percent (30%) of the crop residues were retained after harvesting in minimum tilled plots.

During the 2020 main cropping season, the experiment was executed in a perpetual plot and laid out in a 2 x 2 x 4 factorial arrangement in a randomized complete block design with three replications. Each main plot had eight treatment combinations, i.e, two cropping systems with four levels of nitrogen fertilizer rates. According to the treatment, ten days before seeding, compost was applied in the upper 20 cm soil depth, based on inorganic N equivalency. Similarly, the hybrid maize variety "BH 546" was used as the test crop. The pathway between blocks and plots were 1.5 and 1m, respectively. Each sub-sub-plot had a size of 4.8 m x 3 m (14.4 m^2) and accommodated six maize rows with inter-and intra-row spacing of 80 and 25 cm, respectively. Each row and plot had 12 and 72 plants, respectively.

The phosphorus fertilizer was applied to all plots at sowing as triple superphosphate (TSP) at the recommended rate (20 kg P ha^{1}), in a band in the row. However, the N fertilizer (Urea) was applied in the split form: half at sowing time and the remaining half at the vegetative growth stages of six leaves (V6) of the maize according to the treatments. Other recommended agronomic practices were operated uniformly in all experimental units as per required. Only the central four rows of maize were subjected to data collection. The net plot area had a size of 1.25

m * 3.2 m = 4 m^2 whereby 24 plants per plot were exposed for yield and yield component analysis.

4.2.5 Soil, growth, yield and yield components measurements.

After experimentation, soil samples were collected from each sub-subplots and soil type, then the collected samples were combined as per treatments, making a bulk sample, after manual homogenization, representative composite sub-samples per treatment and site were prepared for selected chemical analysis.

Plant parameters such as normalized vegetation index (NDVI), plant height, aboveground biomass, grain yield, thousand-seed weight and harvest index were collected. The Normalized Difference Vegetative Index (NDVI) was measured from the central two rows at the vegetative growth stages of leaves six (V6) and eight (V8) using a Green Seeker ™ Handheld Optical Sensor Unit (NTech Industries, Inc., USA) following the method used by Verhulst et al. (2010b) and their mean was taken for computation. Plant height was measured (in cm) from ground level to the base of the tassel of five randomly selected plants per plot using a measuring stick just before physiological maturity and the average was taken for computation.

Sun dried, aboveground biomass was weighed at physiological maturity of maize from a net plot area of 4 m^2 of which 250 g samples were taken from each plot and then oven-dried at 70 ^{0}C until a constant weight was adjusted. The grain yield was harvested from a net plot area of 4 m^2 (1.25 m x 3.2 m) by excluding the border rows. The harvested grain yield was adjusted to 12.5% moisture level (Nelson et al., 1985) and it was converted into hectare bases. Thousand-kernel weight was counted using an electronic seed counter from the bulk of threshed seeds and

weighed using a sensitive balance from each plot at harvest and was adjusted to 12.5% moisture content. The harvest index was calculated using the following formula: - as the ratio of grain yield at 12.5% moisture to aboveground dry biomass and multiplied by 100.

$$Harvest\ index\ (\%) = \left(\frac{Grain\ yield}{Biological\ yield}\right) * 100$$

4.2.6 Statistical analysis

Prior to analysis of variance (ANOVA), the normality of the data was checked using the Shapiro-Wilk normality test. Despite the field experiments were carried out for two consecutive years, only the last year's data was used for statistical computation since the third factor (NF) was applied in the second cropping season. Moreover, the two experimental sites were distinctly different in their soil fertility status (Table 4.1). Consequently, the statistically analysis was done independently for each location, using the SAS 9.3 software package (SAS Institute, 2014), considering the experimental treatment as a fixed factor and replication as a random factor. Differences among treatments means were separated with the protected Fisher's least significant difference (LSD) at $P < 0.05$ probability level (Steel and Torrie, 1980). The LSD differences for the main and interaction effects comparisons were calculated using the appropriate standard error terms. Pearson correlation coefficient (r) was performed using SAS software 9.3 (SAS, 2014). All graphs were designed using Origin2021 procedures.

4.3 Results and Discussion

4.3.1 The initial characteristics of the experimental soils

The textural class of the Cambisols at Hawassa Zuria was loam, whereas Phaeozems at Meskan clay separate dominates the soil particles and is thus classified as clay (Table 4.1). The soil pH (H_2O) values were 5.86 and 6.57 at Hawassa Zuria (Cambisols) and Meskan (Phaeozems) sites and rated as moderately acidic and neutral respectively (Benton, 2003). The total nitrogen (TN) content of the soil was higher on Phaeozems at Meskan (0.37%) than Cambisols at Hawassa Zuria (0.26%). Similarly, the soil available P level was lower (4.52 mg kg^{-1}) in Cambisols compared to phaeozems (23.7 mg kg^{-1}). This implies that Cambisols in Hawassa Zuria is more responsive to nitrogen and phosphorus-containing fertilizer application than that Phaeozems in Meskan.

The cation exchange capacity was medium at Hawassa Zuria 20 $cmol_c$ kg^{-1}, which was attributed to low exchangeable Ca^{2+}, Mg^{2+} and K^{+}, while at Meskan the CEC was 62 $cmol_c$ kg^{-1} and rated as higher (Hazelton and Murphy's, 2007). The Ca: Mg ratios were 24.32 and 5.12 for Hawassa Zuria and Meskan soils, respectively, which are greater than 5:1. Thus, calcium may reduce the availability of both Mg and P (Landon, 2014). The K: Mg ratios were 5.97 and 0.29 for Hawassa Zuria and Meskan soils, respectively (Table 4.1). In Meskan soils K: Mg ratio was lower than the treshhold value of 0.7:1 (Loide, 2004). Hence, Mg may reduce the availability and/or uptake of K (Laekemariam et al., 2016). The initial soil information showed a significant soil fertility variation between the experimental soils/sites and, therefore, it is justifiable to conduct more detailed nitrogen studies along with different soil management practices.

Effects of experimental factors and their interactions on selected soil chemical properties.

At Hawassa Zuria, the main effects of TM and N-fertilization (NF) had significant effects on soil pH, organic carbon, total nitrogen, and carbon to nitrogen ratio. The two-way interaction of CS*NF only showed a significant variation in total nitrogen (Table 4.2). However, at Meskan, the main effects of TM and NF revealed a significant ($P < 0.001$) variation on total nitrogen and carbon to nitrogen ratio. Soil pH was significantly influenced by the main factor of NF and the interaction of TM×NF, but not by the other main factors and their interactions (Table 6.2). The main effect of NF and the interaction of TM×NF, CS×NF, and TM×CS×NF had shown a significant ($P < 0.05$) effect on soil organic carbon at Meskan (Table 4.2).

Table 4.2 Analyses of variance indicating the effects of tillage method (TM), cropping system (CS) and N fertilization (NF) on selected chemical properties at 0-20 cm soil depth

S. Variation	DF	Hawassa Zuria				Meskan			
		pH	OC	TN	C: N	pH	OC	TN	C: N
TM	1	*	ns	*	*	ns	ns	*	*
CS	1	ns	ns	ns	ns	ns	ns	*	ns
NF	3	***	***	***	***	***	***	***	***
TM×CS	1	ns	ns	ns	ns	ns	ns	ns	ns
TM×NF	3	ns	ns	ns	ns	*	*	ns	ns
CS×NF	3	ns	ns	*	ns	ns	*	ns	ns
TM×CS×NF	3	ns	ns	ns	ns	ns	***	ns	ns

4.3.2 Effects of tillage, cropping systems and nitrogen fertilization on selected soil chemical properties.

At Hawassa Zuria, tillage methods had a considerable effect on soil pH (H_2O) but not in Meskan. The highest and the lowest pH were obtained from the conventional and minimum tillage, respectively. Previous author also reported similar changes in pH depending on tillage systems (Bleveins et al., 1983). Cropping systems had no significant effect on soil pH at both locations

(Table 4.3). In the contrast, addition of various nitrogen fertilizers showed statistically notable differences in soil pH at both sites. The highest value was observed from sole compost application at 20 t ha^{-1}. The application of compost at the rate of 20 t ha^{-1} improved the soil pH by 5% and 6.1% compared to the control treatment at Hawassa Zuria and Meskan, respectively, suggesting that basic cations were probably added to the soil solution through the decomposition of compost. This result is in agreement to Dikinya and Mufwanzala (2010), who reported that organic manure application to the soil tends to increase soil pH due to their microbial decomposition and mineralization as well as hydroxyl ions released during the mineralization process.

There were no significant changes in organic carbon concentrations across tillage methods and cropping systems in either location (Table 4.3). This could be owing to the fact that the samples were gathered two years after the field trial, which is a short time to see the effect of tillage on soil OC. A similar observation was reported by Geisseler and Horwath (2009). If the experimental period extended, the differences in soil OC would be more apparent. At both sites however, MT provided numerically higher OC contents compared to CT. This was theoretically due to the physical protection of soil OM, residue retention and reduced soil aeration (Awale et al., 2013; Flávia et al., 2015).

Conversely, organic carbon content was significantly affected by N fertilization (Table 4.3). The addition of 20 t ha^{-1} compost provided the higher OC at Hawassa Zuria, which was statistically comparable with the integrated N-treatment. When compared to the unfertilized (control) plot, compost application increased OC by 6.8%. However, at Meskan, the combined use of compost and inorganic nitrogen fertilizer resulted in the highest level of OC (4.11%),

increasing by 8.1% over the unfertilized plot. The present investigation showed that addition of compost significantly enhanced OC contents of the soils. The increase in soil OC after the application of compost is due to the composting material and the rich microbial community, which contributes to the formation of soil organic carbon (Deepak et al., 2017). This observation is consistent with the findings of Dhillon et al. (2018) and Lorenz and Lal (2016), who reported that soil OC content, has been enhanced with the addition of either sole or mixed organic inputs.

Tillage practices had a significant effect on soil total N in both locations, with minimum tillage contributing more to total N than the conventional tillage (Table 4.3). This could be due to the enhanced N protection inside micro and macroaggregates, resulting in lower N losses through leaching and organic matter decomposition (Wyngaard et al., 2012). Earlier research findings revealed that higher mineral N under conventionally tilled soils but lower TN than conservation tillage (Wu et al., 2009). Similarly, Govaerts et al. (2006b) confirmed that adopting minimum tillage usually increased soil total N. Yagioka et al. (2015) pointed out that minimum tillage reduces soil TN through leaching and volatilization.

Likewise, the cropping systems significantly affected the soil total N at Meskan but remarkable variation was not observed at Hawassa Zuria. In both sites, there was a tendency for better soil total N in the haricot bean-maize rotation system compared to maize monocropping (Table 4.3). The findings of this study agree with those of Kirkegaard et al. (2008), which indicated that cereals could benefit from legume-based rotation systems not only in terms of yield but also in terms of soil total nitrogen, as opposed to cereal monoculture. Because legume residues had greater quality and a narrow C: N ratio, which resulted in the quick release of N from the residues, the legume-cereal-based rotation system provided more organic N than monocropping

(Lupwayi et al., 2011). The effect of cropping systems on soil total N is not comparable in the two experimental sites/soils; possibly due to the differences in soil properties as indicated by Giller (2001).

The use of nitrogen fertilizers had a considerable impact on soil TN. The combined application of compost and inorganic nitrogen fertilizer significantly enhanced the soil TN contents at both sites (Table 4.3). The integrated N treatment had the highest TN, 0.26% and 0.39% at Hawassa Zuria and Meskan, respectively, indicating that more N was released through mineralization of the compost added to the soil and due to the existence of high levels of total N in the compost. Our findings are in line with those of Yan et al. (2007), which showed that inorganic nitrogen influences most soil biological processes by promoting microbial carbon use, which is critical for mineralization and nutrient transformation activities. In brief, total nitrogen status in soils showed a better response to the combined application of inorganic N fertilizer with compost than sole inorganic fertilizer.

In both sites, tillage methods had a significant impact on the C: N ratio, with minimum tillage giving a lower C: N ratio than conventional tillage (Table 4.3). The lower C: N ratio in soils cultivated with minimum tillage may help to slow down the loss of nitrogen during organic matter decomposition. Similarly, cropping systems had a considerable impact on the C: N ratio at Meskan, but not at Hawassa Zuria. However, when compared with maize monocropping, the legume-maize rotation system had a lower C: N ratio in both locations. The lower C: N ratio in soils treated with the haricot bean-maize rotation system could contribute to the higher nitrogen availability due to rapid N release from the residues and N-fixation (Lupwayi et al., 2011). The effect of N-fertilization on the C: N ratio was highly significant ($P < 0.001$), the narrower value

was obtained from the integrated N treatment, followed by sole inorganic N fertilizer (Table 4.3). This signifies that there was better mineralization of N from the applied compost. This finding was in line with Mamuye et al. (2021), who found that combining organic and inorganic N-sources enhanced the C: N ratio significantly more than using either organic or chemical N-inputs alone.

Table 4.3 Main effects of tillage, cropping systems and nitrogen fertilization on soil reaction, organic carbon, total nitrogen and C: N ratio of the surface layer of soils (0-20 cm)

Treatments	Hawassa Zuria (Cambisols)				Meskan (Chernozem)			
	pH	**OC**	TN	**C: N**	**pH**	**OC**	TN	**C: N**
		(%)				**(%)**		
Tillage methods								
MT	6.10^{b}	2.61	0.25^{a}	10.52^{b}	6.80	4.00	0.36^{a}	11.31^{b}
CT	6.20^{a}	2.59	0.23^{b}	11.18^{a}	6.80	3.98	0.33^{b}	12.14^{a}
LSD (0.05)	0.06	ns	0.01	0.33	ns	ns	0.02	0.83
Cropping systems								
RCS	6.10	2.61	0.25	10.72	6.80	3.99	0.35^{a}	11.48^{b}
MCS	6.20	2.60	0.24	10.97	6.80	3.99	0.34^{b}	11.97^{a}
LSD (0.05)	ns	ns	ns	ns	ns	ns	0.01	0.37
Nitrogen fertilization								
Control	6.00^{b}	2.51^{c}	0.21^{c}	11.84^{a}	6.60^{d}	3.83^{d}	0.32^{c}	11.94^{b}
20 t ha^{-1} Compost	6.30^{a}	2.68^{a}	0.24^{b}	10.73^{b}	7.00^{a}	4.11^{b}	0.32^{c}	13.02^{a}
46 kg N ha^{-1} +10 t ha^{-1} Compost	6.20^{a}	2.66^{a}	0.26^{a}	10.19^{c}	6.90^{b}	4.14^{a}	0.39^{a}	10.57^{d}
92 kg N ha^{1}	6.10^{b}	2.58^{b}	0.25^{ab}	10.63^{bc}	6.70^{c}	3.88^{c}	0.34^{b}	11.37^{c}
LSD (0.05)	0.1	0.04	0.01	0.47	0.08	0.03	0.01	0.53

Within the columns, means followed by the same letters are not significantly different at $P < 0.05$ according to LSD test.

Effects of treatments and their interactions on growth, yield and yield components.

At Hawassa Zuria, the main effects of TM, CS, and NF had a significant effect on maize grain yield, but the interaction of TM×CS, TM×NF, CS×NF, and TM×CS×NF were insignificant (Table 4.3). At Meskan, only NF revealed a significant ($P < 0.001$) result on grain yield, but other main factors and their interactions were insignificant (Table 4.3). The main effects of CS, NF and the interaction of TM×CS and CS×NF, and TM×CS×NF showed significant ($P < 0.05$)

effects on thousand seed weight and harvest index at Hawassa Zuria. Whereas at Meskan, thousand seed weight and harvest index were significantly influenced by the main effects of TM and CS (Table 4.3). At Hawassa Zuria, the main factors of CS and NF and the interaction of CS×NF and TM×CS×NF had a significant effect on mean NDVI (Table 4.3). Likewise, the mean NDVI of the Meskan site was significantly affected by the main effect of N-rate and the interaction of TM×CS×NF (Table 4.3).

Table 4.3 Significance levels from analysis of variance showing effects of experimental factors and their interaction on growth, yield, and yield components of maize grown at the two sites

Locations	Sources Variation	DF	Parameters							
			BY	**GY**	**SY**	**TSW**	**HI**	**NDVI**	**PH**	**CL**
Hawassa Zuria	TM	1	ns	*	ns	ns	ns	ns	ns	ns
	CS	1	ns	**	ns	**	ns	**	ns	ns
	NF	3	***	***	**	*	*	***	**	**
	TM×CS	1	*	ns	*	ns	**	ns	ns	ns
	TM×NF	3	ns	ns	ns	*	*	ns	**	ns
	CS×NF	3	*	ns	*	**	*	**	ns	ns
	TM×CS×NF	3	ns	ns	ns	***	*	*	**	ns
	CV (%)		7.7	4.6	9.2	4.7	5.4	4.1	3.7	6.2
Meskan	TM	1	*	ns	*	*	*	ns	ns	ns
	CS	1	ns	ns	ns	ns	ns	ns	ns	ns
	NF	3	**	***	ns	**	***	***	ns	ns
	TM×CS	1	ns	ns	ns	ns	ns	ns	ns	ns
	TM×NF	3	ns	ns	ns	ns	ns	ns	ns	ns
	CS×NF	3	ns	ns	ns	ns	ns	ns	ns	ns
	TM×CS×NF	3	ns	ns	ns	ns	ns	*	ns	ns
	CV (%)		8.2	5.2	11.1	2.6	8.3	2.9	3.6	5.3

DF - degree of freedom; BY - biomass yield; GY - grain yield; SY - stover yield; TSW - thousand seed weight; HI - harvest index; NDVI - normalized difference vegetation index; PH - plant height; CL - cob length; CV - coefficient of variation; * - significant at $P < 0.05$; ** - significant at $P < 0.01$; *** - significant at $P < 0.001$; ns - not significant.

4.3.3 Tillage, cropping systems, and nitrogen management effects on maize growth parameters

The results showed that the Normalized Difference Vegetative Index (NDVI) ranged from 0.72 to 0.82 (Table 4.4), indicating that the plants with maximum NDVI would have higher photosynthetic capacity than plants with low NDVI (Ngie et al., 2014). Tillage had no effect on NDVI at both Meskan and Hawassa Zuria. Péter et al. (2019) reported a similar finding. The

cropping system had a significant ($p < 0.05$) effect on NDVI only at Hawassa Zuria. NDVI was higher in the haricot bean-maize rotation system than maize monoculture. This implies that the legume-maize rotation system is a good attribute for better N-availability and is supported by various authors (Tolera et al., 2009).

In both locations, application of N fertilizers had a significant effect on mean NDVI. Nitrogen fertilization significantly increased the average NDVI value compared to the control plot (Table 4.4). The maximum values were recorded at 92 kg N ha^{-1} and 46 kg N ha^{-1} +10 t ha^{-1} compost treatments at Hawassa Zuria and Meskan sites, respectively. However, the minimum NDVI value was obtained from the control treatment, closely followed by sole compost at both locations. The mean NDVI became bigger increasing nitrogen input, indicating that the value was improved most likely due to nitrogen availability and uptake. Similarly, Baral and Abhikari (2015) and Hailu and Tolera (2020) found that spectral vegetation indices improved with N level, which is useful for acquiring information such as photosynthetic efficiency and potential yield indirectly.

Plant height is regarded as an important trait of a plant in terms of biomass. There was a significant difference in maize plant height between tillage methods at Hawassa Zuria, but not at Meskan; numerically, taller heights were recorded in CT compared to MT in both locations (Table 4.4). The tallest plant height in conventionally tilled plots was due to improved soil physical conditions that allow even nutrient distribution and higher porosity (Wasaya et al., 2011). A non-significant variation was found between cropping systems on maize plant height at the two sites. Conversely, nitrogen fertilization significantly ($p < 0.05$) affected plant height at Hawassa Zuria, but no variation was observed at Meskan. At Hawassa Zuria, 92 kg N ha^{-1}

gave the tallest plant (219.83 cm), although it was not statistical different from using 46 kg N ha^{-1} + 10 t ha^{-1} compost. At Hawassa Zuria, application of sole N (92 kg ha^{-1}) and integrated 46 kg N ha^{-1}+ 10 t ha^{-1} compost increased plant height by 5.3 and 4% over the control, respectively. This might be due to an increase in cell elongation and vegetative growth attributed to improved nitrogen availability. However, the shortest plant height (207.9 cm) was found in the sole compost treated plot, which is statistically comparable to the control (unfertilized) plot.

Table 4.4 Means for main effect of tillage, cropping system and nitrogen fertilization on normalized difference vegetative index and plant height of maize grown under different soil types

Treatments	Hawassa Zuria		Meskan	
	NDVI	**PH (cm)**	**NDVI**	**PH (cm)**
Tillage methods				
MT	0.75	211.30	0.77	264.57[b]
CT	0.75	215.60	0.78	275.20[a]
LSD (0.05)	ns	ns	ns	5.77
Cropping systems				
RCS	0.76[a]	214.20	0.78	268.26
MCS	0.74[b]	212.70	0.77	271.52
LSD (0.05)	0.02	ns	ns	ns
Nitrogen fertilization				
Control	0.72[b]	208.80[b]	0.74[d]	267.62
20 t ha^{-1} Compost	0.72[b]	207.90[b]	0.76[c]	268.93
46 kg N ha^{-1} +10 t ha^{-1} Compost	0.77[a]	217.20[a]	0.82[a]	272.37
92 kg N ha^{1}	0.78[a]	219.80[a]	0.79[b]	270.63
LSD (0.05)	0.03	6.69	0.02	ns

*Means within columuns followed by the same letter did not differ significantly across the tillage methods, cropping systems, and N-fertilization at $P \leq 0.05$ according to LSD test.

4.3.4 Main effects of tillage, cropping systems and nitrogen fertilization on yield and yield components of maize grown at the two sites

The mean grain yield and associated yield components were higher at the Meskan than Hawassa Zuria (Table 4.5). The present difference of maize yields between the two sites could be justified by variations in soil properties (Table 4.1). The effect of tillage on maize grain yield was significant ($P < 0.05$) at Hawassa Zuria but not at Meskan, despite high grain yield using CT (Table 4.5). In the present study, grain yield increased by 5% and 0.1% in CT over MT at

Hawassa Zuria and Meskan, respectively. The positive effect of CT on maize grain yield was possibly due to better soil physical conditions, root growth, and infiltration of water, nutrient mineralization, and suppressing weed growth (Arif et al., 2007; Mazzoncini et al., 2011). Similarly, Salem et al. (2015); Wang et al. (2015) reported that CT in a short-term study increased corn yield compared to a minimum or zero tillage due to less soil compaction. Furthermore, our results were also consistent with other studies conducted on maize in the central rift valley of Ethiopia (Sime et al., 2015).

The effect of CT on maize grain yield was not analogous in the two locations. In this study, the influence of CT was more visible in loamy than clay textured soils, suggesting that the effect of tillage on crop productivity differs based on the soil texture, and thus recommendation should be established on the nature of soil or site-specific (Fox and Bandel, 1986; Griffith et al., 1986*).* In the present study, our expectation was more grain yield from MT over that of CT, this was due to residue retention from preceding crops, but MT produced lower grain yields, possibly due to the short stabilization effect of MT practice and N immobilization (Sainju et al., 2015). As described by previous researchers (Araya et al. 2012; Tolessa et al., 2007) minimum tillage effect on grain yield is possible when the residues are retained for a longer time and depends on the gradual build-up of soil fertility.

In long-term evaluation, however, reduced tillage can raise soil physical, chemical, and biological attributes and hence higher crop yields are expected under this tillage system (Sainju et al., 2015). Various studies also indicated that MT along with residue retention significantly improved grain yield by up to 30% for wheat and 40% for grass pea in the driest areas of Tigray, Ethiopia (Araya et al. 2012; Araya et al. 2011). In most cases, yield increments in minimum or

zero tilled plots have occurred after several years of soil physical, chemical, and biological improvement. Therefore, long-term tillage experimentation is vital to figure out the positive effect of MT on the yield and yield components of the maize plant.

Tillage methods had a significant ($p < 0.05$) effect on biomass yield at Meskan but not attained at the Hawassa Zuria (Table 4.5). In both sites, however, there was a tendency of higher biomass yield from CT compared to MT. The CT yielded 2.6 and 9.5% more biomass than the MT at the Hawassa Zuria and Meskan sites, respectively. The possible reason for biomass yield reduction under MT could be due to poor crop establishment and limited root growth (Halvorson et al., 2006; Cid et al., 2014). Goshime et al. (2020) reported similar results and stated that at the initial stage, CT produced superior biomass compared to conservation tillage. A similar observation was also reported by Tolessa et al. (2007) who indicated the need to wait at least three years to see the benefit of minimum tillage on grain yield and yield components.

Cropping systems had significant ($P < 0.05$) impacts on grain yield, biomass, and 1000-seed weight at Hawassa Zuria. In contrast, these parameters did not show significant variation at Meskan (Table 4.5). The haricot bean-maize rotation system increased maize grain yield, biomass, and 1000-seed weight by 4.1, 3.9, and 5.1% respectively compared to maize monocropping (Table 4.5). This might be due to the change in soil available N through legume residue decomposition and atmospheric N_2 fixation. Similarly, Yusuf et al. (2009a) reported that maize grain yield increased by 1.2 to 1.3-fold when cultivated in legume-based cropping sequences. Correspondingly, Tolera et al. (2009) found that the inclusion of pulse crops as a precursor increased corn grain yield compared to maize monocropping at Bako in Western Ethiopia.

In the present study, the effect of the rotation system on yield components was not similar at the two sites. A statistically noticeable variation was observed at Hawassa Zuria; this could be the presence of a reduced amount of initial soil TN (Table 4.1), and thus adopting a legume-based cropping sequence is indispensable to enhancing and sustaining crop production in this area.

Analysis of variance depicted that the grain yield, biomass and 1000-seed weight differed significantly ($p < 0.001$) among N-treatments in both sites. However, the crop responses to the applied N treatments were significantly different between the two sites (Table 4.5). This was probably due to the variation in soil type and initial fertility status. Similarly, Gehl et al. (2005) reported that optimum N-fertilization is influenced by factors including soil type, tillage, irrigation, fertilizer timing and method, and their interactions. The highest grain yields of 4180.5 kg ha^{-1} and 8169.4 kg ha^{-1} were obtained from the application of 92 kg N ha^{-1} and 46 kg N ha^{-1}+ 10 t ha^{-1} compost treatments at Hawassa Zuria and Meskan sites, respectively. The lowest grain yield obtained from Hawassa Zuria was associated with the initial soil total N content and most likely the lowest available N before sowing and fertility status (Table 4.1). The yield obtained from the control treatment was significantly lower ($p < 0.001$) than the yield achieved from either the separate or combined application of compost or inorganic N fertilizer.

At Hawassa Zuria, all parameters improved gradually with increasing nitrogen levels and attained the maximum grain yield, biomass, and 1000-seed weight values from sole inorganic N (92 kg N ha^{-1}), which was closely followed by the combined N-treatment (46 kg N ha^{-1} +10 t ha^{-1} compost) (Table 4.5). The application of sole inorganic N (92 kg N ha^{-1}) increased grain and biomass yields by 27.7 and 19.1% compared to control, respectively (Table 4.5). Similarly, Habatamu (2015) found that application of N fertilizer significantly enhanced the yield and yield

components of corn. Whereas, at Meskan, the integrated use of 46 kg N ha^{-1} +10 t ha^{-1} compost produced the highest grain yield, biomass, and 1000-seed weight. However, a similar response was not observed at Hawassa Zuria to the integrated application. Correspondingly, at the Hawassa Zuria, the response of maize yield to sole mineral N (92 kg ha^{-1}) was not as pronounced as that of Meskan (Table 4.5). This is because of low initial soil total N, leading to a good response to inorganic N fertilizer application.

In this experiment, the growth, yield, and yield components of maize were significantly improved owing to the combined addition of compost with inorganic N fertilizer (Tables 4.4 and 4.5). Compared to the control (non-fertilized plot), the integrated application of 46 kg N ha^{-1} + 10 t ha^{-1} compost increased grain yield by 20.8 and 36.4% at Hawassa Zuria and Meskan sites, respectively. The improvement in maize grain yield in the integrated application was due to the direct addition of N and othe essential nutrients through the decomposition of the compost added to the soil and soil physicochemical improvement, which is caused by organic input. Similarly, Ahmad et al. (2013) and Zahir et al. (2007) reported that the combined application of Urea and compost gave superior maize grain yield over that of either single application or control and thus recommended for yield profitability and sustainable soil productivity. In the present sites, the minimum biomass and grain yields were recorded from the control (unfertilized plot), followed by sole compost.

The harvest index (HI) determines the amount of photosynthetic translocate to the economic parts of the plant (Khademi and Malakotti, 1998). At Meskan, tillage methods had a significant effect on the harvest index but did not exhibit significant variation at Hawassa Zuria (Table 4.5). Conventional tillage gave a higher harvest index over that of minimum tillage. Similarly,

Ahadiyat and Ranamiukhaarac-hchi (2008) reported that conventionally tilled plots gave a higher harvest index. In both sites, cropping systems had no significant effect on the harvest index. Conversely, the application of nitrogen inputs showed significant ($p < 0.05$) variation on the harvest index. The addition of 92 kg N ha^{-1} and 46 kg N ha^{-1} + 10 t ha^{-1} compost treatments gave the highest harvest index when compared to other nitrogen treatments at Hawassa Zuria and Meskan, respectively. This implies that the higher the index, the greater the yield of the harvestable economic product. Eivazi and Habibi (2013); Lawrence (2008); Nemati and Sharifi (2012) reported similar results, in that the harvest index was significantly influenced by nitrogen fertilizer rates.

Table 4.5 Means for the main effects of tillage methods, cropping systems and nitrogen fertilization on total dry biomass and grain yields, 1000-seed weight and harvest index of maize at the two sites

Treatments	Hawassa Zuria				Meskan			
	BY	GY	TSW	HI	BY	GY	TSW	HI
	kg ha^{-1}		(g)	(%)	kg ha^{-1}		(g)	(%)
Tillage methods								
MT	14709.4	3662.6^{b}	278.7	25.04	21833.7^{b}	7064.0	293.0^{b}	29.8^{b}
CT	15099.0	3855.5^{a}	273.7	25.62	23947.5^{a}	7094.9	306.3^{a}	32.6^{a}
LSD (0.05)	ns	142.6	ns	ns	1526.7	ns	4.62	2.2
Cropping systems								
RCS	15189.6^{a}	3835.1^{a}	283.1^{a}	25.4	22914	7076.0	298.1	31.4
MCS	14618.8^{b}	3683.5^{b}	269.3^{b}	25.3	22867	7083.2	301.2	31.0
LSD (0.05)	463.77	128.8	4.96	ns	ns	ns	ns	ns
Nitrogen fertilization								
Control	13570.8^{b}	3273.3^{d}	273.5^{b}	24.3^{b}	20769^{b}	5987.9^{d}	297.2^{b}	29.1^{b}
20 t ha^{-1} Compost	14381.3^{b}	3628.2^{c}	267.7^{b}	25.4^{ab}	22062^{b}	6419.2^{c}	296.7^{b}	30.0^{b}
46 kg N ha^{-1} +10 t ha^{-1} Compost	15495.8^{b}	3954.4^{b}	278.3^{ab}	25.8^{a}	24641^{a}	8169.4^{a}	304.1^{a}	33.4^{a}
92 kg N ha^{1}	16168.8^{a}	4180.5^{a}	285.2^{a}	25.9^{a}	24140^{a}	7741.8^{b}	300.7^{ab}	32.2^{a}
LSD (0.05)	962.13	113.7	11.02	1.15	2159.1	310.2	6.54	2.2

*Means within columuns followed by the same letter did not differ significantly across the tillage methods, cropping systems, and N-fertilization at $P \leq 0.05$ according to LSD test. BY: biomass yield: GY: grain yield; TSW: 1000-seed weight; HI: harvest index.

Interaction effect of tillage methods and cropping systems

The interaction between TM and CS had significant ($p < 0.05$) effects on plant height, biomass yield, and harvest index at Hawassa Zuria (Fig. 4.2). Conventional tillage with HB-maize rotation produced maximum biomass yield (16068.75 kg ha^{-1}) and the highest plant (218.8 cm). This suggests that crop growth was heavily influenced by the tillage system and rotation, which were most likely related to soil aeration and fertility. At Meskan, however, all parameters did not show any significant effect by TM*CS interaction.

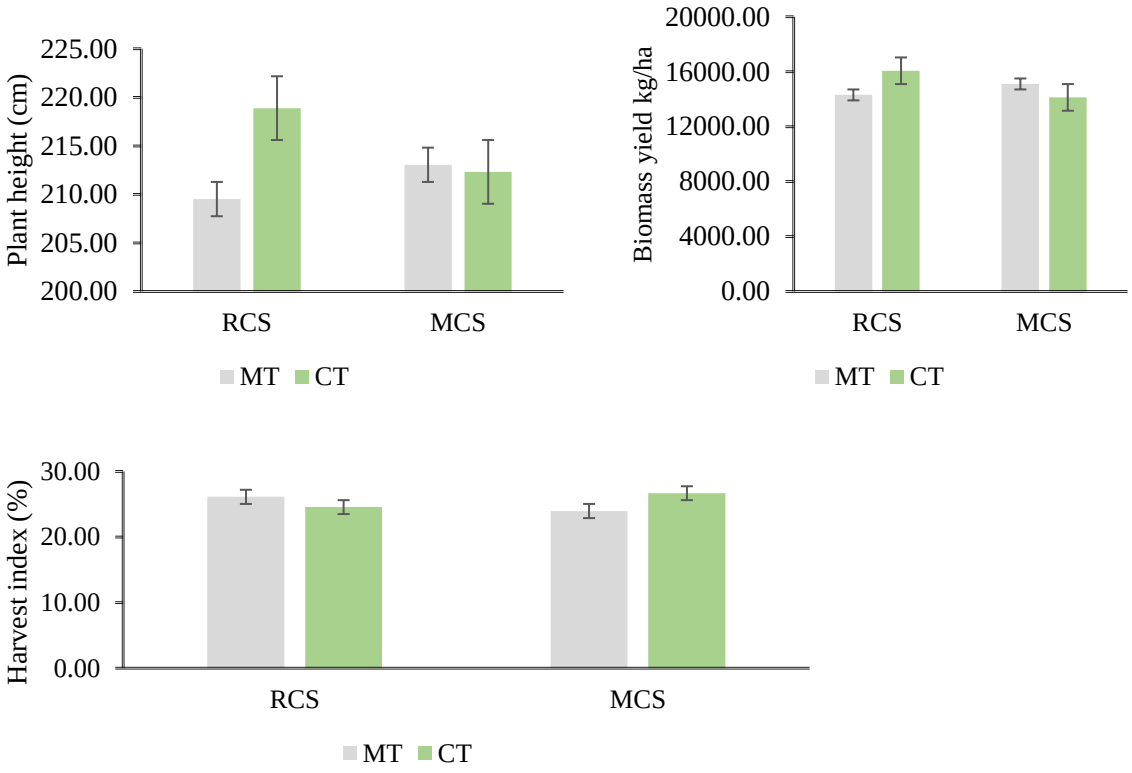

Figure 4.2. The interaction of tillage method and cropping system on plant height, biomass yield, and harvest index of maize grown at Hawassa Zuria.

Interaction effect of tillage method and nitrogen fertilization

Plant height, 1000-seed weight, and harvest index were all significantly ($p < 0.05$) affected by the interaction of TM and NF at Hawassa Zuria. The interaction of CT with 92 kg N ha^{-1} produced the highest plant height, maximum 1000-seed weight, and harvest index. At Meskan, however, interactions had no effect on any of the parameters.

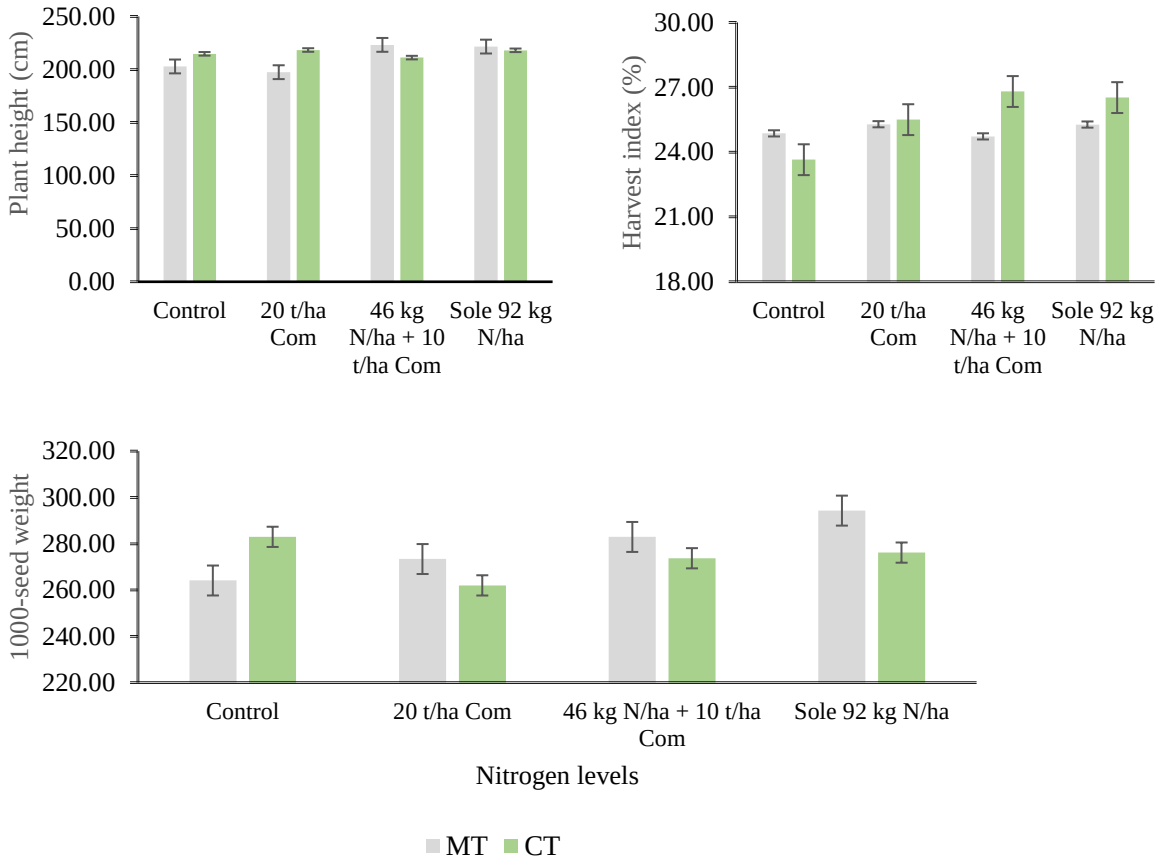

Figure 4.3. The interaction of tillage method and N-fertilization on plant height, 1000-seed weight and harvest index of maize grown at Hawassa Zuria.

Interaction effect of cropping systems and nitrogen fertilization

At Hawassa Zuria, the CS by NF interaction had significant effects on mean NDVI, biomass yield, 1000-seed weight, and harvest index, indicating that cropping systems were affected by

NF and Vis's verse (Fig. 4.4). In contrast, at Meskan site, the interactions had no effect on all the parameters.

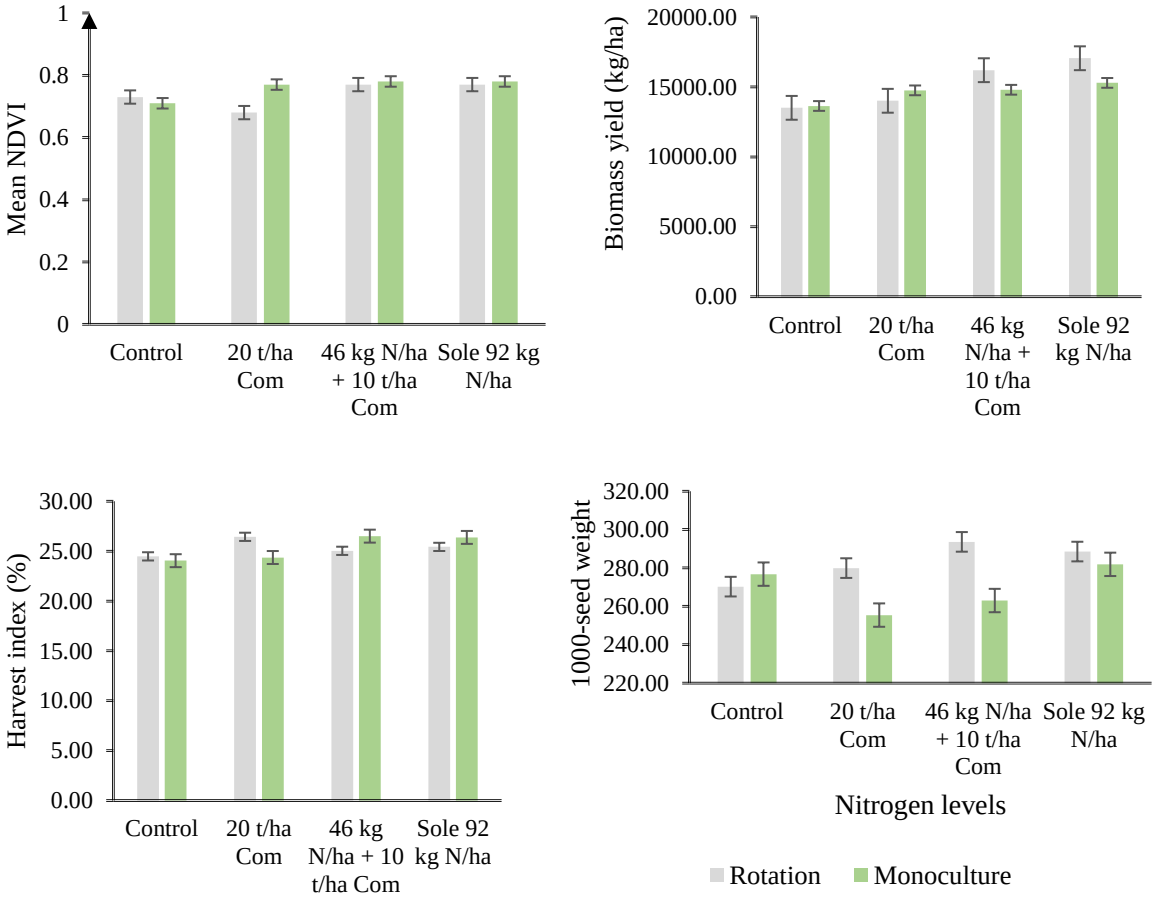

Figure 4.4. Interaction effects of cropping system and nitrogen rate on NDVI, biomass yield, and harvest index and 1000-seed weight of maize grown at Hawassa Zuria.

The three-way interaction of tillage methods, cropping systems and N-fertilization

At Hawassa-Zuria, the three-way interaction of TM, CS, and NF significantly ($p < 0.05$) affected mean NDVI, plant height; 1000-seed weight and harvest index (Table 5 and 6). At Meskan, however, the three-way interaction of TM, CS, and NF had brought significant ($p < 0.05$) variation only on the mean NDVI (Tables 4.3 and 4.6).

Table 4.6 The three-way interaction of tillage methods, cropping systems and nitrogen fertilizer rates

Treatments			Hawassa Zuria				Meskan
			NDVI	PH (cm)	TSW (g)	HI (%)	NDVI
		Control	0.74^{b}	197.87^{c}	267.93^{bc}	25.99^{ab}	0.74^{c}
	RCS	20 t ha^{-1} Compost	0.71^{b}	199.60^{bc}	291.19^{b}	27.81^{a}	0.78^{bc}
		46 kg N ha^{-1} +10 t ha^{-1} Compost	0.74^{b}	222.87^{ab}	312.89^{a}	25.74^{ab}	0.84^{a}
MT		92 kg N ha^{1}	0.74^{b}	217.73^{b}	270.07^{b}	24.93^{b}	0.78^{bc}
		Control	0.71^{b}	207.87^{b}	260.29^{c}	23.75^{b}	0.72^{d}
	MCS	20 t ha^{-1} Compost	0.75^{b}	195.33^{c}	255.59^{c}	22.77^{c}	0.78^{bc}
		46 kg N ha^{-1} +10 t ha^{-1} Compost	0.78^{a}	223.53^{ab}	252.96^{c}	23.71^{b}	0.81^{ab}
		92 kg N ha^{1}	0.79^{a}	225.47^{a}	318.52^{a}	25.62^{ab}	0.73^{cd}
		Control	0.72^{b}	221.00^{ab}	272.64^{b}	22.96^{b}	0.74^{c}
	RCS	20 t ha^{-1} Compost	0.65^{c}	209.93^{b}	268.69^{bc}	24.32^{b}	0.80^{ab}
		46 kg N ha^{-1} +10 t ha^{-1} Compost	0.80^{a}	219.60^{ab}	274.32^{b}	24.17^{b}	0.80^{ab}
CT		92 kg N ha^{1}	0.80^{a}	225.00^{a}	307.05^{ab}	25.91^{ab}	0.75^{c}
		Control	0.71^{b}	208.53^{b}	293.31^{b}	24.34^{b}	0.74^{c}
	MCS	20 t ha^{-1} Compost	0.78^{ab}	226.8^{a}	255.32^{c}	25.93^{ab}	0.78^{bc}
		46 kg N ha^{-1} +10 t ha^{-1} Compost	0.77^{ab}	202.8^{bc}	273.13^{b}	29.33^{a}	0.82^{a}
		92 kg N ha^{1}	0.78^{ab}	211.13^{b}	245.28^{d}	27.15^{a}	0.78^{bc}

4.3.5 Pearson`s correlation coefficient analysis

In both sites, significant associations were detected among plant and soil parameters. At Hawassa Zuria, the NDVI was positively significantly correlated with cob length, biomass and grain yields with r= 0.60, 0.51, and 0.59, respectively (Table 4.7). Whereas in Meskan, biomass, grain yields, harvest index, soil organic carbon and total nitrogen contents were positively significantly associated with NDVI of the leaves with r= 0.50, 0.84, 0.67, 0.58, and 0.80, respectively. Feyisa and Abera (2020) who reported a strong relationship between NDVI and maize grain yield reported a similar observation.

Pearson correlation coefficient of grain yield under different soil management practices was positively significantly correlated with NDVI, cob length, biological yield, and soil nitrogen content with r = 0.59, 0.71, 0.77, and 0.60, respectively in Hawassa Zuria soil. Similarly, in Meskan, grain yield was positively significantly associated with NDVI, cob length, biological yield, harvest index, and soil nitrogen content with r = 0.84, 0.54, 0.73, 0.59, and 0.78, respectively (Table 4.7). The observation is consistent with the finding of Adis et al. (2015) which indicated that there is a strong association among NDVI, grain yield and soil TN.

Table 4.7 Correlation coefficients among soil and plant parameters of maize grown on the two soils from Hawassa and Meskan districts. Upper right side for Hawassa Zuria soil and lower left side for Meskan soil

Parameters	NDVI	PHT	CL	BY	GY	HI	OC	TN
NDVI	1	0.44	**0.60***	**0.51***	**0.59***	0.17	0.13	0.48
PHT	0.18	1	0.38	**0.61***	0.49	-0.18	0.06	0.31
CL	0.36	0.03	1	**0.51***	**0.71****	0.34	0.04	0.36
BY	**0.50***	0.48	0.40	1	**0.77****	-0.29	0.25	**0.54***
GY	**0.84*****	0.21	**0.54***	**0.73****	1	0.39	0.33	**0.60***
HI	**0.67****	-0.27	0.31	-0.11	**0.59***	1	0.18	0.15
OC	**0.58***	0.01	0.36	0.29	0.38	0.26	1	0.64*
TN	**0.80****	0.00	0.45	0.36	**0.78****	**0.72****	0.44	1

NDVI - normalized vegetation index; PHT - plant height; CL - cob length; BY - biological yield; GY - grain yield; HI - harvest index; OC - organic carbon in soil; TN - total nitrogen in soil and C: N - carbon to nitrogen ratio. * - significant levels at $P < 0.05$; ** - significant levels at $P < 0.01$; *** - significant levels at $P < 0.001$; ns - not significant.

4.4 Conclusion

From the results, we concluded that soil management practices differed in their effects on soil chemical properties, yield and yield components. In both soils, CT tended to increase yield and yield components in contrast to the MT. Similarly, nitrogen fertilization affected the grain yield and yield components. However, tillage methods and N-fertilization differed in their effects on soil chemical properties, the MT and integrated N-treatment were improved soil OC and TN concentrations compared to CT and other N-treatments, respectively. Therefore, a CT plus haricot bean-maize rotation system with the addition of sole 92 kg N ha^{-1} and integrated 46 kg N ha^{-1} + 10 t compost ha^{-1} could be recommended for Cambisols in Hawassa Zuria and Phaeozems in Meskan sites, respectively; in order to achieve better yield and yield components. However, in order to ensure sustainable maize production in the studied soils, we concluded that the integrated N-treatment along with MT and legume-based crop rotation, which could enhance soil properties, and will improve yield subsequently ensure sustainable maize production.

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CHAPTER FIVE

Effects of Tillage methods, Cropping systems and Nitrogen fertilization on Nitrogen uptake and Utilization efficiency

5. EFFECTS OF TILLAGE METHODS, CROPPING SYSTEMS AND NITROGEN FERTILIZATION ON NITROGEN UPTAKE AND UTILIZATION EFFICIENCY

Abstract

In the evaluation of crop production, knowledge related to nutrient use efficiency is a critical concept for sustainable agriculture. In the study areas, however, there is scant information on the influence of tillage, cropping systems, and nitrogen fertilization and their interaction on nitrogen uptake and use efficiency of maize. In view of this, field experiments were conducted in the central rift valley of Ethiopia on two different soils for two consecutive years to evaluate the effects of different soil management practices and their interaction on nitrogen uptake and utilization efficiency. A three-factor experiment was arranged as a split-split plot arrangement randomized complete block design with three replications. The MT and CT were used as the main plot, RCS, and MCS as a subplot, and four levels of nitrogen fertilization (Control, 20 t ha^{-1} compost, 46 kg N ha^{-1} + 10 t ha^{-1} compost, and 92 kg N ha^{-1}) as the sub-sub plot. Analysis of variance showed that soil management practices were significantly affecting GNC, GNU, GPC, NHI and NUtE. In both soils, the CT and RCS increased the GNC and GNU, in contrast to the MT and MCS, respectively. Correspondingly, nitrogen fertilization evidently affected the GNC, GNU, GPC and NHI. However, tillage methods differed in their effects on NHI and NUtE; NHI and NUtE were improved through MT compared to CT. Therefore, a CT along with haricot bean-maize rotation system with the addition of integrated 46 kg N ha^{-1} + 10 t compost ha^{-1} could be recommended for Cambisols and phaeozems soils of the study areas. However, in order to ensure sustainable nitrogen utilization in the studied soils, an integrated N-treatment plus MT and legume-based rotation system could be recommended, which could improve NHI and NUtE.

Keywords: Fertilization, grain quality, harvest index, nitrogen uptake, utilization.

5.1 Introduction

In the evaluation of crop production, knowledge related to nutrient use efficiency is a critical concept to ratify sustainable agricultural production and productivity. Nutrient use efficiency (NUE) is a complex and dynamic term containing a range of components. It is the product of absorption efficiency and utilization efficiency (Mi et al., 2007; Hirel et al., 2011). Nutrient use efficiency can be influenced by factors such as nutrient requirement or uptake ability of the crops, the capacity of the soil and fertilizers to supply nutrients, and losses of nutrients from the soil-plant systems, of which crop nutrient requirement is the major factor affecting NUE (Landha et al., 2005). Hence, understanding the driving factors that affect nutrient absorption, assimilation, and mobilization are important to improve crop's NUE (Lewis et al., 2000).

Nitrogen use efficiency can be modified through soil and plant-water management practices (Djaman et al., 2013; Qiu et al., 2015). Soil tillage can remarkably influence N dynamics in the soil by affecting soil aeration, microbial activities, OM decomposition, and nutrient availability (Keshavarz Afshar et al., 2016; Wasaya et al., 2017). Other studies also confirmed that organic matter mineralization can be enhanced through CT (Rusinamhodzi et al., 2011; Panettieri et al., 2013) and hence better yield and N availability (Dinnes et al., 2002). However, CT has the potential to reduce SOM due to enhanced decomposition rate and hence, negatively affect long-term crop productivity, nutrient uptake, and soil health (Zuber et al., 2015).

Pekrun et al. (2003) and Ozpinar and Cay (2009) proved that adopting different tillage systems have their own effects on the delivery of both macro-and micronutrients in topsoil. Among different agricultural management practices currently used, conservation tillage is a technique known to improve the uptake of soil N by the plant (Jin et al., 2012) and to increase the content

of SOM (Lal, 2009). However, at the transitional time, yields, nutrient availability and uptake, particularly N, are the common problem for conservation tillage (Pittelkow et al., 2015). This could be due to the slower decomposition of OM and higher N-immobilization with crop residues (Malhi et al., 2001; Pittelkow et al., 2015).

The availability and dynamics of the key plant nutrients in soils are influenced by cropping patterns. When compared to monocropping, a legume-based rotation system can improve N availability and uptake for successive cereal crops while also reducing N losses (Coulter et al., 2011). Similarly, Fustec et al. (2010) and Kihara and Njoroge (2013) reported that cropping systems can alter soil nutrient status and availability to succeeding crops.

The most critical nutrient for maize is nitrogen (N), which regulates grain yield through its participation in photosynthesis and other biological activities. To produce the optimum grain and biomass yields, maize needs a lot of nitrogen (Amanullah et al., 2009). Despite the huge amount of N-fertilizers used globally to achieve optimal grain yields, its RE is lower, ranging from 35 to 55% (Couto-Vazquez et al., 2016; Kumar et al., 2016). However, a better understanding of NUE mechanisms, such as the utilization of appropriate N fertilizer sources, application rate and time, soil and water management, and cropping system, can aid in maize NUE improvement (Zheng et al., 2016; Wolz et al., 2018).

Crop production with minimum input application is viewed as an alternative strategy in modern agriculture for achieving sustainable agricultural production (Brooker et al., 2016). The judicious uses of N fertilizers have a remarkable consequence to produce sustainable agricultural outputs (Kumar et al., 2016). Earlier studies distinguished that an increase in N input above a certain level, neither leads to an increase in grain production nor N-uptake; rather

it might be a cause for environmental problems such as eutrophication, and greenhouse gases emissions (López-Bellido et al., 2014; Meena et al., 2014) and also result in lodging, susceptibility to disease and pest attacks. Moreover, with an increase in N-rates, an index of NUE (AE and RE) tends to decreases (Barbieri et al., 2008). Conversely, underutilization of N-fertilizers contributes to the depletion of organic matter and be the prime cause for low crop productivity. Therefore, optimum N-management is important to improve yield and N uptake and subsequently to reduce environmental concerns.

Urea is the most widely used N fertilizer in agriculture. Most crops utilized about 30–70% of the applied inorganic N fertilizer; the rest is subject to losses through different ways such as leaching, surface run-off, volatilization, denitrification, and the fixation mechanism in soil (Canfield et al., 2010; Xue et al., 2010a). Mineral nitrogen loss from the soil-plant system not only reduces soil fertility and plant yield but also has a negative effect on the environment. To revert such phenomena, integrated organic and inorganic inputs application is imperative to enhance nutrient use efficiency of the plants particularly N. Previous studies also confirmed that amending soils with organic inputs like manure or compost along with mineral fertilizer improved soil air exchange, water holding capacity and infiltration rate in contrast to sole mineral fertilizers application (Lal 2009; Quilty and Cattle 2011; Fischer and Glaser 2012) and subsequently improved NUE (Tollesia et al., 2001).

There is a need to integrate efforts on the judicious use of different soil management practices to improve NUE and reduce environmental concerns (Kumar et al., 2015). In the study areas, however, information pertaining to the influence of tillage, cropping systems, and nitrogen fertilization and their interaction on nitrogen uptake and use efficiency of maize is scant.

Therefore, field experiments were carried out at Hawassa Zuria and Meskan district to evaluate the effect of different soil management practices and their interaction on nitrogen uptake and use efficiency of maize. The integrated use of organic and inorganic nitrogen fertilizers, along with crop rotation and minimum tillage, were expected to improve maize nitrogen uptake and use efficiency.

5.2 Materials and Methods

5.2.1 Description of the experimental locations

The field experiments were carried out during two consecutive growing seasons (2019 and 2020) at Hawassa Zuria and Meskan districts of the central rift valley of Ethiopia. Section 1.5.1 contains detailed descriptions of the research sites. According to the WRB soil classification system, the soil types for the field trial were Cambisols for Hawassa Zuria and Phaeozems for Meskan (IUSS Working Group, 2015). The soil at Hawassa Zuria has loam textural class, medium OC and TN as rated by Landon (2014), very low available P (Havlin, 1999), and medium CEC as rated by Hazelton and Murphy (2007) (Table 4.1). Whereas the soil at Meskan has a clay textural class with high OC, medium TN, high available P, and CEC as presented in Table 4.1.

5.2.2 Treatment, experimental design and management practices

Two tillage practices were evaluated: conventional tillage (CT) and minimum tillage (MT). The two tillage practices were combined with two cropping systems: haricot bean-maize rotation (RCS) and maize monocropping (MCS). In addition, four levels of nitrogen fertilization (NF) (0, 20 t ha^{-1} compost, 46 kg N ha^{-1} + 10 t ha^{-1} compost, and 92 kg N ha^{-1}) were combined with tillage practices and cropping systems. Treatments were arranged as Split-split plot arrangement randomized as an RCBD (randomized complete block design), with tillage methods as the main plots, cropping systems as sub-plots, and nitrogen fertilization treatments as sub-sub plots, with three replicates; making 48 sub-sub-plots for each experimental site. The management practices are described in detail in section 1.2.3.

5.2.3 Grain yield and stover dry matter yield measurements

At the Hawassa Zuria and Meskan experimental sites, samples of maize grains and stover were collected at harvest, which corresponded to 173 and 175 days after sowing, respectively. The samples were collected from a net plot area of 4 m^2 (1.25 m x 3.2 m) by rejecting the border rows, from three replications. Grain yield and stover dry matter yield were measured using a high-capacity precision balance.

5.2.4 Grain and stover sampling and analysis

From each experimental unit and site, representative samples were randomly taken and partitioned into grain and stover for the determination of N content. The samples were oven-dried at 70 ^{0}C to constant weight thereafter; and the samples were ground and passed through a 0.5 mm sieve. Twenty grams of grain and stovers samples were taken from each experimental unit. The nitrogen contents in the grain and stover were analyzed using the Kjeldahl procedure after wet digestion by H_2SO_4/H_2O_2 (Nelson and Sommers, 1982). The grain and stover N-contents were analyzed in the soil and plant testing laboratory of the Kulumsa Agricultural Research Center.

5.2.5 Nitrogen uptake and use efficiency

The grain and stover nitrogen uptake were computed by multiplying N-content with the respective grain and stover yields, respectively. The total N-uptake was calculated by adding the N-uptake in grain and N-uptake in stover (kg ha^{-1}).

$$Grain\ N\ uptake\ \left(\frac{kg}{ha}\right)$$

$$= \frac{\left(Grain\ N\ content\ \frac{g}{kg} \times grain\ yield\ \frac{kg}{ha}\right)}{1000} - - - - - - - -\ (\text{Equ} - 1)$$

$$Stover\ N\ uptake\ \left(\frac{kg}{ha}\right)$$

$$= \frac{Stover\ N\ content\ \frac{g}{kg} \times stover\ DM\ \frac{kg}{ha}}{1000} - - - - - - - -\ (\text{Equ} - 2)$$

$$Total\ N\ uptake\ \left(\frac{kg}{ha}\right)$$

$$= Grain\ N\ uptake\ \left(\frac{kg}{ha}\right) + Stover\ N\ uptake\ \left(\frac{kg}{ha}\right) - - -\ (\text{Equ} - 3)$$

Agronomic efficiency (AE) is defined as the economic production obtained per unit of nutrient applied. It was calculated by dividing the grain yield to the applied nutrient (Wu et al., 2011).

$$NAE\ (kg\ grain\ per\ kg\ N\ applied)$$

$$= \frac{GYn - GYo}{FN\ applied} -\ (\text{Equ} - 4)$$

Where GYn = grain yield of N fertilized plot, GYo = grain yield of N unfertilized plot, and FN = amount of N applied per plot.

Physiological efficiency (PE), is defined as the ability of a plant to transform N acquired from fertilizer into grain yield. It was computed as grain yield obtained per unit of nutrient uptake.

$$PE\ (kg\ grain\ per\ kg\ N\ uptake) = \frac{GYn - GYo}{TNUn - TNUo} -\ (\text{Equ-5})$$

Where GYn = grain yield from N fertilized plot, GYo = grain yield from N unfertilized plot, TNUn = total N uptake from N fertilized plot, and TNUo = total N uptake from N unfertilized plot.

Apparent N recovery efficiency (ARE), also referred to as applied N-uptake efficiency, is the ratio of the difference in N-uptake between the fertilizer treated and non-treated (control) plots to the applied N rate as described by Azizian and Sepaskhah (2014). It was calculated as:

$$ARE\ (kg\ N\ uptake\ per\ kg\ N\ applied) = \frac{TNUn - TNUo}{FN\ applied} * 100 - - - - - - \text{(Equ} - 6)$$

Where TNUn = total N uptake from N fertilized plot, and TNUo = total N uptake from N unfertilized plot, and FN= amount of N applied.

Nitrogen utilization efficiency (NUtE) was calculated according to (Moll et al., 1982, Huggins and Pan, 1993) using the following equation: -

$$NUtE\ = \frac{Grain\ yield\ (\frac{kg}{ha})}{TNU\ (\frac{kg}{ha})} - \text{(Equ} - 7)$$

Nitrogen harvest index (NHI) was computed using the following formula (Foulkes, Reynolds, and SylvesterBradley 2009):

$$Nitrogen\ harvest\ index\ (\%) = \frac{\left(grain\ N\ uptake\ \frac{kg}{ha}\right)}{Total\ N\ uptake\ kg/ha} \times 100 - - - - - \text{ (Equ} - 8)$$

$$Grain\ protien\ content\ (\%) = Grain\ N\ content\ (\%) \times 6.25 - - - - - - - \text{(Equ} - 9)$$

5.2.6 Statistical analysis

Prior to analysis of variance (ANOVA), the normality of the data was checked using the Shapiro-Wilk normality test. Statistical analysis of variance was computed independently for each location using the SAS 9.3 software package (SAS Institute, 2014). The statistical analysis and its model were described in detailed under section 1.2.9.

5.3 Results and Discussion

Effects of experimental factors and their interactions on grain and stover N-contents and uptakes of maize

The main effects of CS, NF and the interaction of TM×CS and CS×NF, and TM×CS×NF showed significant ($P < 0.05$) effects on gain N-content, N-uptake, and protein content at Hawassa Zuria. Whereas at Meskan, gain N-content, N-uptake, and protein content were significantly influenced by the main effects of CS and NF and the interaction of CS×NF (Appendix Table 2). At Hawassa Zuria, the main factors of TM, CS, and NF and the interaction of CS×NF had a significant effect on NU_tE (Appendix Table 2). Likewise, the NU_tE of the Meskan site was significantly affected by the main factors of TM, CS, and NF and the interaction of CS×NF and TM×CS×NF (Appendix Table 2).

5.3.1 The main effects of tillage methods, cropping systems, and N-fertilization on grain and stover N-contents and uptakes of maize grown at the two sites

Tillage methods had no significant effect on grain N-content in both sites. This result is at par with the findings of Habbib et al. (2016) who indicated no significant effect of tillage on grain N-content. Tillage methods at Hawassa Zuria showed significant variation in stover N-content, grain N-uptake, stover N-uptake, and total N-uptake (TNU), with CT achieving the higher values compared to MT. However, at Meskan, SNU and TNU only revealed significant ($P < 0.05$) variation with higher values of 80.8 and 170.5 kg ha^{-1}, respectively (Table 5.1). Although there were no significant variations observed in grain N-content, stover N-content and N-uptake at Meskan, CT in general, offered higher values compared to MT.

In both soils, the N-content and N-uptake parameters responded positively to CT, possibly due to the stimulation of N-mineralization from organic matter and thereby improved soil mineral N-availability for crop uptake. Significantly higher N-content and total N-uptake under conventionally tilled plots of maize might be due to improved root growth, density, and soil moisture availability (Wang et al., 2015). Similarly, Masvaya et al. (2017) reported that crop yields and N-uptake were superior in CT as compared to MT. Tilling soils through the conventional method usually improves the soil aeration and organic matter decomposition (Dinnes et al., 2002). Similarly, Simić et al. (2020) verified the benefit of conventional tillage for better maize grain yield and enhancement in grain protein content. Conversely, minimum soil disturbance resulted in reduced available soil N, which is largely due to an increase in N-immobilization. A similar finding was reported by Malhi et al. (2001) describing the shifting of CT to MT tends to decrease nutrient concentrations in the soils and thereby uptake, particularly N, which could be improved through the addition of optimal N and inclusion of legume, crops as a precursor. Based on the existing information, MT seems to have lower N-uptake efficiency compared to CT, which is positively coincided with the yield and yield components, and higher value was obtained from CT. Therefore, application of optimum N is advisable to overcome the effect of N-immobilization under MT to enhance N-mineralization.

At Hawassa Zuria, cropping systems had significant ($P < 0.05$) effects on GNC, GNU, SNC, SNU, and TNU; higher values were achieved from the haricot bean-maize rotation system than maize monocropping (Table 5.1). The haricot bean-maize rotation system increased maize GNC, SNC, GNU, SNU and TNU by 17.8, 21.4, 17.6, 28.8 and 25.1% in Hawassa Zuria, respectively, compared to maize monocropping (Table 5.1). Similarly, cropping systems used at Meskan had significant effects on GNC, SNC, GNU, SNU, and TNU. In comparison to maize

monocropping, the haricot bean-maize rotation system improved GNC and GNU by 10 and 12.1%. This was possibly due to the change in inorganic-N availability in the soil caused by previous atmospheric N_2 fixation and legume residue decomposition since legume residues have better quality and a narrow C: N ratio, which results in rapid release of N from the residues (Lafond et al., 2006; Lupwayi et al., 2011). Similarly, Adesoji et al. (2015) found improved N content and uptake in maize following soybean rotation system due to enhanced soil N.

In this study, the mean grain N-content, N-uptake, stover N-content and related components were higher in the Meskan than in Hawassa Zuria at all treatments of nitrogen fertilization (Table 5.1). The differences in N-contents and uptakes in grain and stover between locations were associated with grain and stover yields, whereby Meskan yields were higher than that of Hawassa Zuria (Table 5.1). This could be due to the higher initial soil TN and fertility status of the soil at Meskan as compared to the Hawassa Zuria (Table 4.1).

Analysis of variance depicted that nitrogen fertilization had significant effects on GNC, SNC, GNU, SNU, and TNU in both sites (Table 5.1). In both locations, higher stover and total N-uptake at higher inorganic N levels could be due to more N available for plant uptake (Hussaini et al., 2008). When compared to the unfertilized plot, the combined application of inorganic nitrogen and compost at a rate of 46 kg N ha^{-1} + 10 t ha^{-1} improved GNC, SNC, GNU, SNU, and TNU by 35.4, 46.4, 64.5, 67, and 65.7% in Hawassa Zuria and 24.3, 12.2, 68.2, 23.1, and 46.5% in Meskan, respectively. Our result is in covenant with the findings of Dunjana et al. (2012); Negassa et al. (2005); Rusinamhodzi et al. (2013), which indicated that integrated application of organic and mineral fertilizers at appropriate rates can be an effective approach to improve maize N uptake. In the present study, the grain, stover, and total N-uptake of maize

treated with sole organic input (compost) was lower than that of maize treated with sole inorganic N fertilizer, possibly due to the slow-release nature of the nutrients from organic input as was also reported by Makinde and Ayoola (2010).

Table 5.1 The effects of tillage methods, cropping systems, and N-fertilization on grain and stover N-concentrations and uptakes of maize at the two sites

Treatments	Hawassa Zuria					Meskan				
	GNC	SNC	**GNU**	**SNU**	**TNU**	**GNC**	**SNC**	**GNU**	**SNU**	**TNU**
	(%)		**(kg ha^{-1})**			**(%)**		**(kg ha^{-1})**		
Tillage methods										
MT	0.96	0.33^{b}	35.6	36.4^{b}	71.9^{b}	1.24	0.48	89.03	72.6^{b}	161.8^{b}
CT	0.99	0.41^{a}	39.1	46.9^{a}	86.5^{a}	1.25	0.49	89.7	80.8^{a}	170.5^{a}
LSD (0.05)	ns	0.05	ns	6.53	4.46	ns	ns	ns	4.76	6.36
Cropping systems										
RCS	1.06^{a}	0.40^{a}	40.9^{a}	47.2^{a}	88.08^{a}	1.32^{a}	0.38^{b}	94.5^{a}	59.8^{b}	154.3^{b}
MCS	0.90^{b}	0.34^{b}	33.7^{b}	36.7^{b}	70.41^{b}	1.2^{b}	0.59^{a}	84.3^{b}	93.6^{a}	177.8^{a}
LSD (0.05)	0.09	0.01	3.8	2.6	6.03	0.03	0.01	5.6	9.26	11.9
Nitrogen fertilization										
Control	0.82^{d}	0.28^{d}	26.8^{c}	28.8^{d}	55.65^{c}	1.11^{c}	0.41^{c}	66.9^{d}	61.1^{c}	128.1^{d}
20 t ha^{-1} Compost	0.94^{c}	0.36^{c}	34.2^{b}	38.5^{c}	72.75^{b}	1.18^{c}	0.49^{b}	75.8^{c}	75.8^{b}	151.6^{c}
46 kg N ha^{-1} +10 t ha^{-1} Compost	1.11^{a}	0.41^{a}	44.1^{a}	48.1^{b}	92.21^{a}	1.38^{a}	0.46^{b}	112.5^{a}	75.2^{b}	187.7^{b}
92 kg N ha ^{1}	1.05^{a}	0.43^{a}	44.1^{a}	52.2^{a}	96.37^{a}	1.3^{b}	0.59^{a}	102^{b}	94.7^{a}	198.4^{a}
LSD (0.05)	0.06	0.02	0.06	3.33	4.56	0.07	0.04	4.2	5.14	4.8

Values of a parameter means followed by the same letter did not differ significantly across the tillage methods, cropping systems and N-fertilization at $P \leq 0.05$ according to LSD test. GNC: grain N-content; SNC: stover N-content; GNU: grain N-uptake; SNU: stover N-uptake; TSU: total N-uptake.

According to Xu et al. (2012a), grain protein content (GPC) is an important quality parameter for cereal crops. The present study showed that tillage practice had no considerable effect on GPC in both sites, with maximum values of 6.25 and 8.83 at Hawassa Zuria and Meskan, respectively. Similarly, a non-significant effect of tillage systems on GPC was reported by Sabo et al. (2007). However, cropping systems had a significant effect on GPC (Table 5.2). Maize after haricot bean contained more GPC as compared to maize after maize cropping system. Higher grain protein contents in the legume-based rotation system of the present study might be due to more N-uptake by maize grain under rotation as compared to maize monocropping.

Similarly, nitrogen fertilization increased GPC, as nitrogen plays a vital role in enhancing protein content due to the existence of the amino group, which is a protein building block (Zhang et al., 2010). The unfertilized plot gave the lowest result at both locations, with values ranging from 5.12 to 6.92% at Hawassa Zuria and 6.99 to 9.25% at Meskan. When compared to the unfertilized plot, the integrated usage of mineral N and compost enhanced GPC by 35.7 and 18.5% for Hawassa Zuria and Meskan, respectively. At both sites, the increase in grain protein content corresponded to an increase in the nitrogen levels (Table 5.2).

Nitrogen harvest index (NHI) is the proportion of N in grain relative to total aboveground biomass and is an indicator of N translocation efficiency (Soon and Clayton, 2002). Tillage methods had a significant effect on nitrogen utilization efficiency (NUtE) but not on NHI at Hawassa Zuria, whereas tillage methods had significant impacts on both NHI and NUtE at Meskan (Table 5.2). In both sites, MT had higher NHI and NUtE than CT, implying that MT aided in the efficient utilization of supplied nitrogen (Fagerian, 2014). Different cropping systems had significant effects on NHI and NUtE at Meskan, while NUtE only showed a significant variation due to cropping systems at Hawassa Zuria. However, maize cultivated after haricot bean had higher NHI and NUtE values than maize grown after maize.

Nitrogen fertilization had significant effects on NHI and NU_tE in both sites (Table 4). The combined N-treatment produced the highest NHI, with average values of 48.7% and 60.3% for Hawassa Zuria and Meskan, respectively (Table 5.2). This finding showed that using an organic N-source in conjunction with mineral N-fertilizer could improve the inorganic N utilization efficiency. Similarly, the N application had a significant impact on NU_tE. However, the unfertilized plot had the highest NUtE, whilst the maximum N-levels had the lowest N-

utilization efficiency (Table 5.2). This result is consistent with previous findings by Qiao (2012) and Wassaya (2018) who reported the lowest NUtE in rice and maize were recorded in maximum N-levels.

Table 5.2 Means for the main effects of tillage, cropping systems and nitrogen fertilization on GPC, NHI and NUtE of maize grown at the two sites

Treatments	Hawassa Zuria			Meskan		
	GPC	NHI	NU_tE	GPC	NHI	NU_tE
		(%)			(%)	
Tillage methods						
MT	6.02	49.9	53.0^{a}	7.8	55.65^{a}	44.67^{a}
CT	6.25	45.5	46.4^{b}	7.3	52.72^{b}	42.07^{b}
LSD (0.05)	ns	ns	3.5	ns	2.16	2.33
Cropping systems						
RCS	6.72^{a}	48.0	53.4^{a}	8.3^{a}	61.24^{a}	46.38^{a}
MCS	5.65^{b}	47.3	45.9^{b}	7.3^{b}	47.14^{b}	40.36^{b}
LSD (0.05)	0.55	ns	3.78	0.21	2.87	2.01
Nitrogen fertilization						
Control	5.12^{d}	48.2^{ab}	59.8^{a}	6.9^{9}	52.89^{b}	47.04^{a}
20 t ha^{-1} Compost	5.88^{c}	47.1^{ab}	50.4^{b}	7.4^{c}	50.99^{b}	42.95^{b}
46 kg N ha^{-1} +10 t ha^{-1} Compost	6.95^{a}	48.7^{a}	44.4^{c}	8.6^{a}	60.27^{a}	43.68^{b}
92 kg N ha ^{1}	6.57^{a}	45.9^{b}	44.2^{c}	8.3^{b}	52.59^{b}	39.81^{c}
LSD (0.05)	0.35	2.16	2.6	0.25	2.49	1.73

Means followed by the same letter did not differ significantly across the tillage methods, cropping systems and N-fertilization at $P \leq 0.05$ according to LSD test. GPC: grain protein content; NHI: nitrogen harvest index; NUtE: nitrogen utilization efficiency.

5.3.2 Effects of tillage, cropping systems, and N-fertilization on nitrogen use efficiency components of maize grown at the sites

Agronomic efficiency (AE) is one of the components of NUE, which mainly depends on soil and crop management practices. It ranges from 10 to 30 kg yield per kg of nutrient applied (Dobermann, 2005). In our study, insignificant variation in AE was detected between the MT and CT in both sites. At Hawassa Zuria, the cropping systems showed a statistically significant variance in AE, but not at Meskan. However, higher AE in both sites was recorded in the haricot bean-maize rotation system than in maize monocropping (Table 5.3). Nitrogen fertilization had a significant effect on AE at Meskan but not at Hawassa Zuria. Despite the insignificant difference observed in AE at Hawassa Zuria, the highest value was recorded from the integrated

N-treatment in both sites. This result is consistent with Vanlauwe et al. (2011), who found maximum AE of N with coaddition of mineral fertilizer with compost (36 kg maize grain kg^{-1} N).

Fageria and Baligar (2001) define apparent nitrogen recovery efficiency (ANRE) as the crop's ability to remove nitrogen from the soil. Under current farming practices, its value in cereal crops ranged from 0.17 to 0.33, 0.25-0.49 in research plots, and 0.55-0.96 in well-managed research plots (Balasubramanian et al., 2004). In the present study, tillage methods had no significant effect on ANRE in either location (Table 5.3). Similarly, Alvarez et al. (2008) reported insignificant differences in nitrogen recovery efficiency between different tillage systems. On the other hand, cropping systems had a significant impact on ANRE, with higher ANRE for Hawassa Zuria and Meskan in the haricot bean-maize rotation and maize monocropping, respectively. Carsky et al. (1999) found that maize following soybean had lower ANRE than maize monocropping.

At both sites, ANRE showed a statistically significant variation due to nitrogen fertilization, with a decreasing trend as N-levels increased. Despite the inherent soil fertility differences between the experimental sites, the integrated N-treatment resulted in the highest ANRE of 57% for Hawassa Zuria and 93% for Meskan, indicating that integrated N-treatment caused in less N loss (Table 5.3). This result confirms the fact that organic inputs application reduces the leaching of applied inorganic N fertilizer and promotes better use of applied mineral nutrients (Berihun et al., 2017).

The effect of a single application of compost and mineral N fertilizer on ANRE differed between the two sites; this could be due to the differences in soil textural classes (Table 5.3). Similarly,

Huggins and Pan (2003) found that soil textural classes can be a good attributor for N losses in the form of volatilization, leaching, fixation and immobilization. At Meskan, the sole compost treated plot had a lower ANRE than the mineral N treated plot, but at Hawassa Zuria, the sole mineral N treated plot had a lower ANRE than the compost treated plot. According to Moll et al. (1982) and Huggins and Pan (2003), poor N RE is caused by N fluxes to competing channels such as gaseous N losses, leaching, and biological N immobilization.

Table 5.3 Means for main effects of tillage, cropping system and nitrogen fertilization on AE, PE and ANRE of maize grown at the two sites

Treatments	Hawassa Zuria			Meskan		
	AE	**PE**	**ANRE**	**AE**	**PE**	**ANRE**
Tillage methods						
MT	9.12	20.85	48.57	22.3	29.3	78.5
CT	11.61	23.66	49.41	21.1	29.1	77.0
LSD (0.05)	ns	ns	ns	ns	ns	ns
Cropping systems						
RCS	11.42	18.49^{b}	62.9^{a}	23.8	36.1^{a}	66.7^{b}
MCS	9.31	26.02^{a}	35.1^{b}	19.7	22.3^{b}	88.8^{a}
LSD (0.05)	ns	4.8	7.9	ns	6.01	10.6
Nitrogen fertilization						
20 t ha^{-1} Compost	10.59	22.23	47.5^{ab}	11.98^{c}	23.14^{b}	65.4^{b}
46 kg N ha^{-1} +10 t ha^{-1} Compost	10.64	21.55	55.3^{a}	34.09^{a}	36.77^{a}	93.2^{a}
92 kg N ha ^{1}	9.86	22.99	44.3^{b}	19.07^{b}	27.62^{b}	74.7^{b}
LSD (0.05)	ns	ns	11.67	6.38	7.36	12.9
CV (%)	30.6	31.3	27.16	33.9	29.2	19.2

Means followed by the same letter did not differ significantly across the tillage methods, cropping systems and N-fertilization at $P \leq 0.05$ according to LSD test. AE = Agronomic efficiency PE= physiological efficiency; ANRE= Apparent N-recovery efficiency; CV: coefficient of variation.

In both sites, there was no significant variation in physiological efficiency (PE) across tillage methods. On the other hand, cropping systems had a significant effect on PE, with maize monocropping and haricot bean-maize rotation systems providing higher PE at Hawassa Zuria and Meskan sites, respectively (Table 5.3). At Meskan, N-fertilization had a significant effect on PE; the integrated N-treatment gave the highest value of 36.77 kg grain per kilogram N uptake.

Two-way interaction effects of tillage methods and cropping systems

At Hawassa Zuria, the tillage methods by cropping systems interaction had significant ($P < 0.05$) effects on GNC, GNU, SNC, and SNU (Table 5.4). Minimum tillage by rotation produced the maximum GNC (1.1%) and GNU (41.39 kg ha^{-1}). Conversely, the higher SNC (0.46%) and SNU (56.76 kg ha^{1}) were obtained from CT by rotation interaction. This indicates that crop N-uptake was influenced by tillage and rotation, which were most likely connected to soil moisture, aeration, and N availability. At Meskan, however, none of the parameters showed statistically significant variation.

Table 5.4 The two interactions of tillage method and cropping system on grain N-content, grain N-uptake, stover N content and uptake of maize grown at Hawassa Zuria

TM	**Grain N-content**		**Grain N-uptake**		**Stover N-content**		**Stover N-uptake**	
	RCS	**MCS**	**RCS**	**MCS**	**RCS**	**MCS**	**RCS**	**MCS**
MT	1.10	0.82	41.36	29.74	0.35	0.31	37.58	35.31
CT	1.01	0.99	4047	37.67	0.46	0.37	56.76	38.09

MT: minimum tillage; CT: conventional tillage; RCS: rotation cropping system; MCS: monocropping system.

Two-way interaction effect of tillage method and N-fertilization

At Hawassa Zuria, the interaction of TM by N-fertilization had significant ($p \leq 0.05$) effects on GNC, GNU, SNC, and NHI (Table 5.4). The maximum GNC (1.15%) was obtained from CT by integrated N-treatment interaction while the highest GNU (47.9 kg ha^{-1}) and SNC (0.48%) were achieved from CT by sole 92 kg N ha^{-1} interaction. However, at Meskan, TM by N-fertilization interaction effect was observed only on total N-uptake, where the highest total N-uptake (199.2 kg ha^{-1}) was achieved from MT by sole compost (20 $tonha^{-1}$) interaction.

Table 5.5 The two interactions of tillage method and N-fertilization on GNC, GNU, SNC. NHI and TNU of maize

Treatments		Hawassa Zuria				Meskan
		GNC (%)	GNU (kg ha^{-1})	SNC (%)	NHI (%)	TNU (kg ha^{-1})
MT	Control	0.85	27.43	0.22	55.69	122.40
	20 t ha^{-1} Compost	1.07	41.30	0.37	48.68	199.23
	46 kg N ha^{-1} +10 t ha^{-1} Comp.	0.92	33.09	0.33	48.56	144.73
	92 kg N ha ^{1}	1.01	40.39	0.39	46.56	180.03
CT	Control	0.79	26.19	0.34	42.02	133.73
	20 t ha^{-1} Compost	1.15	46.91	0.45	48.74	194.40
	46 kg N ha^{-1} +10 t ha^{-1} Comp.	0.96	35.33	0.39	45.66	158.48
	92 kg N ha ^{1}	1.10	47.85	0.48	45.41	195.42

GNC: grain N-content; SNC: stover N-content; GNU: grain N-uptake; TSU: total N-uptake; NHI: nitrogen harvest index.

Two-way interaction effect of cropping systems and N-fertilization

At Hawassa Zuria, the interaction of CS by NF revealed significant effects on SNC, SNU, TNU, NHI, and NUtE. Likewise, at Meskan, CS by NF showed significant interaction effects on GNC, SNC, SNU, TNU and NUtE parameters (Table 5.6).

Table 5.6 Interaction effects of cropping systems and nitrogen fertilization on GNC, SNC, SNU, TNU and NHI.

Treatments		Hawassa Zuria				Meskan			
		SNC (%)	SNU (kg ha^{-1})	TNU	NHI (%)	GNC %	SNC	SNU (kg ha^{-1})	TNU
RCS	Control	0.26	26.93	57.7	54.86	1.24	0.34	47.8	120.8
	20 t ha^{-1} Compost	0.50	60.89	108.4	44.31	1.34	0.43	72.1	177.7
	46 kg N+10 t Com. ha^{-1}	0.40	41.66	78.5	47.23	1.26	0.38	56.1	135.9
	92 kg N ha^{-1}	0.46	59.20	107.8	45.66	1.45	0.38	63.2	182.6
MCS	Control	0.30	30.76	53.7	42.85	1.00	0.49	74.4	135.3
	20 t ha^{-1} Compost	0.33	35.32	76.0	53.11	1.30	0.75	117.2	215.9
	46 kg N+10 t Com. ha^{-1}	0.32	35.44	66.9	46.99	1.10	0.60	95.6	167.3
	92 kg N ha^{-1}	0.40	45.30	84.9	46.32	1.31	0.54	87.1	192.8

GNC: grain N-content; SNC: stover N-content; GNU: grain N-uptake; SNU: stover N-uptake; TSU: total N-uptake.

The three-way interactions of tillage methods, cropping systems and N-fertilization

At Hawassa-Zuria, the three-way interaction of TM, CS and NF significantly ($p \leq 0.05$) affected GNC, GNU and SNC (Fig. 5.1). At Meskan, however, the three-way interaction had brought significant ($p \leq 0.05$) variation on the SNC, TNU and NUtE parameters (Fig. 5.1).

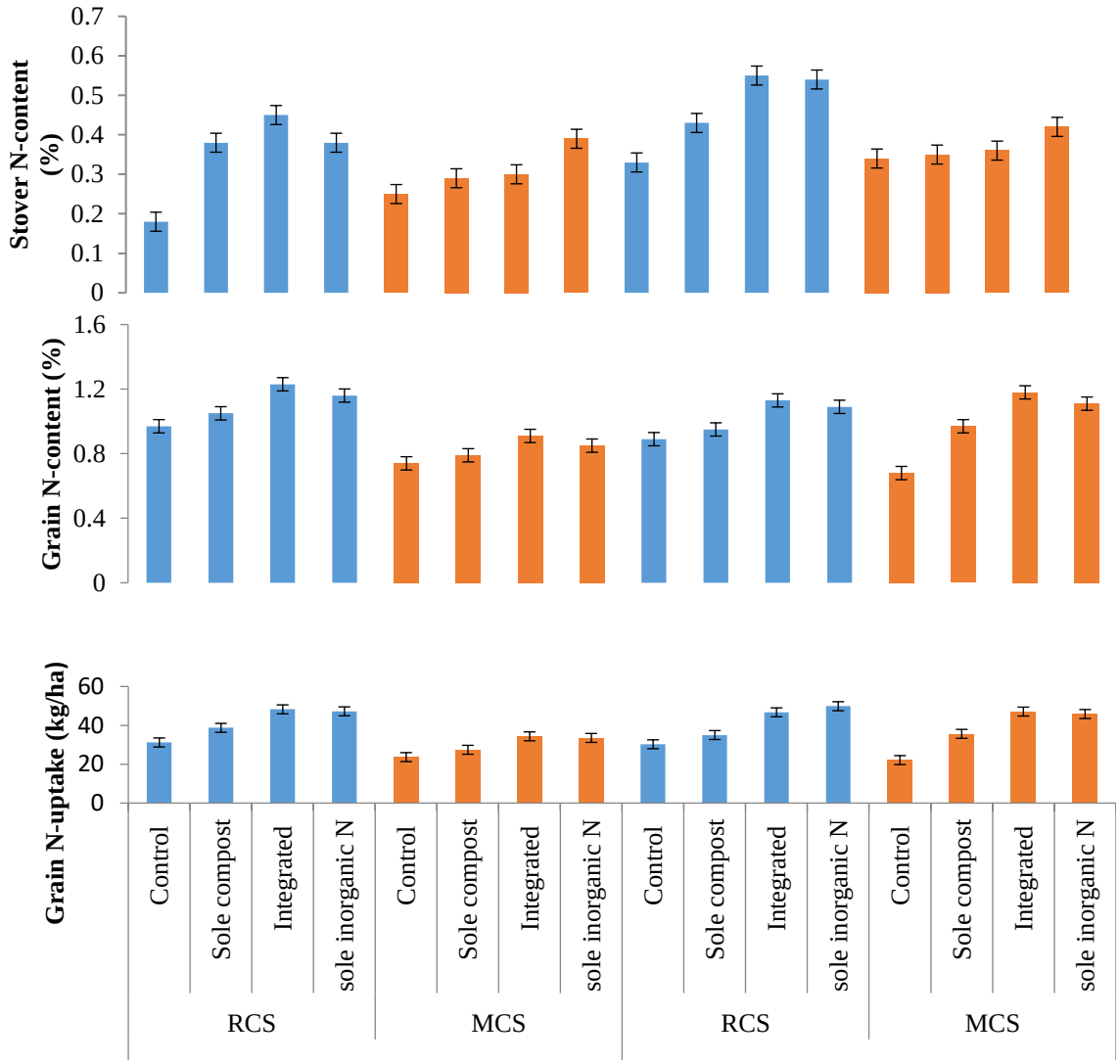

Figure 5.1. Interaction effects of tillage methods, cropping systems and nitrogen fertilization on grain and stover nitrogen concentration and grain N-uptake of maize growth at Hawassa Zuria soil.

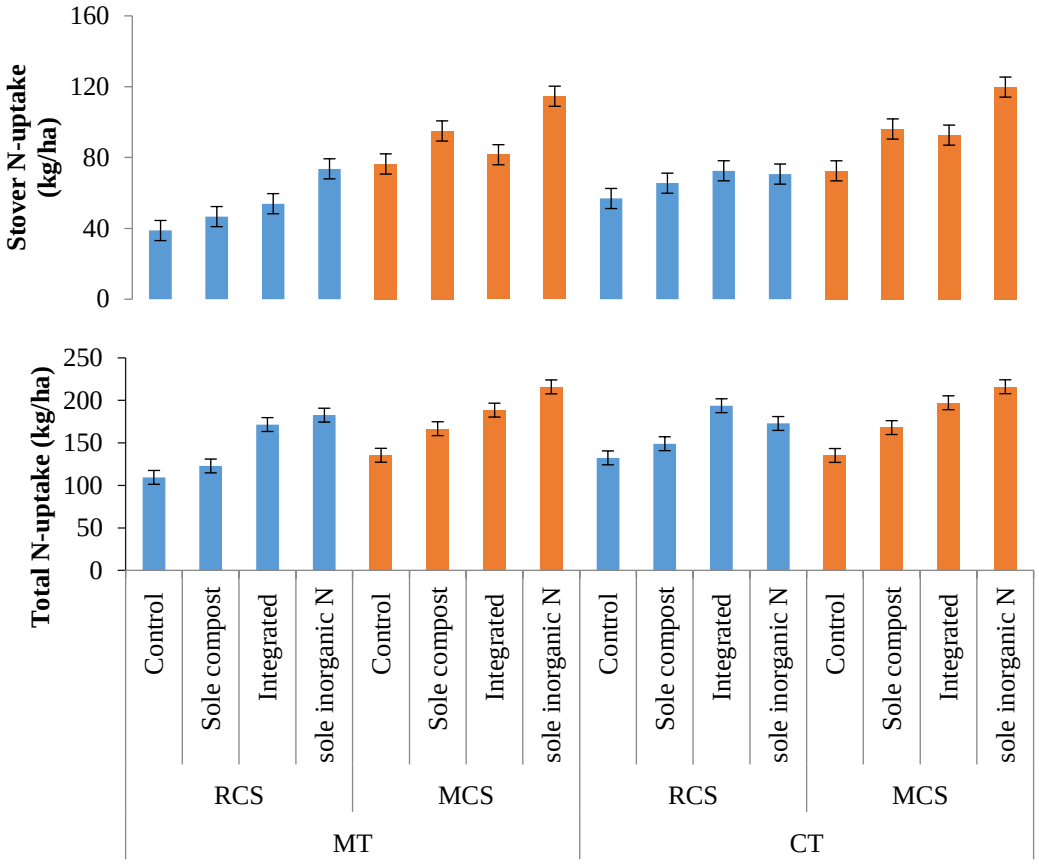

Figure 5.2. Interaction effects of tillage methods, cropping systems and nitrogen fertilization on stover nitrogen uptake and total N-uptake of maize growth at Meskan soil.

5.3.3 Pearson`s correlation coefficients

Pearson correlation coefficient of grain yield under different soil management practices were positively and significantly correlated with GNC, GNU, TNU, GPC, AE, PE and ANRE (r = 0.71, 0.89, 0.93, 0.71, 0.81, 0.63 and 0.73) in Hawassa Zuria and (r = 0.73, 0.95, 0.84, 0.74, 0.93, 0.86 and 0.78) in Meskan, respectively (Table 5.7). This observation is consistent with the findings of Milena et al. (2020) which indicated that grain yield was positively and highly correlated with grain protein content (r=0.82), and nitrogen uptake.

In our investigation, the association between GY to ANRE was stronger than that of GY to PE at Hawassa Zuria. This tells us applying N-containing fertilizers is more recommended for Hawassa Zuria in order to enhance maize productivity rather than adopting practices that contribute to efficient N-utilization, which might probably be due to smaller initial soil total N content. This result is concomitant with the findings of Bingham et al. (2012), which indicated a stronger association between maize grain yields to ANRE over that of GY to PE. However, at Meskan, the correlation between GY to PE was stronger than GY to ANRE, suggesting physiological efficiency is more vital than apparent N-recover efficiency (Table 5.7). Thus, adopting improved soil and crop management practices are essential to augment grain yield in contrast to applying additional N-inputs, probably due to the presence of higher initial soil total N at Meskan site than that of Hawassa Zuriya. In both sites, grain yield positively significantly correlated with the components of N-use efficiency, indicating NUE can be increased by improving the grain yield per unit of N application.

Table 5.7 Pearson`s coefficients of correlation for gain, stover yields, N uptake and N use efficiency of maize grown with two tillage methods, two cropping system and four nitrogen levels at Hawassa Zuria (upper right side) and at Meskan (lower left side).

	GY	SY	GNC	SNC	GNU	SNU	TNU	GPC	NHI	NU_tE	AE	PE	ANRE
GY	1.	0.62**	0.71***	0.83**	0.89***	0.84**	0.93***	0.71**	-0.21	-0.86***	0.81***	0.63**	0.73**
SY	0.44	1	0.17	0.61*	0.38	0.79**	0.68**	0.17	-0.64**	-0.63**	0.38	0.31	0.41
GNC	0.73**	0.29	1	0.55	0.96***	0.49	0.73**	1.00***	0.34	-0.72**	0.71**	0.37	0.75**
SNC	0.23	0.03	-0.20	1	0.72**	0.96***	0.94***	0.55*	-0.56**	-0.95***	0.71**	0.37	0.77**
GNU	0.85***	0.40	0.90**	0.03	1	0.68**	0.88**	0.95***	0.13	-0.83***	0.79**	0.48	0.79**
SNU	0.36	0.33	-0.11	0.95***	0.16	1	0.95**	0.49	-0.60*	-0.91***	0.64**	0.33	0.71**
TNU	0.84***	0.48	0.48	0.68**	0.73**	0.79**	1	0.73*	-0.34	-0.96***	0.76**	0.43	0.80**
GPC	0.74**	0.29	1.00***	-0.21	0.91***	-0.10	0.49	1	0.34	-0.72**	0.71**	0.37	0.75**
NHI	0.27	-0.12	0.71**	-0.76***	0.50*	-0.76**	-0.22	0.71*	1	0.40	-0.08	-0.04	-0.14
NU_tE	-0.36	-0.47	0.00	-0.87***	-0.20	-0.97**	-0.80**	0.01	0.70**	1	-0.77***	-0.44	-0.83***
AE	0.93***	0.34	0.76**	0.05	0.92**	0.15	0.67**	0.76**	0.43	-0.17	1	0.80***	0.91***
PE	0.86**	0.33	0.72**	-0.12	0.80**	-0.03	0.47	0.73*	0.52*	0.00	0.86***	1	0.53*
ANRE	0.78**	0.33	0.53*	0.49	0.72**	0.57*	0.84***	0.53*	-0.03	-0.60*	0.81***	0.62*	1

Significant at *p < 0.05, **p < 0.01, ***p < 0.001; ns: not significant. GY: grain yield; SY: stover yield; GNC: grain N-content; SNC: stover N-content; GNU: grain nitrogen uptake; STU: stover nitrogen uptake; TNU: total nitrogen uptake; GPC: grain protein content; **NU_tE**: nitrogen utilization or internal efficiency; AE: agronomic efficiency; PE: Physiological efficiency; ARE: apparent N recovery efficiency.

5.4 Conclusion

The results revealed that soil management practices had different effects on GNC, GNU, GPC, NHI, NUtE and N-utilization efficiency components. In both soils, the CT and RCS increased the GNC and GNU, in contrast to the MT and MCS, respectively. We observed that N-content, uptake, and use efficiency were stimulated under CT compared to the MT. In comparison to maize monocropping, the haricot bean-maize rotation system improved grain N-uptake and NUE in both soils. Correspondingly, nitrogen fertilization evidently affected the GNC, GNU, GPC and NHI. However, tillage methods differed in their effects on NHI and NUtE; NHI and NUtE were improved through MT compared to CT. Therefore, a CT along with haricot bean-maize rotation system with the addition of integrated 46 kg N ha^{-1} + 10 t compost ha^{-1} could be recommended for both soil types of the study areas. However, to ensure sustainable nitrogen utilization in the studied soils of the study area, an integrated N-treatment plus MT and legume-based rotation system could be recommended, which could improve NHI and NUtE.

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CHAPTER SIX

Short-term Effects of Tillage, Cropping systems, and Nitrogen fertilization on Soil organic carbon and Total nitrogen Stocks

6. SHORT-TERM EFFECTS OF TILLAGE, CROPPING SYSTEMS, AND NITROGEN FERTILIZATION ON SOIL ORGANIC CARBON AND TOTAL NITROGEN STOCKS

Abstract

The use of integrated soil management practices is vital to improve the soil physical and chemical properties and bring about changes in soil fertility and function. However, the impacts of soil management practices on soil properties were not properly investigated in soils of the study areas. Thus, the present study was conducted to evaluate the short-term effects of tillage methods, cropping systems, and N-fertilizations and their interaction on OC and TN stocks. A three-factor experiment was laid out as a split-split plot arrangement in a randomized complete block design with three replications. The MT and CT were used as the main plot, RCS, and MCS as a subplot, and four levels of nitrogen fertilization (Control, 20 t ha^{-1} compost, 46 kg N ha^{-1} + 10 t ha^{-1} compost, and 92 kg N ha^{-1}) as the sub-sub plot. Soil samples from (0–20 cm) and (20-40 cm) depths were collected from each experimental unit and location. A total of one hundred nighty-two composite samples were used for the analysis of variance using SAS software. Soil management practices have varying effects on soil OC and TN stocks. In the surface soil layers, MT gave higher OC and TN stocks compared to CT in both soils/locations. Similarly, N treatments had significant effects on the OC and TN stocks at both locations in the 0-20 cm but not in the 20-40 cm soil depth. The application of sole compost (20 t ha^{-1}) provided the maximum (5.17 kg m^{-2}) and (8.77 kg m^{-2}) OC stocks for Hawassa Zuria (Cambisols) and Meskan (Phaeozems), respectively. The maximum TN stocks of 0.51 kg m^{-2} on Cambisols and 0.83 kg m^{-2} on Phaeozems were achieved from the integrated and sole inorganic N treatments, respectively. The study highlights that MT along with legume-based rotation system and use of organic input or integration with mineral N fertilizer are possible alternatives to improve soil OC and TN stocks and thus ensure sustainable production. However, a long-term study should be carried out to declare a detailed understanding of the response of soil properties to different soil management practices.

Keywords: - Minimum tillage, rotation, soil properties, soil management, stocks.

6.1 Introduction

Deterioration of soil fertility and concomitant food insecurity are extensive challenges in sub-Saharan Africa (SSA), with 23% of the populace being undernourished and over 35 million humans expected to be food insecure via 2050 (Lal et al., 2015; FAO and ECA, 2018). In Sub-Saharan Africa (SSA), low agricultural productivity is largely attributed to low soil fertility (Nduwumuremyi et al., 2013). The depletion of soil fertility and extensive soil degradation are the major constraints limiting crop productivity and natural resource conservation in Ethiopia (Zeleke et al., 2010). A similar observation was reported by Wakene et al. (2007), who indicated that low soil fertility is the major bottleneck in resource-poor farmers for sustainable agricultural production and productivity. Therefore, adopting farming systems, which might be robust to improving soil fertility and health, is a crucial strategy for sustainable crop production.

Soil management actions can shake the sustainable use of soil resources through their influence on soil quality, stability, and resilience. Successful soil management to maintain soil quality depends on the understanding of how the soil responds to agricultural practices over time (Wakene, 2001). In the past several decades, agricultural management practices consisting of intensive tillage, continuous cropping and low-level input application have resulted in the degradation of soil and environmental qualities by increasing erosion and nutrient leaching (Gebrekidan, 2003; Kimetu et al., 2008; Vanlauwe et al., 2010). Furthermore, in the face of climate change (CC), where rainfall patterns are changing and temperatures are rising, climate-smart agriculture technologies could help smallholder farmers (FAO, 2010).

Tillage is the most important practice in crop cultivation and has a major effect on the carbon pool, either negative with conventional plowing or positive when conservation tillage is applied

(IPCC, 2000). The primary objective of tillage in crop production is to produce suitable soil physical conditions for seed germination and plant growth. However, tilling soil frequently can be a prime cause of soil structure degradation due to the gradual loss of soil organic matter, leading to soil erosion and compaction and low moisture availability for plants (Gupta et al., 2002).

Conventional tillage has been reported to deteriorate soil properties (Mangalassery et al., 2015; Nivelle et al., 2016). Davidson and Ackerman (1993) advocate that generally up to 40% of the total carbon in the top 30 cm of the soil is lost due to tillage compared to uncultivated lands. Moreover, plowing the field in a conventional method leads to hardpan formations (Wasaya et al., 2011). Conventional tillage can hasten the organic matter decomposition rate and thus reduce the soil quality (Parras-Alcántara et al., 2015). For instance, lower bulk density was observed in conventionally tilled soils, which induced a greater total porosity (Lipiec et al., 2006). Similarly, Tiritan et al. (2016) observed a negative effect of conventional tillage on soil properties. Conversely, conservation tillage is known to improve soil physicochemical properties (Divito, 2012; Busari et al., 2015) and soil quality (Plaza et al., 2013). Soil organic carbon concentrations significantly improved under reduced tillage along with green manure application (Garcia-franco et al., 2015).

Cropping systems have been reported to enhance and/or maintain soil quality by influencing the soil environment primarily through differences in the quantity and quality of crop residue as well as root exudates returned to the soil (McDaniel et al., 2014; Tiemann et al., 2015). Previous findings revealed that diversifying crops into rotations could result in relatively higher organic carbon contents (Gal et al., 2007; Abdollahi et al., 2015). In contrast, continuous monocropping

along with conventional tillage can negatively affect soil organic carbon contents and thereby poor physical, chemical, and biological soil properties (Mariangela and Francesco, 2010; Wyngaard et al., 2012).

Nitrogen dynamics in soils were remarkably influenced by tillage practice as compared to N fertilization (Salinas Garcia et al. 1997). Previous studies showed that soils under conventional tillage have higher mineral N but lower TN than those under conservation tillage (Verachtert et al., 2009; Wu et al., 2009). However, the total N content of the soils in conservation tillage mostly depends on the amount of crop residues retained on the surface of the soil and the sampling depth (Govaerts et al., 2007). Hence, careful uses of soil resources along with proper tillage methods are indispensable for chemical and physical components of soil fertility to ensure sustainable agricultural productivity.

Soil organic matter (SOM) storage in farming systems is determined by the balance of carbon addition from crop residues vs carbon losses through SOM decomposition (Awale et al., 2013). Thus, the degree to which a tillage technique influences SOM turnover is generally determined by the frequency and timing of soil disturbance, depth of soil disturbance, and degree of soil-residue mixing (Cookson et al., 2008; Machado, 2011). Soil organic matter loss contributes to a variety of soil degradation processes, including erosion, compaction, salinization, nutrient insufficiency, biodiversity loss, and desertification, all of which are accompanied by a decrease in soil fertility (Lal, 2015). The effects of soil and crop management practices on SOC and TN dynamics, in part, depend on soil properties and environmental factors, such as soil texture, clay mineralogy, topography, and climate (Campbell et al., 1996).

Although the individual effects of tillage methods, cropping systems, and nitrogen fertilization on soil properties, particularly organic carbon and total nitrogen stocks, have been studied so far and documented elsewhere, their interaction was not properly investigated in the study areas. Moreover, conventional tillage coupled with continuous monocropping and inadequate external input application is a significant constraint on crop production in the central rift valley of Ethiopia. Therefore, the present study was initiated to examine the short-term effects of tillage methods, cropping systems, and N fertilization and their interaction on selected soil chemical properties including organic carbon and total nitrogen stocks. We hypothesized that reduced tillage along with crop rotation and integrated organic and inorganic nitrogen application would improve the soil carbon and nitrogen stocks.

6.2 Material and Methods

6.2.1 Description of the study area

The experiments were conducted in the Hawassa Zuria and Meskan districts of the Central Rift Valley of Ethiopia during the 2019 and 2020 growing seasons. Detail descriptions of the study sites are provided in section 1.2.1.

6.2.2 Treatment, experimental design and management practices

Two tillage practices were evaluated: CT and MT. The two tillage practices were combined with two cropping systems: haricot bean-maize rotation (RCS) and maize monocropping (MCS). In addition, four levels of nitrogen fertilization (NF) (0, 20 t ha^{-1} compost, 46 kg N ha^{-1} + 10 t ha^{-1} compost, and 92 kg N ha^{-1}) were combined with tillage practices and cropping systems. Treatments were arranged as Split-split plot arrangement with tillage methods as the main plots, cropping systems as sub-plots, and nitrogen fertilization treatments as sub-sub plots and laid out in randomized complete block design (RCBD), with three replicates. The management practices are described in detail in section 1.2.3.

6.2.3 Soil Sampling and Analysis

From field experiments, soil sampling and analysis were performed twice. First, before the imposition of the treatments, three representative soil samples were prepared from 0-20 and 20-40 cm soil depths per experimental site during March 2019 to determine the initial fertility status of the experimental sites. At the end of experimentation, which is after the second crop harvest (November 2020), three random soil samples per sub-subplot were collected from 0-20 and 20-40 cm soil depths at each experimental location, following the standard soil sampling procedure.

After manual homogenization, representative composite subsamples per experimental unit and site were prepared for soil organic carbon and total nitrogen analysis.

Soil physical and chemical analysis

The bulk density of the soil was estimated as described in section 1.2.5.1. Similarly, the soil organic carbon and total nitrogen contents of the soil were analyzed and estimated following the procedure described in detail in section 1.2.5.2. Soil OC (kg C m^{-2}) stock was computed using the method described by Batjes (1996) as indicated in the following equation:

$$SOC\ stock\left(\frac{g}{m2}\right) = OC\ \left(\frac{g}{kg}\right) * BD\ \left(\frac{kg}{\mathrm{m3}}\right) * D\ (m) - - - - - (Equ.1)$$

where OC= carbon content of the soil, D= defined soil depth and BD= dry bulk density.

Similarly, the total nitrogen stock (kg N m^{-2}) was calculated by multiplying the percentage of total nitrogen (g/kg), soil bulk density (kg m^{-3}) and the defined depth classes (0–20 and 20-40 cm) for each treatment. Total nitrogen stock (TNS) was calculated for each sample depth:

$$TNS\ \left(\frac{g}{m2}\right) = TN\left(\frac{g}{kg}\right) * BD\left(\frac{kg}{m3}\right) * D(m) - - - - - -Equ.2$$

where TN= nitrogen content of the soil, D= defined soil depth (0–20 and 20-40 cm) and BD= dry bulk density.

Table 6.1 The initial selected properties of the experimental soils at two soil depths

Soil properties	**Unit**	**Hawassa Zuria (Cambisols)**		**Meskan (Phaeozems)**	
		0-20 cm	**20-40 cm**	**0-20 cm**	**20-40 cm**
Bulk density	g cm^{-3}	0.94	1.09	0.99	1.02
OC	g kg^{-1}	25.5	19.5	42.5	40.04
TN	g kg^{-1}	2.6	1.8	3.77	3.13
Organic carbon stock	kg m^{-2}	4.8	4.2	8.43	8.22
Total nitrogen stock	kg m^{-2}	0.49	0.38	0.75	0.64

6.2.4 Statistical analysis

The effect of the treatments on soil OC and TN stocks was statistically analyzed using SAS computer software version 9.3 (2014). The statistical analysis and its model are described in detail in section 1.2.9.

6.3 Results and Discussion

6.3.1 Selected properties of the experimental soils prior to treatment application

The surface soils had bulk density of 0.94 and 0.99 g cm^{-3} for Cambisols in Hawassa Zuria and Phaeozems in Meskan sites, respectively. In both soils/sites, bulk density showed increasing tendency with soil depth (Table 6.1). The organic carbon stocks in the surface soil (0-20 cm) were 4.8 and 8.43 kg m^{-2} at Hawassa Zuria on Cambisols and Meskan Phaeozems, respectively (Table 6.1). The higher organic carbon stock was observed at the Meskan site as compared to Hawassa Zuria soil; this may be attributed to the presence of higher clay separates in the former than in the latter. Batjes (1998) showed that clay content was the major environmental factor that controlled the behaviour of OM in the soil. The total nitrogen stocks of the surface soil depth (0-20 cm) were 0.49 and 0.75 kg m^{-2} for Cambisols and Phaeozems in Hawassa Zuria and Meskan, respectively (Table 6.1). In contrast to BD, the soil OC and TN stocks decreased generally decreased with increasing soil depth (Table 6.1).

6.3.2 The main effects of tillage, cropping systems, and N fertilization on soil BD, OC and TN stocks

The effects of tillage and cropping systems on soil bulk density were insignificant (Table 6.2). However, maximum values of 0.99 and 1.1 g cm^{-3} for the Hawassa Zuria and Meskan sites were recorded from minimum tillage. In the present study, relatively lower bulk density in surface soil (0-20 cm) was recorded in conventional tillage, which might be due to the formation of loose soil structure by breaking soil aggregates. Conversely, the application of N fertilizers brought significant variation to the soil bulk density in the surface layer at Hawassa Zuria but not at Meskan. The lowest bulk density was recorded in the compost-only treated plot at

Hawassa Zuria (Table 6.2). This was due to the improvement of soil structure by the applied organic input (compost).

Tillage methods had a significant effect on the OC stock at the surface soil layer (0-20 cm) at Hawassa Zuria (Cambisols) but not at Meskan (Phaeozems). Despite a nonsignificant difference of tillage methods on OC at Meskan, MT resulted in numerically higher OC stocks in both soils as compared to CT (Table 6.2). The beneficial effect of MT on the OC stock was most likely due to the incorporation of residues from previous crops, which were less susceptible to breakdown or microbial attack. Conversely, the lower OC stock resulting in CT might be due to accelerated OM oxidation by stirring the soil and decomposition, which is favored by strong microbial activities (Six et al., 2002; Murage et al., 2007; Zheng et al., 2018). Tillage methods had a significant effect on the OC stock at the sub-surface soil depth (20-40 cm) at Meskan but not at Hawassa Zuria. Although nonsignificant variation between tillage methods on OC was observed in subsurface soil depth (20-40 cm) at Hawassa Zuria (Cambisols), CT resulted in a slightly higher OC stock than MT, suggesting that both above- and belowground crop residues were incorporated into the soil depth by tillage operation. Our result is in line with earliar studies (Six et al., 2002; Conceição et al., 2013).

Concerning cropping systems, there was no substantial variation in OC stock across soil depths and soils/sites (Table 6.2). Despite the nonsignificant effect of cropping systems on the OC stock, maize monocropping maintained a slightly superior OC stock at both sites than the haricot bean-maize rotation system, owing to improved root biomass retention in the soil. However, different N treatments had a significant effect on the OC stock at both locations (soils) in the surface soil depth (0-20 cm) but not in the subsurface soil layer (20-40 cm) (Table 6.2). At

Hawassa Zuria, the application of sole compost (20-ton ha^{-1}) resulted in the maximum (5.17 kg m^{-2}) OC stock, which was statistically similar to the integrated and sole inorganic N treatments (Table 6.2). The soil OC stock increased by 3.8 and 2.8% due to sole application of compost and integrated N treatments, respectively, compared to the unfertilized plot. Similarly, at Meskan, the maximum OC stock was recorded in the sole inorganic N treatment, which was statistically similar to the sole compost treatment. When compared to the unfertilized plot, the sole compost and inorganic N treatments improved the soil OC stock by 6.3% and 6.6%, respectively.

Tillage methods significantly affected the soil TN stock at the surface soil depth (0-20 cm). There was a tendency for better total N stock caused by MT at the 0-20 cm soil depth in both locations. This was due to the protection of organic N within the micro- and macroaggregates and thereby reduced N losses through leaching and mineralization of organic matter. Similarly, cropping systems had a significant effect on the TN stock in surface soil depth at Meskan but not at Hawassa Zuria.

The effect of N fertilization was highly significant ($p < 0.001$) on the TN stock at the surface soil depth (Table 6.2). The maximum TN stocks of 0.51 kg m^2 on Cambisols att Hawassa Zuria and 0.83 kg m^2 Phaeozems at Meskan soils were attained from the integrated and sole inorganic N treatments, respectively. At subsurface soil depth, at Hawassa Zuria, the TN stock was significantly affected by N fertilization, and the maximum (0.41 kg m^{-2}) was obtained in the plot amended with integrated N treatment. However, at Meskan, no significant variation was observed among the N treatments at 20-40 depth. At the 20-40 cm soil depth, the effect of N fertilization on the TN stock was not analogous in the two soils. In this study, the influence of

N fertilization was more visible in loamy-textured Cambisols than in clay-textured Phaeozems, suggesting that the nitrate form of N leached from the above soil layer, which was aggravated by CT and soil texture.

Table 6.2 Main effects of tillage, cropping systems and nitrogen fertilization on soil bulk density, organic carbon and total nitrogen stocks

Treatments	Hawassa Zuria (Cambisols)						Meskan (Phaeozems)					
	0-20 cm			20-40 cm			0-20 cm			20-40 cm		
	BD	**OCS**	**TNS**	**BD**	**OCS**	**TNS**	**BD**	**OCS**	**TNS**	**BD**	**OCS**	**TNS**
Tillage methods												
MT	0.99	5.15^{a}	0.49^{a}	1.11	4.55	0.39	1.10	8.57	0.76^{a}	1.06^{b}	7.84^{b}	0.63^{b}
CT	0.97	5.02^{b}	0.45^{b}	1.12	4.58	0.38	1.07	8.49	0.71^{b}	1.11^{a}	8.09^{a}	0.66^{a}
LSD (0.05)	ns	0.09	0.02	ns	ns	ns	ns	ns	0.03	0.18	ns	0.02
Cropping systems												
RCS	0.97	5.07	0.48	1.12	4.54	0.39	1.07	8.53	0.75^{a}	1.08	7.94	0.65
MCS	0.98	5.09	0.47	1.11	4.59	0.38	1.08	8.52	0.72^{b}	1.09	7.99	0.65
LSD (0.05)	ns	ns	ns	ns	ns	ns	ns	ns	0.03	ns	ns	ns
Nitrogen fertilization												
Control	0.99^{a}	4.98^{b}	0.42^{c}	1.11	4.48	0.37^{b}	1.08	8.23^{b}	0.70^{c}	1.10	8.04	0.65
20 t ha^{-1} Com	0.96^{b}	5.17^{a}	0.47^{b}	1.12	4.49	0.38^{b}	1.06	8.75^{a}	0.68^{c}	1.09	8.01	0.65
46 kg N ha^{-1} +10 t ha^{-1} Compost	0.96^{b}	5.12^{a}	0.51^{a}	1.12	4.74	0.41^{a}	1.08	8.37^{b}	0.74^{b}	1.08	7.81	0.65
92 kg N ha ^{1}	0.98^{ab}	5.07^{ab}	0.50^{a}	1.11	4.55	0.39^{a}	1.05	8.77^{a}	0.83^{a}	1.07	7.95	0.64
LSD (0.05)	0.02	0.13	0.02	ns	ns	0.03	ns	0.22	0.04	ns	ns	ns

6.3.3 Interaction effects of tillage, cropping systems and N fertilization on BD and OC stock

At Hawassa-Zuria, the three-way interaction of TM×CS×NF significantly ($p \leq 0.05$) affected BD and OC stocks at the 0-20 cm soil depth, whereas at Meskan, the three-way interaction brought significant ($p \leq 0.05$) variations in the BD and OC and TN stocks (Tables 6.3 and Appendix Table 4). The highest OC stock value was reported at Hawassa Zuria when MT interacted with a legume-based rotation system and sole compost, while the highest OC and TN stocks were observed at Meskan when MT interacted with a rotation system and sole inorganic

N treatment (Tables 6.3 and Appendix Table 4). When compared to the initial OC stock, the combined application of MT + RCS + sole compost and MT + RCS + integrated N treatment improved soil OC stock in the surface soil depth by 9.8% (0.47 kg m^{-2}) and 8.1% (0.39 kg m^{-2}) at Hawassa Zuria, respectively. The combined application of MT + RCS + sole inorganic N improved OC and TN stocks by 9.25% (0.78 kg m^{-2}) and 20% (0.15 kg m^{-2}) at Meskan, respectively.

Table 6.3 The three-way interactions of tillage methods, cropping systems and nitrogen fertilization on soil bulk density, organic carbon and total nitrogen stocks

		Treatments	**Hawassa Zuria**		**Meskan**		
			0-20 cm		**0-20 cm**		
			BD (g cm^{-3})	**OCS** (kg m^{-2})	**BD** (g cm^{-3})	**OCS**	**TN**
						kg m^{-2}	
		Control	1.01± 0.03	5.08± 0.26	1.07± 0.02	8.24± 0.19	0.76± 0.02
	RCS	20 t ha^{-1} Compost	0.98± 0.00	5.27± 0.10	1.05± 0.02	8.61± 0.14	0.72± 0.02
		46 kg N+10 t ha^{-1} comp.	0.97± 0.05	5.19± 0.22	1.12± 0.06	8.60± 0.52	0.74± 0.08
		92 kg N ha^{-1}	0.98± 0.01	5.02± 0.15	1.08± 0.02	9.21± 0.23	0.90± 0.07
MT		Control	0.96± 0.03	4.81± 0.13	1.06± 0.02	8.05± 0.06	0.68± 0.04
	MCS	20 t ha^{-1} Compost	0.98± 0.03	5.17± 0.28	1.01± 0.03	8.28± 0.28	0.67± 0.03
		46 kg N+10 t ha^{-1} comp.	0.97± 0.03	5.18± 0.04	1.12± 0.02	8.74± 0.07	0.78± 0.05
		92 kg N ha^{-1}	1.03± 0.02	5.15± 0.22	1.08± 0.02	9.04± 0.22	0.86± 0.05
		Control	0.98± 0.04	4.91± 0.15	1.07± 0.04	8.07± 0.24	0.68± 0.09
	RCS	20 t ha^{-1} Compost	0.94± 0.05	5.02± 0.24	1.08± 0.02	8.88± 0.26	0.65± 0.02
		46 kg N+10 t ha^{-1} comp.	0.93± 0.01	4.94± 0.09	1.07± 0.04	8.46± 0.39	0.76± 0.02
		92 kg N ha^{-1}	1.00± 0.03	5.16± 0.24	1.03± 0.01	8.38± 0.06	0.79± 0.05
CT		Control	1.03± 0.03	5.10± 0.19	1.11± 0.02	8.56± 0.09	0.66± 0.08
	MCS	20 t ha^{-1} Compost	0.96± 0.02	5.11± 0.12	1.12± 0.04	9.01± 0.22	0.66± 0.01
		46 kg N+10 t ha^{-1} comp.	0.99± 0.02	5.17± 0.07	1.01± 0.02	7.68± 0.15	0.66± 0.02
		92 kg N ha^{-1}	0.93± 0.02	4.75± 0.05	1.05± 0.03	8.67± 0.24	0.78± 0.03

6.4 Conclusion

In the current investigation, different soil management practices have varying effects on soil OC and TN stocks. In the surface soil layer (0-20 cm), MT gave higher OC and TN stocks compared to CT in both locations. Similarly, the application of N fertilizers brought significant impacts on the OC and TN stocks at both locations in the 0-20 cm soil depth. At the 0-20 cm soil depth, the three-way interaction brought significant variation on OC stock at Hawassa-Zuria (Cambisols) and soil OC and TN stocks at Meskan (Phaeozems). In conclusion, MT along with a legume-based rotation system and use of organic input or integration with mineral N fertilizer could be recommended for both soils to improve soil OC and TN stocks and thus ensure sustainable production.

6.5 Reference

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CHAPTER SEVEN

Summary, Conclusions and Recommendation

SUMMARY, CONCLUSIONS AND RECOMMENDATION

In Ethiopia, per capita food production is declining and not keeping pace with population growth. The major driving factor is low soil fertility, which is caused by poor cropping practices such as continuous cropping, minimal external inputs application, complete removal of crop residues, and accelerated soil erosion are among the key factors contributing to low soil fertility. Thus, addressing the declining soil fertility challenge is one of the top priority issues to increase crop productivity and production in the country. In this regard, knowledge, and application of integrated soil fertility management method are vital to address soil fertility problems to ultimately enhance crop yield and production. In the study areas, however, there is scarce information on the effects of tillage, cropping systems, and nitrogen fertilization and their interaction on soil properties and crop yield. Therefore, the present study was conducted to characterize and identify the soils of the study areas and assess the combined effects of tillage methods, cropping systems, and nitrogen fertilization on soil properties including OC and TN stocks, maize productivity, and N- uptake and use efficiency in the soil types.

The study was conducted in two districts, at Dore Bafeno kebele in Hawassa Zuria district and Bati Dubeno in Meskan district, in the Central Rift Valley of Ethiopia. The experimental sites were selected purposively based on their potential for maize production under conventional tillage and monocropping system as well as on their difference in soil fertility status. Two pedons, one from each site, were excavated and the morphological, physical and chemical properties of the soils were characterized. The results revealed that the soils had considerable variation in morphological, physical, and chemical properties within and among the profiles that could be related to their origins from different parent materials.

The two pedons were very deep (>190 cm) and not restricted by the parent materials and/or groundwater. The textural class of the soils in theDore Bafeno pedon was loam, whereas that of Bati Dubano was clay. The profiles had granular and subangular blocky structures at the surface and subsurface horizons, respectively. The pH of the surface soils was moderately acidic (6.18) and neutral (6.94) in the pedons of Dore Bafeno and Bati Dubano sites, respectively. In both pedons, the soil pH increased gradually with soil depth and the soils of the surface horizons had very low electrical conductivity.

The OC content in the surface soils of Dore Bafeno and Bati Dubano pedons were medium and high, respectively. The total nitrogen content of the surface soils of the two pedons were in the medium range, which might be due to nitrogen removal through crop harvest and continuous cultivation, suggesting that external N containing inputs are required for sustainable production. The total N distribution within the pedons accompanied a comparable pattern to that of OC, implying that the OM was the major source for TN.

The available phosphorus content of the soils in the pedons ranged from very low to very high. In the surface horizons, the available P content of the soils in Dore Bafeno and Bati Dubano pedons was low (4.36) and very high (23.16 mg kg^{-1}), respectively, and could be considered as deficient to sufficient. The cation exchange capacity of the soils in Dore Bafeno pedon varied from 22 to 32 cmolc kg^{-1}, while in Bati Dubano pedon ranged from 56 to 66 $cmol_c$ kg^{-1}. In both pedons, PBS was greater than 50 and had an increasing tendency with depth.

According to WRB, the soil of the Dore Bafeno site at Hawassa Zuria had a Mollic epipedon and a Cambic subsurface horizon, and this soil was classified as Cambisols. Moreover, the profile had loamy and clay loam textural classes in a layer ≥ 30 cm thick, with the surface soils

ploughed to a depth of ≥ 20 and OM content greater than 1% throughout the profile. These properties were suitable for clayic, aric and humic supplemental qualifiers, respectively. Therefore, the soil is classified as **Cambisol (Loamic, Aric, Humic).** On the other hand, the Bati Dubano site at Meskan had a Mollic surface horizon and a PBS (> 50) throughout the profile and classified as **Phaeozems**. The profile had a PBS (> 50) throughout the profile to be classified as **Someric** principal qualifier. Furthermore, the profile had a textural class of clay throughout the profile and the surface soils ploughed to a depth of ≥ 20, these properties are suitable for Pantoclayic and Aric supplemental qualifiers, respectively. Therefore, the soil is classified as **Someric Phaeozems (Pantoclayic, Aric).** The significant variations in the physicochemical properties of the studied soils, indicating site-specific soil management is required for each soil in order to maintain and improve soil organic matter and essential plant nutrients.

The results evidently demonstrated that the combined application of compost and inorganic N fertilizer significantly improved soil chemical properties, plant growth, and nitrogen uptake, compared to the unfertilized or separate addition of compost and inorganic N fertilizer. Based on the aforementioned results, it could be concluded that the combined application of 92 kg ha^{-1} N + 10 t ha^{-1} compost and 46 kg ha^{-1} N + 10 t ha^{-1} were the best treatments for Cambisols in Hawassa Zuria and Phaeozems in Meskan districts, respectively, which improved shoot dry matter by 179.5 and 284.5%, compared to the unfertilized pot, respectively.

Analysis of variance showed that soil management practices were significantly affecting grain yield, N-uptake and selected soil chemical properties. In both soils, the conventional tillage and haricot bean-maize rotation system increased the yield and yield components, and N-uptake in

contrast to the minimum and maize monocropping, respectively. However, tillage practices differed in their effects on soil chemical properties, organic carbon and total nitrogen stocks, which were improved through MT compared to CT.

Similarly, nitrogen fertilization significantly affected the yield and yield components, N-uptake, N-use efficiency components and selected soil chemical properties. The addition of sole inorganic 92 kg N ha^{-1} and integrated 46 kg N ha^{-1} + 10 t ha^{-1} compost N treatments gave the highest grain yields on Cambisols and Phaeozems at Hawassa Zuria and Meskan sites, respectively. However, in both soils, integrated use of mineral and organic (46 kg N ha^{-1} + 10 t ha^{-1} compost) inputs were significantly improved soil chemical properties as well as grain N-content, N-uptake and nitrogen use efficiency components when compared to other nitrogen treatments.

At the 0-20 cm soil depth, the three-way interaction of tillage methods, cropping systems and nitrogen fertilization brought significant variation on OC stock on Cambisols at Hawassa-Zuria and soil OC and TN stocks on Phaeozems at Meskan. The highest OC stock was reported on Cambisols at Hawassa Zuria when MT interacted with a legume-based rotation system and sole compost, whereas the highest OC and TN stocks were observed on Phaeozems at Meskan when MT interacted with a rotation system and sole inorganic N treatment. The study highlights that MT along with legume-based rotation system and use of organic input or integration with mineral N fertilizer are possible alternatives to improve soil OC and TN stocks.

It is concluded that (1) maize is significantly responded to N fertilizer application in both soils indicating insufficient soil N content in soils of the study sites. (2) Significantly higher yields of maize and N-uptake were recorded with treatments involving combined application of

inorganic and organic N-sources suggesting a synergistic interaction between the two N sources. (3) With respect to tillage, significantly higher yield and N uptake of maize were obtained with CT treatment than MT, which might be due to the short stabilization effect of MT and N immobilization. (4) With respect to the soil chemical characteristics, the MT and integrated N-treatments outperformed the CT and other N-treatments in terms of soil OC and total N concentrations, respectively. (5) Regardless of treatment, Phaeozems at Meskan site produced greater maize yields than Cambisols at Hawassa Zuria site, showing that Phaeozems has better soil fertility and quality than Cambisols.

Therefore, a CT plus haricot bean-maize rotation system with the addition of sole inorganic N at 92 kg ha^{-1} and integrated 46 kg N ha^{-1} + 10 t compost ha^{-1} should be recommended, to achieve better yield and yield components as well as N-use efficiency, for Cambisols in Hawassa Zuria and Phaeozems in Meskan study sites, respectively. Nevertheless, to ensure sustainable maize production in the studied soils, we recommended that the integrated application of 46 kg N ha^{-1} + 10 t ha^{-1} compost along with MT and legume-based crop rotation, which can enhance soil properties, and in the long run will improve yield, and N-uptake as well as utilization efficiency. This is because the field study was carried out only for two consecutive years and generated short-term results. Therefore, a longer-term study should be carried out at similar soils/sites to assess the long-term effects of tillage practices, cropping systems, and nitrogen fertilization on soil properties, and yield and yield components as well as nitrogen utilization efficiency.

Appendices

Appendex Table

Appendix Table 1 Profile Description Sheet

Profile ID No 1	
Location	Hawassa Zuria, Dore Bafeno
Date of examination	March 18, 2019
Surveyor	Ashenafi Nigussie
Coordinates	07° 1' 0.83" N Latitude and 38° 22' 26" E Longitude
Elevation	1713 m a.s. l
Human influence	Ploughing
Surrounding landform	Level land
Slope	2%
Moisture condition	Dry
Drainage	Well drained
Soil type	Bula local soil name; Scientific name is Cambisols
Groundwater table	Not observed up to 200+ cm depth
Parent materials	Igneous Rock (Ignimbrite Type)
Erosion	None
Rock outcrops/stoniness	None
Present land use	Cultivated land
Rootable depth	80 cm

Horizon	Depth (cm)	Descriptions
Ap	0-40	Very dark grey (2.5Y3/2) moist; loam; weak, fine, Granular; very friable, slightly sticky and slightly plastic; few, fine roots; Clear and smooth boundary.
Bw1	40-80	Black (2.5Y2.5/1) moist; clay loam; Moderate, fine, subangular blocky; loose, slightly sticky and slightly plastic; very few, very fine roots; clear and smooth boundary.
Bw2	80-130	Dark olive-brown (2.5Y3/3) moist; loam; weak, fine, subangular blocky; loose, slightly sticky and slightly plastic; none, none roots; gradual and smooth boundary.
BC	130-200+	Olive-brown (2.5Y4/4) moist; loam; moderate, coarse crible; Friable, none sticky and none plastic; very few, no roots.

Profile ID No 2	
Location	Meskan, Bati Dubano
Date of examination	May 10, 2019
Surveyor	Ashenafi Nigussie
Coordinates	08° 05' 33" N Latitude and 38° 26' 75" E Longitude
Elevation	1841 m a.s. l
Human influence	Ploughing
Surrounding landform	Level land
Slope	2%
Moisture condition	Dry
Drainage	Well drained
Soil type	Kosi local soil name; Scientific name Phaeozems
Ground water table	Not observed up to 200+ cm depth
Parent materials	Igneous Rock (Basaltic Type)
Erosion	None
Rock outcrops/stoniness	None
Present land use	Cultivated land
Root able depth	140 cm

Horizon	Depth (cm)	Descriptions
Ap	0-20	Black (10YR 2/1) moist; clay; weak, coarse, Granular; friable, slightly sticky and slightly plastic; many, very fine to coarse roots; Abrupt and smooth boundary.
A_1	20-40	Black (10YR 2/1) moist; clay; strong, moderate, subangular blocky; friable, slightly sticky and slightly plastic; few, very fine to coarse roots; Abrupt and smooth boundary.
Bk_1	40-100	Black (10YR 2/1) moist; clay; weak, fine, subangular blocky; friable, slightly sticky and slightly plastic; very few, very fine roots; clear and smooth boundary.
Bk_2	140-200+	Black (10YR 2/1) moist; clay; weak, fine, subangular blocky; very friable, slightly sticky and slightly plastic; very few, very fine roots; gradual and smooth boundary.
Btkg	140-200+	Glayic (Glay 1 2.5/N) moist; clay; weak, fine, Granular; very friable, slightly sticky and slightly plastic; very few no root.

Appendix Table 2 Surface soil physico-chemical properties prior treatment application (0-20 cm)

Soil properties	Hawassa Zuria				Meskan			
	S1	S2	S3	Mean	S1	S2	S3	Mean
Physical properties								
Sand (%)	42	40	42	41.33	16	16	18	16.67
Silt (%)	34	34	32	33.33	34	36	34	34.67
Clay (%)	24	26	26	25.33	50	48	48	48.67
Silt: clay ratio	1.42	1.31	1.23	1.32	0.68	0.75	0.71	0.71
Chemical properties								
pH	6.00	5.86	5.87	5.91	6.80	6.60	6.30	6.57
EC (ds/m)	0.03	0.03	0.03	0.03	0.08	0.09	0.08	0.08
Organic carbon (%)	2.54	2.42	2.69	2.55	3.98	4.29	4.29	4.25
Total nitrogen (%)	0.25	0.26	0.27	0.26	0.38	0.36	0.39	0.38
C: N	10.14	9.30	9.97	9.80	10.47	11.92	11.50	11.30
Available P (mg kg^{-1})	4.36	4.52	4.20	4.36	22.69	23.00	25.53	23.74
Ca (cmolc kg^{-1})	10.44	7.80	8.38	8.87	39.25	40.13	38.60	39.33
Mg (cmolc kg^{-1})	0.44	0.38	0.42	0.41	7.92	7.79	7.28	7.67
K (cmolc kg^{-1})	2.13	2.13	1.92	2.06	0.86	1.31	1.10	1.09
Na (cmolc kg^{-1})	1.55	1.69	1.55	1.59	0.51	0.51	0.52	0.51
CEC (cmolc kg^{-1})	22.00	20.00	22.40	21.47	61.00	65.00	60.00	62.00
Fe (mg kg^{-1})	2.09	2.12	2.30	2.17	0.37	0.22	0.62	0.41
Mn (mg kg^{-1})	1.82	2.03	2.16	2.00	3.30	1.51	3.75	2.85
Cu (mg kg^{-1})	0.12	0.12	0.19	0.14	0.59	0.97	0.65	0.74
Zn (mg kg^{-1})	1.14	0.84	1.19	1.06	0.87	0.98	0.75	0.86

S1= sample 1; S2= sample 2; S3= sample 3

Appendix Table 3 Analysis of variance showing effects of experimental factors and their interaction on yield, and N-uptake and use efficiency components of maize grown at the two sites

Locations	Sources Variation	DF	Parameters											
			GY	SY	GNC	GNU	SNC	SNU	GPC	NHI	NUtE	AE	PE	RE
Hawassa Zuria	TM	1	*	ns	ns	ns	*	*	ns	ns	*	ns	ns	ns
	CS	1	**	ns	**	**	***	**	**	ns	**	ns	*	**
	NF	3	***	**	***	***	***	***	***	*	***	ns	ns	**
	TM×CS	1	ns	**	*	*	**	**	*	ns	ns	ns	ns	**
	TM×NF	3	ns	ns	*	*	*	ns	**	***	ns	ns	ns	ns
	CS×NF	3	ns	**	ns	ns	***	***	ns	***	*	ns	ns	ns
	TM×CS*NF	3	ns	ns	*	*	*	ns	*	ns	ns	ns	ns	ns
	CV (%)		**4.6**	**9.2**	**6.9**	**8.3**	**4.6**	**9.37**	**6.8**	**5.6**	**6.1**	**35.4**	**30.6**	**22.9**
Meskan	TM	1	ns	ns	ns	ns	ns	*	ns	*	*	ns	ns	ns
	CS	1	ns	ns	**	**	***	**	**	**	**	ns	**	**
	NF	3	***	*	***	***	***	***	***	***	***	***	**	**
	TM×CS	1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	TM×NF	3	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	CS×NF	3	ns	ns	**	ns	*	**	**	ns	*	ns	ns	*
	TM×CS*NF	3	ns	ns	ns	ns	ns	*	ns	ns	*	ns	ns	ns
	CV (%)		**5.2**	**11.1**	**3.8**	**5.6**	**10.9**	**7.9**	**3.8**	**5.5**	**4.7**	**33.9**	**29.2**	**19.2**

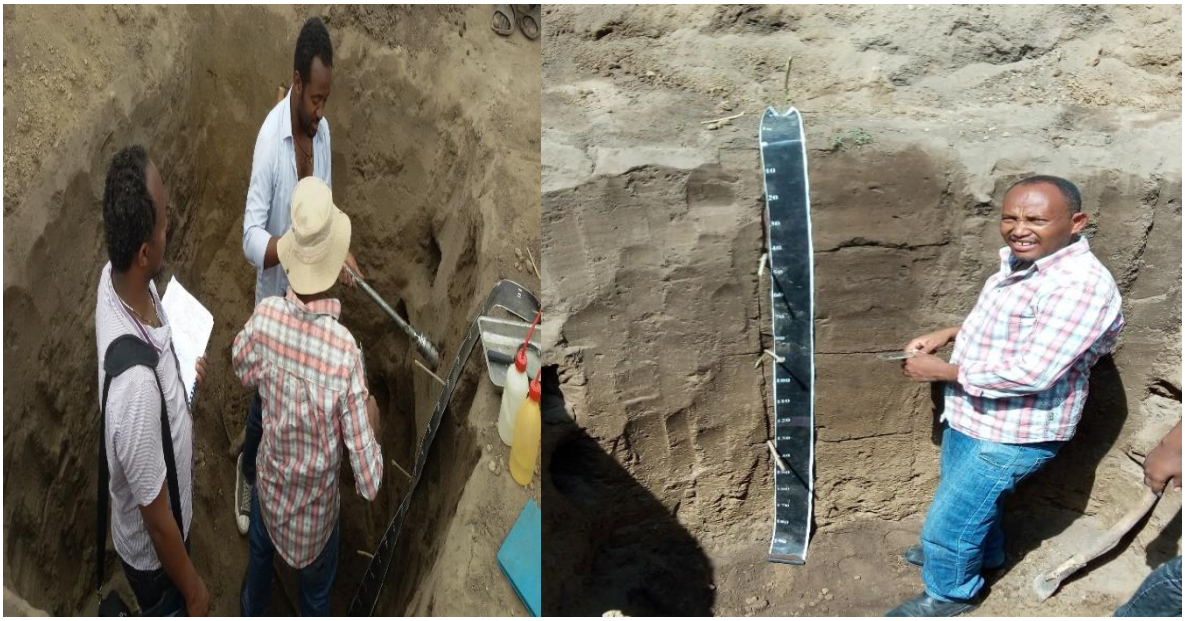
DF: degree of freedom; GY: grain yield; SY: stover DM yield; GNC: grain N-content; GPC: grain protein; GNU: grain N-uptake; SNC: stover N-content; SNU: stover N-uptake; GPC: grain protein content; NHI: nitrogen harvest index; AE = Agronomic efficiency (kg grain per kg applied N); PE= physiological efficiency (kg grain per kg N-uptake); ANRE= Apparent N-recovery efficiency (%); CV: coefficient of variation. *: significant at $P < 0.05$; **: significant at $P \leq 0.01$: ***: significant at $P \leq 0.001$; ns: not significant.

Appendix Table 4 Analyses of variance showing the effects of tillage methods, cropping systems and N fertilization on soil BD, OC and TN stocks at 0-20 cm and 20-40 cm soil depths

S. Variation	DF	Hawassa Zuria						Meskan					
		0-20 cm			20-40 cm			0-20 cm			20-40 cm		
		BD	OCS	TNS	BD	OCS	TNS	BD	OCS	TNS	BD	OCS	TNS
TM	1	ns	*	*	ns	ns	ns	ns	ns	ns	*	ns	ns
CS	1	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns
NF	3	*	*	***	ns	ns	ns	ns	***	***	ns	ns	ns
TM×CS	1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
TM×NF	3	*	ns	ns	ns	ns	ns	**	**	ns	ns	ns	*
CS×NF	3	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	*	*
TM×CS×NF	3	**	**	ns	ns	ns	ns	*	**	**	ns	ns	ns
CV (%)		2.7	3.13	6.10	2.6	7.34	9.2	2.75	2.91	5.96	3.16	3.80	4.98

DF: degree of freedom; BD: bulk density; OCS: organic carbon stock; TNS: total nitrogen stock; *: significant at $P < 0.05$; **: significant at $P \leq 0.01$: ***: significant at $P \leq 0.001$; ns: not significant.

Different photos taken during the study work



Soil profile description at Hawassa Zuria

Soil profile description at Meskan

Soil laboratory analysis at college of Agriculture Hawassa University

Greenhous experiment at Awada

Compost preparetion at Wondo genete agricultural research center

First year field experiment at Hawassa Zuria

First year field experiment at Meskan

Second year field experiments at Hawassa Zuria and Meska

BIOGRAPHICAL SKETCH

The author was born on 04 November 1985 GC from Ato Nigussie Adafre and W/o Leke Bokan in Wonji town of Adama Worda, East Shewa zone, Oromia region, Ethiopia. He attained his primary school education at Wonji Mishen and secondary school education from grades 9-11 and 12 at Wonji and Amigna Gesgare compressive secondary high schools, respectively. He joined Jimma University College of Agriculture and Veterinary Medicine in 2002 and graduated with a BSc degree in Horticulture in 2006. He then worked as a crop production and protection expert as well as a coffee agronomist for the South Nation Nationality People Region State, Hadiya zone, West Badawacho woreda rural development office. Then, the author joined Hawassa University for his MSc studies in 2009 and graduated with MSc in Plant Sciences specialization in Agronomy in 2012. He was then recruited by the Ethiopian Institute of Agricultural Research in the former Soil and Water Research Directorate and worked as a researcher in various levels at Wondo Genet Agricultural Research Center until he joined the Graduate Studies program of Hawassa University to pursue a PhD degree in Soil Science.