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Department of Geography and Environment Studies

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Evaluation of Alternative Soil Amendments to Improve Soil Fertility and response to bread Wheat (*Triticum aestivum*) Productivity in Ada'a District, Central Ethiopia

A Thesis Submitted to Addis Ababa University, the school of graduate studies, in partial fulfilment of the Requirement for the Degree of Masters of Art in Geography and Environmental Studies, specialization: Natural Resource and Environmental Management

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This is to certify that the thesis prepared by **Genizeb Ayaye**, entitled: ***Evaluation of Alternative Soil Amendments to Improve Soil Fertility and response to Bread Wheat (Triticum aestivum L.) Productivity in Ada'a district, Central Ethiopia*** *and* submitted in partial fulfillment of the requirements for the Degree of Master of Arts (Geography and Environmental Studies, Specialization: Natural Resource and Environmental Management) complies with the regulation of the university and meets the accepted standards with respect to originality and quality.

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Abstract

A field experiment was conducted during 2014 main cropping season in Ada'a district, central highlands of Ethiopia to evaluate the impacts of soil fertility amendments to improve soil fertility and response to bread wheat production. Soil samples were taken at a depth of 0-20 cm before and after treatment. Similarly, relevant agronomic traits were recorded from each plot. The amendments included 16 solo and combined application of compost, bio slurry and inorganic fertilizers including control field. The wheat variety used for the study was, Kekeba Pica flor. The design was randomized complete block with three replication. To compute the numerical data, SPSS software was used. The soil analyses results before treatment indicated that the soil is in a conducive ranges of pH for most crops and clayey in texture with very low organic carbon, low total N, high available P, K and CEC. The percent base saturation was very high with Ca and Mg dominating cations. The soil analyses results after treatment indicated that there was insignificant difference ($P<0.05$) as a result of fertility amendment options but the soil is in a favorable ranges of pH for most crops and clayey in texture with very low organic C, low total N, high available P and K. Dense to very dense bulk densities were measured in the soil. The percent of base saturation was very high with Ca and Mg dominant cations. Exchangeable K and Na were in the range of medium. The CEC value falls under high range. The highest organic carbon, total N and available P and K were obtained as a result of the solo application of dry matter compost at the rate of 96 N & 69 kg P ha^{-1}. The agronomic analysis results revealed that there was a significant difference ($P<0.001$) in all the agronomic traits. The highest plant height, spike length, spikelet spike-1 and 1000 grain weight were obtained from the application of compost at the rate of 64.4 N & 46 kg P ha^{-1} along with inorganic fertilizer at the rate of 98.5 N & 46 kg P ha^{-1} while the highest grain yield and biomass yield were obtained from the application of 96 N & 69 kg P ha^{-1} inorganic fertilizers. The lowest grain yield and biomass yield were obtained from control field. Therefore, it can be concluded that solo application of dry matter compost can be an alternative to soil fertility improvement while combined application of dry matter compost along with inorganic fertilizers can be an option for wheat production in the study area.

Key words: *Dry matter compost, Dry matter bio Slurry, Inorganic Fertilizers, Soil Fertility, Soil Amendments, Wheat Productivity, Vertisols, Ada'a district, Central Ethiopia*

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Acronyms

ADARDO	Ada’a District Agricultural and Rural Development Office
ADLI	Agricultural Development Led Industrialization
AEZs	Agro Ecological Zones
ANOVA	Analysis of Variance
AU	African Union
CSA	Central Statistics Agency
CV	Coefficient of Variance
DAP	Di ammonium Phosphate
DZMS	Debire Zeit Metrological Station
EARI	Ethiopian Agricultural Research Institute
FAO	Food and Agricultural Organization of the United Nation
GDP	Gross Domestic Product
GIS	Geographic Information System
GNI	Gross National Income
IMF	International Monetary Fund
ISFM	Integrated Soil Fertility Management
ISFMOs	Integrated Soil Fertility Management Options
LU/LC	Land Use/ Land Cover
Masl	Meter above Sea Level
MoA	Ministry of Agriculture
MoARD	Ministry of Agriculture and Rural Development
MOFED	Ministry of Finance and Economic Development
PASDEP	Plan for Accelerated and Sustained Development to End Poverty
RCBD	Randomize Complete Block Design
SPSS	Statistical Package for Social Science
SSA	Sub-Sahara African
SWC	Soil and Water Conservation
USDA	United States Development Agency
WB	World Bank

CHAPTER ONE

1. INTRODUCTION

1.2 Background and Justification

Agriculture contributes for more than 46% of the GDP and 90% of the export earnings, and supports 85% of the labor force of Ethiopia (MOFED, 2005). The current development strategy of Ethiopia is Agricultural Development Led Industrialization (ADLI). This strategy has been adopted since 1994/95 and focuses on productivity improvement of smallholder's agriculture through diffusion of fertilizers, improved seeds and setting up credit schemes. However, soil fertility decline and accompanied low level of agricultural production have been voiced to be still among the serious challenges of the strategy (MOARD, 2008).

Very low or low soil fertility status of agricultural land of smallholders is mentioned as one of the main constraints of crop yields in Ethiopia. Many empirical studies (for example, Assefa, 2005; Balesh, 2005; Hailu, 2010; Getachew *et al.,* 2012; Bogale, 2014) have documented the problem of low soil nutrient reserves and negative nutrient balances in croplands with few or no external nutrient inputs compared to the nutrient status of forest areas, grazing or well managed lands. In Ethiopia, century-long, low input agricultural production, poor agronomic management practices, limited awareness of communities, absence of proper land use planning have aggravated soil fertility depletion (FAO, 1998; Gete *et al.,* 2010). The problem is more serious in the highlands where most of the human and livestock population is found (Assefa, 2005; Mitiku *et al.,* 2006; Hailu, 2010). This is mainly due to the complete removal of crop residues from farm lands for household energy and livestock feed, use of manure as a source of fuel instead of using it for soil fertility maintenance, low levels of inorganic fertilizer application and lack of appropriate and in-situe SWC practices (FAO, 1998; Eyasu, 2002; Haileslassie *et al.,* 2005; Aklilu, 2006). Thus, the mitigation of soil fertility depletion is currently a pressing issue and major national concern.

Wheat (*Triticum aestivum L.*) is one of the important grain crops produced worldwide. Wheat is one of the most important cereals cultivated in Ethiopia. It ranks 4th after Tef (*Eragrostis tef*), Maize (Zea mays) and Sorghum (Sorghum bicolor) in area coverage and 3rd in total production (CSA, 2007).

In Ethiopia, it is largely grown in the mid and highlands of the country and constitutes roughly 10% of the annual cereal production and plays an appreciable role in supplying the population with carbohydrates, protein and minerals (Schulthess *et al.,* 1997). The crop is grown well at an altitude ranging from 1500 to 3000 masl while the most suitable agro ecological zones falls between 1900 and 2700 masl. Accordingly, the major wheat producing areas in Ethiopia are located in Arsi, Bale, Shewa, Ilubabor, Western Hareghe, Sidamo, Tigray, Northern Gonder and Gojam zones (Bekele *et al.,* 2000). Wheat in the study area is the 3rd important crop in terms of total production after *tef* and chickpea (Bogale, 2014).

At a country level, wheat shows an increasing trend in terms of area coverage which is about 2.56 million ha (CSA, 2008). However, its productivity (1.17 tons ha^{-1}) is very low due to poor soil fertility and crop management practices. Moreover, farmers who have the experience and resources to prepare compost and bio slurry often manage to have much less than the amount required (Getachew and Taye, 2005).

Dry matter compost and bio slurry are valuable organic amendments for agricultural soils. They can serve as a source of plant nutrients and can improve soil structure and water holding capacity (Oldare *et al.,* 2011).

The most common inorganic fertilizers used in Ethiopia for cereal production are Urea and DAP. Continuous application of these fertilizers may intensify the depletion of important soil nutrients that may not appear with these inorganic fertilizers and may increase soil acidy. Inorganic fertilizers are also costly for farmers to apply as much as the required amount for optimum level of production. In contrast, sole application of compost and bio slurry may be constrained because of lack of access to these amendments, low nutrient content and high labor demand for preparation and transportation to farming field. Thus, the integrated use of inorganic fertilizers and locally available soil amendments such as compost and slurry are assumed to be the best approach for achieving higher fertilizer-use efficiency, improve crop yield and economic feasibility (Getachew *et al.,* 2012).

Recent studies indicated that the interaction effect between combined inputs and practices can provide almost double the crop yield benefits compared to fertilizers applied separately (Getachew and Taye, 2005; Våje, 2007; Dercon and Hill, 2009). It is often believed that ISFM based crop production systems plays an important roles in restoring soil fertility, availability of plant nutrients, enhancing crop growth and productivity (Vanlauwe *et al.,* 2010; Gete *et al.,* 2010).

1.2 Statement of the problem

Ethiopia is one of the fastest growing non-oil economies in Africa. Ethiopian economy is heavily reliant on agriculture as the main source of income and food security and employment opportunity for a vast majority of its population (WB, 2012).

An agricultural system involving a combination of organic and inorganic fertilizers is believed to be environmentally friendly, technically appropriate, economically viable and socially acceptable (FAO, 1998). In practice, sustainable agriculture uses less external inputs and employs locally available natural resources more efficiently (Lee, 2005).

Subsistence farmers in the highlands and mid-altitude areas of Ethiopia widely cultivate major crops such as wheat and barley but these crops suffer from year to year decline in productivity. The low yield of wheat in Ethiopia is primarily due to depleted soil fertility (Asnakew *et al.,* 1991; Tanner *et al.,* 1993), low level of inorganic fertilizer usage and not combining use of organic and inorganic fertilizers (Asnakew *et al,* 1991; Amsal *et al.,* 1997; CSA, 2000) and the unavailability of other crop management inputs (Asnakew *et al.,* 1991).

Soil fertility and crop yields are generally much lower in the developing countries and there is a need for increased use of fertilizers to increase yields to produce sufficient food for the expanding populations and to maintain soil fertility status. Soil fertility depletion and widespread soil degradation are the major biophysical root causes of declining per-capita food production and natural resource conservation in SSA (Sanchez *et al.,* 1997; Farouque and Tekeya, 2008).

In Ethiopia, century-long, low input agricultural production systems, poor agronomic management practices, limited awareness of communities and absence of proper land use planning have aggravated soil fertility degradation. Low soil fertility is one of the factors limiting the yield of cereal crops including wheat (Amsal *et al.,* 1997).

Application of compost and bio slurry along with inorganic fertilizer helps in proper nutrition of crop and maintenance of soil fertility. Various trials have compared the yields from inorganic fertilizer, organic fertilizers and or combination of both. In many cases, combination of organic and inorganic fertilizers have produced higher yields (Sajjad and Shad, 2014)

In Ethiopia, organic resources amendment such as animal dung (as dry matter compost and bio slurry) and crop residues are largely used for competing uses, especially as household energy sources instead of being recycled to maintain soil fertility status (Aklilu, 2006).

Current levels of dry matter compost and bio slurry application with inorganic fertilizers are much lower than required to maintain a dynamic equilibrium in soil organic matter content. Hence, integrated application of organic and inorganic fertilizers can improve yield of Wheat and soil fertility status of the study area (Bogale, 2014).

However, there have been limited literatures (for example, Assefa, 2005; Balesh, 2005; Eyasu, 2009; Hailu, 2010; Bogale, 2014) in previous studies regarding the soil fertility status, soil nutrient balance, nutrient mining and depletion, major causes and its implications and possible solutions. But, it is clearly revealed that, none of those authors have associated and integrated the use of alternative soil amendments to improve soil fertility and response to bread wheat production.

Thus, owing the above stated research gaps, the study was aimed at evaluating alternative soil amendments to improve soil fertility and response to bread wheat production on small holder's farming systems in Ada'a district of central highlands of Ethiopia.

To achieve the stated objective, both primary and secondary data were collected. Accordingly, before and after the treatment, soil samples were taken at the depth of 0-20 cm and the selected physical and chemical properties were analyzed in the soil and plant analytical laboratory of National Soil Testing Center and Debire Zeit Agricultural Research Center to determine the soil fertility status of the study area. Similarly, crop yield and yield components of bread wheat were collected and recorded from each plot to analyze productivity variation as a result of applied soil fertility amendment options and finally a tool called SPSS (Version-20) was employed to analyze the overall numerical values.

1.3 Objective of the study

1.3.1 General objective

The general objective of the study was to evaluate the impact of alternative soil amendments to improve soil fertility and response to wheat production in Ada'a district of central highlands of Ethiopia.

1.3.2 Specific objectives

Based on the stated general objective of the study, the following specific objectives have been formulated;

- To examine the effect of solo and combined application of compost, bio slurry, Nitrogen and P fertilizers on the improvement of soil fertility in Ada'a district,
- To compare the effect of solo and combined application of compost, bio slurry, Nitrogen and P fertilizers on the production of bread wheat in the study area,
- To determine the optimum rates of fertilizer application from the perspectives of soil fertility improvement.
- To determine the optimum rates of fertilizer application from the perspectives of increased bread wheat production in the study area.

1.4 Research Hypotheses and Questions

Based on the aforementioned objectives, the following research hypotheses and questions were forwarded.

- There is no significant difference in soil fertility status between plots that receive no, solo and combined application of compost, bio slurry, and Nitrogen and P fertilizers.
- There is no significant difference in production of Bread wheat between plots that receive no, solo and combined application of compost, bio slurry, and Nitrogen and P fertilizers.
- What are the optimum rates of fertilizer application from the perspectives of soil fertility improvement in the study area?
- What are the optimum rates of fertilizer application from the perspectives of increased Bread wheat production in the study area?

1.5 Scope of the study

The experimental study was conducted in Kumbursa village of Adana district, central highlands of Ethiopia. The study was carried on the ‘evaluation of the impact of alternative soil amendment options to improve soil fertility and response to bread wheat (*Tritium aestivum L.*) production’ of 2014 main cropping season in small holders’ farming plots. The experiment was restricted on the application of organic (compost and bio slurry) and inorganic (Nitrogen and P fertilizers) resources to improve soil fertility status and bread wheat production of the study area. The experiment was laid out in Randomized Complete Block Design (RCBD) having 3 replication. The net plot size was 3 x 3 m (9 m^2) with 1 m row spacing and a total of 48 plots leaving 3 outer rows and edge of 0.5 m length at both ends of each plot. The experimental design comprises six amendment combinations; (1) bio slurry, (2) compost, (3) inorganic fertilizer, (4) bio slurry + inorganic fertilizer, (5) compost + inorganic fertilizer and (6) absolute control.

1.6 Significance of the study

The finding of the study can contribute on the evaluation of the impact of alternative soil amendments to improve soil fertility and response to bread wheat production. These findings provide up-to-date information for agricultural sectors in planning and decision making. It also serves as a baseline literature for further study.

1.7 Limitation of the study

Being an experimental study, it had its own limitation. The experiment was conducted only for one main cropping season (2014) to evaluate the impact of soil fertility amendments and response to bread wheat production. Thus, it is not possible to identifying the significant effects of solo and combined application of dry matter bio slurry, dry matter compost and inorganic fertilizers on the soil fertility status of the study area within such a limited time or season.

1.8 Thesis outline

This thesis was organized in five sections. The first section gave an overview on the general introduction. The second section reviewed the previous works related to soil fertility, soil fertility amendments, wheat productivity and analytical framework. The third section presented research methodologies while section four described results and discussions of the study. The last section presented the conclusion and recommendation part that drawn from the study.

CHAPTER TWO

2. REVIEW OF RELATED LITERATURE

2.1 Overview of Soil Fertility and Productivity

Soil fertility is the status of a soil with respect to its ability to supply elements which are essential for plant growth without a toxic concentration of any elements. Thus, soil fertility focuses on the adequate and balanced supply of elements or nutrients to satisfy the needs of plants. Because plants have evolved in different climates and on different soils, plants have different needs for the essential nutrients and different tolerances of the toxic elements. Soil productivity encompasses soil fertility plus all the other factors affecting plant growth, including soil management. Soil productivity is a measure of the soil's ability to produce a particular crop or sequence of crops under a specified management system. All productive soils are fertile for the crops being grown, but many fertile soils are unproductive because they are subjected to drought or other unsatisfactory growth factors or management practices. There is a strong positive correlation in productive soils between fertility and physical properties so that highly productive soils have desirable physical properties as well as high fertility (Foth and Ellis, 1997).

Low soil fertility is recognized as a constraint to increased food production and farm incomes in many parts of Sub-Saharan African (Shepherd and Soule, 1998). Ethiopia is one of the Sub-Saharan countries with highest rates of nutrient depletion due to lack of adequate synthetic-fertilizer input, limited return of organic residues and manure, high biomass removal from farm lands, high soil erosion rate and leaching loss of nutrient elements. The annual nutrient deficit in the country is estimated at 41 kg N, 6 kg P, and 26 kg K ha^{-1} yr^{-1} (Stoorvogel and Smaling, 1993).

Soil fertility and plant nutrition are an important components of plant production. Productive capacity of soils requires the provision of adequate and balanced amounts of nutrients to ensure proper growth of the plants. The fact on the ground is that, soil nutrient status of most farming systems is widely constrained by the limited use of inorganic and organic fertilizers and by nutrient loss mainly due to erosion and leaching (Balesh *et al.*, 2007).

2.2 Soil Fertility Status in Ethiopia

Agriculture in Ethiopia has long been a priority and focus of national policy such as Agricultural Development Led Industrialization (ADLI) and various large scale programs such as the Plan for Accelerated and Sustained Development to End Poverty (PASDEP) (Alemayehu, 2008).

However, the sector is characterized by low productivity and the prevalence of a fragmented smallholder/subsistence farmer population that is relegated to highly degraded/marginal land (WB, 2010). Low productivity can be attributed to limited access by small farmers to agricultural inputs, financial services, improved production technologies, irrigation and agricultural output markets and, more importantly, to poor land management practices that have led to severe land degradation in some areas. Therefore, the sector is also characterized by low input-low output and labor-intensive rain fed farming systems reliant on the use of animal power (PIF, 2010).

Ethiopia faces a wider set of soil fertility issues beyond inorganic fertilizer use which has historically been the major focus for extension workers, researchers, policymakers and donors. These issues interact and include loss of soil organic matter, macronutrient (N, P and K) and micronutrient (Fe, Mn, Zn, Cu, B, Mo and Cl) depletion, topsoil erosion, acidity, salinity and deterioration of other physical soil properties (Gete *et al.*, 2010).

In terms of soil nutrients and fertility, Ethiopia has one of the highest rates of nutrient depletion in Sub-Sahara African. The estimated annual nationwide loss of phosphorus and nitrogen resulting from the use of dung and crop residues for fuel is equivalent to the total amount of commercial fertilizer use. However, the use of fertilizer and improved seeds are limited despite government efforts to encourage the adoption of modern agricultural practices. Land degradation and nutrient depletion are further exacerbated by overgrazing, deforestation, population pressure and the poor land use planning and tenure system (PIF, 2010).

2.3 Soil Fertility Characteristics Affecting Crop Production

Several factors contribute to reducing the fertility status and quality of soil in Ethiopia. The major ones being land degradation because of massive deforestation, human and livestock population pressure, limited use of crop residue and animal dung and little or no use of modern technologies to restore soil fertility (Taye and Yifru, 2010).

Physical and chemical properties of soil are the major determinant factors of soil fertility status. Different physical and chemical properties of the soil relate to one another and hence, the presence of one can indicate the status of the other (Brady and Weil, 2004).

2.3.1 Soil Physical Properties

The physical properties of soils determine their adaptability to cultivation and the level of biological activity that can be supported by the soil. Soil physical properties also largely determine the soil's water and air supplying capacity to plants. Many soil physical properties change with changes in land use system and its management practices such as intensity of cultivation, the instrument used and the nature of the land under cultivation, rendering the soil less permeable and more susceptible to runoff and erosion losses (Sanchez, 1976).

Soil texture

Texture of a soil refers to the size-composition of elementary grains (sand, silt and clay contents) in a soil. Soil texture determines a number of physical and chemical properties of soils. It affects the infiltration and retention of water, soil aeration, absorption of nutrients and nutrient stock, microbial activities, tillage and irrigation practices (Foth, 1990). It is also an indicator of some other related soil features such as type of parent material, homogeneity and heterogeneity within the profile, migration of clay and intensity of weathering of soil material or age of soil (Miller and Donahue, 1995).

Soil texture is also one of the inherent soil physical properties less affected by management. The rate of increase in stickiness or ability to mould as the moisture content increases depend on the content of silt and clay, the degree to which the clay particles are bound together into stable granules and the organic matter content of the soil (White, 1997). Over a very long period of time, pedogenic processes such as erosion, deposition, eluviation and weathering can change the textures of various soil horizons (Brady and Weil, 2002).

Soil Bulk Density

Measurement of soil bulk density (the mass of a unit volume of dry soil) is required for the determination of compactness, as a measure of soil structure, for calculating soil pore space and as indicator of aeration status and water content (Barauah and Barthakulh, 1997). Bulk density also provides information on the environment available to soil microorganisms. White (1997) stated that values of bulk density ranges from < 1 g/cm^3 for soils high in OM, 1.0 to 1.40 g/cm^3

for well- aggregated loamy soils and 1.2 to 1.8 g/cm^3 for sands and compacted horizons in clay soils. Bulk density normally decreases as mineral soils become finer in texture. Soils having low and high bulk density exhibit favorable and poor physical conditions respectively (Mitiku *et al*, 2006).

Bulk density normally decreases as mineral soils become finer in texture. Soils having low and high bulk density exhibit favorable and poor physical conditions, respectively. Bulk densities of soil horizons are inversely related to the amount of pore space and soil OM (Brady and Weil, 2002). Any factor that influences soil pore space will also affect the bulk density. For instance, intensive cultivation increases bulk density resulting in reduction of total porosity.

2.3.2 Soil chemical Properties

Soil chemical properties are the most important among the factors that determine the nutrient supplying power of the soil to the plants and microbes. The chemical reactions that occur in the soil affect processes leading to soil development and soil fertility build up. Minerals inherited from the soil parent materials overtime release chemical elements that undergo various changes and transformations within the soil.

Soil Reaction (pH)

Soil reaction (usually expressed as pH value) is the degree of soil acidity or alkalinity, which is caused by particular chemical, mineralogical and/or biological environment. Soil reaction affects nutrient availability and toxicity, microbial activity, and root growth. Thus, it is one of the most important chemical characteristics of the soil solution because both higher plants and microorganisms respond so markedly to their chemical environment (Troeh and Thompson, 1993).

Descriptive terms commonly associated with certain ranges in pH are extremely acidic (pH < 4.5), very strongly acidic (pH 4.5-5.0), strongly acidic (pH 5.1-5.5), moderately acidic (pH 5.6-6.0), slightly acid (pH 6.1-6.5), neutral (pH 6.6-7.3), slightly alkaline (pH 7.4-7.8), moderately alkaline (pH 7.9-8.4), strongly alkaline (pH 8.5-9.0) and very strongly alkaline (pH > 9.1) (Foth and Ellis, 1997).

The degree and nature of soil reaction influenced by different anthropogenic and natural activities including leaching of exchangeable bases, acid rains, decomposition of organic materials**,** application of commercial fertilizers and other farming practices (Brady and Weil, 2002).

Soil organic matter

Soil organic matter (SOM) is the organic fraction of soil derived from the decayed tissue of plants, animals and from animal excreta (Teklu, 2005). SOM content in liquid digested slurry and slurry compost has a major influence on the physical and chemical properties of soils. Soil organic matter also helps to bind soil particles together that improve the physical properties of the soil making it easier for roots to penetrate (Gurung *et al.*, 1997). OM forms complexes with micro nutrients and prevents them from being lost through leaching (Ilaco, 1985). During anaerobic fermentation process, about 25 to 30 % of the OM from the manure is converted into biogas while the rest becomes available as residual manure (Chendu, 2006).

Total nitrogen

Nitrogen occurs in soils in both organic and inorganic compounds of which plants absorb N in its cationic form (NH_4^+) and anionic form (NO_3^-) and obtain readily available N forms from different sources. The total N content of a soil is directly associated with its OC content and its amount on cultivated soils is between 0.03 % and 0.04 % by weight (Tisdale *et al.,* 1995).

The major sources include biological N fixation by soil microorganism's mineralization of organic matter and industrial fixation of N gas and fixation as oxides of N by atmospheric electrical discharge. The availability of N through biological N fixation is influenced by soil pH and its mineral nutrient status, photosynthesis, climate and crop management. Similarly, mineralization of organic N to inorganic forms depends on temperature, level of soil moisture and supply of oxygen (Tisdale *et al.,* 1995).

Soils have little capacity to retain oxidized forms of N and ammonium accumulation in soils is small; consequently, most of the soil N is associated with SOM. Release of N from SOM is slow and unpredictable. If SOM is depleted, as occurs in cultivated soils, N for plant growth is limited (Brady and Weil, 2004). The N content is lower in continuously and intensively cultivated and highly weathered soils of the humid and sub humid tropics due to leaching and in highly saline and sodic soils of semi- arid and arid regions due to low SOM content (Tisdale *et al*., 1995).

Because of their low soil organic matter content, most of the Vertisols in Ethiopian highlands have low total N content and there is a high crop response to N fertilizers in these areas. On account of rapid nitrification, most of the N added as fertilizer containing NH_4 or NH_2 is subject to leaching or denitrification soon after application (Desta, 1986).

The N content is lower in continuously and intensively cultivated and highly weathered soils of the humid and sub humid tropics due to leaching and in highly saline and sodic soils of semi arid and arid regions due to low organic matter content (Tisdale *et al*., 1995).

Carbon to Nitrogen ratio

Carbon (C) to nitrogen (N) ratio (C/N) is an indicator of net N mineralization and accumulation in soils. Organic matter rich in carbon provides a large source of energy to soil microorganisms. Consequently, it brings population expansion of microorganism and higher consumption of mineralized N. Dense populations of microorganisms inhibit the upper soil surface and have an access to the soil N sources. If the ratio of the substrate is high there will be no net mineralization and accumulation of N (Attiwill and Leeper, 1987). They further noted that as decomposition proceeds, carbon is released as CO_2 and the C/N ratio of the substrate falls. Conversion of carbon in crop residue and other organic materials applied to the soil into humus requires nutrients (Lee, 2005).

Available Phosphorus

Phosphorus (P) is known as the master key to agriculture because lack of available P in the soils limits the growth of both cultivated and uncultivated plants (Foth and Ellis, 1997). Phosphorus is among the most limiting nutrients for food production in the sub-humid and humid tropical highlands of East Africa (Sanchez *et al.,* 1997). Next to N, P is the most limiting nutrient in Vertisols agricultural (Finck and Venkateswarlu, 1982) and this holds true for Ethiopian soils and the problem in Ethiopia is further exacerbated by nutrient mining due to the prevailing low-input agriculture.

Phosphorus is unique among the anions in that it has low mobility and availability, which is determined by soil pH and the consequent reactions of P with Al^{3+}, Fe^{3+} and Ca^{3+}. It is difficult to manage because it reacts so strongly with both solution and solid phases of the soil. While P occurs in a multitude of inorganic and organic forms in the soil, the plant available forms of P are limited primarily to solution HPO_4^{-2} and $H_2PO_4^-$, with the dominant forms determined by the soil pH (Tisdale *et al.*, 1995).

Studies show that the total P status of some representative major soil types in Ethiopia is low (Piccolo and Huluka, 1985). Most of the Vertisols in the Ethiopian highlands, 70% of the cases, are reported low in available P content which is below 5 ppm or <5 mg kg^{-1} (Berhanu, 1985).

Potassium

Except nitrogen, potassium is a mineral nutrient plants require in the largest amounts. Potassium (K) is involved in photosynthesis, sugar transport, water and nutrient movement, protein synthesis and starch formation. It also helps to improve disease resistance, tolerance to water stress, winter hardiness, tolerance to plant pests and uptake efficiency of other nutrients (Zublena, 1997).

Cation Exchanging Capacity

The ability of a soil to retain cations such as potassium (K^+), ammonium (NH^{4+}), hydrogen ($H^{+)}$, calcium (Ca^{++}) and magnesium (Mg^{++}) in a form that is available to plants is known as cation exchange capacity (Ilaco, 1985). The Cation exchange capacity (CEC) of soils also defined as the capacity of soils to adsorb and exchange cations (Brady and Weil, 2002). Cation exchange capacity is an important parameter of soil because it gives an indication of the type of clay minerals present in the soil, its capacity to retain nutrients against leaching and assessing their fertility and environmental behavior. Generally, the chemical activity of the soil depends on its CEC. The higher the CEC, the higher the negative charge and the more cations that can be held, the more nutrients the soil can supply. There is a fairly constant equilibrium between adsorbed cations and those moving freely in the soil moisture. When the equilibrium is disturbed, ion exchange between the solid and liquid soil phases occur, resulting in either adsorption or release of cations (Samuel *et al,* 2000).

In general, CEC is crucial factor in the determination of soil fertility for two fundamental reasons. The first reason is that, the total quantities of nutrients available to plants as exchangeable cations depend on it. The second reason is that, it can influence the degree to which hydrogen and aluminum ions occupy the exchange complex and thus, affect the pH of soils (Sahlemedihn and Taye, 2000).

Exchangeable Bases

The base-exchange properties of soils influence plant nutrition and the desirability of the soil as a growth medium. Nutrient cations held as exchangeable bases are in a readily available state, but are not readily leached from soils. The levels of exchangeable cations in a soil are usually of more immediate value in advisory work than the CEC, because they not only indicate existing nutrient status but can also be used to assess balances amongst cations.

According to Landon (1991), the levels of exchangeable cations is of great importance because many effects, for example soil structure and nutrient uptake by crops, are influenced by the relative concentrations of cations as well as their absolute levels. Soils in high rainfall areas and under continuous cultivation and fertilization with inorganic N containing fertilizers are characterized by low contents of exchangeable bases and the subsequent deficiencies of Ca, Mg and K (Saikh *et al.,* 1998). However, Vertisols and high organic matter containing soils retain more basic cations, which are mainly dominated by exchangeable Ca and Mg (Eylachew, 2001). The predominant exchangeable cations, which accounts for up to 80% of the exchange complex, is Ca, followed by Mg: K and Na contribute nearly equal proportions (Berhanu, 1985).

The cations in productive agricultural soils are present in the order, $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$. Deviations from this order can create ion imbalance problems for plants. High Mg, for example, in soils formed from serpentine rocks inhibits Ca uptake by plants. High Na occurs in soils where drainage is poor and evaporation rates exceed rainfall. High Na creates problems of low water flow in soils and availability for plants (Bohn *et al.,* 2001).

2.4 Ways of Improving Soil Fertility Status in Ethiopia

Multiple interventions are needed to address these soil fertility issues including, but not limited to, chemical and organic nutrient sources. Positive steps have been made in many areas by MoARD and EIAR, and achievements in the scale-up of inorganic fertilizer use are especially noteworthy (Gete *et al*., 2010; Taye and Yifru, 2010). Main soil fertility interventions possible include:

Organic nutrient sources

Animal waste and crop residues applied to soil in the form of manure, untreated crop residues, and/or compost. Impact is broad—it improves organic carbon and nutrient levels, nutrient retention, reduced topsoil erosion, and mitigated acidity and salinity; and effects are long-lasting (more than 2 seasons); local materials are low-cost. Recent efforts have increased focus on compost but manure use remains extremely low.

Inorganic fertilizer

Synthetic concentrated macronutrients (N, P and/or K) applied to soil. These can have a large yield impact, but only under the right soil conditions and with adequate soil and water physical management- nutrients applied, for example, to acidic or saline soils can become fixated and hence unavailable; on depleted topsoil, nutrients can be leached away.

- Application per hectare in Ethiopia has increased five times since the 1980s and is better than the sub-Saharan Africa average , but rates and coverage vary significantly, and focus on DAP and Urea means only N and P provided (not K).
- Currently a large portion of EIAR resources is focused on testing crop yield response to N and P fertilizers, and regional tailoring of DAP and Urea fertilizer recommendations, as these were the priorities identified from the Murphy (1968) studies in the 1950s-60s. Initial blanket recommendations were adjusted for major cereals and soil types in the early 1990s, but aside from selected exceptions (e.g. some districts in Amhara region) efforts on regional tailoring still have some way to go.

Bio-fertilizer

Cultures of nutrient-releasing bacteria and fungi applied to seeds; organisms make nutrients available to plants from surrounding environment. The effective nutrient impact can vary and needs extensive on-site evaluation to ensure varieties are fit for use; in some cases they can provide robust results as effects are not hindered by acidic or saline conditions in the same way as inorganic fertilizers. The most promising bio-fertilizer at present are Rhizobium inoccula to enhance biological nitrogen fixation of legumes, but current production in Ethiopia is small. All other bio-fertilizers would require significant research prior to commercialization and opportunities exist to engage with international initiatives to evaluate other bio-fertilizers across a wide range of environments.

Intercropping, crop rotation and fallowing

Allowing for natural replenishment of soil nutrients by co-planting legumes with grains, alternating legumes and cereals on the same plot in consecutive seasons, or leaving portions of land periodically fallow. Nutrient level increases through these techniques are less than with applied fertilizers, but can help reduce the need for supplements. Projects in other SSA countries (e.g. the World Agroforestry Center, ICRAF) with food security issues have found fallowing impractical, and intercropping a better balance of benefits and feasibility. Currently in Ethiopia most farmers practice some crop rotation, but effectively on two thirds of land [li]; intercropping and fallowing are largely not used

Lime

Crushed rock (e.g. limestone, chalk) applied to soil to reduce acidity levels. Under acidic conditions, makes nutrients available to plants by balancing pH, and prevents acidity-related crop damage. A national acidity management project, including lime production and distribution, is underway through MoARD and EIAR but is in early stages

Physical land management techniques, erosion and moisture management

Includes on-farm soil preparations such as minimum tillage, mulching and tied ridging, as well as large-scale land management practices (e.g. terracing, soil/stone bund construction, use of grass/forage strips and other agro-forestation, watershed conservation, irrigation and drainage). Practices reduce topsoil erosion and also benefit all other major soil issues. Successful practices have been developed in food-insecure areas (e.g. Tigray) but are not well spread to the rest of the country.

The exact set of issues and interactions present in any one area will vary significantly. It is clear, then, that soil fertility needs to be managed using multiple interventions given the complex, multiple and interacting issues at hand and multiple possible interventions. In addition, solutions need to be integrated, holistic and locally-tailored to have substantial and lasting impact. Some examples exist from experimental plots in Ethiopia where multiple interventions have been applied and resulted in greater crop yields.

Soil fertility amendments are also made by adding traditional fertilizer to the soil such as cow manure, organic compost, crop residues, bio slurry and inorganic fertilizer (Takashi and Yuma, 2010 ; Sajjad and Shad, 2014).

2.5 Wheat Production in Ethiopia

Wheat (*Triticum aestivum* L.) is one of the major cereal crops of the world ranking second after paddy rice both in acreage and production among the cereal crops. It provides more nourishment for the nations of the world than any other food crops. It supplies carbohydrate, protein, minerals and vitamins (FAO, 2006).

Ethiopia is one of the largest wheat producers among the countries in the Sub Saharan Africa (Hailu, 1991). Wheat is grown in the highlands of the country at altitudes ranging from 1500 to 3000 masl. Currently, wheat is one of the major cereals dominating food habits and dietary practices and is known to be a major source of energy and protein for the highland population in Ethiopia (Abera, 1991) and it is the most widely produced crop following *tef* (Getachew, 1991).

Ethiopia's current annual wheat production of approximately 3.24 million ton is insufficient to meet domestic needs (CSA, 2006). The low mean national yield for wheat is primarily due to depleted soil fertility, low fertilizer usage and the unavailability of other improved crop management inputs (Asnakew *et al.,* 1991; Getachew, 1991). There are a number high yielder improved bread wheat varieties which have been released by different agricultural research centers in Ethiopia.

The bread wheat variety, Kekeba Pica flora released in 2010 has been verified to be one of the most productive variety in Ethiopia among the recently released improved bread wheat varieties and it is one of the bread wheat variety which have been widely adopted by the majority of wheat growing farmers in Ada'a district of central highland of Ethiopia. However, according to Tanner *et al*. (1993) and Amsal *et al*. (1995), recently-released bread wheat cultivars are highly responsive to improved management systems and relative to older wheat lines, exhibit an economic response to higher rates of nutrient application.

It is evident that application of fertilizer greatly increases grain yields and facilitates the adoption of improved high-yielding varieties and hence, greater usage of inorganic fertilizer has been advocated as a primary means of increasing wheat grain yield in Ethiopia (Tanner *et al*., 1993; Amsal *et al*., 1997). Asnakew *et al.* (1991) reported that the use of inorganic fertilizers in Ethiopia have made a contribution to crop yield growth to date although there is potential for further improvement.

2.5.1 Yield and Yield Components

Yield and yield components of cereal crops consists of plant height, numbers of productive tillers, spike length, number of spikelet spike^{-1}, grain yield, 1000 Grain Weight, harvest index and total biomass (Chatterjee and Maiti, 1985). Application of N fertilizer increased the number of spike by increasing the number of tillers and it also increased spike length. Moreover, concentration of N resulting from increasing rate of applied increased number of spikelet spike^{-1} and there by increased grain yield. Among all the yield attributes of wheat, spike number per m^{2} is highly correlated with grain yield and it is the most important factor that causes variation in grain yield (Miller *et al.,* 1991).

Likewise, number of spikelet spike^{-1} is another important yield attribute of wheat. Increasing N application results in greater number of wheat spikelet spike^{-1} (Sagar and Reddy, 1992). Since the grain size in wheat is fairly constant, sink capacity is primarily limited by spikelet number, which in turn, has a close association with N nutrition of the crop (Shiga and Sekiya, 1976). However, application of excessive amount of N has a detrimental effect on spikelet formation, which in turn, reduces grain yield (Keulen, 1983).

Since the rate of carbohydrate flow has been used as a determining factor in plant organ proliferation, an increase in completion for metabolic supply among tillers decreases the production of spikelet spike^{-1}. On the other hand, as the number of spikelet increase with increased N supply, deleterious competition for carbohydrate would take place among spikelet, and weak spikelet in the lower part of spikes would take place among spikelet, and weak spikelet in the lower part of spikes would fail to be fertilized, or would abort immediately after fertilization (Wada, 1969). It is also possible that vigorous vegetative growth can cause a heavy drain on soluble carbohydrate resulting in reduction of its availability for spikelet formation. All these physiological changes resulted in increased number of unfilled spikelet spike^{-1} (Hasegawa *et al*., 1994), subsequently the yield response to Nitrogen fertilization is negative. The number of filled spikelet spike^{-1} shows increasing trend to a certain level of Nitrogen supply and then decreases with further increase of Nitrogen fertilizer level.

The effect of nitrogen on grain yield is partly attributes to increase in grain weight of wheat. In contrast, there are also reports that higher nitrogen level resulted in reduced grain weight (Thakur, 1993). Since the proportion of filled at spikelet at flowering is influenced by assimilate supply (Ingram *et al*., 1991) increased number of spikelet spike^{-1} and vigorous vegetative growth owing to high Nitrogen application induce competition for carbohydrate available for grain filling and spikelet formation (Wada,1969). This reduces the kernel weight because of insufficient supply of carbohydrate to the individual grain.

2.6 Application of Organic and Inorganic Fertilizers

2.6.1 Application of Organic Fertilizers

Organic farming is a system of raising plants and animals that attempts to recreate natural cycles and which does not use chemical inputs such as fertilizer and pesticides (Edwards *et al.,* 2007). All of these inputs provide macronutrients, micronutrients and organic matter to soil (Takashi and Ayumi, 2010).

Sustainable agricultural practices, as far as it rely on renewable local or farm resources, present desirable options for enhancing agricultural productivity for resource constrained farmers in developing countries (Menale *et al,* 2008).

Compost and bio slurry improves the physical, chemical and biological quality of soil besides providing both macro and micro nutrients to crops. The improvement in qualities include improvement in soil structure, water holding capacity, electrical conductivity, bulk density, lesser soil erosion, preventing the leaching of nutrients and provide nutrients to soil micro flora (Fentaw, 2010).

2.6.1.1 Effect of Bio slurry Application on Crop Growth and Soil Fertility Status

Biogas dregs and slurry are by-products of biogas production generated from cattle dung. These residues especially biogas slurry are a good source of plant nutrients and can improve soil fertility and properties (Garg *et al*., 2005). The farmer needs to use inorganic fertilizer to increase crop production. However, if only inorganic fertilizers are continuously applied to the soil without adding organic manure, productivity of land will decline.

Maskey (1978) conducted several field and laboratory studies using manure in which bio slurry was compared to dry slurry and the mineral fertilizer. In the amendment plan, it was also included use of 50 % of dry slurry plus mineral fertilizer. In the experiment, Wheat was taken as a reference crop. The mineral fertilizer amendment resulted highest yield followed by dry slurry and wet slurry. Biogas slurry (dry) yielded 2 % higher than control where as wet slurry yielded even 55.4 % higher than control.

Dhussa (1985) compiled the results of some of the experiments performed until the mid-eighties to study the effects on the discharge of biogas yield of rice, wheat, corn, cotton, cucumber, tomato, mong been and sunflower. The result is 15 and 16 % indicated that wheat and cotton yields, while corn and rice increased by 9 and 7 %. Another report states that did double cucumber than control, the application of biogas slurry at 15 tons ha^{-1}, the amount exceeds 15 tons ha^{-1} less cucumber yield. The same author stated that the application of manure at 10 tons ha^{-1} in combination of NPK on 45, 60 and 30 kg ha^{-1} respectively produced the best results and both N and P content of the soil increased after slurry application. The results indicated that wheat and cotton yields were increased by 15 % and 16 that the maize and rice increased by 9 and 7 %.

Yu *et al.* (2010) suggested that the application of biogas slurry can lead to nitrate accumulation reduction in fruit compared with fertilizer, the biological breakdown of organic matter in manure is a slow process that is better for nutrient uptake by the plant, and this organic matter may accelerate of the soil nitrification process that nitrate accumulation in soils and the further reduction of NO_3^- N uptake will decrease.

2.6.1.2 Effect of Compost Application on Crop and Soil Fertility Status

Compost is an aerobically decomposed organic material derived from plants and animal source. It is rich in nutrients, used in gardens, landscaping, horticulture and agricultural field crops (Martens, 2000). Compost is an alternative to inorganic fertilizers, which is cheaper than other sources of nutrients and relatively safe (Rindle, 1997). It enhances soil fertility, soil structure and water storage capacity for two or more years, unlike inorganic fertilizer (Fen taw, 2010).

Jagadeeswari and Kumaraswamy (2000) noted that use of composts with mineral fertilizer increased yield and production of wheat, green beans, gram and rice. Grain and straw yields of rice were significantly higher in amendments that received compost application with NPK than in no compost with NPK amendments, thereby highlighting the beneficial effects of compost to increase the crop yield.

Sarwar *et al.* (2007) conducted an experiment to assess possible impact on the cultivation of compost from different organic substrates such as plant residues, tree leaves, fruit and vegetable waste. Decomposition of organic matter was used in rice, wheat crop production in normal soil.

Compost was applied without and with fertilizer (Rice and wheat 100-70-70: 140-110-70 NPK kg ha^{-1}) to examine the likely effects of compost on crop yields. Grain yield and yield components (plant height, number of fertile tillers and 1000 GW) of rice and wheat increased significantly with the use of organic material in the form of compost, both at the level. Combining compost with fertilizer enhanced biomass and grain yield of both crops. This amendment was cost-effective over the other. On the basis of experimental results, a recommendation for farmers has been formulated that should compost plant residues for use in the soil on the growth of sustainable crop production. In this way you can improve soil fertility improvement in net productivity of land.

Zaller and Kopke (2007) studied the impact of using traditional composting manure (FYM) and two types of composted FYM bio dynamically over 9 yr^{-1} on soil chemical properties, microbial biomass and respiration, decomposition rates of grass and clover root production, activity and biomass of earthworms in the wheat, and gives the grass-clover, potatoes, winter wheat, field beans, spring wheat, winter rye crop marketing. Their results showed that plots which received prepared or not prepared FM (30 Mg ha^{-1} yr^{-1}) had significantly increased soil pH, P and K concentrations than plots without FYM application. Application of FM also affect the soil C / N ratio, root length density, the activity of sucrose, the basic microbial respiration, metabolic quotient and crop yields. Biodynamic preparation of FM with fermented residues of six plant species (6 g Mg^{-1} FM) significantly decreased soil microbial respiration and basic metabolism ratio compared to other prepared FM prepared with Achillea. Furthermore, the use of fully prepared FM led to significantly higher biomass and abundance of earthworms or anecic endogeic than plots where FYM prepared not been applied.

2.6.1.3 Advantage of Using Organic Fertilizer over Inorganic Fertilizers

Maintenance of high crop yield under intensive cultivation is possible only through the use of fertilizers. Inorganic fertilizers are usually rather expensive for the low income and small scale farmers. Organic manures such as cow dung, poultry manure, crop residues and biogas slurry in liquid and composted form can be used as an alternative for the inorganic fertilizer (Dong and Li, 2010). Nutrients contained in organic manures are released more slowly and are stored for a longer time in the soil, thereby ensuring a long residual effect, supporting better root development, leading to higher crop yields even better than the yield of inorganic fertilizer (Eadwards *et al*., 2007).

Soil fertility status is improved by activating the soil microbial biomass. To meet crops' nutrient supply, organic fertilizers are, however, required in rather large quantities but there is no adverse side effect of excessive application of organic manure to the soil since the excess of nutrients present in it becomes available for subsequent crops due to its residual effect. On the contrary, if inorganic fertilizers are applied in very large amount, it is detrimental to the soil condition, thereby affecting crop production. Besides, it will also have adverse indirect impact on food chain through land, water, and air pollution resulting from leaching, run off, and spraying respectively (Menale *et al.,* 2009). Application of organic manures sustains cropping systems through better nutrient recycling and plays a direct role in plant growth as a source of all necessary macro and micronutrients in available forms during mineralization, thereby improving both the physical and bio chemical properties of the soil (Menale *et al.,* 2009).

2.6.2 Application of Inorganic Fertilizers

Inorganic fertilizers are used in modern agricultural system to correct known plant nutrient deficiencies; to provide high levels of nutrition, to maintain optimum soil fertility conditions and to improve crop quality. The different types of inorganic fertilizers are usually classified according to the three principal elements namely N, P and K (Samuel *et al.,* 2000). Inorganic fertilizer usually comes in either granular or powder form in bags and boxes or in liquid formulations in bottles. In Ethiopia, farmers' uses only Urea and DAP. These two fertilizers were recommended since their nutrient content of Nitrogen and Phosphorus is high compared to other types of inorganic fertilizers (Takashi and Ayumi, 2010).

According to the report by Alemayehu (2008), about 10 % of the total land of Ethiopia is under crop cultivation but fertilizer is applied only on 40 % of the cultivated land and the rate of application is below the optimal dosage level (Eyasu, 2009). The blank recommendation for Ethiopia is 100kg of DAP and 50 kg urea ha^{-1} but farmers apply between 7 and 10 kg ha^{-1} annually (Eyasu, 2002).

2.6.3 Balanced Application of Organic and Inorganic Fertilizers

Plants absorb nutrients from soil for their growth and yield. The nutrients removed from the soils must be replenished through outer sources. Application of inorganic fertilizers alone is not sufficient for crops growth (Dong and Li, 2010).

Along with inorganic ones, organic fertilizers need to be applied to maintain the minimum soil organic matter level for the maintenance of physical, chemical and microbial properties of soil. Therefore, application of both chemical and organic fertilizer based on the needs of the crops being grown is quite essential for sustaining the soil fertility (Eyasu, 2002).

According to the available nutrients contained in the organic fertilizer, it needs to be applied in bulks compared to inorganic fertilizers. It should be noted that farmers can not solely depend upon organic fertilizer as it has to be applied in large amount (Anushiya, 2010).

On the other hand, there are improved variety of crops which are responsive to high inputs and as such desired yield cannot be achieved unless recommended dose of plant nutrients are supplied in the form of mineral fertilizers. Hence, there is a need to apply both organic and inorganic fertilizers in a balanced way to get expected output or the crop yield (Zebider, 2011).

2.7 Analytical Framework of the study

The analytical framework of the study was designed based on the literature reviewed on the evaluation of alternative soil amendments to improve soil fertility and response to bread wheat production in Ada'a district, central highlands of Ethiopia. The fertility status is much influenced by the types and levels of fertilizers applied, the physical and chemical properties of the soil. Soil fertility status and soil properties have a two way relation. The fertility status of the soil also affects the yield and yield components of bread wheat.

Types of fertilizers including organic fertilizers (dry matter bio slurry and compost) and inorganic fertilizers (Urea and DAP) as well as its level applied are the most influential factors for the improvement of soil fertility status of the study area.

Soil physical (texture and bulk density) and chemical properties (pH, Total N, available P, available K, organic C, CEC, exchangeable bases (Ca, Mg, Na & K) and percent of base saturation) are assumed to be the most important explanatory variables on the soil fertility status and in return, soil fertility status determines the physical and chemical properties of the soil.

Likewise, yield and yield components (plant height, spike length, spikelet spike^{-1}, numbers of tillers plant^{-1}, 1000 GW, total biomass yield, grain yield and harvest index) of bread wheat are powered by the soil fertility status of the study area (Figure 1).

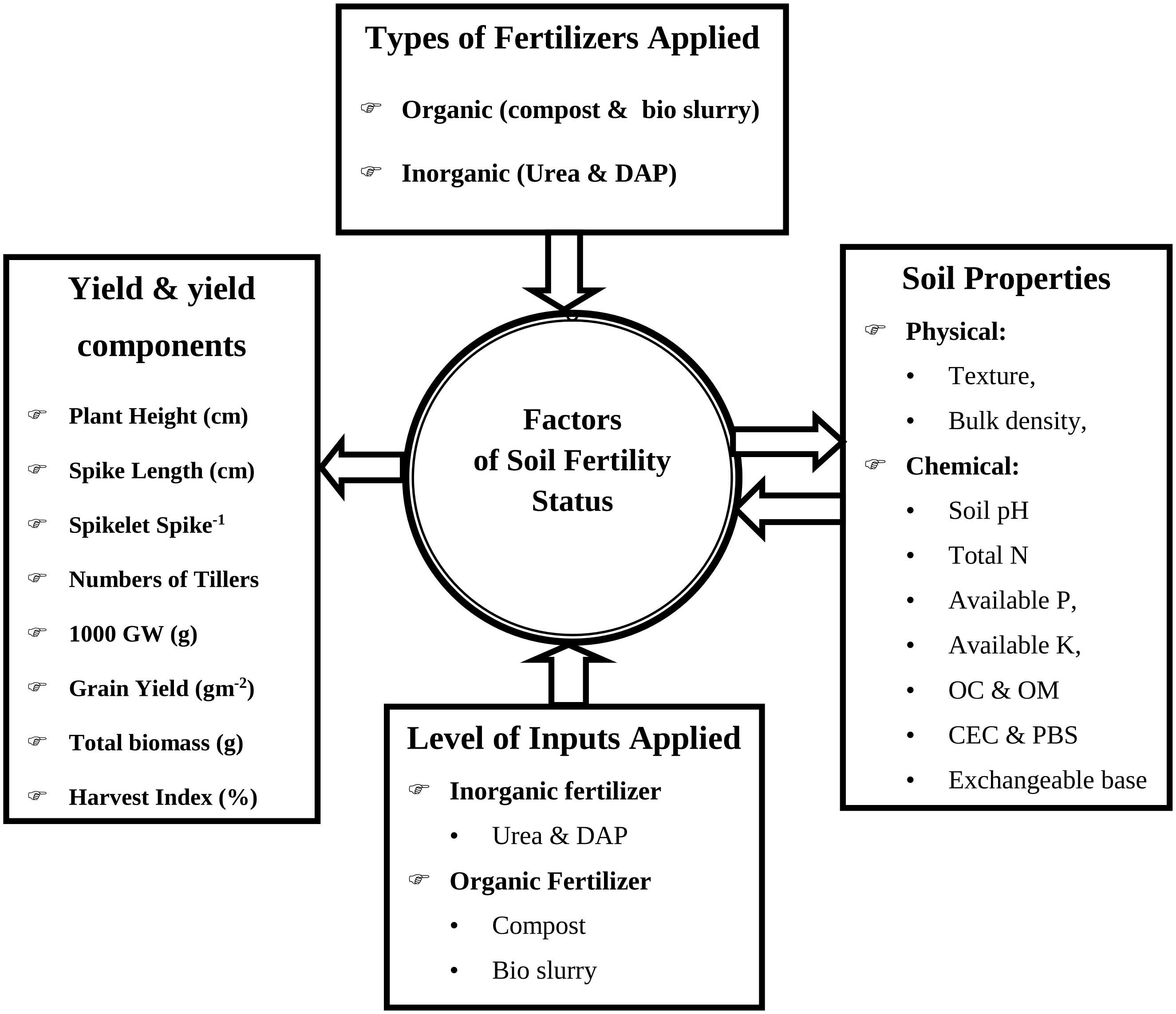


Figure 1. Analytical framework of the study; Author’s mental map, 2015

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Description of Experimental Site

3.1.1 Study Area

On farm experiment was conducted in the 2014 main cropping season on a vertisols of Ada'a district of central highlands of Ethiopia. Ada'a district is one of the 11 districts in East Shewa Zone of Oromia Regional State and is located at about 45 km South East of Addis Ababa. The total area of the district and *Ude* kebele is 89,430 ha and 2,448 ha respectively. Relatively, the district is bounded by Lume district in the East, Akaki Kality sub City in the West, Bora and Liben-Zukala district in the south and Ginbichu district in the North. Astronomically, the district is located at 8^0 32' 30"- 8^o 57' 30" North & 38^o 47' 30"- 39^o 12' 30" East (Figure 2).

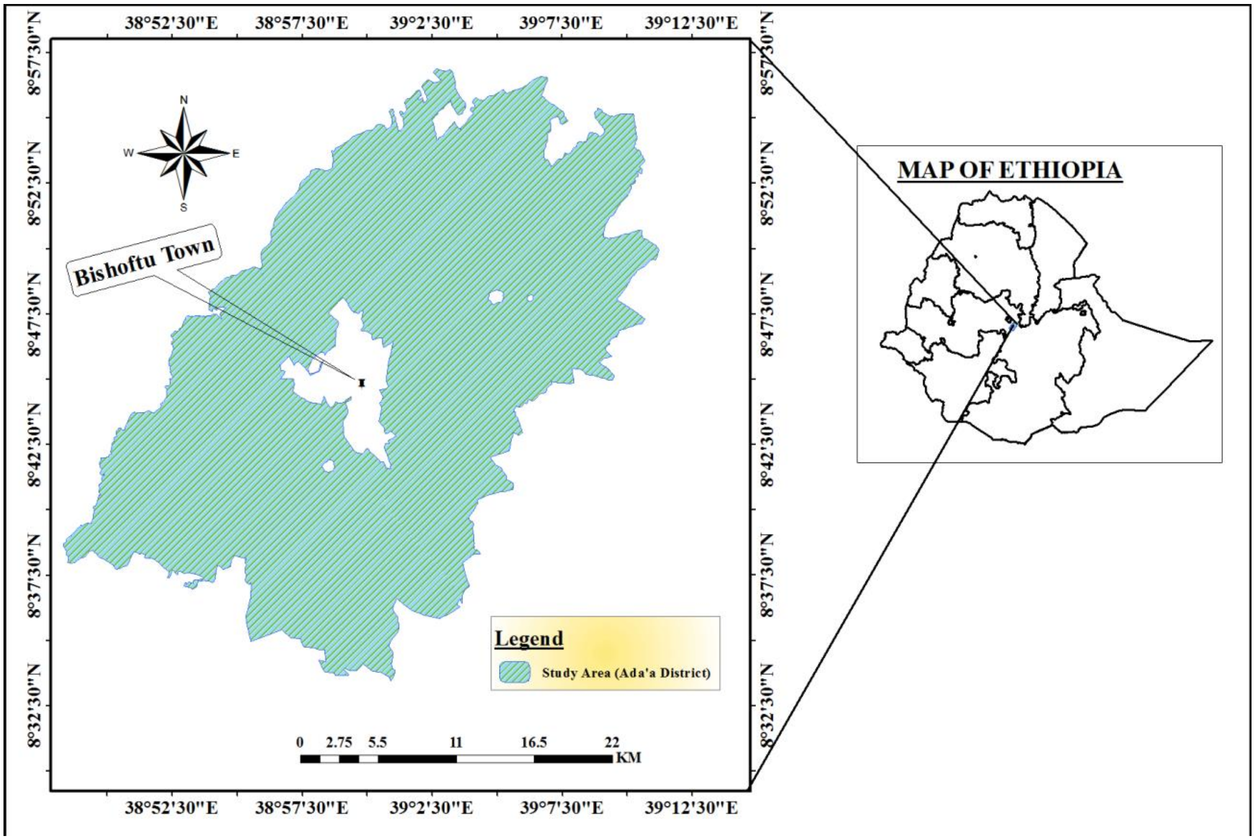


Figure 2. Location map of the study area; Author's skill map from Ethio GIS (2007), 2015

3.1.1.1 Relief

The relief of Ada’a district varies within an altitudinal ranges of 1780 to 2804 masl while the altitudinal variations of Ude kebele rages from 1908 to 2036 masl (Figure 3). The district is characterized by Dega and Weyena dega traditional agro climatic zonation which ranges from 1500 to 3200 masl (Ethio GIS, 2007).

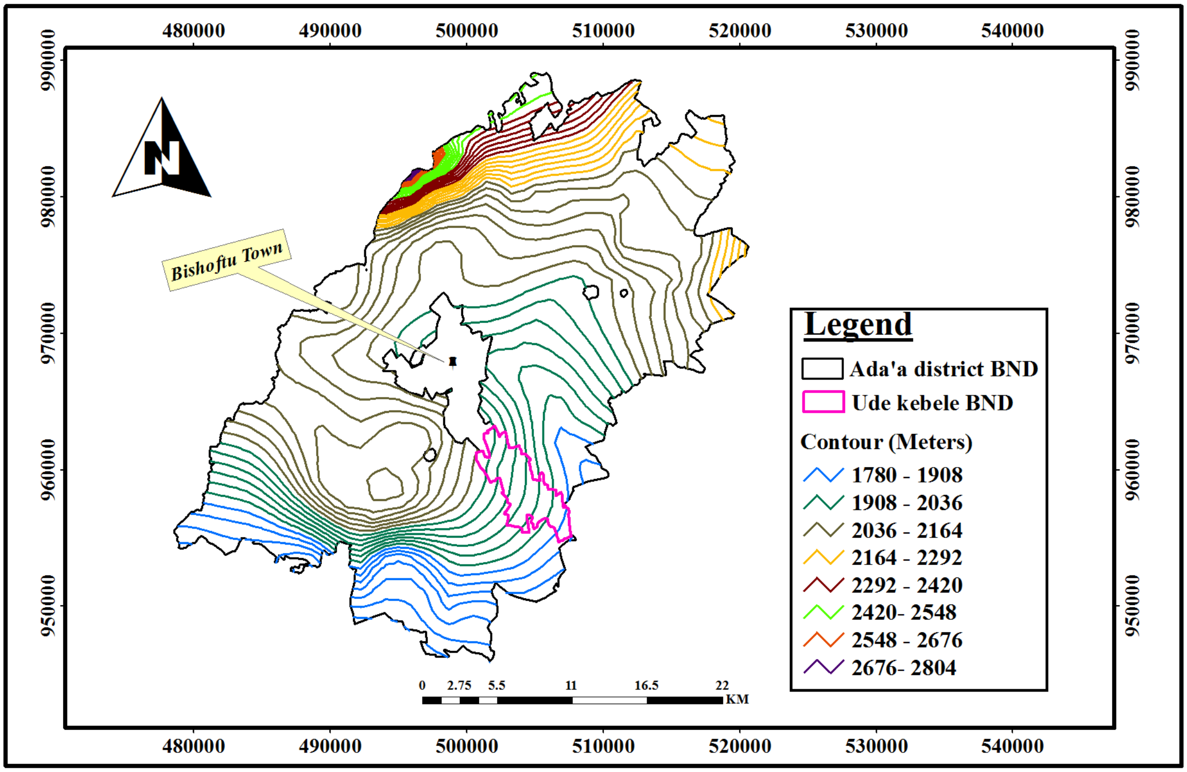
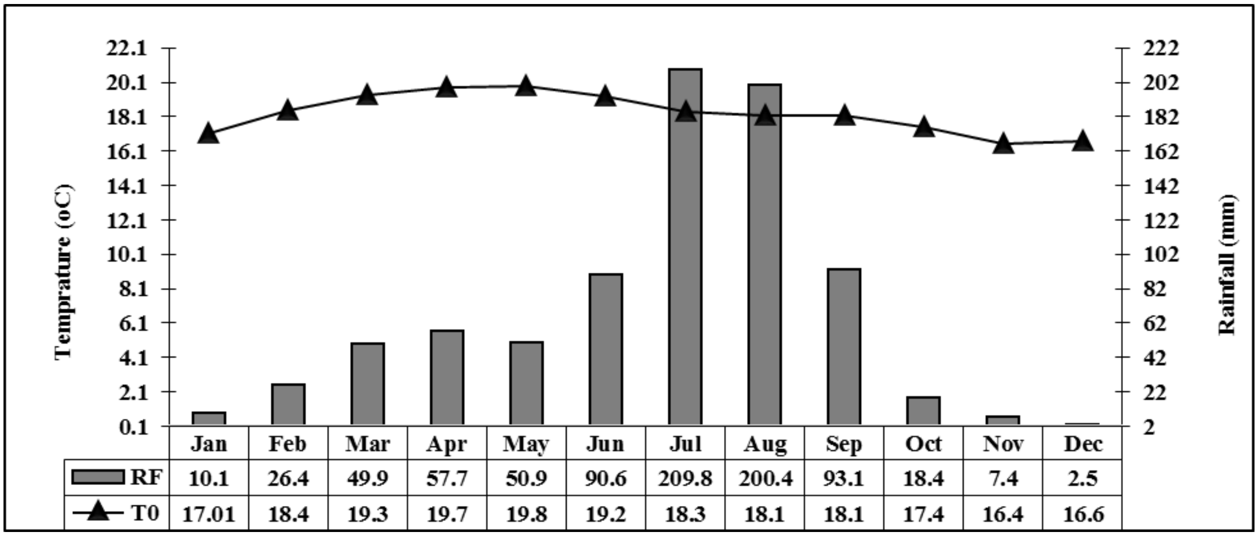


Figure 3. Relief map of the study area; Author’s skill map from Ethio GIS (2007), 2015

3.1.1.2 Rainfall and Temperature

Climatic data that witnessed over the last 50 years (1964-2014) of Ada’a district indicated that the study area has extended wet season from March to September with mean monthly rainfall varying from 2.5 to 209.8 mm with a total annual average of 818.3 mm. The mean annual temperature of the district ranges from 16.4 ^{0}C to 19.8 ^{0}C and the hottest months are April and May (DZMS) (Figure 4 and Appendix 1 and 2).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
▬ RF	10.1	26.4	49.9	57.7	50.9	90.6	209.8	200.4	93.1	18.4	7.4	2.5
─▲─ T0	17.01	18.4	19.3	19.7	19.8	19.2	18.3	18.1	18.1	17.4	16.4	16.6

Figure 4. Mean monthly rainfall (mm) and temperatures (°C) of the study area, DZMS, 2015

3.1.1.3 Land Use/Land Cover

The dominant Land use and Land cover (LU/LC) types of Ada'a district is cropland which covers 51% while degraded land, settlement/building, forest land, water body and pasture/grazing land account for 19.2%, 8.9%, 7.4%, 7.1% and 6.4% of the total area respectively (Ethio GIS, 2007; ADARDO, 2010; Bogale, 2014).

3.1.1.4 Agro Ecology Zonation

The district is divided into two Agro Ecological Zones (AEZs); Dega (moist) and Woyena Dega (moist and dry). Moist Dega accounts 49 ha (0.05%) and Moist Woyena Dega and dry Woyena Dega accounts 77,344 ha (86.5) and 12,037 ha (13.5%) of the total area respectively. Therefore, the study kebele *(Ude)* falls under Moist Woyena Dega Ecological Zone (Ethio GIS, 2007) (Figure 5).

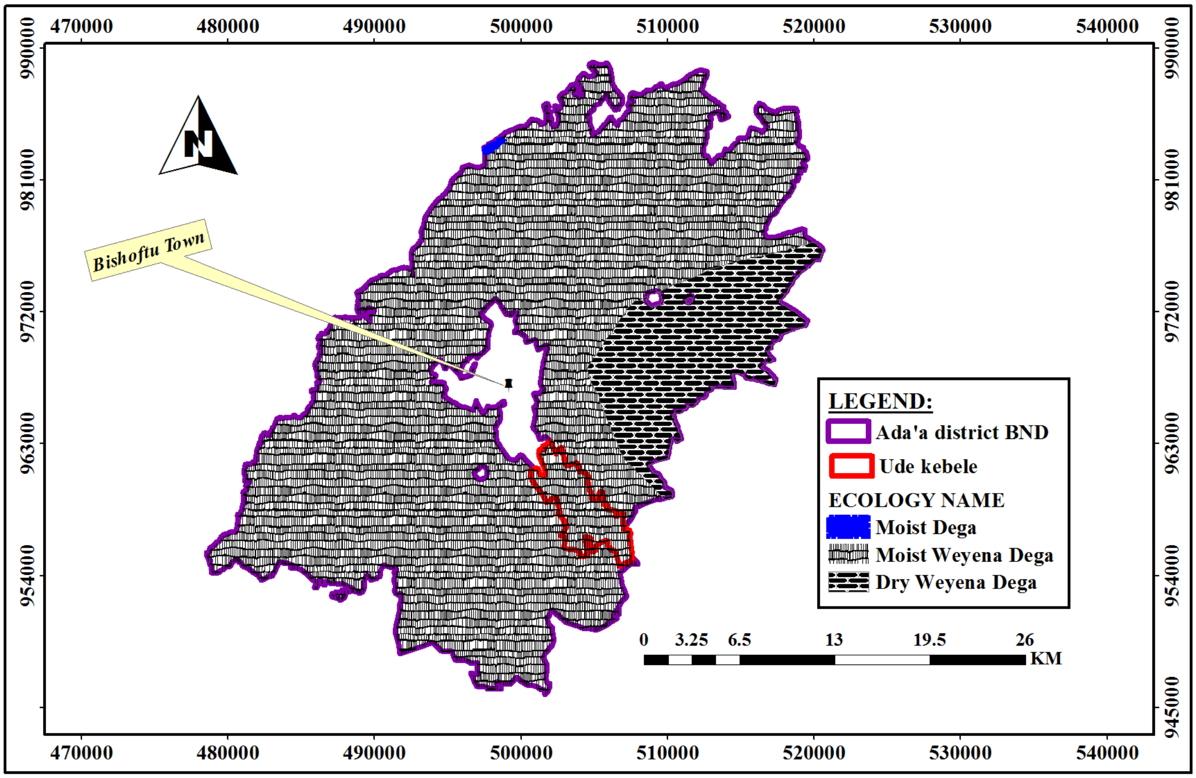


Figure 5. AEZs map of the study area; Author's skill map from Ethio GIS (2007), 2015

3.1.1.5 Soil types

Ada'a district has six soil units; Chromic Luvisols, Eutric Nitosols, Luvic Phaeozems, Orthic Solonchaks, Pellic Vertisols and Vertic Cambisols which accounts 12066 ha (13.5%), 1248 ha (1.4%), 1409.6 ha (1.6%), 358.6 ha (0.4%), 53373.8 ha (59.6%) and 20974 ha (23.5%) of the total area respectively. The dominant soil unit of the district is pellic vertisols which is followed by vertic cambisols and 100% of the soil type of the study kebele (Ude) is vertisols (Ethio GIS, 2007) (Figure 6). Texturally, the soils of the area are classified as sand silt (3%), clay (88%) and clay loam (9%) (Bogale, 2014).

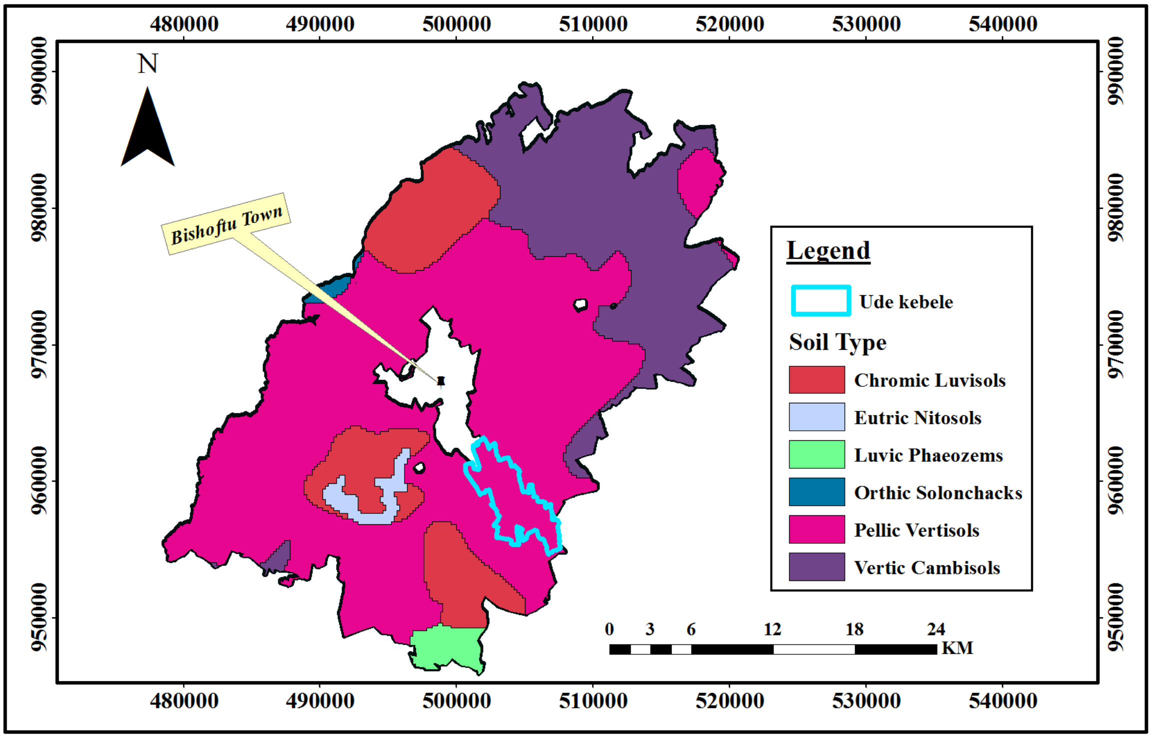


Figure 6. Soil map of the study area; Author's skill map from Ethio GIS (2007), 2015

3.1.1.6 Vegetation types

The land cover is dominated by scattered trees and shrubs which are found around settlements, farmlands, shrubs, trees and grasses in the enclosure areas. Important forests include the government protected Dirre-Garbicha, Tedecha and Ude community forests (Bogale, 2014). The vegetation in the area has been categorized under the Semi-humid woodland with a mixture of broad and narrow leaved species. The dominant climax vegetation types of the district are Juniprus forest, Juniperus woodland and Podocarpus forest (Ethio GIS, 2007).

3.1.1.7 Population

Total population of Ada'a district is 355,343 of these 175,788 are men and 179,555 are women and 142,866 or 40.2% of its population are urban dwellers which is greater than the Zone average of 32.1% (CSA, 2007).

3.1.1.8 Agricultural activities

Smallholder farmers manage crop and animal production in an integrated way, to maximize returns from their limited land and capital, minimize production risk, diversify sources of income, and provide food security and increase productivity (Assefa, 2005).

The agricultural activities carried out in the area include both crop production and animal husbandry, in which the latter plays a complementary role. The farming system in the area is therefore, denoted by close interdependence and integration of crop cultivation and animal husbandry (Bogale, 2014).

Crop Production System

In smallholders farming practices, Crop production systems involves the traditional '*Maresha*', plowing with a pair of oxen (Assefa, 2005). The agro-ecologies in the district is best suited for diverse agricultural production. There are a number of rivers and crater lakes that are being used for irrigated agriculture, particularly for horticultural crop production. Two cropping seasons are practiced in the study area where the Belg (short rainy season) extends from March to April and Meher (main rainy season) extends from June to September. The district is known for its best quality wheat production that dominates the agricultural production system which accounts (43%) next to *Tef* production (45%). Wheat is also cultivated in sizeable quantities in medium to high altitude areas of Ada'a district (ADARDO, 2010).

Livestock production system

Animal production system play a significant role in the mixed farming system of the study area.

The farm animals provide draught power for cropping, offspring to the household and fertilizer for crops and natural pasture lands in the form of manure. Dried animal manure is also used as fuel. Crop residues and grass are used as feed for livestock. Outputs from livestock, such as milk, meat and eggs are important sources of food for the farm household. Sales of animal products and live animals are important sources of cash and means of savings. External inputs to the livestock include purchased salt and veterinary services (Assefa, 2005). The total livestock population of the district is 375,914 which comprises cattle, goat, sheep, horse, mule, donkey and poultry which accounts 27027, 61375, 37135, 20116, 20025, 26222 and 184014 of the total livestock population respectively (ADARDO, 2010).

3.2 Sampling Design

3.2.1 Site Selection and Criteria

Ada'a is one of the district in Oromia Regional State of central highlands of Ethiopia where bread wheat is significantly produced. Criteria based purposive sampling technique was used to select *Ude* kebele from the rest of 23 kebeles of the district. Basically, the study area was selected based on the following criteria:

- The research is part of *Afri-flame* project of AU which works on the impacts of adapting small scale biogas digesters and soil fertility improvement on small holder's farming systems in Sub-Saharan Africa,
- The agronomic requirement of the tested crop variety (Kekeba Picaflor); altitude (1800-2200 masl) and rain fall (>500 mm) are within the altitudinal range of Ada'a district generally (1780-2804 masl) and Ude kebele specifically (1908-2036 masl (Figure 3)) and an average rainfall of 818.3 mm (Figure 4). Agro ecologically, the district is largely dominated by moist Woyne Dega and Ude Kebele is in this zone (Figure 5). Since the dominant soil type of the district is Pellic Vertisol, the study kebeble is also located in this soil type (Figure 6).
- The study area is ideal for Bread wheat production.

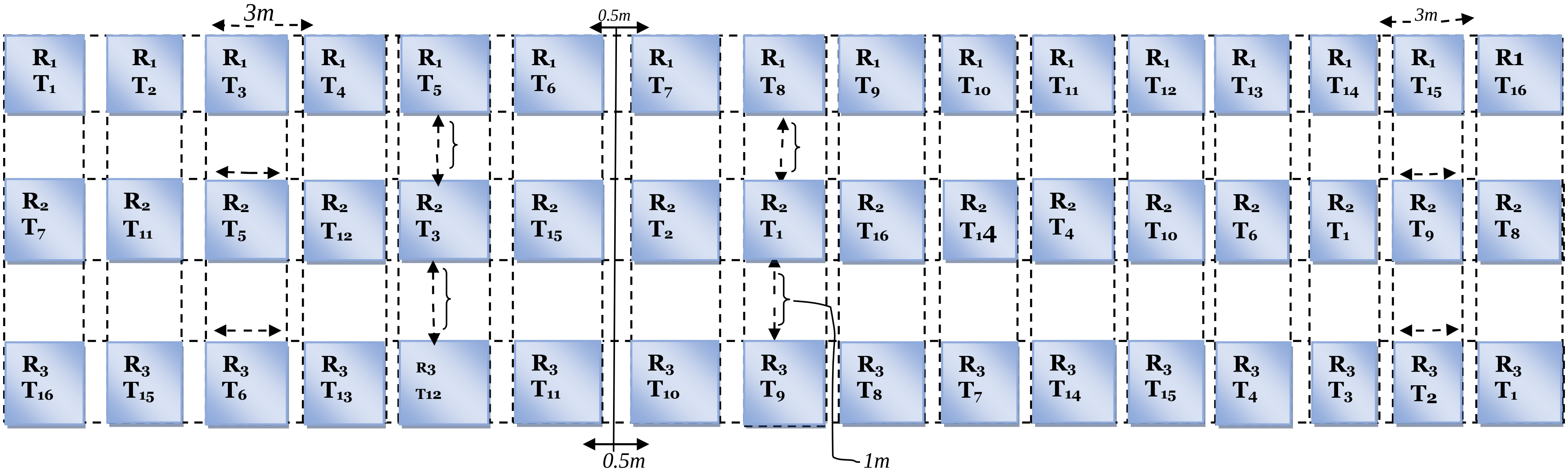
3.3 Types and Sources of Data

The types of data used in the study were both primary (collected from the experiment trials) and secondary data (baseline that was collected in 2014 (Bogal, 2014). The primary data included yields (crop and residues) and yield components of Bread wheat of trial plots, and samples' lab results of soil, bio-slurry, compost, yield and residue.

3.4 Field Experiment

3.4.1 Experimental Design and Field layout

The experiment was laid out in Randomized Complete Block Design (RCBD) having 3 replications. The net plot area measured 3.0 m x 3.0 m (9.0 m^2). Each replication (block) had 16 plots and the total numbers of plots were 48. Spacing between replication was 1.0 m with 0.5 m between plots. The experiment amendment comprised 6 amendments, viz (1) bio slurry, (2) compost, (3) inorganic fertilizer, (4) bio slurry + inorganic fertilizer, (5) compost + inorganic fertilizer and (6) control. The amendment combinations and the field layout are shown in Figure 7.



R_1 T_1	R_1 T_2	R_1 T_3	R_1 T_4	R_1 T_5	R_1 T_6	R_1 T_7	R_1 T_8	R_1 T_9	R_1 T_{10}	R_1 T_{11}	R_1 T_{12}	R_1 T_{13}	R_1 T_{14}	R_1 T_{15}	R1 T_{16}
R_2 T_7	R_2 T_{11}	R_2 T_5	R_2 T_{12}	R_2 T_3	R_2 T_{15}	R_2 T_2	R_2 T_1	R_2 T_{16}	R_2 T_{14}	R_2 T_4	R_2 T_{10}	R_2 T_6	R_2 T_1	R_2 T_9	R_2 T_8
R_3 T_{16}	R_3 T_{15}	R_3 T_6	R_3 T_{13}	R3 T12	R_3 T_{11}	R_3 T_{10}	R_3 T_9	R_3 T_8	R_3 T_7	R_3 T_{14}	R_3 T_{15}	R_3 T_4	R_3 T_3	R_3 T_2	R_3 T_1

T1-T3= Bio slurry; T4-T6= Compost; T7-T9= inorganic Fertilizer; T10-T12= Bio slurry + Inorganic Fertilizer; T13-T15= Compost + Inorganic Fertilizer; T16= Control

Figure 7. Amendment combinations and field layout

3.4.2 Amendments

Fertility amendment played an important role in improving the soil fertility status and bread wheat production of the study area. There were five different amendments: (i) bio-slurry, (ii) compost, (iii) inorganic fertilizer (Urea and DAP), (iv) combination of bio-slurry and inorganic fertilizer, and (v) combination of compost and inorganic fertilizer and one control factor (Figure 8). Application rates for each of the five amendments were at three treatments:

(i) Bio slurry with three treatments (32 kg N and 23 kg P ha^{-1}, 64 kg N and 46 kg P ha^{-1}, 96 kg N and 69 kg P ha^{-1}).

(ii) Compost with three treatments (32 kg N and 23 kg P ha^{-1}, 64 kg N and 46 kg P ha^{-1}, 96 kg N and 69 kg P ha^{-1}).

(iii) Urea & DAP fertilizers with three treatments (32 kg N and 23 kg P ha^{-1}, 64 kg N and 46 kg P ha^{-1}, 96 kg N ha^{-1} and 69 kg P ha^{-1}).

(iv) Combination of bio-slurry and inorganic fertilizer, with three treatments (4900 kg ha^{-1} + 32 kg N & 23 kg P ha^{-1}, 7350 kg ha^{-1} + 145 kg N & 82.5 kg P ha^{-1}, 9800 kg ha^{-1} + 93 kg N & 46 kg P ha^{-1}).

(v) Combination of compost and inorganic fertilizer, with three treatments (4600 kg ha^{-1} + 48.6 kg N & 23 kg P ha^{-1}, 6900 kg ha^{-1} + 73 kg N & 34.5 kg P ha^{-1} and 9200 kg ha^{-1} + 98.5 kg N & 46 kg P ha^{-1}).

Thus, in these approach 15 treatments and one-control trials; each with three replicates (a total of 16 treatments x 3 replicate = 48 trial plot) has been used (Table 1).

Figure 8. Field experiments showing one among the three replication of each treatment

Table 1. Amendments and their rates of application

Treatments	Replicates	Rate of application
T_1	3	9800 kg ha^{-1} dry matter bio Slurry[1] (64 N & 46 P kg ha^{-1})
T_2	3	4900 kg ha^{-1} dry matter bio Slurry (32 N & 23 P kg ha^{-1})
T_3	3	14300 kg ha^{-1} dry matter bio Slurry (96 N & 69 P kg ha^{-1})
T_4	3	9200 kg ha^{-1} dry matter compost[2] (64 N & 46 P kg ha^{-1})
T_5	3	4600 kg ha^{-1} dry matter compost (32 N & 23 P kg ha^{-1})
T_6	3	13800 kg ha^{-1} dry matter compost (96 N & 69 P kg ha^{-1})
T_7	3	100 kg Urea and 100 kg DAP fertilizer (64 N & 46 P kg ha^{-1})
T_8	3	50 kg Urea & 50 Kg DAP fertilizer (32 N & 23 P kg ha^{-1})
T_9	3	150 kg Urea & 150 kg DAP fertilizer (96 N & 69 P kg ha^{-1})
T_{10}	3	4900 kg^{-1} dry matter bio slurry (32 N & 23 P kg ha^{-1}) + inorganic fertilizer (32 N & 23 P kg ha^{-1})
T_{11}	3	7350 kg ha^{-1} dry matter bio slurry (48 N & 34.5 P kg ha^{-1}) + inorganic fertilizer (145 N & 82.5 P kg ha^{-1})
T_{12}	3	9800 kg ha^{-1} dry matter bio slurry (63.7 N & 46 P kg ha^{-1}) + inorganic fertilizer (93 N & 46 P kg ha^{-1})
T_{13}	3	4600 kg ha^{-1} dry matter compost (32 N & 23 P kg ha^{-1}) + inorganic fertilizer (48.6 N & 23 P kg ha^{-1})
T_{14}	3	6900 kg ha^{-1} dry matter compost (34.5 N & 34.5 P kg ha^{-1}) + inorganic fertilizer (73 N & 34.5 P kg ha^{-1})
T_{15}	3	9200 kg ha^{-1} dry matter compost (64.4 N & 46 P kg ha^{-1}) + inorganic fertilizer (98.5 N & 46 P kg ha^{-1})
T_{16}	3	0 kg ha^{-1} (Control)

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[1] *Dry matter bio-slurry with 0.0065 and 0.0047, N & P-contents respectively.*

[2] *Dry matter compost with 0.0070 and 0.0050, N & P-contents respectively.*

3.4.3 Land Preparation, Sowing and Harvesting

The experimental field was prepared by using local plough called *Maresha*. Accordingly, the field was plowed four times; the 1st ploughing was done at the beginning of May, the 2nd plowing was at the middle of May, the 3rd ploughing was at the middle of June and the final was accompanied on 23 July 2014 and amendment was conducted within the same date. Harvesting was undertaken on 12 November 2014 and finally threshing time was on 26 November 2014.

The seed was bought from the surrounding smallholder farmers of Ada'a district. The tested variety used in the study was improved bread wheat variety (Kekeba Pica flora released in 2010 by EARI); widely grown by smallholder's farmers of the study area. A wheat seed was drilled in rows in each plot uniformly. The sowing rate of the wheat was 100 kg ha^{-1} and inorganic fertilizers with three levels (50 kg urea & 50 kg DAP, 100 kg urea & 100 kg DAP and 150 kg urea & 150 kg DAP) was applied at the time of sowing.

Dry matter bio slurry was obtained through the outlet of biogas digesters of cattle dung which was already installed in Kumbursa village of Ada'a district. Fine grained compost was obtained from the surrounding farmers who prepared it for their own use and commercial purposes. Then, both bio slurry and compost were weighed according to the treatment plan and applied before five days sowing of wheat seed (Table 1 and Figure 9).

Figure 9. Application of compost (left) and bio slurry (right) before five days sowing of wheat seed

3.5 Data Collection

3.5.1 Soil Sampling

To assess the fertility status of the soil, Surface (0-20 cm depth) soil samples were collected at different points from each block before treatment. Similarly, surface soil samples of the same depth were collected just after harvest from each amendment by taking samples from three points of each 48 plots. The soil samples were bagged, properly labeled and transported to the laboratory for preparation and analysis following standard laboratory analysis methods.

Thus, soil physical properties (texture and bulk density) and chemical properties (pH, available phosphorous, available potassium, organic carbon, total nitrogen, cation exchanging capacity and exchangeable bases were taken, tested and analyzed before and after amendment of wheat in order to carry out proper soil analysis and interpretation.

3.5.2 Soil Laboratory Analysis

The soil samples were analyzed for selected parameters relevant to the study at the soil and plant analytical service laboratory of the National Soil Testing Center and Debire Zeit Agricultural Research Center. Standard laboratory procedures were followed in the analysis of the selected physical and chemical properties considered in the study.

3.5.2.1 Analysis of Soil Physical Properties

Hydrometer method (Gee and Bauder, 1979) was applied to determine soil texture distribution (clay, silt and sand) of the study area. Soil textural class names were assigned based on the relative contents of the percent sand, silt, and clay separates using the soil textural triangle of the USDA. Soil bulk density was determined from undisturbed (core) samples which was dried at 105 ^{0}C for 24 hours (Baruah and Barthaku, 1997).

3.5.2.2 Analysis of Soil chemical Properties

Soil pH was measured potentiometrically using a digital pH meter in a 1:2.5 soil water suspension (Van Reeuwijk, 1992). Soil organic carbon was determined by wet digestion method and following the assumptions that soil organic matter is composed of 58% carbon, the conversion factor, 1.724 was used to convert the organic carbon in to organic matter (Walkley and Black, 1934). Determination of total N of the soil was carried out through Kjeldahl digestion, distillation and titration procedures of the wet digestion method (Black, 1965).

Available phosphorus was determined colorimetrically using Olsen's method (Olsen, 1952). Exchangeable bases were extracted with 1M buffered ammonium acetate extractant; K and Na was then measured using flame photometer and Ca and Mg were measured using absorption spectrophotometer. The CEC was determined by 1M buffered ammonium acetate extraction method and distillation of the ammonium saturated soil in a kjeldahl distillation apparatus while receiving the distillate in boric acid and then titrating with sulfuric acid. The percent base saturations of the soil samples were calculated as the percentage of the sum of the basic exchangeable cations (Ca, Mg, K and Na) to the CEC.

3.6 Agronomic Data Collection

To identify the productivity of the study area, yield and yield components of bread wheat were collected from each plot using the following procedures:

1. **Plant height (PH):** For the experiment on wheat, plant height was measured at maturity stage, from ten random plant samples of the harvestable rows, from the ground level to the tip of the spike including the awns using a measuring tape.
2. **Spike length (SL):** Spike length was measured by calculating the average spike length of ten random plant samples in the harvestable rows, following the measurement from its base to the tip excluding awns.
3. **Number of spikelet's per spike (NSPS):** The number of spikelet in each spike of the ten randomly selected plants of each plots was counted at the crop maturity and average was calculated.
4. **Number of tillers per plant (NTPP)**: Total tillers for randomly selected plants were counted at the time of maturity and averaged plant^{-1} was calculated.
5. **Thousand Grain Weight (TGW):** Grain weight of thousand seeds sampled at random from total grain harvest of the experimental plot was recorded on analytical balance expressed in gram/kg.
6. **Total Biomass yield (TBY) (kg ha^{-1}):** Biomass or biological yield was measured by weighing the total above ground plant biomass within each central rows of 1m^{2}.
7. **Grain yield (kg ha^{-1}):** All the grain received from each plot was weighed and on the basis of grain yield plot^{-1}, grain yield ha^{-1} was calculated in kilograms as per the following formula:

$$\frac{\textbf{Grain yield plot (kg)}}{\textbf{Plot size (m}^2\textbf{)}} * 10{,}000$$

8. **Harvest Index (HI):** was calculated by dividing the weight of dry grain yield by the total dry biomass weight (TBY) (TBY = weight of harvested grain and residue) ;

$$\mathbf{HI} = \frac{\mathbf{GY}}{\mathbf{TBY}} * 100$$

3.7 Statistical Analysis

Data on the soil sampling and wheat productivity were subjected to analysis of variance (ANOVA) using Statistical Package for Social Science (SPSS Version-20) to evaluate the impact of soil fertility amendment options and response to bread wheat production of the study area. Results were presented as means with Least Significance Difference (LSD) at 5% probability level (Steel *et al*, 1997). Pearson's simple linear correlation coefficient values were computed to examine the magnitude and direction of relationships among agronomic genotypes using the mean values.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

On-farm experiment was carried out during 2014 main cropping season to evaluate the impact of alternative soil amendments to improve soil fertility and response to bread wheat production in vertisols of Ada'a district, central highlands of Ethiopia. Soil and crop samples were collected from the trial plots and analyzed in the soil and plant analytical laboratory of National Soil Testing Center and Debire Zeit Agricultural Research Center. Both soil and plant data were subjected to statistical analysis (ANOVA) and the results obtained were presented and discussed in the following sections.

4.1 Characterization of the Soil of the study area

Soil analytical data is important to identify the level of nutrients in the soil and to determine suitable rates and types of fertilizers for recommendation.

4.1.1 Pre- treatment soil characteristics

The soil of the study area was initially characterized in order to assess its fertility status before the establishment of the cropping systems and application of amendment options. The baseline data was then used for measuring changes after application of different soil fertility amendments.

The analyzed soil characteristics included soil particle size distribution (texture), Bulk density, soil pH, soil organic C, total N, available P, available K, CEC, Percentage of base saturation and exchangeable bases (Ca, Mg, Na and K) which were determined from the composite surface (0-20 cm) soil samples collected from the experimental plots before integrated soil fertility amendment options were presented in Table 2.

4.1.1.1 Soil texture

The results revealed that the surface soil of the field before integrated soil fertility amendment options is clayey in texture. As indicated in Table 2, the clay content varied from 62.0 to 64.0 % (with the mean value of 63 %). The sand fraction ranged from 10.0 to 12.0 % (with a mean of 11.2 %) while the silt fraction varied from 25 to 26% (with the mean value of 25.8 %).

The silt to clay ratio of the soil of the study area before treatment was 0.41. This ratio is one of the indices used to assess the rate of weathering and determine the relative stage of development of a given soil. According to Young (1976), a ratio of silt to clay <0.15 is considered as low and indicative of an advanced stage of weathering and/or soil development while >0.15 indicates that the soil is young contains easily weatherable minerals. Hence, the soil of the study area is young that contain easily weatherable minerals.

4.1.1.2 Bulk density

The bulk density of the field soil before treatments varied from 1.47 to 1.49 g/cm^3 (with the mean value of 1.48 g/cm^3). According to the rate established by Landon (1991), this range falls within the category of dense to very dense status (Appendix 12).

4.1.1.3 Soil reaction (pH)

The average pH of the field soil before treatment was 6.76 (ranging from 6.6 to 6.9) qualifies for the neutral soil reaction class (pH 6.6-7.0) set by Foth and Ellis (1997) while working with Ethiopian soils. According to the rate established by Landon (1991), the soil reaction of the study ranges from slightly acidic to neutral (Appendix 11)

4.1.1.4 Soil organic Carbon

The soil organic carbon content of the field before the application of treatment ranged from 1.2 to 1.4 % (with the mean of 1.3 %). Therefore, according to Landon (1991) the soil organic carbon content of the soil of the trial plots could be classified as very low (Appendix 13). Similarly (Bogale, 2014) also reported that the soil organic carbon status of the study area was within the range of very low.

4.1.1.5 Total Nitrogen

The total N contents of the soil varied from 0.09 % to 0.12 % (with mean value of 0.01 %) as presented in Table 2. Similar findings by Bogale (2014) indicated that the study area has total nitrogen within the range of low. Thus, the soil of the trial plots before amendment falls under the low N fertility class of Landon (1991) and Tekalign *et al.* (1991) (Appendix 14).

4.1.1.6 Carbon to Nitrogen ratios

The carbon to nitrogen (C: N) ratios were 11.1 to 14.3 observed in the soil of the trial plots before amendment. Thus, the C/N ratio of the trial plots falls under medium rate (Landon, 1991) (Appendix 13) and it is within the optimum range for arable lands which ranges from 8:1 to 15:1 and usually between 10:1 and 12:1 as indicated by Rowell (1994).

4.1.1.7 Available Phosphorus and Potassium

The soil of the trial plots contained available P ranging from 41.71 mg kg^{-1} to 42 mg kg^{-1} (with the mean value of 41.83 mg kg^{-1}). Thus, the available P of the trial plots before amendment falls under high range (Landon, 1991 and Olsen *et al,* 1954) (Appendix 14).

Regarding to available K of the field, the numerical value varied from 3.0 to 3.1 mg kg^{-1} with mean of 3.1 mg kg^{-1}. Thus, the available potassium of the trial plots falls under high soil fertility. Bogale (2014) also reported that Soil fertility analysis of the trial plots showed shat K is very high.

4.1.1.8 Cation Exchange Capacity and Percent Base Saturation (PBS)

According to the rating suggested by Landon (1991) and FAO (2006), the CEC values of the soil fall under the high rate. As indicated in Table 2, the CEC value ranged from 35.7 cmol (+) kg^{-1} to 36.9 cmol (+) kg^{-1} with the mean value of 36.44 cmol (+) kg^{-1}. Thus, the CEC of the trial plots falls within high classification rate of both Landon (1991) and FAO (2006) (Appendix 15).

The percentage of base saturation (%BS) which is computed by summing exchangeable bases and divided by CEC ratio and thus, the Percentage of base saturation of the trial plots ranged from 85 % to 89 % with the mean value of 87 %. According to the rating (Appendix 15), the percent of base saturation of the trial plots before the application of soil fertility amendment falls under very high rate of classification rate and it indicates that the soil is suitable for most crops.

4.1.1.9 Basic Exchangeable Cations

Exchangeable Ca followed by Mg was the predominant cation in the exchange site (Table 2). The mean exchangeable Ca and Mg contents of the experimental plots before the application of soil fertility amendments or treatments were 19.42 and 11.62 cmol (+) kg^{-1} while that of exchangeable Na and K were 0.32 and 0.36 cmol (+) kg^{-1}, respectively. According to rate established by FAO (2006), exchangeable Ca of the trial plots falls under high classification rate and Mg falls under very high rates while both Na and K fall under medium rates (Appendix 15).

As indicated in Table 2, the proportions of the cations of the trial plots were in the order of Ca > Mg > K > Na. This might be related to the parent material from which the soils have been developed i.e. basalt rock and their differential attraction to the soils' exchange complex which is approximately in that order. Generally, exchangeable Na and K contributed very small proportion to the CEC (Table 2).

Table 2. Selected Physic-chemical properties of soils samples before amendment in Ada’a district, central highlands of Ethiopia

Selected soil Properties	**Unit**	**Trial samples**					**X^{-}**	**S**	**CV***
		1	**2**	**3**	**4**	**5**			
Depth	cm	0-20	0-20	0-20	0-20	0-20	0-20		
Particle size	%								
Clay		63	62	63	63	64	63	0.71	1.12
Silt		26	26	26	25	26	25.8	0.45	1.73
Sand		11	12	11	12	10	11.2	0.84	7.47
Textural class		clay	clay	clay	clay	clay	clay		
Bulk Density	g/cm^{3}	1.48	1.47	1.49	1.47	1.49	1.48	0.01	0.68
Total N	%	0.09	0.12	0.11	0.11	0.12	0.11	0.01	11.13
Available P	mg kg^{-1}	42	41.9	41.71	41.8	41.72	41.83	0.12	0.30
Available K	mg kg^{-1}	3.0	3.1	3.1	3.1	3.1	3.1	0.1	1.9
Organic Carbon	%	1.3	1.4	1.3	1.2	1.4	1.3	0.1	5.8
Carbon to Nitrogen ratio		14.3	11.8	12.2	11.1	11.4	12.2	1.3	10.5
Soil pH	H_2O	6.9	6.8	6.8	6.7	6.6	6.76	0.11	1.69
CEC	cmol (+)/kg soil	35.7	36.3	36.9	36.5	36.8	36.44	0.48	1.31
Exchangeable Bases	cmol (+)/kg soil								
Ca^{+2}		19.62	19.66	19.26	19.43	19.13	19.42	0.23	1.17
Mg^{+2}		11.44	11.60	11.53	11.82	11.71	11.62	0.15	1.28
Na^{+}		0.31	0.32	0.32	0.31	0.32	0.32	0.01	1.73
K^{+}		0.26	0.38	0.39	0.40	0.38	0.36	0.06	15.92
Percent Base Saturation	%	89	88	85	88	86	87	1.44	1.65

X^{-} : Mean; S: Standard Deviation; CV*: coefficient of Variance expressed in percentage;

4.1.2 Response of soil properties to applied soil fertility amendments

Efficient use of nitrogen and P fertilizers plays major role in successful soil fertility management and crop production. Similarly, bio-fertilizers like bio slurry and compost contain live or latent cells of efficient strains of nitrogen fixing, phosphate solubilizing or cellulolytic micro-organisms used for application to seed, soil or composting areas with the objective of increasing number of such micro-organisms and accelerate those microbial processes which augment the availability of nutrients that can be easily assimilated by plant tissues.

The analysis of soil is an important parameters to identify the level of nutrients in the soil and other parameters to determine suitable rates and types of fertilizer for recommendation.

4.1.2.1 Physical soil properties

Soil texture

Particle size distribution has an important bearing in soil water movement, aeration, root extension, oxidation-reduction processes, nutrient and organic matter contents as well as composition. The variation in sand, silt and clay fractions were affected by soil amendment inputs applied. Sand, silt and clay value were not statistically significant ($P<0.05$) among the applied soil fertility amendment options. The laboratory analysis results, as presented in Figure 10 and Appendix 3, indicated that the particle size distribution at the depth of 0-20 cm of the experimental field was dominated by clay fraction (60%). The mean clay contents of the trial plots ranged between 61.6 and 64 %. The lowest clay percentage was 61.6 % that gained from the sole application of inorganic fertilizers in T9, which coincides with the marginal range of total clay requirement for Vertisols. The highest clay percentage was observed in the application of dry matter compost in T5, which is 64 % (Figure 10 and Appendix 3). The result is similar with the work of Berhanu (1985); reported that vertisols in Ethiopia generally contain more than 60 % clay content in the surface layer (0-20 cm depth).

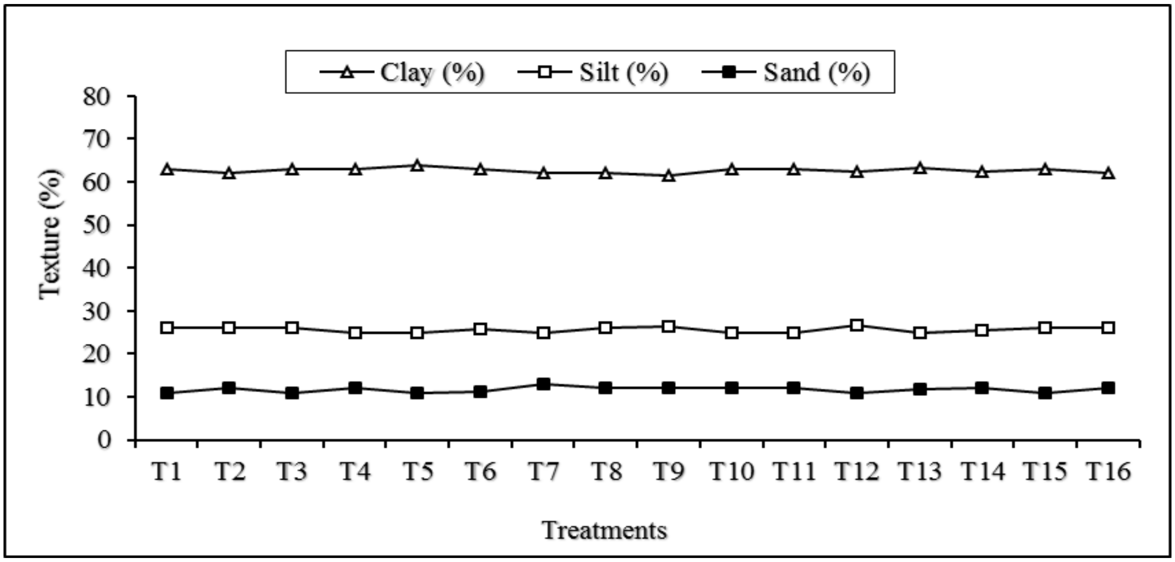

Figure 10. Effects of amendments on the soil textural distribution

Bulk Density

Bulk density sample was taken from each plot (Appendix 9) and value was not statistically significantly ($p<0.05$) in all applied soil fertility amendment options. All treatments containing dry matter bio slurry caused an increase bulk density ranging from 1.44 to 1.46 g/cm^3. The highest numerical value of bulk density (1.46 g/cm^3) was observed on the application of dry matter bio slurry at the rate of 32 N & 23 kg P ha^{-1} in T2 and the lowest value of bulk density (1.44 g/cm^3) was appeared at the rate of 96-69 kg ha^{-1} Nitrogen and P in T3. Thus, in the application of dry matter bio slurry, using the minimum rate as presented in Table 1 (32 N & 23 kg P ha^{-1}) results the highest value of bulk density (Figure 11 and Appendix 3) while in the application of dry matter compost, the highest value (1.42 g/cm^3) was recorded from 32 N & 23 P kg ha^{-1} dry matter compost in T5 and the lowes value of bulk density (1.4 g/cm^3) was apeared in the application rate of 96 N & 69 kg P ha^{-1} in T6. Thus, for smallhoders' farmers who are using compost as means of soil fertility improvement, adapting the maximum rate of dry matter compost is advisable. With the application of inorganic fertilizer, the highest bulk density (1.49 g/cm^3) was obtained from 96 N & 69 P kg ha^{-1} in T9 while the lowest (1.47 g/cm^3) was obtained from the application of 32 N & 23 kg P ha^{-1} in T8.

In the combined application of dry matter bio slurry along with inorganic fertilizers, the highest (1.46 g/cm^3) was appeared at the rate of 63.7 N & 46 kg P ha^{-1} bio slurry plus inorganic fertilizer at the rate of 93 N & 46 kg P ha^{-1} in T12 while the lowest (1.45 g/cm^3) was obtained under 48 N & 34.5 kg P ha$^{-1)}$ plus inorganic fertilizer at the rate of 145 N & 82.5 kg P ha^{-1} in T11. Hence, for those smallholders' farmers in the study area, using combined application of bio slurry which stated in T11 is advisable while in the combined application of dry matter compost along with inorganic fertilizers, the highest and the lowest values of bulk density was 1.42 and 1.44 g/cm^3 that appeared in T15 and T13 respectively.

Across all the applied soil fertility amendments, the highest bulk density was obtained from the application of inorganic fertilizer that ranged from 1.4 to 1.49 g/cm^3 as compared with other soil fertility amendment options that stated in Table 1. Generally, the bulk density of the trial plots lies between 1.4 to 1.49 g/cm^3 with the mean value of 1.45 g/cm^3 which is statistically in significant ($P<0.05$) among the applied soil fertility amendment options. However, numerically the highest mean (1.49 g/cm^3) value of bulk density was recorded on the application of inorganic fertilizer in T9 while the lowest mean (1.4 g/cm^3) value was recorded under the application of compost in T6 (Figure 11 and Appendix 3). Thus, from these discussion, application of dry matter compost makes the soil more lighter than else which in turn leads good aeration system in the soil, better pore space that allows microorganism to move easily and like. According to the rating suggested by Landon (1991), the bulk density qualifies from dense to very dense. However, the bulk density of the soil after treatment is slightly lower than the bulk density that appears before treatment. The reason is that, application of soil amendment options except inorganic fertilizer makes the soil more lighter, high aeration, higher pore space (Muhammad, 2011) while compaction resulting from intensively cropping before amendment and the very nature of vertisols might have caused the relatively higher bulk density values of the study area.

As observed from figure 11 and Appendix 3, application of dry matter compost make the bulk density lower than else. The ranges of bulk density values observed in this study were within the ranges expected in most mineral soils as indicated by Hillel (1980). Thus, the bulk density of the study area qualifies dense to very dense (Landon, 1991) as indicated in Appendix 12.

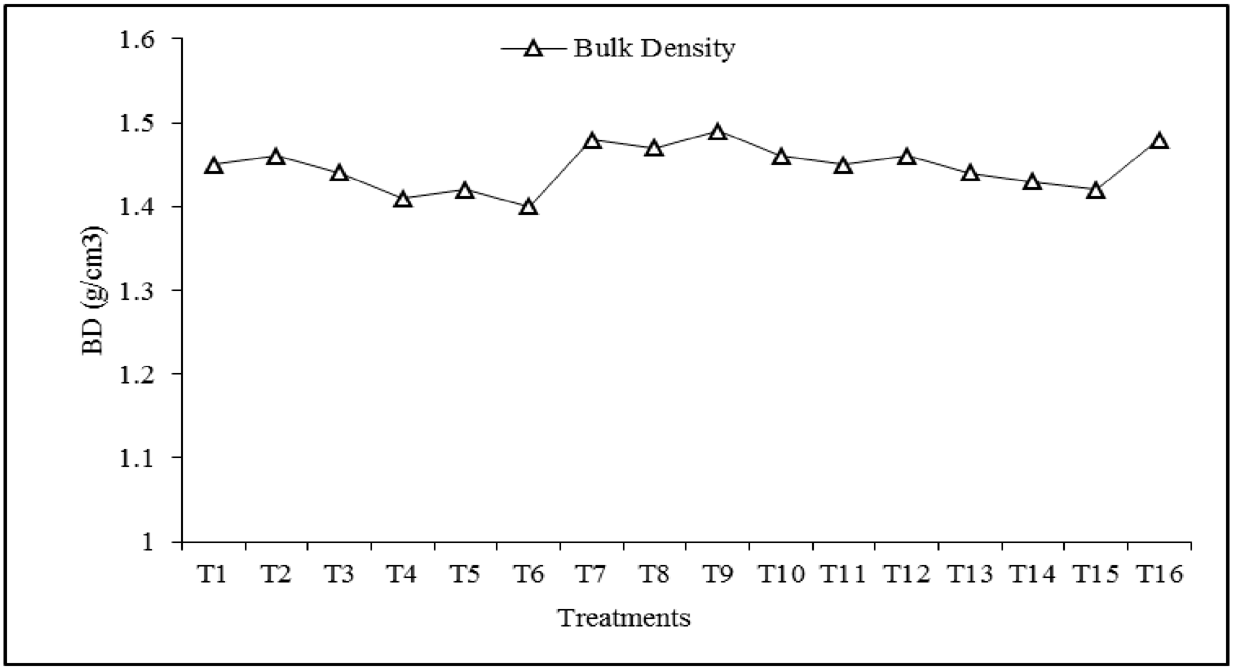

Figure 11. Effect of amendments on soil bulk density

4.1.2.2 Chemical Properties

Soil reaction (pH)

Soil pH is an indicator of soil acidity and basicity. Most soils have a pH in the range of 4 to 10. The pH of a particular soil, such as 5 or 8, reflects a certain chemical and mineralogical environment in that soil, and thus the pH is of great importance to plant roots and microbial activity. For these reasons, soil pH is one of the most important factors affecting soil fertility and so is commonly managed to increase crop yields.

Generally, pH is a major driver of soil fertility. The mean pH value of the experimental field ranged between 6.78 - 6.84 and was not statistically significant ($p<0.05$) affected by soil amendment options. In the solo application of dry matter bio slurry, the highest soil reaction (6.82) was obtained from the rate of 96 N & 69 kg P ha^{-1} in T3 while the lowest soil reaction (6.8) was observed under the application of 64 N & 46 kg P ha^{-1} in T2. From this result, the maximum application rate of dry matter bio slurry as presented in Table 1 results higher soil reaction while the lowest values of soil reaction was gained as a result of T2. However, for those smallholders' farmers who have no opportunity to use the maximum rate of dry matter bio slurry, it is advisable to use the medium rate of dry matter bio slurry. In the application of dry matter compost, the highest and the lowest soil reactions were 6.84 and 6.83. The highest numerical value was obtained from 96 N & 69 kg P ha^{-1} in T6 while the lowest soil reaction was observed under the application rate of 64 N & 46 kg P ha^{-1} in T4 and 32 N & 23 kg P ha^{-1} in T5. This result shows that application of the maximum rate of dry matter compost is advisable for smallholders' farmers of the study area but if they have no opportunity to get the maximum rate, it is recommendable to apply either the rate at which indicated in T1 or 2 (Table 1). However, from economical aspects, using the minimum rate of dry matter compost is advisable to produce bread wheat in the study area.

In the solo application of inorganic fertilizer as a soil fertility amendment, the highest (6.79) and the lowest (6.78) soil reaction was appeared from the rate of 32 N & 23 kg P ha^{-1} in T8 and in both rates of 64 N & 46 kg P ha^{-1} and 96 N & 69 kg P ha^{-1} in T7 and T9. Here, it can be concluded that applying the minimum rate of inorganic fertilizer as soil fertility amendments is recommendable option for smallholders' farmers to produce bread wheat in the study area.

With regarding of the combined application of dry matter bio slurry along with inorganic fertilizers, the highest numerical figure (6.8) was appeared in the application rate of both T11 and T12 (Table 1, Figure 12 and Appendix 4) while the lowest figure of soil reaction (6.79) was obtained under the application of dry matter bio slurry (32 N & 23 kg P ha$^{-1)}$ plus inorganic fertilizer (32 N & 23 kg P ha^{-1}) in T10. Thus, the results are similarly in T11 and 12 and it shows that using the two rates of inorganic fertilizers is possible in the study area for those farmers who have no potential to use the maximum rate as presented in Table 1. But from economical aspects, using the medium rate that indicated in T11 (Table 1) is advisable otherwise using the maximum rate will leads wastage. Similarly, in the combined application of dry matter compost along with inorganic fertilizer, the maximum and the minimum numerical values were 6.82 and 6.81 that observed in T14 and in both T13 and T15. Thus, using the rate that presented in T13 is recommendable for small holders' farmers in the study area. The pH values observed in the experimental field are within the ranges of mildly acidic to neutral soil reactions as indicated by Foth and Ellis (1997). The pH of Vertisols increases with depth, the topsoil being neutral or weakly acid. According to Berhanu (1985), about 61% of the Vertisols have pH values of 5.5-6.7, 21% have pH values of 6.7-7.3, and 9% have pH values of more than 8. Thus, the soil pH of the experimental field was in the range of favorable for most crops (Tekalign, 1991) (Appendix 11) as most Ethiopian Vertisols do (Berhanu, 1985).

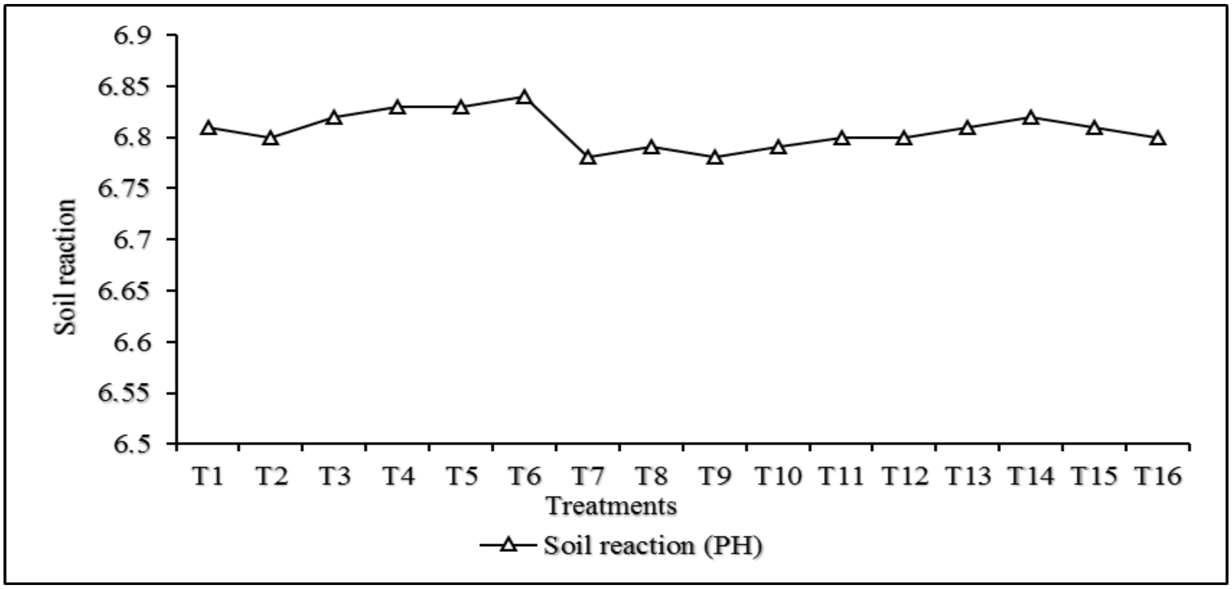

Figure 12. Effects of amendments on the soil reaction of the study area

Soil organic Carbon

The soil organic carbon of the experimental field ranged from 1.29 to 1.41 % (with the mean of 1.35 %) (Figure 13 and Appendix 4) but the effect of soil fertility amendments were not statically significant ($p<0.05$). With the solo application of dry matter bio slurry as a soil fertility amendment option, the highest result of soil organic carbon (1.36 %) was obtained from 96 N & 69 kg P ha^{-1} in T3 while the lowest result of soil organic carbon (1.32) was observed with the application of 32 N & 23 kg P ha^{-1} in T2.

In the solo application of dry matter compost, the highest soil organic carbon (1.41 %) was obtained from 96 N & 69 kg P ha^{-1} in T6 while the lowest soil organic carbon (1.39 %) was observed under the application rate of 32 N & 23 kg P ha^{-1} in T5 and with regarding to inorganic fertilizer the highest value of soil organic carbon (1.31 %) was resulted from 32 N & 23 kg P ha^{-1} in T8 while the lowest (1.29) organic carbon was obtained from 96 N & 69 kg P ha^{-1} in T9.

In the combined application of dry matter bio slurry along with inorganic fertilizer as a soil fertility amendment option, the highest result of soil organic carbon was 1.35 that observed in T12 while the lowest was 1.32 % that results from T10 while in the combined application of dry matter compost along with inorganic fertilizers, the highest organic carbon content was 1.39 %

which was gained from the rate of 64.4 N & 46 kg P ha^{-1} plus inorganic fertilizer at the rate of 98.5 N & 46 kg P ha^{-1} in T15.

Generally, from all the applied soil fertility amendment alternatives, the remarkable content of soil organic carbon (1.41 %) was obtained from the application of dry matter compost in T6. However, the lowest value was recorded from control plot in T16. This result is similar with the finding of Getachew *et al.* (2014) that also reported that relatively higher soil organic carbon was recorded on experimental plots, which received from compost than plots received inorganic fertilizers. Muhammad (2011) also reported that the application of compost results better soil organic carbon content as compared with other ISFM options and control plots.

Soil Organic carbon levels are usually low in Vertisols, particularly when they are cultivated continuously, as in the case of Ethiopia. This is the case in spite of their dark color, which is thought to be due to the formation of organic matter-smectite complexes. Therefore, the soil of the study area falls under a very low carbon fertility class as per the classification of Landon (1991) as presented in Appendix 13.

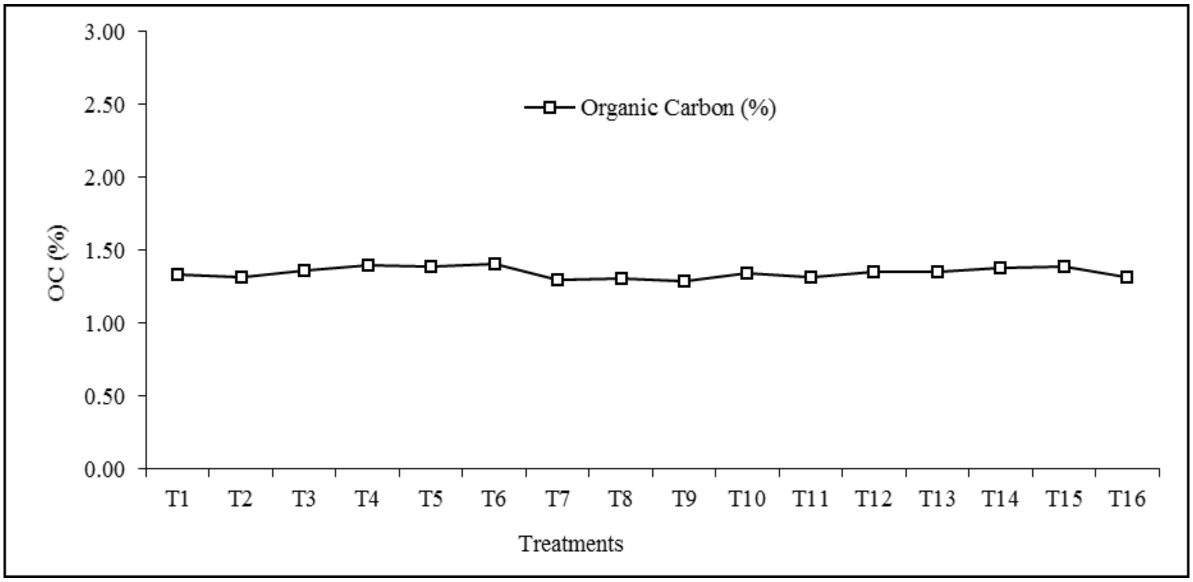

Figure 13. Effects of amendments on organic carbon of the soil

Total nitrogen

Nitrogen is the most limiting nutrient in the tropics and critical shortage of this nutrient brings significant grain/biomass yield reduction. Most Ethiopian black or dark grey soils are N-depleted and more than 50% of cultivated lands are N-responsive soils (Yihenew, 2002).

The mean value of total N was highest (0.13 %) on the application of dry matter compost in T6 and T4 and the lowest (0.1%) under the application of inorganic fertilizer at the rate of 96 N & 69 kg P ha^{-1} in T9 and 64 N & 46 kg P ha^{-1} in T7 as indicated in Figure 14 and Appendix 5, it was significantly ($p<0.001$) affected by the amendments. In the application of dry matter bio slurry, the numerical values of total N was similar (0.12 % at two rates; T1 and T3) and in the application of dry matter compost, the highest and the lowest total N were 0.13 % and 0.12 % observed in both T6 & T4 and T5, respectively while in the application rates of inorganic fertilizers, total nitrogen was highest (0.11 %) and relatively lowest (0.1 %) in T8 and in both T7 and T9 respectively.

In the combined application of dry matter bio slurry along with inorganic fertilizers, the highest and the lowest values of total nitrogen content was 0.12 % and 0.11 % which were observed in T11, 12 and T10, respectively while in the application of dry matter compost along with inorganic fertilizers, the highest and the lowest total nitrogen content was 0.12 % and 0.11 % that observed both in T14, T15 and T13 respectively.

Generally, across all the applied soil fertility amendments, the application of dry matter compost at the rate of 64 N & 46 kg P ha^{-1} in T4 and T6 96 N & 69 kg P ha^{-1} resulted in the highest total nitrogen content.

According to Berhanu (1980), total N contents of Vertisols of the Central highlands and Eastern lowlands of Ethiopia varied from 0.08 to 0.22 %. Furthermore, other research work (Tekalign *et al.,* 1988) conducted in Ethiopia on Vertisols also indicate that N is the most deficient nutrient element than any other essential element in these soils and has called for the application of inorganic fertilizers and need for a sound management of soil organic matter.

The study was in agreement with the findings of Muhammad (2011) that also reported that plots receiving compost have more total nitrogen content than any plots that received other soil fertility amendments. Getachew and Bekele (2005) also reported that the total N of soil was significantly improved due to the application of farmyard manure.

Thus, it can be concluded that the soil of the study area falls under the low N fertility class of Landon (1991) and the low to medium class of Berhanu (1980) as presented in Appendix 14.

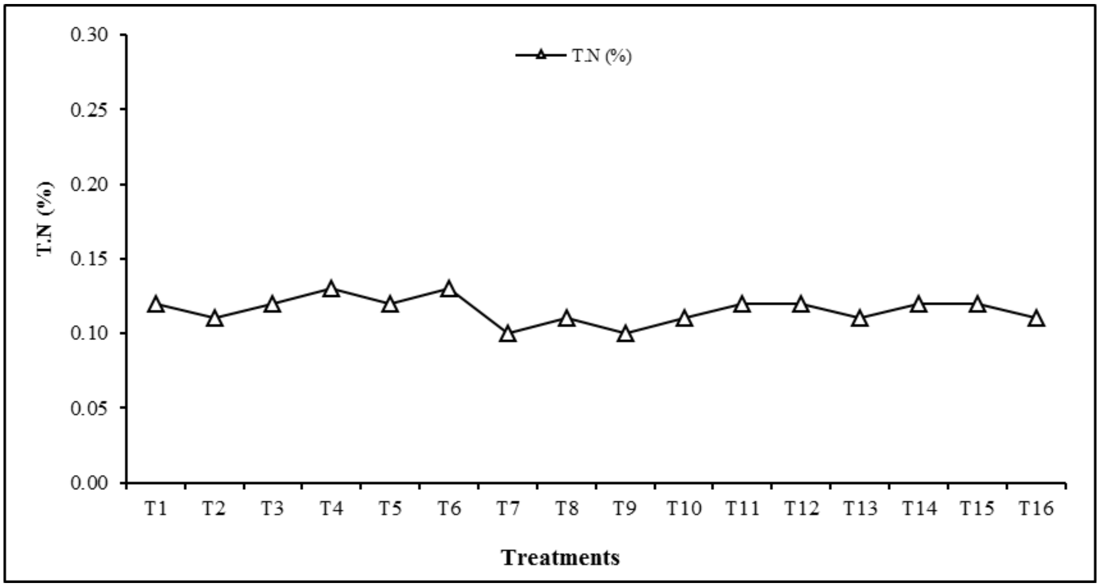

Figure 14. Effects of amendments on the total nitrogen of the soil

Carbon to Nitrogen ratio

The carbon to nitrogen (C/N) ratios of the soils at the trial plots was not statistically significantly ($P<0.05$) affected by the applied integrated soil fertility amendment options. Considering the main effects of experimental amendments, higher mean C/N ratio value of 13 was found within the application of 100 kg urea and 100 kg DAP of inorganic fertilizer in T7 while the lower C/N ratio value of 10.8 was found within the application of dry matter compost in T4 and T6 (Figure 15 and Appendix 5). As indicated in Figure 15 and Appendix 4, in the application of dry matter bio slurry as soil fertility management options, the highest and the lowest C/N ratio was 12 and 11.1 that observed in T2 and T1 respectively while in the application of dry matter compost, the highest and the lowest numerical values were 11.6 and 10.8 that appeared in T5 and in both T4 and T6.

The reason is that compost had narrower C: N ratio than that of bio slurry and inorganic fertilizer and supplied more quickly nutrients than bio slurry and inorganic fertilizer (Sarwar *et al.* (2007).

Muhammad (2011) also reported that the application of compost have better C/N ratio results as compared with other soil fertility amendment options and control fields.

In the solo application of inorganic fertilizers, the highest (13) and the lowest (11.9) were seen in T7 and T9. With regarding to the combined application of dry matter bio slurry along with inorganic fertilizers as an integrated soil fertility amendment options, the highest and the lowest C/N ratio numerical values were 12.2 and 11 that appeared in T10 and T11 respectively while in the combined application of dry matter bio slurry along with inorganic fertilizers, 12.3 was the highest C/N ratio that shown in T13 and the lowest C/N ratio was 11.5 that observed in T14. Therefore, the C/N ratio of the study area qualifies medium rate (10.8-13) as per Landon (1991).

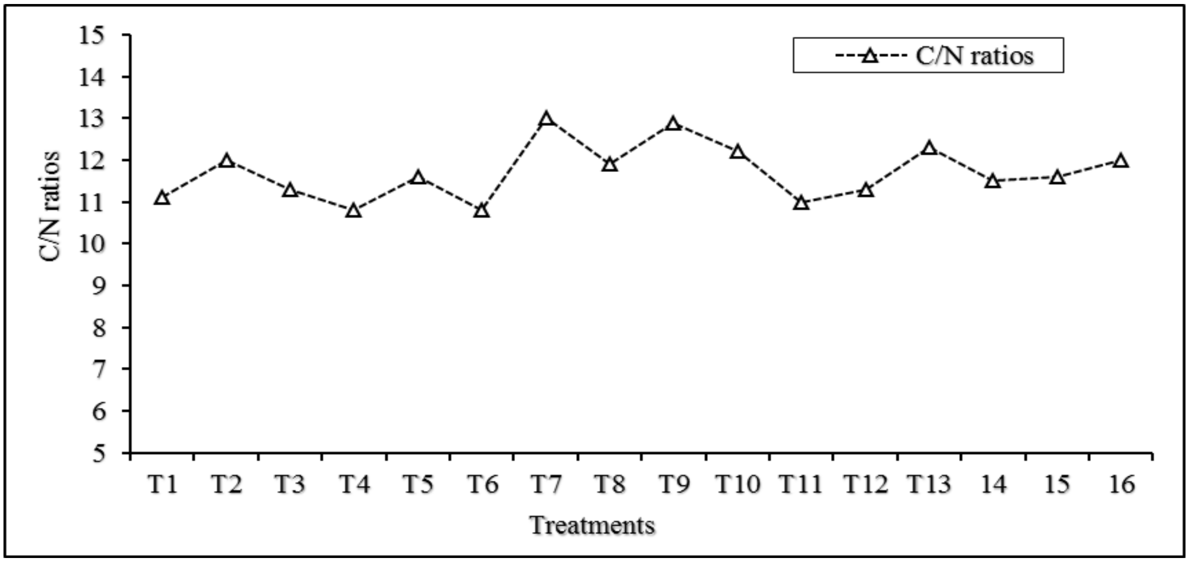

Figure 15. Effects of amendments on the C/N ratio of the soil

Available phosphorus

Phosphorus (P) is a critical element in natural and agricultural ecosystems and its management need is second only to the need for the management of N for the production of healthy plants and profitable yields (Brady and Weil, 2002).

The available phosphorus (P) was not statistically significantly ($p<0.05$) affected by the amendments. However, in the solo application of dry mater bio slurry as a soil fertility amendment option, the highest and the lowest content of available phosphorous were 41.82 mg kg^{-1} and 41.80 mg kg^{-1} that observed under the application rate of 96 N & 69 kg P ha^{-1} in T3 and 32 N & 23 kg P ha^{-1} in T2, respectively.

With regardings to the solo application of dry matter compost, the highest and the lowest avaliable phospherous were 41.9 mg kg^{-1} and 41.83 mg kg^{-1} that resulted from the applied rate of 96 N & 69 kg P ha^{-1} and 32 N & 23 kg P ha^{-1}) in T6 and T5, respectively while in the application rate of inorganic fertilizer highest avaliable phospherous (41.8 mg kg^{-1}) and the lowest avaliable phospherous (41.55 mg kg^{-1}) was obtained from 50 kg Urea & 50 Kg DAP fertilizer (32 N & 23 kg P ha^{-1}) in T8 and 150 kg Urea & 150 kg DAP fertilizer (96 N & 69 kg P ha^{-1}) in T9. Here using the maximum rate of inorganic fertilizer (96 N & 69 kg P ha^{-1}) is not advisable and it is wastage. This shows that using the minmum rate of inorganic fertilizer as presented in T8 is advisable for wheat production in the study area.

In the combined application rate of dry matter bio slurry along with applied inorganic fertilizers, the main effect on the avaliable phospherous was observed under the application of dry matter bio slurry (63.7 N & 46 kg P ha^{-1}) plus inorganic fertilizers (93 N & 46 kg P ha^{-1}) in T12 that resulted in 41.79 mg kg^{-1} while the minimum avaliable phospherous (41.5 mg kg^{-1}) was observed from both application rates of 32 N & 23 kg P ha^{-1} along with inorganic fertilizers at the rate of 32 N & 23 kg P ha^{-1} and 48 N & 34.5 kg P ha^{-1} plus inorganic fertilizer at the rates of 145 N & 82.5 kg P ha^{-1} in T10 and T11 respectively. Here, applying the maximum rate of combination can give more available phosphorous than other treatment options but for those smallholders' farmers who do not have the potential to access the maximum rate of combination, it is advisable to apply the minimum rate of combined application of dry matter bio slurry along with inorganic fertilizer in T10 as presented (Table 1) which have similar result with T11. However, cost wise, applying the rate indicated in T10 is better than that of T11. Similarly, in the combined application of dry matter compost along with inorganic fertilizers, the maximum (41.81 mg kg^{-1}) available phosphorous was appeared as a result of 9200 kg ha^{-1} dry matter compost (64.4 N & 46 kg P ha^{-1}) along with inorganic fertilizers (98.5 N & 46 kg P ha^{-1}) in T15 and 4600 kg ha^{-1} dry matter compost (32 N & 23 kg P ha^{-1}) plus inorganic fertilizer (48.6 N & 23 kg P ha^{-1}) in T13 while the minimum avaliable phospherous (41.7 mg kg^{-1}) was observed in the combined application of 6900 kg ha^{-1} dry matter compost (34.5 N & 34.5 kg P ha^{-1}) plus inorganic fertilizer (73 N & 34.5 kg P ha^{-1}) in T14. Thus, it can be concluded that applying the minmum and the maximum rates of combined application of dry matter compost along with chemical fertiizer resuted the highest numerical values of Avaliable phosphrous (41.81 mg kg^{-1}) but from resource conservation and thrifty aspect, using the minimum rate of combined application rate is recommended for those smallholders' farmers who are producing wheat in the trial plots.

Generally, across all the applied soil fertiliy amendment opions indicaed in Table 1 and the observed results from figure 16 and Appendix 5, it can be concluded that application of dry matter compost in T6 gave better than the other types and rates of soil fertility amendment options. Muhammad (2011) also reported that application of dry matter compost resulted more phosphorous than other treatments because it supplied nutrients more quickly than dry matter bio slurry and inorganic fertilizers.

Mohammed *et al.* (2005) observed low levels of available P in the surface horizon of the cultivated soils of the Chercher highlands in Eastern Ethiopia. Moreover, Berhanu (1985) reported that available P in most vertislos of Ethiopia is below 5 mg kg^{-1}. In general, existence of low contents of available P is a common characteristic of most of the soils in Ethiopia (Tekalign and Haque, 1991; Yihenew, 2002; Wakene and Heluf, 2003) which is in contrast with the P content observed in the soil of the study area. However, in contrast to those researchers, the study result of available P of the soils of the study area qualifies high range of available P (Figure 16 and Appendix 14). In this scenario, Muhammad (2011) contended available phosphorous can exist at high range depending on the soil characteristics of the study area and the amendment options applied.

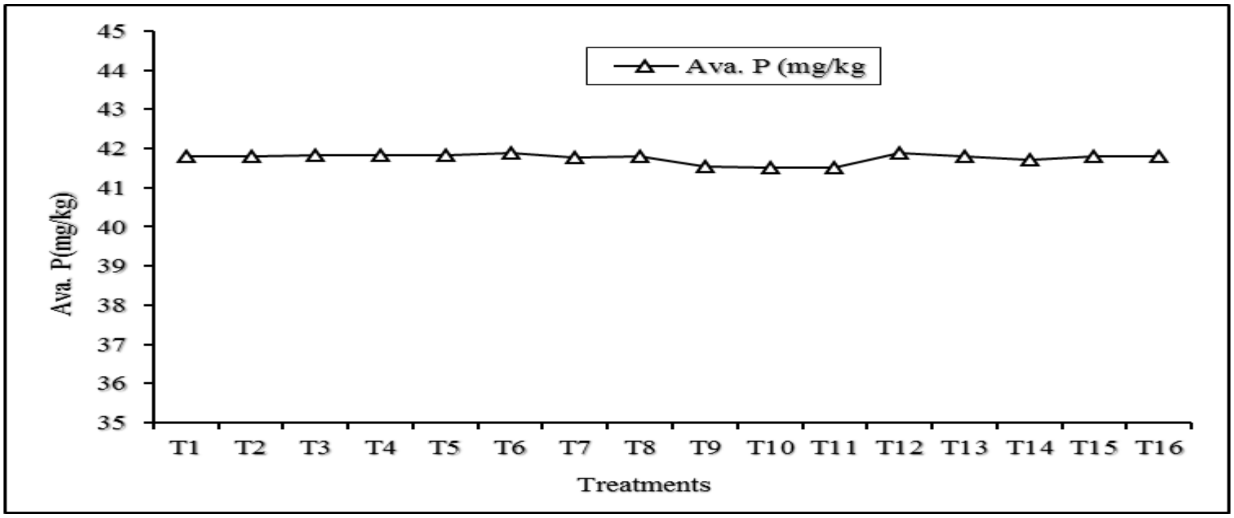

Figure 16. Effects of amendments on the available phosphorous (Olsen) of the soil

Available Potassium

The soil of the trial plots after applied treatment options contained available K ranging from 3.05 mg kg^{-1} to 3.13 mg kg^{-1} (with the mean value of 3.10 mg kg^{-1}). In treatment based, application of solo bio slurry as an integrated soil fertility management option, the highest and the lowest available K were 3.12 and 3.11 mg kg^{-1} that appeared in the application rates of 32 N & 23 kg P ha^{-1} dry mater bio slurry in T2 and both rates of 64 N & 46 kg P ha^{-1} and 96 N & 69 kg P ha^{-1} in T1 and T3 respectively. Here, it can be concluded that using the medium rate of dry matter bio slurry is advisable for wheat producers of the study area otherwise applying the minimum rate is not productive while the maximum rate is also not productive and wastage too.

In the application of dry matter compost as an integrated soil fertility management, the highest and the lowest numerical values were 3.13 and 3.12 that appeared in T6 and in both T4 and T5 (Figure 17 and Appendix 5). Thus, applying the maximum rates of dry matter (Table 1) is recommended for wheat production in the study area. However, for those wheat producers who do not have the opportunity to get the maximum rate, applying the minimum rate is advisable even though the result is smaller than the maximum rate but it is better than the medium one in resource conservation and economical aspects.

In the application of inorganic fertilizers, the highest available K (3.1 mg kg^{-1}) was obtained in T8 and T9 while the lowest numerical value of available K (3.09 mg kg^{-1}) was appeared in T7. Thus applying the medium rate of inorganic fertilizer as indicated in T8 recommended than the other rates of applications (Table 1).

With regarding of the combined application of dry matter bio slurry along with inorganic fertilizers as means of soil fertility management, the highest available K (3.07 mg kg^{-1}) was observed in T12 while the lowest available K (3.05 mg kg^{-1}) in T11 while in the combined application of dry matter compost along with inorganic fertilizers, the highest and the lowest available K were 3.12 and 3.07 mg kg^{-1} that observed in T15 and T13. So, the available K of the trial plots after amendment falls from medium to high available K fertility class of Landon (1991) and high available P fertility class of Olsen *et al* (1954).

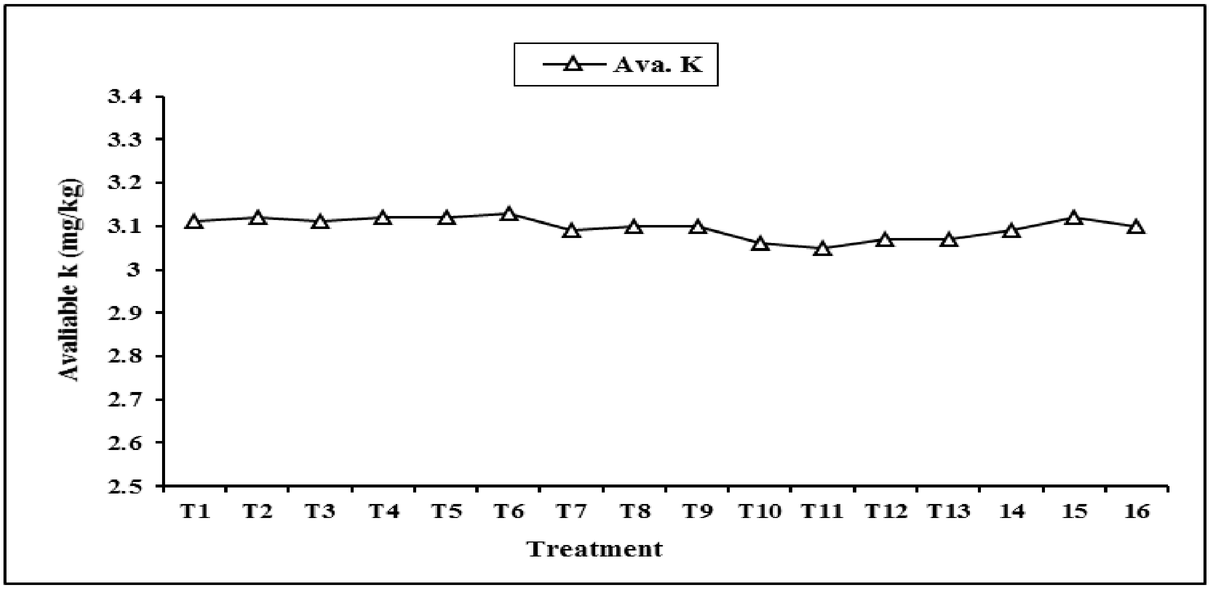

Figure 17. Effects of amendments on available Potassium

Basic exchangeable cations

Exchangeable Ca followed by Mg was the predominant cation in the exchange site (Table 3). In the solo application of dry matter bio slurry as means of soil fertility amendments, the highest value of exchangeable Ca was 19.63 cmol (+) kg^{-1} that observed in T3 while the lowest exchangeable Ca (19.61 cmol (+) kg^{-1}) was observed in T2.

Under the application of dry matter composts as an integrated soil fertility management option, the highest and the lowest Ca was 19.65 and 19.63 cmol (+) kg^{-1} that appeared in T6 and T5 respectively while in the solo application of inorganic fertilizers, the highest mean value of Ca was 19.6 cmol (+) kg^{-1} that appeared in both T7 and T8 and the lowest Ca was 19.59 cmol (+) kg^{-1} that observed in T9. Here, applying of the two rates of inorganic fertilizers that indicated in T7 and T8 resulted the highest numerical values of exchangeable Ca. However, from cost minimization and environmental as well as resource conservation principles, using the rate that indicated in T8 (Table 1) is advisable.

Concerning the combined application of dry matter bio slurry along with inorganic fertilizers, highest value of exchangeable Ca was 19.58 cmol (+) kg^{-1} that was observed in T11 where as the lowest exchangeable Ca was 19.56 cmol (+) kg^{-1} that appeared in T12 while in the combined application of dry matter compost along with inorganic fertilizers, the highest and the lowest exchangeable Ca content were 19.62 and 19.54 cmol (+) kg^{-1} respectively.

Generally, the exchangeable Ca contents of the trial plots varied from 19.54 to 19.65 cmol (+) kg^{-1} with the mean values of 19.60 cmol (+) kg^{-1}. However, from all soil fertility amendments applied, solo application of compost showed remarkable values of exchangeable Ca. Thus, the exchangeable Ca of the study area falls under high rate of FAO (2006) (Appendix 15).

Exchangeable Mg of the experimental field varied from 11.5 cmol (+) kg^{-1} at T8 to 13.2 coml (+) kg^{-1} at T4 (Table 3). With application of dry matter bio slurry, the highest and the lowest exchangeable Mg contents were 12.82 and 13.09 cmol (+) kg^{-1} that observed in T1 and T3 while in solo application of dry matter compost, the highest exchangeable Mg was 13.2 cmol (+) kg^{-1} in T4 and the lowest numerical values of exchangeable Mg was 12.73 cmol (+) kg^{-1} in T5.

In solo application of inorganic fertilizers, the highest and the lowest Mg content were 11.5 and 11.45 cmol (+) kg^{-1} in T8 and T9 respectively. With regarding to the combined application of dry matter bio slurry along with inorganic fertilizers, the highest and the lowest numerical values of Mg contents were 11.78 and 11.67 cmol (+) kg^{-1} that appeared in T12 and T10 respectively while the highest and the lowest Mg contents in the combined application of dry matter compost along with inorganic fertilizers were 12.23 and 11.48 cmol (+) kg^{-1} that observed in T15 and T13, respectively. Thus, the exchangeable Mg of the study area falls under the rate of very high (FAO, 2006) (Appendix 15).

The high contents of exchangeable Ca and Mg show that the soil parent material primarily rich in basic cations and the divalent cations are retained in higher concentrations and for longer periods by the soil colloidal particles because of their higher selectivity coefficient over the monovalent cations. A high content of these two cations has also been reported in Vertisols of Bichena and Woreta areas (Yihenew, 2002) and in soils of Jelo micro-catchment (Mohammed *et al.,* 2005).

The exchangeable Na content of the trial plots varied from 0.31 to 0.34 cmol (+) kg^{-1} (Table 3). In solo application of dry matter bio slurry as an integrated soil fertility management option, 0.33 cmol (+) kg^{-1} was the highest numerical value that observed in T3 and 0.32 cmol (+) kg^{-1} was the minimum Na content that appeared in T1 and T2. Here it can be suggested that applying the maximum rate of dry matter bio slurry is recommendable for those smallholders' farmers of the study area. However, for those farmers who have no capacity to afford the maximum rate, applying both rates as indicated in T1 and T2 (Table 1) is recommendable and here from resource management and environmental protection points of view, applying the minimum rate of dry matter bio slurry in T2 as presented in Table 1 is recommended rates for those wheat producers of the study area. In the applied rates of dry matter composts, T5 and T6 resulted the highest values of exchangeable Na (0.33 cmol (+) kg^{-1}) while the lowest value was 0.32 cmol (+) kg^{-1} that observed in T4. What we consider here is that both rates indicated in T5 and T6 resulted the highest Na contents but to avoid wastage and to minimize the cost incur as well as from the environmental conservation points of view, applying the rate stated in T5 (Table 1) is advisable to produce bread wheat for smallholders' farmers of the study area. In the solo application of inorganic fertilizers, all rates that applied in the trial plots have similar exchangeable values of Na (0.31 cmol (+) kg^{-1}) (Table 3).

In the case of combined application of dry matter bio slurry along with inorganic fertilizers, 0.34 cool (+) kg^{-1} was the highest exchangeable Na in T12 and the lowest Na content was 0.31 cmol (+) kg^{-1} that appeared in T11 while in the combined application of dry matter compost along with applied inorganic fertilizers, the highest and the lowest exchangeable Na were 0.32 and 0.31 cmol (+) kg^{-1} that observed in both T14 & T5 and T13 respectively. From observed result, both rates stated in T14 and T15 have similar exchangeable Na so that those wheat producers of the trial plots can apply both rates. Nevertheless, from cost minimization, environmental protection and resource conservation points of view, applying the rate stated in T14 is better than the rate stated in T15. Thus, the observed exchangeable Na value falls under low rate of FAO (2006) as indicated in Appendix 15.

Similarly, the exchangeable K of the experimental plots ranges from 0.36 cmol (+) kg^{-1} in T12 to 0.42 cmol (+) kg^{-1} in T6. Regarding the applied dry matter bio slurry as a soil fertility management options, 0.4 and 0.38 cmol (+) kg^{-1} were the highest and the lowest K contents that have been observed in T3 and T2 respectively while in the application of solo dry matter bio slurry, the highest and the lowest values of exchangeable K were 0.42 and 0.39 cmol (+) kg^{-1} that have been appeared in T6 and T5 respectively.

In the solo application of inorganic fertilizers, 0.4 and 0.38 cmol (+) kg^{-1} were the highest and the lowest values of exchangeable K that observed in T8 and T9. In the combined application of dry matter bio slurry along with inorganic fertilizers as an integrated soil fertility management, 0.38 and 0.36 cmol (+) kg^{-1} were the highest and the lowest exchangeable K that appeared in T11 and T12 while in the combined application of dry matter compost along with the applied inorganic fertilizers, the highest and the lowest exchangeable K were 0.41 and 0.38 that have been observed in T15 and T13. Thus, the exchangeable K of the experimental plots falls under the medium range of FAO (2006) as indicated in Appendix 15.

Generally, in the experimental plots of the study area, the proportions of the cations were in the order of Ca > Mg > K > Na. This might be related to the parent material from which the soils have been developed i.e. basalt rock and their differential attraction to the soils' exchange complex which is approximately in that order. Generally, exchangeable Na and K contributed very small proportion to the CEC.

Cation Exchange Capacity and Percent Base Saturation

As indicated in Table 3, CEC among the applied soil fertility amendment options, the lowest CEC (35.7) cmol (+) kg^{-1} in the sole application of bio slurry in T1 while the highest (37.9 cmol (+) kg^{-1}) was obtained at T5 and T15 (Table 3). Although the OM content of the soil is very low, the amount and type of clay might have been very important in contributing to the CEC values. The type of clay could most probably be montmorillonite with a shrinking and swelling behavior with extensive internal and external surfaces that can attract or adsorb many cations. This is in line with the findings of Mebit (2006) who reported very high CEC on Vertisols. Thus, the CEC of the trial plots falls a high classification rate (Landon, 1991; FAO, 2006) (Appendix 15).

The percentage of base saturation of the trial plots ranged from 84.16 in both rates of T13 & T14 to 92.86 % in T1 with the mean value of 87.1 %. Thus, the PBS of the trial plots falls from high to very high rate of FAO (2006) classification rate (Appendix 15) and it indicates that the soil is suitable for most crops.

Table 3. Effect of amendments on Calcium, Magnesium, sodium, potassium, CEC and PBS in Ada'a district, central highlands of Ethiopia

Treatments	**Exchangeable bases**					
	Ca	**Mg**	**Na**	**K**	**CEC**	**%BS**
	cmol (+) kg^{-1}					
T1	19.62	12.82	0.32	0.39	35.7	92.86
T2	19.61	12.97	0.32	0.38	36.1	92.19
T3	19.63	13.09	0.33	0.4	36.7	91.14
T4	19.64	13.2	0.32	0.41	37.6	89.41
T5	19.63	12.73	0.33	0.39	37.9	87.28
T6	19.65	12.78	0.33	0.42	37.6	88.24
T7	19.6	11.46	0.31	0.39	37.3	85.15
T8	19.6	11.5	0.31	0.4	37.4	85.05
T9	19.59	11.45	0.31	0.38	37.5	84.61
T10	19.57	11.67	0.32	0.37	37.4	85.37
T11	19.58	11.72	0.31	0.38	37.8	84.63
T12	19.56	11.78	0.34	0.36	37.7	84.99
T13	19.56	11.48	0.31	0.38	37.7	84.16
T14	19.62	12.23	0.32	0.4	37.8	86.16
T15	19.54	12.11	0.32	0.41	37.9	85.44
T16	19.52	11.44	0.32	0.38	36.4	86.98
$\bar{X}$	19.60	12.16	0.32	0.39	37.28	87.10
S	0.04	0.68	0.01	0.02	0.68	2.85
CV (%)	0.19	5.56	2.80	4.08	1.83	3.28
p	NS	NS	NS	NS	NS	-

NS: not statistically significant level at P<0.05

4.2 Response of Yield and Yield components to soil fertility amendments

The major yield and yield components measured for the study were plant height, spike length, number of productive tillers plant^{-1}, number of spikelet's spikes^{-1}, grain yield m^{-2} or ha^{-1}, total biomass yield, 1000 grain weight and harvest index (Appendix 10). Results showed all genotypes or traits of wheat were significantly ($p<0.001$) affected by the application of different soil fertility management and wheat productivity options as indicated in Table 1.

4.2.1 Plant height

Plant height is not a yield component especially in grain crops but it indicates the influence of various nutrients on plant metabolism. For the experimental plots, plant height was measured at maturity stage, from ten random plant samples of the harvestable rows, from the ground level to the tip of the spike including the awns using a measuring tape (Appendix 10a). Response of applied bio slurry and compost along with different rates of inorganic fertilizers on plant height are shown in Figure 18 and Appendix 7. Plant height was significantly influenced ($P<0.001$) due to the application of soil fertility amendment levels.

All amendments containing dry matter bio slurry caused an increase in plant height ranging from 2 to 9 % over control at maturity stage. The maximum plant height (87 cm) was observed on the application of dry matter bio slurry at the rate of 14300 kg ha^{-1} (96 N & 69 kg P ha^{-1}) in T3 while in the application of dry matter compost, the maximum plant height (87.6 cm) at the maturity stage was obtained from 13800 kg ha^{-1} (96 N & 69 kg P ha^{-1}) compost in T6. With regarding of inorganic fertilizer application, the lowest (80 cm) plant height was recorded from the application of fertilizer at the rate of 50 kg urea and 50 kg DAP (32 N & 23 kg P ha^{-1}) in T8 and the highest plant height (96 cm) was recorded from the application of fertilizer at the rate of 150 kg urea and 150 kg DAP (96 N & 69 P kg ha^{-1}) in T9.

Across all rates of amendment, the tallest plant height (103.3 cm) of wheat at the maturity stage was recorded from the application of dry matter compost along with inorganic fertilizers at the rate of 9200 kg ha^{-1} compost (64.4 N & 46 kg P ha^{-1}) plus fertilizer (98.5 N & 46 kg P ha^{-1}) in T15 as compared with other applications. Tallest plant might be due to the application of balanced application of amendments with improved methods, while other application may be the more wastage of amendments with decreased availability to crops plant.

Comparative analysis of dry matter compost and bio slurry indicates that effect of compost with fertilizer showed better results on plant height than control and even than bio slurry plus inorganic fertilizer amendment.

Generally, it can be concluded that, the application of dry matter compost along with inorganic fertilizer is the recommended option in the trial plots followed by application of dry matter bio slurry along with inorganic fertilizer, solo inorganic fertilizer, dry matter compost and bio slurry, respectively. The increase in plant height on the application of dry matter compost in combination with inorganic fertilizer was in line with the results reported by Sarwar *et al.* (2007).

Similarly, the findings of Getachew *et al.* (2008) indicated that wheat plant height tended to increase in the mixed application of organic and inorganic fertilizers as compared to sole application of inorganic fertilizer. Jagadeeswari and Kumaraswamy (2000) also noted that the use of composts along with inorganic fertilizer increased yield and production of wheat. The second largest plant height (102 cm) was recorded with the application dry matter bio slurry along with inorganic fertilizer in T12 while the shortest plant height (78 cm) was recorded from the control plots in T16 (Figure 18 and Appendix 7). This indicates that dry matter compost along with inorganic fertilizer in T15 showed a remarkable impact on the plant height of bread wheat in the study area.

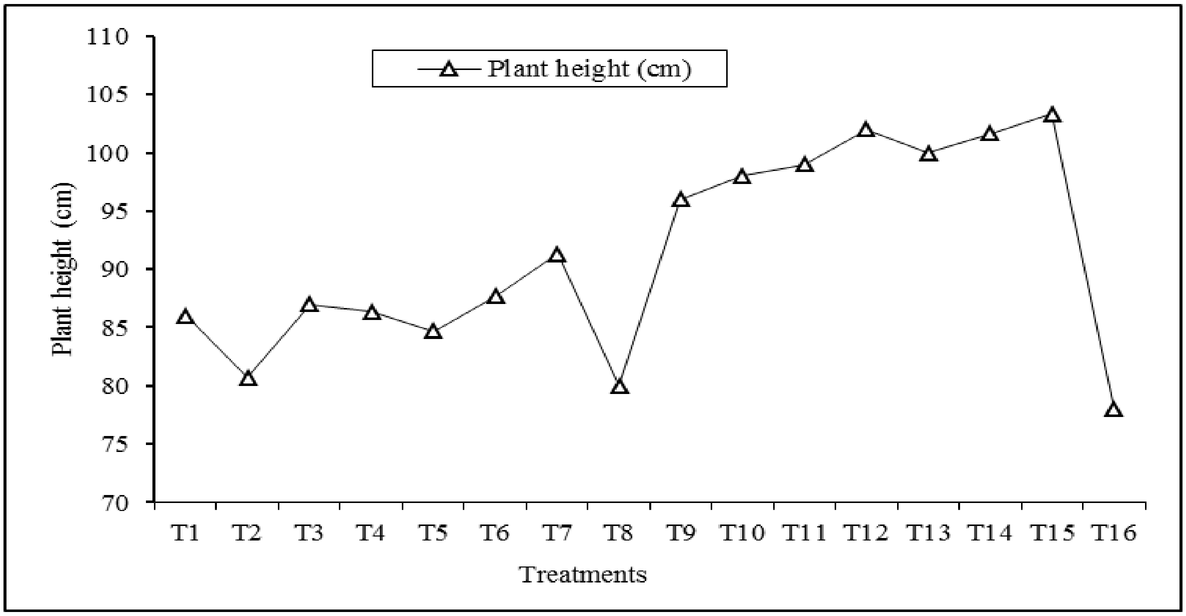

Figure 18. Effects of amendments on the plant height of wheat

4.2.2 Spike Length

Spike length or ear size is among the major yield components of wheat that can affect its productivity. Ear size is considered as a yield contributing factor because larger spikes have more grains as compared to shorter ones which ultimately leads towards better grain yield. Spike length was measured by calculating the average spike length of ten random plant samples in the harvestable rows, following the measurement from its base to the tip excluding awns (Appendix 10b). Spike length of the tested crop was statistically significantly at 0.01% probability level ($P<0.001$) with the application of soil fertility amendment options. Accordingly, the largest spike length resulted from dry matter bio slurry was 8 cm followed by 7.67 and 7.33 cm that obtained from 64 N & 46 kg P ha^{-1}, 96 N & 69 kg P ha^{-1} and 32 N & 23 kg P ha^{-1} in T1, T2, and T3, respectively while the largest spike length as a result of dry matter compost application was 8 cm in T4 and T6.

In the application of inorganic fertilizer, the largest spike length was 9 cm in T7, 8.33 cm in T9 and 7.33 cm in T8. Similarly, the largest spike length (9 cm) as a result of inorganic fertilizer was obtained in T7 with the application of 100 kg urea and 100 kg DAP fertilizer (64 N & 46 kg P ha^{-1}) followed by 8.33 and 7.33 cm with the application of 150 kg urea and 150 kg DAP (96-69 kg ha^{-1} inorganic) and 50 kg urea and DAP fertilizer (32 N & 23 kg P ha^{-1} inorganic) in T9 and T8 respectively.

The evident from the data that numerically the largest average spike length (9.67 cm) was produced from the application of dry matter compost along with inorganic fertilizer in T15. However, the smallest spike length (6.67 cm) was recorded in T16 (control plot). Almost similar findings were described by Alam *et al.,* 2003. This indicated that compost gave outstanding results when applied along with inorganic fertilizer (Figure 19 and Appendix 7).

4.2.3 Number of productive tillers

Number of tillers m^{-2} in wheat crop is one of the most important agronomic component that can be considered for enhancing wheat productivity. Total tillers for randomly selected plants were counted at the time of maturity and averaged plant^{-1} was calculated (Appendix 10c). The response of bio slurry, compost and different levels of inorganic fertilizer on number of productive tillers per plant is shown in Figure 19 and Appendix 7. The data clearly showed that application of bio slurry and compost with different level of inorganic fertilizer statistically significantly affected the number of productive tillers per plant at significant level of 0.1 ($p<0.001$) according to LSD test. Experimental results showed that the highest number of tillers (9.0) was produced with the solo application of inorganic fertilizer rate in T9, combined application of dry matter bio slurry along with inorganic fertilizers at all rates in T10, T11, T12 and application of dry matter compost with inorganic fertilizer in T13 and T14 while the second highest number of tillers (8.67) was produced by the application of dry matter bio slurry in T1. The smallest productive tiller (5.0) was recorded from the control plot in T16 (Figure 19 and Appendix 7). The result confirmed that the efficient and balanced availability of nutrients to crops led to enhanced numbers of tillers.

Therefore, it can be concluded that, application of dry matter bio slurry plus inorganic fertilizers in all three levels, inorganic fertilizer at the maximum rate (Table 1) and application of dry matter compost along with inorganic fertilizer in T13 and T14 are the recommended rate of amendment options that produce maximum numbers of tillers per plant in the study area. These results are directly in line with the finding of Hussain *et al*, (2008). Similarly, dry matter bio slurry along with inorganic fertilizer overall showed better results than other amendments in number of productive tillers. Rehman *et al.* (2008) also reported that application of compost along with inorganic fertilizer leads maximum productive tillers. Muhammad (2011) also reported that application of dry matter bio slurry along with inorganic fertilizer resulted maximum numbers of productive tillers than any other amendments.

4.2.4 Number of Spikelet's per spike

The number of spikelet per spike of the ten randomly selected plants of each plot was counted at the crop maturity (Appendix 10d) and average was calculated.

Effect of dry matter bio slurry and compost in the presence of variable rates of inorganic fertilizers and its integration on number of spikelet per spike is shown in Figure 19 and Appendix 7. The data clearly indicated that the application of dry matter bio slurry and compost with different levels of inorganic fertilizer significantly ($p<0.001$) affected the number of spikelet per spike per plot.

From the applied dry matter bio slurry rate, the highest spikelet per spike (16.33) was obtained from the application dry matter bio slurry at the rate of 96 N & 69 kg P ha^{-1} in T3 followed by 32

N & 23 P kg ha^{-1} in T2 that resulted the second number of spikelet per spike (16) while in the application of dry matter compost, the largest spikelet per spike was 16.33 followed by 16 and 14.33 that resulted from the application of compost at the rate of 96 N & 69 kg P ha^{-1} in T6, 64 N & 46 kg P ha^{-1} in T4 and 32 N & 23 kg P ha^{-1} in T5, respectively. Similarly, the highest number of spikelet per spike (17) was obtained from the application of inorganic fertilizer at the rate of 64 N & 46 kg P ha^{-1} in T7 followed by 16.67 and 14.67 numbers of spikelet per spike under the application rate of 96 N & 69 kg P ha^{-1} and 32 N & 23 kg P ha^{-1} in T9 and T8, respectively. Here, it can be recapped that, instead of using 96 N & 69 P kg ha^{-1} to increase the number of spikelet per spike in the study area, it is better to use 64 N & 46 kg P ha^{-1} otherwise, wastage of nutrient will happen.

From the observed result, the influence of dry matter compost application along with various levels of inorganic fertilizers on the number of spikelet's spike^{-1} was significantly higher than other amendment options. The inorganic fertilizers application along with dry matter compost in T14 and T15 resulted in the highest number of spikelet's spike^{-1} (18) while relatively the number of spikelet's spike^{-1} was lower (13.67) under control plot in T16 (Table 8). The findings of Muhammad (2011) outsmarted this study in such a way that the application of compost along with inorganic fertilizer leads to maximum numbers of spikelet per spike.

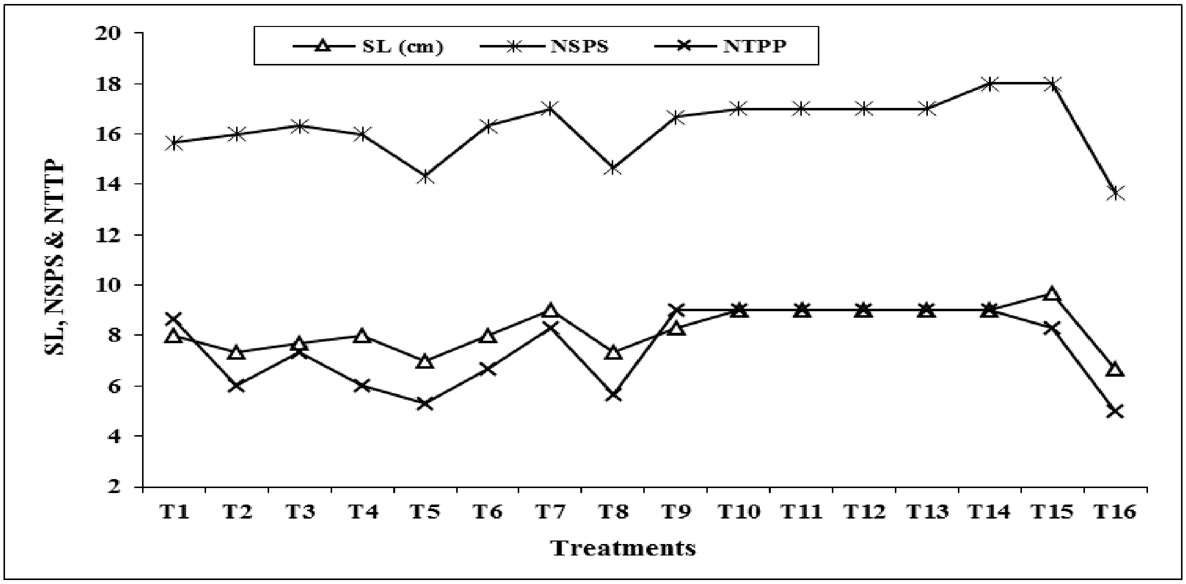

Figure 19. Effects of amendments on the spike length, no. of spikelet spike^{-1} and productive tillers plant^{-1}.

4.2.5 Grain yield

Grain yield is the final result that can be studied through its yield components (Appendix 10j). All the grain obtained from each plot was weighed and on the basis of grain yield plot^{-1}, grain yield ha^{-1} was calculated in kg ha^{-1} or Qt ha^{-1}. The effect of various amendment levels applied on grain yield gm^{-2} was significant at 0.1% probability level ($p<0.001$). The highest grain yield under the application of dry matter bio slurry was 59.67 that obtained from 64 N & 46 kg P ha^{-1} in T1 followed by 57.67 and 48.67 Qt/ha that obtained 96 N & 69 kg P ha^{-1} in T3 and 32 N & 23 kg P ha^{-1} in T2, respectively. Regarding to the effect of dry matter compost, the highest grain yield was 57 Qt/ha in T6 followed by 51.33 in T4 and 39.33 in T5. Under the inorganic fertilizers application, the highest grain (69.67 Qt/ha) was registered from the application of 96 N & 69 P kg ha^{-1} in T9 followed by 56.67 Qt/ha in T7 and 43.3 Qt/ha from T8. The grain yield value of bread wheat under 96 N & 69 P kg ha^{-1} in T9 was the highest (696.67 gm^{-2} which is 69.67 Qt/ha) among the applications and followed by grain yield of 666.67 gm^{-2} or 66.67 Qt/ha recorded in the application of dry matter compost along with inorganic fertilizers in T15. Similar findings of Getachew *et al* (2012) revealed that inorganic fertilizer has an immediate benefit, but from a natural resource management point of view, efficient management and utilization of organic nutrient sources and the required inorganic fertilizers in correct balance may contribute to longer-term sustainability of agricultural productivity and an integrated farming system in the highlands of the country, where soil erosion is serious and the resultant soil fertility depletion is alarming.

However, the lowest grain yield (260 gm^{-2} or 26 Qt/ha) was obtained under control field in T16 (Figure 20 and Appendix 8). In the experiment, grain yield in control plots (with no application of any treatments) were low and steadily declined (Bationo *et al.,* 1993). This shows that the potential for continuous wheat production on these soils is very limited in the absence of soil amendments.

4.2.6 Total biomass yield

Biomass or biological yield was measured by weighing the total above ground plant biomass within each central rows of 1m^{2} (Appendix 10g). The total above ground biomass of the crop was statistically significance at 0.1% probability level ($P<0.001$) (Figure 20 and Appendix 8). The highest total biomass yield as a result of dry matter bio slurry application was 135.00 Qt/ha in T1 followed by 130.67 and 120 Qt/ha in T3 and T2 respectively while with the application of dry matter compost, the highest biomass yield was 136.67 Qt/ha in T6 followed by 122.33 and 89.67 Qt/ha in T4 and T5 respectively. Similarly, with the application of inorganic fertilizer, the highest total biomass yield was 158 Qt/ha in T9 followed by 137 and 120 Qt/ha in T7 and T8 respectively. Relatively the highest dry biomass yield (1580 gm^{-2}) was obtained due to the application of inorganic fertilizer in T9 followed by the application of dry matter compost along with inorganic fertilizer in T15 that resulted 1576.7 gm^{-2} or 157.67 Qt/ha while the lowest dry biomass yield (880 gm^{-2} or 88 Qt/ha) was obtained from the control field in T16 (Figure 20 and Appendix 8).

Increased biomass production with increasing rates of dry matter compost and inorganic fertilizers was observed. Highly significant and positive correlations of total above ground biomass with grain yield (r =0. 952**), spike length (r = 0.819**), number of spikelet spike^{-1} (r = 0.877**), plant height (r = 0. 832**), numbers of tillers (r = 0.853**), TGW (r =0. 468**) and harvest index (r = 0. 496**) were recorded (Table 4).

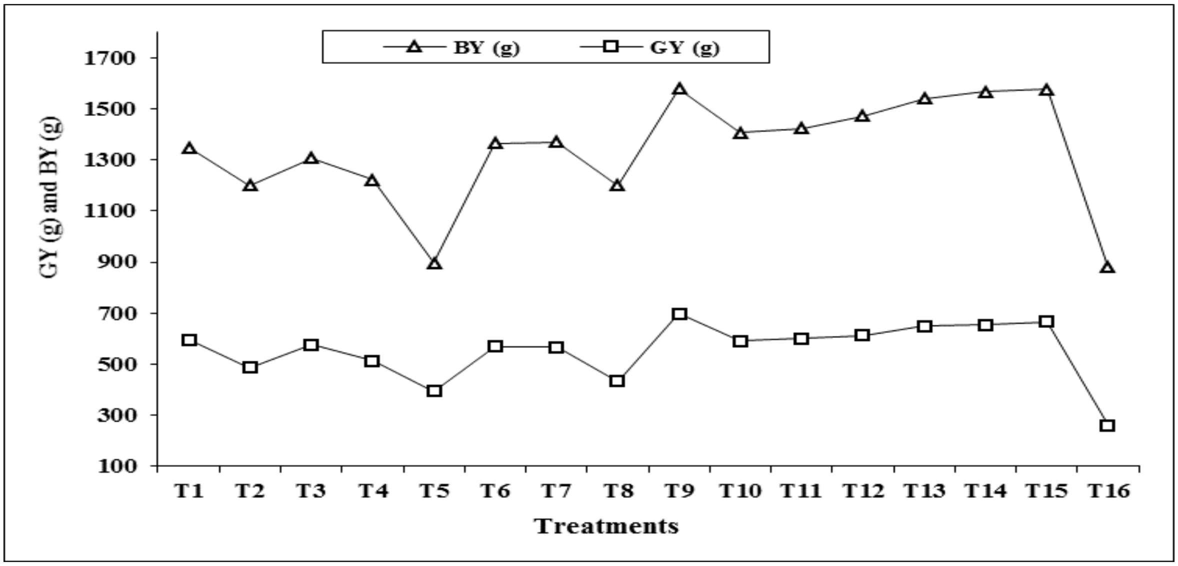

Figure 20. Effects of treatments on the biomass yield (BY) and grain yield (GY) of Wheat

4.2.7 Thousand Grain Weight

Grain weight of thousand seeds sampled at random from total grain harvest of the experimental plot was recorded on analytical balance expressed in gram. TGW is an important agronomic trait of which have positive correlation with grain yield. More the TGW ultimately enhanced grain yield will be obtained. Means concerning the comparative effect of bio slurry and compost with different levels of inorganic fertilizer on TGW is presented in Figure 21, Appendix 8 and Appendix 10k).

Means concerning the comparative effect of bio slurry and compost along with different levels of inorganic fertilizers on TGW is explored by Figure 21. Based on the result of variance analysis, 1000 grain weight of the tested crop was significant at 0.1 % probability level ($P<0.001$). In the application of dry matter bio slurry options, the highest TGW (41.33 gm^{-2}) was obtained from the rate of 32 N & 23 kg P ha^{-1} in T2 followed by 40.33 and 40.0 gm^{-2} TGW resulted from 96 N & 69 kg P ha^{-1} in T3 and 64 N & 46 kg P ha^{-1} in T1, respectively. Here, it can be concluded that using the minimum rate is better than the other two options to improve TGW of wheat in the study area otherwise, using the two indicated dry matter bio slurry option is not economical. Regarding the effect of dry matter compost application on the TGW, the highest TGW was registered from the application of compost 96 N & 69 kg P ha^{-1} in T6 that resulted 42.67 gm^{-2} followed by 42 and 40.67 gm^{-2} obtained from the application of compost 64 N & 46 P kg ha^{-1} and 32 N & 23 kg P ha^{-1} in T4 and T5, respectively. Concerning, the application of inorganic fertilizers, the maximum TGW (43.33 gm^{-2}) was obtained from the 96 N & 69 kg P ha^{-1} in T9 followed by 42.33 and 40 gm^{-2} that obtained from 64 N & 46 kg P ha^{-1} and 32 N & 23 kg P ha^{-1} in T7 and T8 respectively. Therefore, using the maximum rate of inorganic fertilizer to increase TGW of the wheat in the study area is the best option.

Relatively, the application of inorganic fertilizers along with dry matter compost in T15 resulted in the maximum TGW (45 gm^{-2}) followed by 43 gm^{-2} observed under T9 of inorganic fertilizers rate while 1000 grain weight value was comparatively lower (40 gm^{-2}) under T1, T8 and T14. However, the lowest TGW value (38.67 gm^{-2}) was observed under the control field in T16 (Figure 21 and Appendix 8).

4.2.8 Harvest index

Harvest index (HI) was calculated as the ratio of grain yield to above ground dry biomass and significantly ($p<0.001$) affected by the amendments applied (Appendix 8). The maximum HI that obtained with the application of dry matter bio slurry was 44% in both T1 and T2 while the minimum HI was recorded in T3. This result indicates that using the minimum rate of dry matter bio slurry as indicated in Table 1 is recommended to get more HI value in the study area. The maximum value of HI gained as a result of compost application was 43.67 % in T5 followed by 42 and 41.67 in T4 and T6 respectively.

Comparatively, the application of inorganic fertilizers at the rate of 96 N & 69 kg P ha^{-1} in T9 resulted in the maximum HI (44.3 %) and the second HI value (44%) was recorded with the application of dry matter bio slurry in T1 while the minimum value of HI (29.3%) was obtained from the control field in T16 (Figure 21 and Appendix 8).

Most of the indices obtained due to different combinations of organic and inorganic fertilizers rates ranged from 36 to 42%, which was in line with that of Mengel and Kirkby (1996), who reported that harvest indices of modern wheat cultivars normally range from 35 to 40 %.

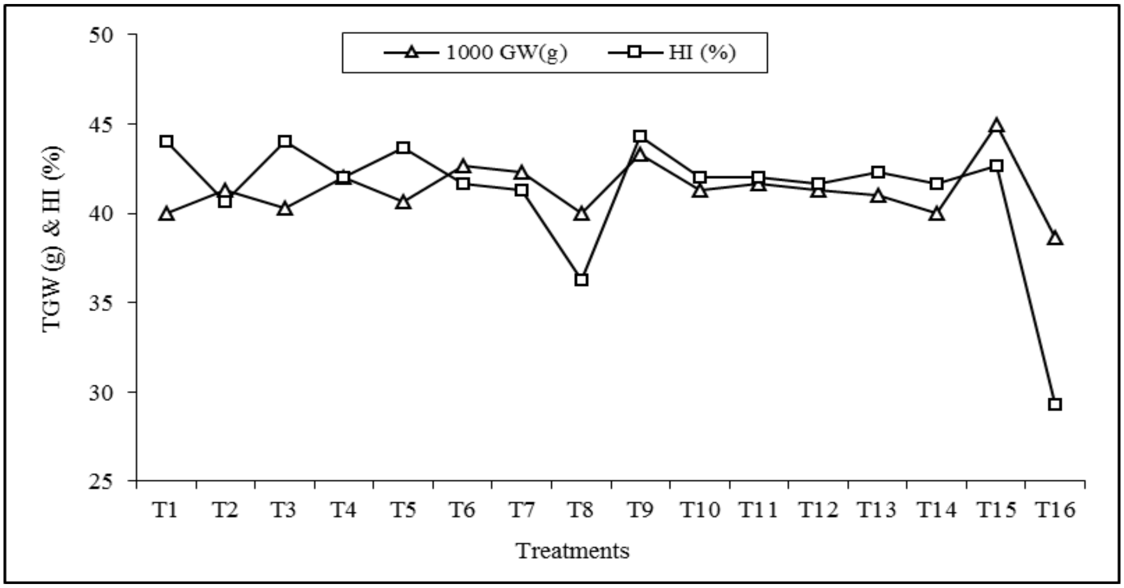

Figure 21. Effects of amendments on the 1000 grain weight and harvest index of Wheat

4.2.9 Correlation among agronomic traits of bread wheat

Correlation analysis between yield related traits and grain yield is presented in Table 4. The correlation analyses revealed that, there was a significant ($P < 0.001$) positive correlation between grain yield and yield related traits of bread wheat. Grain yield was significantly and positively correlated with plant height (r = 0.808**), spike length (r = 0.779**), numbers of spikelet spike^{-1} (r = 0.871**), numbers of tillers (r= 0.850**), biomass yield (r = 0.952**), 1000 grain weight (r = 0.496**) and harvest index (r = 0.731**).

Similar research findings also indicated that grain yield is positively correlated with biomass, spike length, number of productive tillers and plant heights of barley and wheat (Getachew and Taye, 2005).

Table 4. Pearson's correlation matrix among yield traits and grain yield of bread wheat

	PH (cm)	SL (cm)	SPS (No.)	TPP (No.)	BY (Qt/ha))	GY (Qt/ha)	TGW (g)	HI (%)
PH (cm)	**1.00**							
SL (cm)	.879**	**1.00**						
SPS (No.)	.839**	.821**	**1.00**					
TPP (No.)	.838**	.796**	.783**	**1.00**				
BY (Qt/ha)	.832**	.819**	.877**	.853**	**1.00**			
GY (Qt/ha)	.808**	.779**	.871**	.850**	.952**	**1.00**		
TGW (g)	.430**	.520**	.488**	.316*	.468**	.496**	**1.00**	
HI (%)	.449**	.408**	.554**	.496**	.496**	.731**	.389**	**1.00**

*PH= Plant Height; SL= Spike Length; NSPS= Spikelet per Spikes; NTPP= Tillers per Plant; BY= Biomass Yield; GY= Grain Yield; TGW= 1000 Grain Weight; HI= Harvest Index; Qt/ha: Quintal per hectare; ** and * indicate significant at P < 0.01 and P < 0.05 level, respectively*

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The test crop used in the experimental plots was improved wheat variety (Pica flora), which was widely adopted and produced by the smallholder's farmers in the study area. Solo and combined application of dry matter bio slurry, compost and inorganic fertilizers were applied as integrated soil fertility amendment options. The design was randomized complete block with three replication. Surface soil samples (0-20 cm depth) were collected before and after amendment to determine the soil fertility status of the study area. Similarly, relevant agronomic genotypes were recorded from the experimental plots to examine the improvement of wheat productivity as a result of soil amendment options.

The lowest value of bulk density (1.40 g/cm^3), the highest organic carbon (1.41 %), total N (0.13 %), available P (41.82 mg kg^{-1}), available K (3.13 mg kg^{-1}) and exchangeable Ca (19.65 cmol (+) kg^{-1}), were obtained from the solo application of dry matter compost at the rate of 96 N & 69 P kg ha^{-1} in T6. Exchangeable Mg (13.2 cmol (+) kg^{-1}) was obtained from solo application of dry matter compost at the rate of 64 N & 46 P kg ha^{-1} in T4 while the highest values of exchangeable Na (0.34 cmol (+) kg^{-1}) was observed in the combined application of dry matter compost along with inorganic fertilizers at the rate of 63.7 N & 46 kg P ha^{-1} plus 93 N & 46 kg P ha^{-1} in T12 respectively. From the observed results, it can be concluded that, application of dry matter compost showed a remarkable result as a meanse of integrated soil fertility management option but the difference was statistically insignificant.

The selected agronomic genotypes were measured, recorded and analyzed in the course the experiment to evaluate the productivity of bread wheat as a result of soil fertility amendment options. The result revealed that there was a significant difference ($P<0.001$) in all the agronomic genotypes or traits measured in test crop. The highest yield traits of wheat (plant height, spike length, spikelet spike^{-1} and TGW,) were obtained from the application of dry matter compost at the rate of 64.4 N & 46 kg P ha^{-1} along with inorganic fertilizer at the rate of 98.5 N & 46 kg P ha^{-1} in T15.

The grain yield of bread wheat under 96 N and 64 kg P ha^{-1} in T9 was highest (696.67 gm^{-2} or 69.67 Qt/ha) among the applications and followed by grain yield of 666.67 gm^{-2} or 66.67 Qt/ha recorded in the application of compost along with inorganic fertilizers in T15. Similarly, the highest dry biomass yield (1580 gm^{-2}) was obtained due to the application of inorganic fertilizer in T9 followed by the application of compost along with inorganic fertilizer in T15 that resulted 1576.7 gm^{-2} or 157.67 Qt/ha while the lowest dry biomass yield (880 gm^{-2} or 88 Qt/ha) was obtained from the control field in T16. This shows that application of inorganic fertilizer at the rate of 96 N and 64 kg P ha^{-1} is the optimum rate for the productivity of bread in the study area. However, the use of organic fertilizer has multiple effects on improving soil and water resources. It enhances not only soil fertility status by the slow release of nutrients but also conserves soil moisture and protects soil from erosion. Thus, the effects of dry matter compost and bio slurry are not as immediate as inorganic nutrient sources, but their effects are long-lasting and sustainable.

Therefore, it can be concluded that solo application of dry matter compost can be an alternative to soil fertility improvement while combined application of dry matter compost along with inorganic fertilizers can be an option for wheat production in the study area. The results of this experiment are expected to be reproducible in similar agro-ecologies and farming systems of the country.

5.2 Recommendation

It is known that the government of Ethiopia was formulated different policies to maintain soil fertility status and improve crop productivity. In spite of its efforts, till crop productivity is greatly troubled by insufficient application of crop specific and site demanded soil fertility amendment options. In line with this, the following recommendation were forwarded to strengthen those efforts so far on practices:

- For resource limited stallholders' farmers in the central highlands of Ethiopia, the combined application of dry matter compost and other organic resources along with inorganic fertilizers is indispensable for maintaining soil fertility status and improving crop productivity.
- The highest application of inorganic fertilizers at the rate of 96 N & 69 P kg ha^{-1} tested in this study gave promisingly highest grain yield, biomass yield and harvest indexes. Thus, inorganic fertilizers should be evaluated at higher rates than blanket application used before irrespective of soil types and agro-ecology. Nevertheless, from organic agriculture points of view that conserves the soil fertility and sustainable productivity, using compost along with inorganic fertilizer regarding of soil nutrient availability and agro ecological aspect have to be applied.
- A detailed and comprehensive parcel based soil fertility status data and map have to be develop to tailoring fertilizer recommendations to specific soil fertility conditions.
- This experiment should be continued for some more years to ascertain the long term effects soil fertility amendments on the physic-chemical properties of the soil and crop yields.

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APPENDIX

Appendix 1. Monthly and yearly total rainfall (mm) at the of the study area (1964-2014)

Year	*Jan*	*Feb*	*Mar*	*Apr.*	*May.*	*June*	*July*	*Aug.*	*Sep.*	*Oct.*	*Nov.*	*Dec.*	*Total*	*Mean*
1965	*27.7*	*0*	*55.3*	*19.2*	*0*	*25.4*	*237*	*114.4*	*75.2*	*50.3*	*0*	*0*	*604.5*	*50.3*
1966	*0*	*95.6*	*10*	*113.2*	*0*	*72.4*	*167*	*354.6*	*88.3*	*26.6*	*0*	*0*	*928*	*72.3*
1967	*0*	*0*	*42.3*	*17.4*	*98.7*	*58.2*	*246.7*	*213.5*	*91.5*	*18.2*	*96.6*	*0*	*883.1*	*73.5*
1968	*3.6*	*98.6*	*6.3*	*105.5*	*0*	*77*	*145.8*	*96.5*	*142*	*0*	*4.5*	*0*	*679.8*	*56.6*
1969	*19.8*	*67.8*	*3.6*	*62.5*	*68.5*	*137.9*	*189.9*	*230.2*	*76.4*	*0*	*4*	*0*	*893.3*	*74.4*
1970	*43.2*	*39.4*	*43*	*29.6*	*32.7*	*36.3*	*261*	*261.8*	*94.7*	*13.3*	*0*	*0*	*855*	*71.2*
1971	*1.4*	*0*	*7.8*	*22.7*	*80.6*	*133.4*	*203.6*	*255.8*	*91.6*	*1.6*	*0*	*0*	*798.5*	*66.5*
1972	*0*	*136.7*	*52.8*	*50.3*	*31.9*	*77.5*	*209.4*	*181.4*	*74.6*	*4.5*	*12.2*	*4.2*	*835.5*	*69.6*
1973	*0*	*0*	*0*	*3.2*	*43.3*	*78.1*	*214.6*	*182.8*	*127.8*	*27.8*	*0*	*0*	*647.6*	*53.9*
1974	*0*	*19.4*	*130.9*	*0*	*62.1*	*84.2*	*215*	*160.1*	*148*	*0*	*0*	*0.4*	*820.1*	*68.3*
1975	*0*	*1.7*	*10.6*	*67.3*	*32.5*	*154.2*	*270*	*171.1*	*77.1*	*19.4*	*0*	*0.8*	*804.7*	*67*
1976	*0*	*0.2*	*44.9*	*106*	*83.5*	*85.5*	*239.3*	*236.4*	*81.3*	*3.2*	*52.4*	*3*	*935.7*	*77.9*
1977	*55.8*	*0.2*	*44.9*	*127.7*	*48.5*	*91.6*	*216.4*	*103.9*	*79.9*	*112.7*	*3.9*	*0*	*885.5*	*73.7*
1978	*2.4*	*18.8*	*10*	*82.9*	*48.5*	*91.6*	*239.3*	*215.1*	*81.3*	*3.2*	*0*	*0*	*793.1*	*66*
1979	*49.7*	*5.5*	*75.8*	*8.8*	*97.1*	*63.4*	*236.6*	*136.9*	*68.8*	*11.6*	*0*	*0*	*752.2*	*72.6*
1980	*26.1*	*13.2*	*25.3*	*11.9*	*47.9*	*65.7*	*252.7*	*195.9*	*49*	*19.5*	*0.9*	*0*	*728.1*	*60.7*
1981	*0*	*31.9*	*229.2*	*76.1*	*26.2*	*36*	*227.4*	*171.3*	*122.5*	*0*	*0*	*3.3*	*926.9*	*77.2*
1982	*17.8*	*60.5*	*51*	*31.1*	*0*	*84*	*121.3*	*157.1*	*72.9*	*121.9*	*21.9*	*0*	*739.5*	*61.6*
1983	*0*	*13*	*40.8*	*41.7*	*149.6*	*122.7*	*113.4*	*327.8*	*59.5*	*19*	*0*	*0.7*	*877.5*	*73.1*
1984	*0*	*11*	*38.6*	*0*	*131.6*	*91.9*	*242*	*213*	*84.4*	*0*	*0*	*0*	*806.7*	*67.2*
1985	*0*	*0*	*10.2*	*83.6*	*70.3*	*44.5*	*324*	*286.7*	*79.5*	*2.2*	*0*	*0*	*903.2*	*75.2*
1986	*0*	*23.6*	*51.7*	*141.6*	*72.4*	*166.8*	*142*	*152.5*	*90.1*	*3.2*	*0*	*0*	*844.7*	*70.3*
1987	*0*	*25.6*	*221.9*	*97.2*	*182.2*	*74.2*	*93.4*	*159.5*	*36.2*	*4.2*	*0*	*0*	*895.4*	*74.6*
1988	*8.3*	*37.6*	*2.1*	*52.9*	*22.8*	*121.8*	*155.3*	*245*	*190.4*	*16.7*	*0*	*0*	*852.9*	*71*
1989	*0*	*24.3*	*80.2*	*99.4*	*3.4*	*61.9*	*222.5*	*202.5*	*103.3*	*27.4*	*0*	*12.1*	*836.7*	*69.7*
1990	*0*	*143.9*	*60.5*	*75.7*	*28.1*	*61.8*	*208.6*	*146*	*141.6*	*0.5*	*0*	*0*	*966.7*	*72.2*
1991	*0.3*	*37.6*	*54.3*	*7.9*	*1.9*	*47.2*	*169.7*	*191.5*	*50.1*	*4.6*	*0*	*7.2*	*572.3*	*47.6*
1992	*11*	*98.5*	*4.7*	*37*	*9.9*	*78.7*	*289.5*	*251*	*118.9*	*23.8*	*6.7*	*0.9*	*940.6*	*78.3*
1993	*1.8*	*52.8*	*0*	*96.9*	*37.6*	*177.7*	*184*	*213.2*	*117.7*	*3.2*	*0*	*0.2*	*825.2*	*68.7*

1994	*0*	*0*	*17.5*	*53.6*	*69.5*	*95.9*	*257.5*	*158.7*	*107.6*	*0*	*14*	*0*	*774.3*	*64.5*
1995	*0*	*18.3*	*10.8*	*75.7*	*9.2*	*41.4*	*208*	*185.8*	*100.6*	*0*	*0*	*0*	*652.8*	*54.4*
1996	*32*	*0*	*70.5*	*38.8*	*70*	*206.6*	*298.2*	*173.4*	*53.2*	*0*	*5.2*	*0*	*949.9*	*79.1*
1997	*43.1*	*0*	*13.8*	*54.1*	*3.1*	*71.6*	*223.2*	*184.8*	*52*	*42.7*	*16.3*	*0*	*704.7*	*58.7*
1998	*15.4*	*56*	*16.2*	*54.5*	*60.7*	*77.9*	*198.5*	*322.8*	*91.1*	*73.1*	*0*	*0*	*966.2*	*80.5*
1999	*0*	*0*	*28.3*	*1*	*15*	*134.3*	*236.6*	*279.6*	*54.1*	*59.6*	*0*	*0*	*808.5*	*67.3*
2000	*0*	*9.1*	*20.5*	*49.2*	*69.3*	*52.1*	*185.3*	*210.1*	*115.7*	*26.2*	*37.2*	*2.2*	*767.7*	*63.9*
2001	*0*	*9.1*	*172.4*	*25*	*106.1*	*55*	*308.2*	*116.8*	*48.2*	*2.1*	*0*	*0*	*842.9*	*70.2*
1002	*8.4*	*7.6*	*43.2*	*33.3*	*20.6*	*161.7*	*214.8*	*166.6*	*76.2*	*0.3*	*0*	*12.9*	*745.6*	*62.1*
2003	*26.8*	*52.9*	*58.1*	*53.7*	*12.3*	*84.8*	*295.7*	*347.4*	*45.2*	*0*	*0.1*	*56.5*	*1033.5*	*86.1*
2004	*22.2*	*6.7*	*52.8*	*89.3*	*25.5*	*141.1*	*168.8*	*224.5*	*76.3*	*12.4*	*6.8*	*0*	*826.4*	*68.8*
2005	*34.7*	*0*	*95.5*	*83.4*	*57.4*	*103.3*	*179.9*	*138.2*	*129.3*	*0*	*6.7*	*0*	*828.4*	*69*
2006	*2.1*	*52.9*	*76*	*63.8*	*83.9*	*121.3*	*239.5*	*142.2*	*97.9*	*61.9*	*0*	*11.9*	*953.4*	*79.4*
2007	*9.7*	*8.7*	*32.2*	*48.6*	*65.5*	*68*	*210.7*	*173.1*	*174.9*	*11.3*	*3.3*	*0*	*806*	*67.1*
2008	*0*	*0*	*0*	*50.4*	*51.4*	*74.8*	*173.7*	*249.2*	*144.6*	*7.1*	*60.8*	*0*	*812*	*67.6*
2009	*20.2*	*0*	*82*	*60.4*	*76.8*	*64.9*	*178.8*	*152.9*	*70.4*	*45.3*	*1*	*7.6*	*760.3*	*63.3*
2010	*0*	*34.5*	*71.7*	*139.8*	*24.6*	*111*	*155.9*	*104.1*	*174.9*	*12.4*	*6.7*	*0*	*835.6*	*69.6*
2011	*0.2*	*0*	*106.3*	*17*	*112.5*	*29.2*	*134.6*	*241.7*	*82.6*	*0*	*0*	*0*	*724.1*	*60.3*
2012	*0*	*0*	*26.2*	*53.8*	*18*	*71.4*	*197.4*	*256.5*	*103*	*0*	*0*	*0*	*726.3*	*60.5*
2013	*0*	*0*	*41.1*	*78.3*	*56.9*	*121.2*	*219.7*	*141*	*64.1*	*16*	*0*	*0*	*738.3*	*61.5*
2014	*22.2*	*6.7*	*52.8*	*89.3*	*25.5*	*141.1*	*168.8*	*224.5*	*76.3*	*12.4*	*6.8*	*0*	*826.4*	*68.8*
Mean	*17.1*	*18.348*	*19.306*	*19.724*	*19.792*	*19.182*	*18.28*	*18.138*	*18.106*	*17.35*	*16.362*	*16.546*	*216.7*	*18*

Appendix 2. Monthly and yearly total rainfall (mm) of the study area (1964-2014)

Years	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total	Mean
1965	15.6	14.5	17.2	18.4	17.6	17.1	14.3	14.1	14.6	14.7	14.5	14.3	186.9	15.5
1966	15.4	14.7	16.2	16.6	19	17.9	16	15.9	16.4	17.2	14.3	15	194.9	16.2
1967	16.6	16.9	17.2	16.9	16.6	16.5	13.8	12.8	13.1	13.7	12.9	13.1	180.1	15
1968	13	12.5	13.3	12.9	14.6	14	13	14.5	15.6	16.8	16.3	15.6	172.1	14.3
1969	16.2	15.7	15.9	16.1	15.8	15.2	15	15.2	16	15.7	15.8	14	186.6	15.5
1970	15.6	16.5	14.5	16.3	17.7	16.6	15.8	15.7	16.4	16.8	16	15.9	193.8	16
1971	15.5	16.5	16	16.7	17.6	16.3	15.5	15.8	16.5	17.6	16.3	15.7	194	16.1
1972	17	16	16.9	16.8	17.5	16.9	16.2	17	17.3	17.3	18	16.8	203.7	16.9
1973	17.4	20.4	18	18.4	18.2	15.4	19.1	19.1	17.8	16.3	15.4	13	208.3	17.3
1974	20.1	20.5	19.2	20.9	20.4	19	18.1	18.1	17.7	18.4	16.4	16.6	225.4	18.7
1975	16.6	20.7	22	20.4	20.5	19.9	18.4	17.6	18.3	16.3	15.7	16.2	222.6	18.5
1976	16.4	19.3	19.3	18.9	17.6	19.6	20	19.1	18.3	17.8	17.2	16.5	220	18.3
1977	18.6	19.5	19.3	19.1	19.6	20.1	18.8	17.3	16.7	18.5	15.9	15.2	218.6	18.2
1978	17.9	18.2	18	19	19.1	19.3	18.7	18.9	19.1	17.9	17.3	15.1	218.5	18.2
1979	14	15.1	17.8	18.9	18.6	18.1	16.6	18.8	18.3	17.9	17	18.1	209.2	17.4
1980	18	20.2	21.6	21.7	21.6	20.4	18.9	18.8	18.6	17.6	17	15.9	230.3	19.1
1981	18.1	18.9	19.8	19.3	19.8	20.2	18.8	18.3	18.4	16.4	16	15.9	219.9	18.3
1982	17.9	19.3	19.3	20	20.4	19.4	18.5	18.1	17.6	16.4	17	17	221.4	18.4
1983	16.8	19.6	21.4	21.7	21	19.8	19.8	18.3	18.7	17.5	14.9	15.5	224.8	18.7
1984	16	16.3	19.9	21.2	20.6	19.5	15.7	18.7	18.3	16.5	17.1	16.5	216.3	18
1985	17.6	15.6	21.2	20.1	20	19.5	17.5	18	17.9	16.7	16.4	16.4	216.9	18
1986	16.5	19.9	19.7	20.5	20.3	19.1	20.2	19.3	17	17	17	17.3	222.6	18.5
1987	18.1	19.2	20.5	19.5	20.2	19.7	18.8	19	19.4	18.7	17.1	17.5	229.1	10.9
1988	18.6	20.6	21	20.8	21	20.1	18.8	18.6	18.4	17.2	14.5	15.6	225.2	18.7
1989	16	17.9	19.8	19.5	19.4	19.5	18.8	18.7	18.3	16.6	16.1	17.8	218.4	18.2
1990	17.1	20	19.1	19.4	19.9	19.3	19	18.9	18.6	16.7	16.8	16.1	220.9	18.4
1991	18.7	19.6	20.4	20.8	21.5	21	18.8	18.6	18.7	18.6	16.4	16.2	229.3	19.5
1992	18	19.4	21	21.2	21.9	20.2	18.5	18.4	17.8	17.3	16.2	17.4	227.3	18.9

1993	*17.8*	*18.2*	*18.9*	*20.5*	*20*	*19.3*	*18.9*	*18.8*	*18.7*	*17.6*	*16.4*	*16.2*	*221.3*	*18.4*
1994	*17.4*	*19*	*20.9*	*21.3*	*21.5*	*20*	*19.1*	*18.4*	*18*	*17*	*16.9*	*16.1*	*225.6*	*18.8*
1995	*17.1*	*19.7*	*20.4*	*20.8*	*21.7*	*20.5*	*18.7*	*18.8*	*17.8*	*17.7*	*16.5*	*18.6*	*228.3*	*19*
1996	*18.6*	*19.5*	*21.1*	*20.5*	*20.3*	*18.7*	*18.7*	*19.8*	*18.8*	*17.3*	*16.3*	*16.3*	*227.4*	*18.9*
1997	*18.5*	*19.7*	*21*	*20.4*	*21.7*	*20.8*	*19.4*	*19*	*19.5*	*19*	*18.6*	*21*	*240.6*	*20*
1998	*18.6*	*20.6*	*21.3*	*22.2*	*21.6*	*21.8*	*19.5*	*21.9*	*19*	*18.4*	*16.7*	*15.1*	*236.7*	*19.7*
1999	*17.3*	*18.2*	*19.8*	*21.1*	*21*	*19.9*	*19.9*	*19.1*	*18.8*	*17.6*	*15.3*	*15.5*	*223.5*	*18.6*
2000	*16.7*	*17.5*	*19.5*	*22.2*	*20.7*	*18.9*	*18.8*	*18.1*	*18.6*	*17.2*	*16.4*	*16*	*220.6*	*18.3*
2001	*16.9*	*18.8*	*19.8*	*19.9*	*19.8*	*18.6*	*18.9*	*18.8*	*18.9*	*17.3*	*16.4*	*15.6*	*187.1*	*18.7*
2002	*17.3*	*19.9*	*19.6*	*20.9*	*21.1*	*20.6*	*20.6*	*18.6*	*19.7*	*17.4*	*16.6*	*16.7*	*229*	*19*
2003	*16.8*	*19.6*	*21.4*	*21.7*	*21*	*19.8*	*19.8*	*18.3*	*18.7*	*17.5*	*14.9*	*15.5*	*224.8*	*18.7*
2004	*15.4*	*14.7*	*16.2*	*16.6*	*19*	*17.9*	*16*	*15.9*	*16.4*	*17.2*	*14.3*	*15*	*194.9*	*16.2*
2005	*16.6*	*16.9*	*17.1*	*16.5*	*20.1*	*19.3*	*18.3*	*19.1*	*20*	*17.2*	*16.6*	*16.2*	*163.3*	*18.1*
2006	*17.3*	*19.9*	*19.6*	*24.3*	*20.5*	*19.5*	*18.7*	*18.5*	*17*	*18.6*	*17.6*	*17*	*228.5*	*19*
2007	*18.3*	*19.6*	*20.4*	*19.9*	*17.3*	*20.3*	*19.3*	*18.8*	*19.7*	*17.6*	*16.9*	*16.8*	*225.9*	*18.8*
2008	*18.3*	*18.9*	*19.7*	*22*	*21.5*	*20.3*	*19.6*	*18.7*	*19.8*	*18*	*15.9*	*15.6*	*228.3*	*19*
2009	*17.3*	*18.7*	*21.5*	*19.9*	*21.4*	*21.5*	*20.3*	*19.8*	*19.3*	*17.9*	*16.4*	*17.4*	*231.9*	*19.3*
2010	*17.3*	*19.9*	*19.6*	*20.9*	*21.1*	*20.6*	*20.6*	*18.6*	*19.7*	*17.4*	*16.6*	*16.7*	*229*	*19*
2011	*15.7*	*18.7*	*19.9*	*20.9*	*19.1*	*19.4*	*20.2*	*19.9*	*19.9*	*17*	*17.7*	*16.4*	*224.8*	*18.7*
2012	*16.7*	*17.8*	*19.5*	*20.4*	*19.3*	*20.9*	*19.2*	*18.5*	*19*	*16.5*	*16.8*	*16.3*	*221.4*	*18.4*
2013	*17.2*	*18.4*	*21.6*	*20.9*	*20.2*	*20.1*	*18.7*	*18.9*	*18.7*	*21*	*18.2*	*30.1*	*244*	*20.3*
2014	*18.5*	*19.7*	*21*	*20.4*	*21.7*	*20.8*	*19.4*	*19*	*19.5*	*19*	*18.6*	*21*	*240.6*	*20*
Mean	*10.118*	*26.398*	*49.932*	*57.646*	*50.912*	*90.604*	*209.824*	*200.428*	*93.056*	*18.428*	*7.36*	*2.478*	*818.3*	*68.1*

Appendix 3. Effect of alternative soil fertility amendment options on soil physical properties after treatment in Ada’a district, central highland of Ethiopia

Treatment	*Soil Physical Properties*				
	Clay	*Silt*	*Sand*	*Textural Class*	*BD (g/cm^3)*
		(%)			
T1	*63*	*26*	*11*	*Clay*	1.45
T2	*62*	*26*	*12*	*Clay*	1.46
T3	*63*	*26*	*11*	*Clay*	1.44
T4	*63*	*25*	*12*	*Clay*	1.41
T5	*64*	*25*	*11*	*Clay*	1.42
T6	*63*	*25.8*	*11.2*	*Clay*	1.4
T7	*62*	*25*	*13*	*Clay*	1.48
T8	*62*	*26*	*12*	*Clay*	1.47
T9	*61.6*	*26.3*	*12.1*	*Clay*	1.49
T10	*63*	*25*	*12*	*Clay*	1.46
T11	*63*	*25*	*12*	*Clay*	1.45
T12	*62.4*	*26.6*	*11*	*Clay*	1.46
T13	*63.2*	*24.9*	*11.9*	*Clay*	1.44
T14	*62.5*	*25.5*	*12*	*Clay*	1.43
T15	*63*	*26*	*11*	*Clay*	1.42
T16	*62*	*26*	*12*	*Clay*	1.48
$\bar{X}$	*62.67*	*25.63*	*11.70*	-	*1.45*
S	*0.62*	*0.56*	*0.59*	-	*0.03*
CV (%)	*1.00*	*2.20*	*5.04*	-	*1.83*
p	*NS*	*NS*	*NS*	-	*NS*

BD: Bulk Density; X^- : Mean; S: standard deviation; CV: Coefficient of variances; p: probability value; NS: not statistically significant level at P<0.05

Appendix 4. Effect of alternative soil fertility amendment options on soil pH, organic carbon, and organic matter in Ada'a district, central highland of Ethiopia

Treatment	Soil chemical Properties		
	pH (H_2O)	O.C (%)	OM (%)
T1	6.81	1.33	2.29
T2	6.8	1.32	2.28
T3	6.82	1.36	2.34
T4	6.83	1.40	2.41
T5	6.83	1.39	2.40
T6	6.84	1.41	2.43
T7	6.78	1.30	2.24
T8	6.79	1.31	2.26
T9	6.78	1.29	2.22
T10	6.79	1.34	2.31
T11	6.8	1.32	2.28
T12	6.8	1.35	2.33
T13	6.81	1.35	2.33
T14	6.82	1.38	2.38
T15	6.81	1.39	2.40
T16	6.8	1.32	2.28
$\bar{X}$	6.81	1.35	2.32
S	0.02	0.04	0.06
CV (%)	0.26	2.78	2.78
p- value	NS	NS	NS

X^-: Means; S: standard deviation; CV: Coefficient of Variance; NS: not statistically significant level at $P<0.05$

Appendix 5. Effect of amendments on Total Nitrogen, Carbon to Nitrogen ratios, Available Phosphorous and Potassium in Ada'a district, central highland of Ethiopia

Treatments	***Soil chemical Parameters***			
	T.N (%)	***C/N***	***Olsen P (mgkg^{-1})***	***Ava. K (mgkg^{-1})***
T1	*0.12*	*11.1*	*41.81*	*3.11*
T2	*0.11*	*12*	*41.8*	*3.12*
T3	*0.12*	*11.3*	*41.82*	*3.11*
T4	*0.13*	*10.8*	*41.83*	*3.12*
T5	*0.12*	*11.6*	*41.82*	*3.12*
T6	*0.13*	*10.8*	*41.9*	*3.13*
T7	*0.10*	*13*	*41.77*	*3.09*
T8	*0.11*	*11.9*	*41.8*	*3.1*
T9	*0.10*	*12.9*	*41.55*	*3.1*
T10	*0.11*	*12.2*	*41.5*	*3.06*
T11	*0.12*	*11*	*41.5*	*3.05*
T12	*0.12*	*11.3*	*41.79*	*3.07*
T13	*0.11*	*12.3*	*41.81*	*3.07*
T14	*0.12*	*11.5*	*41.7*	*3.09*
T15	*0.12*	*11.6*	*41.81*	*3.12*
T16	*0.11*	*12*	*41.8*	*3.1*
$\overline{\mathbf{X}}$	*0.12*	*11.7*	*41.75*	*3.10*
S	*0.01*	*0.7*	*0.12*	*0.02*
CV	*7.72*	*5.75*	*0.29*	*0.78*
p-value	*NS*	*NS*	*NS*	*NS*

X^{-}: mean; s: standard deviation; CV: coefficient of variance; NS: not statistically significant level at P<0.05

Appendix 6. Effect of amendments on Calcium, Magnesium, sodium, potassium, CEC and PBS in Ada’a district, central highlands of Ethiopia

Treatments	***Exchangeable bases***					
	Ca	***Mg***	***Na***	***K***	***CEC***	***%BS***
	cmol (+) kg^{-1}					
T1	*19.62*	*12.82*	*0.32*	*0.39*	*35.7*	*92.86*
T2	*19.61*	*12.97*	*0.32*	*0.38*	*36.1*	*92.19*
T3	*19.63*	*13.09*	*0.33*	*0.4*	*36.7*	*91.14*
T4	*19.64*	*13.25*	*0.32*	*0.41*	*37.6*	*89.41*
T5	*19.63*	*12.73*	*0.33*	*0.39*	*37.9*	*87.28*
T6	*19.65*	*12.78*	*0.33*	*0.42*	*37.6*	*88.24*
T7	*19.6*	*11.46*	*0.31*	*0.39*	*37.3*	*85.15*
T8	*19.6*	*11.5*	*0.31*	*0.4*	*37.4*	*85.05*
T9	*19.59*	*11.45*	*0.31*	*0.38*	*37.5*	*84.61*
T10	*19.57*	*11.67*	*0.32*	*0.37*	*37.4*	*85.37*
T11	*19.58*	*11.72*	*0.31*	*0.38*	*37.8*	*84.63*
T12	*19.56*	*11.78*	*0.34*	*0.36*	*37.7*	*84.99*
T13	*19.56*	*11.48*	*0.31*	*0.38*	*37.7*	*84.16*
T14	*19.62*	*12.23*	*0.32*	*0.4*	*37.8*	*86.16*
T15	*19.54*	*12.11*	*0.32*	*0.41*	*37.9*	*85.44*
T16	*19.52*	*11.44*	*0.32*	*0.38*	*36.4*	*86.98*
$\bar{X}$	*19.60*	*12.16*	*0.32*	*0.39*	*37.28*	*87.10*
S	*0.04*	*0.68*	*0.01*	*0.02*	*0.68*	*2.85*
CV (%)	*0.19*	*5.56*	*2.80*	*4.08*	*1.83*	*3.28*
p	*NS*	*NS*	*NS*	*NS*	*NS*	-

NS: not statistically significant level at P<0.05

Appendix 7. Effects of amendments on plant height, spike length, number of spikelet's per spike and numbers of productive tillers in Ada'a district, central highlands of Ethiopia

Treatments	*Agronomic Traits*			
	PH (cm)	*SL (cm)*	*NSPS*	*NTPP*
T1	*86*	*8*	*15.67*	*8.67*
T2	*80.67*	*7.33*	*16*	*6*
T3	*87*	*7.67*	*16.33*	*7.33*
T4	*86.33*	*8*	*16*	*6*
T5	*84.67*	*7*	*14.33*	*5.33*
T6	*87.67*	*8*	*16.33*	*6.67*
T7	*91.3*	*9*	*17*	*8.33*
T8	*80*	*7.33*	*14.67*	*5.67*
T9	*96*	*8.33*	*16.67*	*9*
T10	*98*	*9*	*17*	*9*
T11	*99*	*9*	*17*	*9*
T12	*102*	*9*	*17*	*9*
T13	*100*	*9*	*17*	*9*
T14	*101.67*	*9*	*18*	*9*
T15	*103.33*	*9.67*	*18*	*8.33*
T16	*78*	*6.67*	*13.67*	*5*
$\bar{X}$	*91.35*	*8.25*	*16.29*	*7.58*
S	*8.6*	*0.88*	*1.22*	*1.54*
CV (%)	*9.4*	*10.7*	*7.5*	*20.3*
p-value	*.000****	*.000****	*.000****	*.000****

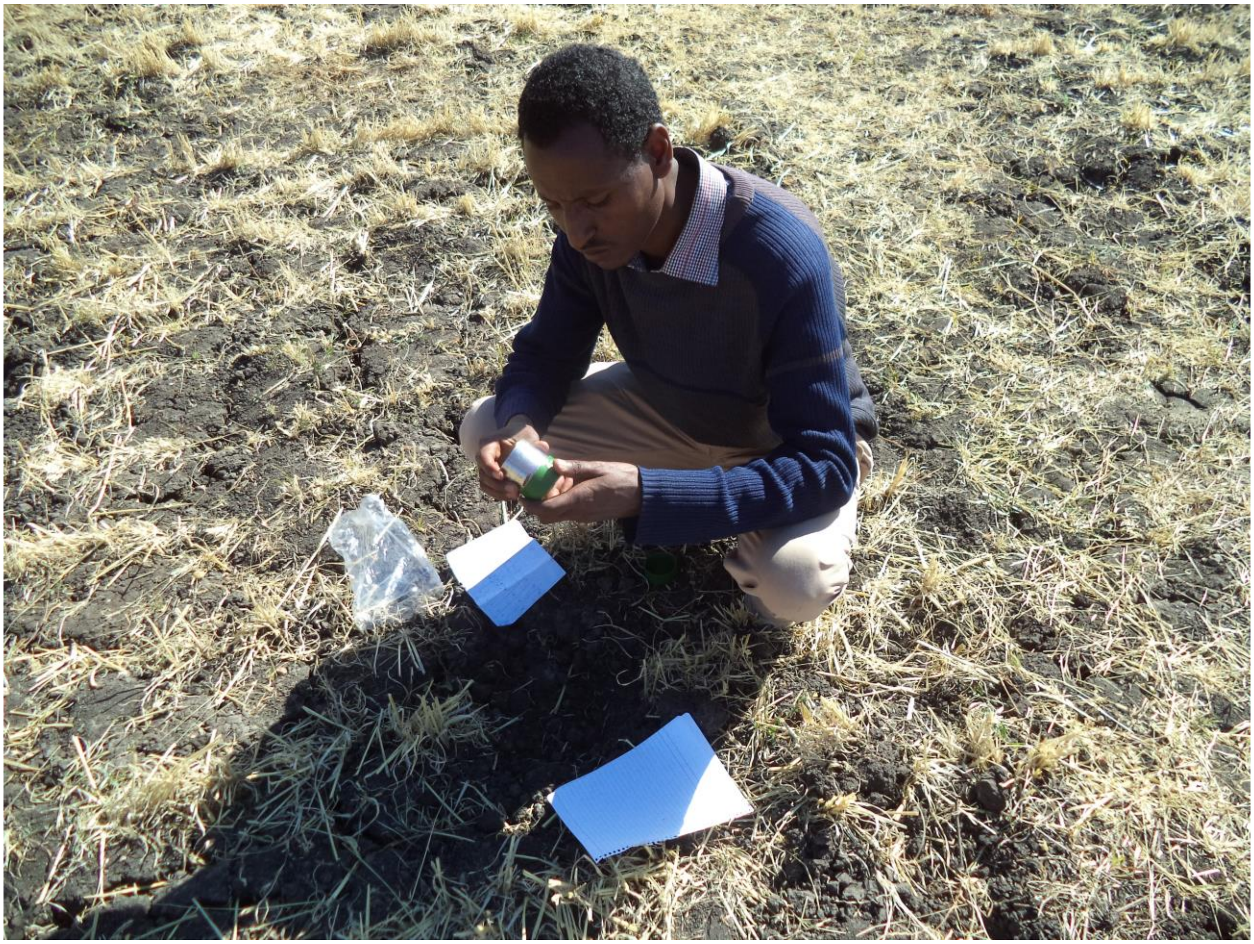
PH: Plant Height, SL: Spike Length; NSPS: Numbers of Spikelet per Spike; NTPP: Numbers of tillers per plant; $\bar{X}$ *: Mean; S: Standard Deviation; CV: Coefficient of Variances; *** = significant at* $p < 0.001$

Appendix 8. Effects of amendments on total biomass yield, grain yield, thousand grain weight and harvest index in Ada'a district, central highlands of Ethiopia

Amendments	**Agronomic Traits**			
	BY	**GY**	**1000 GW (g)**	**HI (%)**
	(Qt/ha)			
T1	135.00	59.67	40	44
T2	120.00	48.67	41.33	40.67
T3	130.67	57.67	40.33	44
T4	122.33	51.33	42	42
T5	89.67	39.33	40.67	43.67
T6	136.67	57.00	42.67	41.67
T7	137.00	56.67	42.33	41.3
T8	120.00	43.33	40	36.3
T9	158.00	69.67	43.33	44.3
T10	140.67	59.00	41.33	42
T11	142.33	60.00	41.67	42
T12	147.33	61.33	41.33	41.67
T13	154.00	65.00	41	42.33
T14	156.67	65.33	40	41.67
T15	157.67	66.67	45	42.67
T16	88.00	26.00	38.67	29.3
$\overline{X}$	133.50	55.42	41.3538	41.2218
S	21.202	11.240	1.52199	3.68161
CV (%)	15.9	11.40	1.52	3.68
p-value	.000***	.000***	.000***	.000***

BY: Biomass Yield; GY: Grain yield; 1000 GW: thousand grain weight; HI: Harvest Index; **X^-**: *mean; S: Standard Deviation; CV: Coefficient of Variances; *** = significant at $p < 0.001$.*

Appendix 9. Soil sampling (Bulk density)



Appendix 10.Yield and yield traits of bread wheat

Appendix 10a. Measuring of plant height (cm)

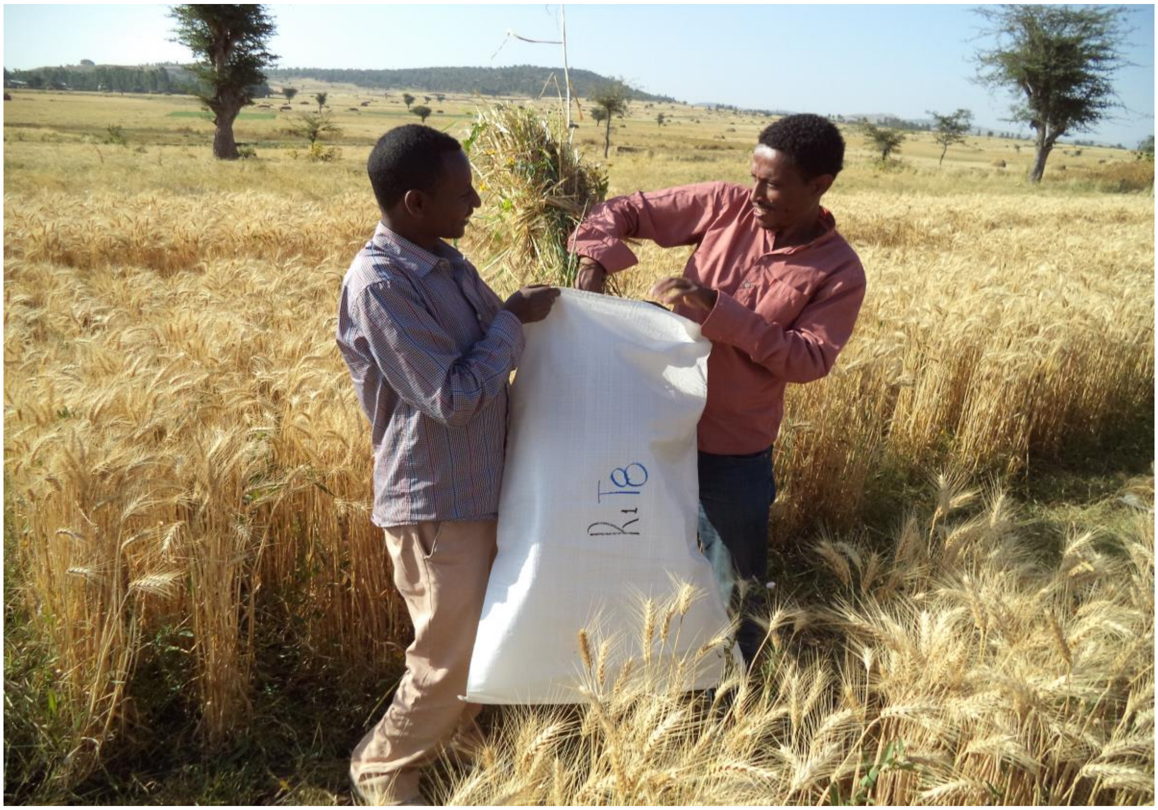
Appendix 10b.Measuring of spike length (cm)

Appendix 10c.Counting of numbers of productive tillers per plant (N<u>o</u>)

Appendix 10d. Counting of numbers of spikelet per spike (N<u>o</u>)

*Appendix 10e. Putting the metal quadrant to the center of the plot(1m*1m) for harvesting*

Appendix 10f. Putting the harvested wheat to the labeled sacks for drying



Appendix 10g. Total biomass yield in the sacks (grain yield plus biomass)

Appendix 10h. Separating the grain from the straw using wind

Appendix 10i. Putting the seeds in to the labeled kits

Appendix 10j. Labeled grain yield

Appendix 10k. Counting of thousand grain weight

11. Soil pH rating for 1: 2.5 soil to water ratio suspension

pH value	*Ratings*
< 4.5	*Very strongly acid*
4.5-5.2	*Strongly acid*
5.3-5.9	*Moderately acid*
6.0-6.6	*Slightly acid*
6.7-7.3	*Neutral*
7.4-8.0	*Moderately alkaline*
> 8.0	*Strongly alkaline*

Source: Tekalign (1991)

Appendix 12. Rating for bulk density

Bulk density (g/cm^3)	*Rating*
1.2	*Good*
1.4	*Dense*
1.6	*Very dense*

Source: Landon (1991)

Appendix 13. Rating for organic carbon (OC) and C/N ratios

**OC*	**C/N ratio*	*Rating*
>20	*>25*	*Very High*
10-20	*16-25*	*High*
4-10	*11-15*	*Medium*
2-4	*8-10*	*Low*
<2	*<8*	*Very Low*

*Source: *Landon (1991)*

Appendix 14. Ratings for organic matter (OM), total N and available P

OM (%)[a]	*Total N (%)*[b]	*Available P (mg kg^{-1})*[c]	*Rating*
> 5.17	*> 0.25*	*> 10*	*High*
2.59-5.17	*0.12-0.25*	*5-10*	*Medium*
0.86-2.59	*0.01-0.12*	*< 5*	*Low*
< 0.86	*< 0.01*	*Not Given*	*Very Low*

Source: [a]Tekalign (1991), [b]Berhanu (1980), [c]Olsen et al. (1954)

Appendix 15. Ratings for exchangeable basic cations, CEC and %BS

*Ca**	*Mg**	*K**	*Na**	*CEC**	*CEC***	*%BS*	*Rating*
Cmol (+) kg^{-1}							
> 20	*> 8*	*> 1.2*	*> 2*	*> 40*	*>40*	*> 80*	*Very high*
10-20	*3-8*	*0.6-1.2*	*0.7-2*	*25-40*	*25-45*	*60-80*	*High*
5-10	*1-3*	*0.3-0.6*	*0.3-0.7*	*12-25*	*15-25*	*40-60*	*Medium*
2-5	*0.3-1*	*0.2-0.3*	*0.1-0.3*	*6-12*	*5-15*	*20-40*	*Low*
< 2	*< 0.3*	*< 0.2*	*< 0.1*	*< 6*	*<5*	*< 20*	*Very Low*

*Source: * and **= FAO (2006) and Landon (1991) respectively,*