STUDYING THE INFLUENCE OF MANURING AND CROP ROTATION ON CROPS PRODUCTIVITY AND SOIL PROPERTIES

ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
ANRS-BoFED	Amhara National Regional State Bureau of Finance and Economic Development
BD	Bulk Density
$^{\circ}C$	Degree Celsius
CEC	Cation Exchange Capacity
cm	Centimeter
CSA	Central Statistical Authority
CV	Coefficient of Variation
EARO	Ethiopian Agricultural Research Organization
EIAR	Ethiopian Institute of Agricultural Research
FAO	Food and Agriculture Organization
FSB	Fresh Sesbania Biomass
FYM	Farmyard Manure
g	Gram
GM	Green Manure
GY	Grain Yield
ha	Hectare
K	Potassium
Kg	Kilogram
LSD	Least Significance Difference
m	Meter
masl	Meter Above Sea Level
N	Nitrogen
P	Phosphorus
OC	Organic Carbon
pH	Power of Hydrogen
PH	Plant Height

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t	Tone
RCBD	Randomize Complete Block Design
SAS	Statistical Analysis System
TSW	Thousand Seed Weight

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ABSTRACT

Soil nutrient depletion has been the greatest concern for decades for Ethiopian agriculture. The most important soil physico-chemical properties are below the critical level to support crop growth. Inappropriate crop and soil management practices are the causes for soil depletion. Overlaying of synthetic fertilizer, removal of crop residue, continuous cropping and low level of organic manure use are the deep-rooted challenges of the agro-ecosystem of the highlands of Ethiopia. Hence experiments were initiated with the aim of investigation of the effect of long-term organic fertilizer application and sound rotation pattern on the productivity of crops and soil quality parameters. Four levels of organic treatments and five levels of crop rotations were arranged factorially and laid out in Randomized Complete Block Design (RCBD) with four replications. The organic treatments include V1 = 0 t/ha farmyard manure (FYM); V2 = 2.5 t/ha fresh sesbania biomass (FSB); V3 = 5 t/ha FYM and V4 = 5 t/ha FYM + 2.5 t/ha FSB. Whereas the crop rotations were R1 = wheat-clover-potato; R2 = clover-wheat under sown lupine-potato; R3 = potato-clover-wheat; R4 = wheat under sown lupine-potato under sown lupine-wheat and R5 = lupine-potato under sown lupine-wheat. The rotation pattern of wheat-faba bean-potato and 1 t/ha FYM was also used as farmers practice without the factorial combination. Data of plant height and grain yield of wheat; marketable and unmarketable yield of potato and fresh and dry biomass yield of clover were recorded to measure the agronomic performance of each crop. In addition, the cation exchange capacity (CEC), soil reaction (pH), total nitrogen (N), available phosphorus (P), soil organic carbon (SOC) and bulk density of experimental soil were analyzed and recorded following the standard methods before commencing and at the end of the experiment. The data were subjected to analysis of variance (ANOVA) using General Linear Model (GLM) procedures. The experimental results showed that the types of preceding crops and the levels of organic treatments were greatly influenced the performance of each crop and physico-chemical properties of experimental soil. The productivity of potato, wheat and clover showed incredible variation in response to the variation of the organic treatments and crop rotation patterns. The yield of potato, wheat and clover were increased three to four times in response to sound rotation pattern and organic treatments compared to respective untreated check. Similarly, the organic carbon, cation exchange capacity, total nitrogen, phosphorus,

potassium, pH and bulk density of experimental soil were markedly improved in response to organic matter application and crop rotations. In general, maximum crop yield and soil quality improvement obtained at maximum level of organic treatments and sound rotation pattern. Hence it could be concluded that organic matter applications of 5 t/ha FYM + 2.5 t/ha FSB and respective sound rotation pattern of each crop be viewed an alternative soil fertility management options at Awi climatic and soil conditions.

CHAPTER 1. GENERAL INTRODUCTION AND METHODOLOGY

1.1 Background and Justification

Ethiopia is the second most populous country in Africa after Nigeria and its economy relays largely upon agriculture. The country is well known by having wide ranges of altitude from 110 m below sea level of Dalol Depression in Afar Region to 4533 meter above sea level of Semen Mountains in Amhara Region (UNICEF, 2016). Due to its high altitude variations, the country encompasses all kinds of climate, namely topical in lowlands, sub-tropical in medium highlands and temperate in the highlands, and thereby the country is endowed with all kinds of crops, animals and forest trees.

Agriculture is the main stay to Ethiopian population. The sector accounts 46.3% of the nation's Gross Domestic Product (GDP) and 83.9 % of exports. about 80% of the labor force engaged in the sector and remains a key source of economic growth (GTP, 2016). The country is endowed with a wider climatic and soil conditions that support growing of multiples of crop types. According to CSA (2016) different kinds of cereals, pulses, oil, horticulture and industrial crops are grown in the country. Cereals, pulses and oil crops cover about 95% of the total area of production (CSA, 2016). Cereals alone cover 75 % of the total area and out of which tef covers the largest area followed by maize, sorghum, wheat and barley, respectively. However, the productivity of these major food crops is very low, much below that of Sub-Saharan and world averages (GTP, 2016).

Although agriculture is the engine of economic growth of the country, the sector is highly constrained by multiples of factors such as a scarce and scant knowledge of improved practices, poor soil fertility management, luck of improved seeds, lack of irrigation facilities and limited capacity to respond to environmental shock (Tamene Lakew *et al.*, 2017). In addition, social factors such as persistent conflicts, the absence of strong institutions, ineffective policies, lack of incentives for professional workers, prevalence of diseases and insect pests, and inappropriate input and output markets are the causes for slow growth of the sector (Asenso and Jemaneh, 2014).

Currently, soil-related challenges become the fundamental problems for Ethiopian agriculture and are of a major reason for slow growth of food production. According to Elias Eyasu (2002), over 50 percent of the crop lands of the Ethiopian highlands are in an advanced stage of soil degradation and make crop production unsustainable. A continuous exploitative cropping, severe form of soil erosion, high levels of nutrient mining and poor soil fertilization efficiency are verified as the main causes of poor soil productivity and lower average yield across each crop (Elias Eyasu, 2002). Recent estimates using satellite imagery showed that problematic soil hotspots cover about 23% of the land area of the country (Yihnew Gebreselassie *et al.*, 2016). In the meantime, the average current soil loss rate is horrific and laying between 42 to 100 tons per hectare per year. Similarly, estimated soil nutrient losses for the highlands of Ethiopia are high, exceeding 122 kg N ha^{-1} yr^{-1}, 13 kg P ha^{-1} $yr^{-1}$and 82 kg K ha^{-1} yr^{-1} (Amare Haileslassie *et al.*, 2005). This leads to the decline of crop productivity between 0.2 and 1.8 percent per year (Hurni, 1993). Furthermore, Sutcliffe (2003) noted that if soil erosion in Ethiopia continues at current rates, over 6 million hectares of additional pasture and cropping land might become out of production by 2020. Similarly, about 40-75% of the world's agricultural land's productivity reduced due to land degradation (IFPRI, 2000).

Such a high level of soil degradation markedly influences the key soil properties that directly support the productivity of cultivated land. The biological, chemical and physical properties of soils are the three major types of soil quality indexes affected by improper crop and soil mismanagement practices. Of which, the biological properties of soils are the key properties that limit plant growth and productivity as the result of their degradation. According to Solomon Abate (1994), biological soil degradation is the process that leads to a decline of soil organic matter through mineralization, while by and large nothing is returned back to the soil as source of organic matter. Under normal condition, the majority of organic matter is concentrating near the soil surface in the form of decaying leaves and stems (Eswaran *et al.*, 1999). Soil and crop mismanagement on the topsoil results in a rapid decrease in soil organic matter levels and therefore causes a loss of food for soil microorganisms (Bezuayehu Tefera *et al.*, 2003). Once the organic matter layer is depleted, the structural stability as well as the chemical and physical properties of soils deteriorated seriously, which in turn results in the depletion of nutrients and diminishing soil productivity and ultimately crop yields. In addition, the declining of soil organic matter has a far-reaching effect on the important soil nutrients. According to Solomon (1994), the availability of nitrogen and phosphorous is largely dependent on the organic matter content of the soil, and nutrient contents of soils can be dropped from 20% to 7% in less than three years of continuous cultivation and poor soil fertility management strategies.

The second most important component of soil properties that determine soil and crop productivity is the soil chemical properties. The chemical properties of the soil directly influence the availability and quantity of plant nutrients that support crop growth. Crop and soil management directly influence the chemical properties of the soil, and unwise use of farm resources leads to acidification, leaching, salinization, a decrease in cation retention capacity and fertility depletion that limit most the productivity of agricultural lands. According to FAO, (2015), soil chemical properties are severely deteriorated in large areas of Sub-Sahara Africa (SSA) due to erosion, leaching, removal of crop-residues and cow dung, and continuous cultivation of the land without adequate fertilization. According to Stoorvogel and Smaling (1990), the highlands of Ethiopia has lost about 41 kg of N/ha from agricultural lands between 1982 and 1992. Furthermore, by the year 2000 other studies reported that nitrogen deficiencies in the Ethiopian highlands account over 100 kg/ha per year (Steinfeld, 1998). Similarly, Kejela Kuma (1992) found that the loss of nutrients from the eroded soil in a 100 ha catchment area of Anjeni was about 210 kg N, 680 kg P and 160 kg organic matter per hectare per year. The pH of the soil as one of the chemical properties of the soil has also big effect on soil and crop productivity. Gete Zeleke (2015) found that 40% of Ethiopian cultivated land classified as strongly acidic with the pH range of 4.5-5.5. Soils with a low pH can fix nutrients such as P, Mo and Ca and making unavailable to plants. On the contrary, however, high soil acidity enhances the solubility and availability of Cu, Mn and Al up to the level of toxicity for crops and animal feeds (Yohanis Tadesses, 1992).

Soil physical properties are the third most important properties of the soil that determine crop growth and productivity. It largely determines the soil's water and air supplying capacity to plant

(Sahrawat and Pathak, 2010). Inappropriate crop and soil management distract the physical properties of the soil, and leads to sealing, compaction and induce reduction in aeration and water permeability within the soil system. According to Bezuayehu Tefera (2003), the reduction in water and air circulation in the soil system ultimately reduces crop productivity. Low level of organic matter is one of the prominent factors contributing to lowering the physical properties of the soil. Hence, organic amendment definitely has been utilized for decades to improve the physical properties of cultivated land (Bezuayehu Tefera, 2003).

In general, the condition of chemical, biological and physical properties of the soil is an indicator for the suitability of the soil for plant growth and development. The definition of soil fertility is relatively complex and be defined to these perspectives. According to Abbott (2007), soil fertility is the capacity of the soil to provide the physical, biological and chemical needs of the plant for the growth, productivity, reproduction and quality. Similarly, Brady and Weil (1999) defined as the quality of a soil that enables to provide essential chemical elements in quantities and proportions for the growth of specified plants. In other ways, fertile soil has an abundance of plant nutrients including nitrogen, phosphorus and potassium, an abundance of minerals including zinc, manganese, boron, iron, sulfur, cobalt, copper, magnesium, molybdenum, and chlorine and an abundance of organic matter. In addition, fertile soil has a pH ranging from 5.5 to 6.2 and good drainage. It is also the component of overall soil productivity.

However, nutrient depletion is alarmingly increasing in dimension in every corner of the country due to lack of sustainable soil fertility management. According to Mahmud *et al.*, (2005), about 9.6% of the total area of the country was not able to sustain crop production. On top of this, approximately 41% of the total farmland of the country is acidic, of which nearly one third faces the problem of aluminum toxicity (EATA, 2013). The direct cost of this soil fertility depletion was estimated to be 3-7% of agricultural GDP (Berry *et al.*, 2003). Even though the extent of this problem varies spatially depending on variation in geology, relief, ecology, rainfall, land use, soil types and population density the problem is exceptionally severe in the highlands of the country, where 88% of human and 77% of the total livestock population is concentrated (Teklu Ejra, 2005). This in turn, threatens the agricultural sector and the livelihoods of millions of rural households (Mitiku Haile *et al.,* 2007).

An obvious strategy to tackle the fertility challenges of the country is increasing the scale and extent of fertilizer use from different sources (Tamene Lake *et al.,* 2017). However, the soundness of soil fertility measures is under question in the country. The chemical form of soil fertilization has stereotypically believed an answer to nutrient deficient soils (Tamene Lake *et al.,* 2017). Of course, inorganic fertilizers are the major method of replenishing soil fertility and boosting crop performance in Sub-Saharan Africa in the past decades (FAO, 2004). Increasing the inputs of inorganic nutrients has played a major role in increasing the supply of food to a continually growing world population in the past. However, an extensive use of inorganic fertilizer leads exhaustion of arable land in Ethiopia. According to Adugnaw (2014) over application of inorganic fertilizers causes inefficient use, large losses and imbalances of nutrients in the cultivated lands. Moreover, sole use of chemical fertilizers is causing deterioration in soil physico-chemical and biological properties as well as costly for smallholder farmers. It also leads to environmental contamination in a number of areas in the developed world. On the other hand, insufficient application of nutrients have contributed to soil fertility depletion in the developing countries (Goulding *et al.,* 2008).

Hence, sustainable soil fertility management argued fundamentally important to maintain high level of soil quality and sustain crop productivity. The systems of sustainable soil fertility management unquestionably improve the quality of deteriorated soil to better suit for crop growth. The concept of sustainable farming viewed in different perspectives for many years. According to Dsouza *et al.* (1993), sustainable agriculture can be broadly defined as an agricultural system involving a combination of sustainable production practices in conjunction with the discontinuation or the reduced use of production practices that are potentially harmful to the environment. More specifically, the Food and Agricultural Organization argues that sustainable agriculture conserves resources and it is environmentally non-degrading, technically appropriate and economically and socially acceptable (FAO, 2008). In practice, sustainable agriculture uses fewer external off-farm inputs and employs locally available natural organic manure more efficiently (Lee, 1987).

According to Willekens *et al. (* 2014), the most universal methods of sustainable soil fertilization for sustainable increase of crop production and productivity are the use of crop rotations, adoption cover crops, maintaining crop residues and rely on organic soil fertility amendments such as animal and green manure. This are collectively called organic fertilizer. According to Kumar *et al.*, (2004), organic fertilizer comprises a variety of plant and animal derived products including animal manures and human wastes, green manure, wood ashes, garden kitchen refuse, tree litter, crop residues and others. Theoretically, any organic material can be used as fertilizer, but some are less suitable than others. For instance, wood, corns talks, large masses of wet material, weed with seeds and diseased plants are not generally suitable for amendment (Lal, 2009). Similarly, manure from carnivores is not suitable for composting as it contains dangerous pathogens (Palm *et al*., 2001). However, manure from bats, sheep, ducks, pigs, goats, cows, pigeons and any other vegetarian animals is the best materials used as source of organic fertilizer. It contains large amounts of carbon, nutrient and beneficial microbes. Indeed, special care requires on the utilization of organic materials for soil amendment.

Furthermore, organic fertilizers/manures have also special benefit in drought striking regions. It improves the water holding capacity of the soil and reduces the risk of drought damages caused by erratic distribution of rainfall. In sandy soils, manure acts as a sponge to retain water in the soil that would otherwise drain down below the reach of plant roots. In this way, compost helps to protect the plant against drought. In the clay soil, also compost helps to add porosity to the soil. This helps the soil to drain more easily, so that it does not stay waterlogged and does not dry out into a brick like substance (Ashraf *et al.,* 2004).

There are also conditions at which manures are less helpful for soil amendments. The freshness and immaturity of organic material are the most important consideration in manure management. Firstly, the undecomposed fresh manure contains organic acids that can burn the tender roots of young plants, overheat a compost pile and killing off earthworms and friendly bacteria (Dalzell *et al.*, 1997). Secondly, immature composts have its own demand for nutrients to break down the biomass and the compost microorganisms may immobilize nutrients and starve the soil. Nutrient immobilization is specifically high when compost made from raw materials containing a very high C:N ratio

Generally, the quality of farm yard manure (FYM) depends on animal type, feed source and handling techniques of the manure (Elias Eyasu, 2002). Certain tools used to measure the qualities of organic amendments that are ready for application. According to Ge *et al.*, (2013) the ratio of carbon to nitrogen is important parameter to determine the quality of your compost. A C:N ration of below 20:1 considered as good compost. The other important quality parameter is the level of important soil nutrients available in a given farmyard manure. Composts are dilute sources of N, P and K compared to inorganic fertilizer and may not be possible to prepare enough compost to meet all the nutrient needs of the crop.

On average, well decomposed manure must contains at least 0.5 percent N, 0.2 percent P_2O_5 and 0.5 percent K_2O (Sankaranarayanan, 2003).

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Admiring the multitude functions, manures of different sources are among a well-established nutrient and land management practices undertaken by smallholders of Ethiopia for centuries (Ketema Mengistu and Bauer, 2011). This locally called “Fig” in Awi Administrative Zone. “Fig” is the oldest and most widely practiced means of nutrient replenishment in the study areas in particular. Furthermore, manures of such source were the only ways of improving soil fertility before the advent of chemical fertilizer. Similarly, farmyard manure is the most important source of an organic amendment in Awi Zone. The farming community uses farmyard manure ever since the time of immemorial. Nutrient replenishing of the cultivated land is their priority and rising of their productivity.

Hence, redirecting the conventional ways of soil fertility management using inorganic fertilizers to organic fertilizer is highly essential to uphold the agriculture sector of the country in a sustainable manner. In this regard, the role farmyard manure has a far-reaching effect in

Ethiopian soil fertility management owing to the availability of significantly larger size of cattle and other animals in the country. It is a guarantee for smallholder farmers who suffered with ever escalating price of inorganic fertilizer and for amending degraded farmland. It is also a blessing in restoring the soil properties of the degraded land. Several research reports underline the importance of farmyard in restoring problematic soils. According to Karažija *et al. (*2015), farmyard manure enables to modifying the physical, chemical and biological properties of the soil of cultivated lands into the better ones which are of more suitable to crop production. Physically, functions well in enhancing aggregate stability, and thereby improving soil structure, porosity and water-holding capacity, as well as, reducing soil bulk density (Mutegi, 2012). Stability of aggregates prevents surface sealing and soil erosion, improves water infiltration, and enhances water holding capacity (Martínez-Blanco *et al.,* 2013). Soil porosity is important for root proliferation, gas exchange and water retention and movement. Moreover, FYM improves the retention of plant nutrients and increases the soil biodiversity (Lal, 2009). The chemical properties of the soil are the second important parameter improved up on farmyard manure. FYM checks pH; improve EC and nutrient supply of the soil. Organic inputs also enhance CEC particularly in sandy soils and reduce Al toxicity and P-fixation in strongly acid soils with oxide mineralogy (Negassa Wakene *et al.,* 2007).

The biological properties of the soil improved through organic soil fertilization. Soil organic matte (SOM) stimulates the activities of macro fauna and microorganisms in the soil, which in turn contribute to the nutrient release. The biological properties of soils usually respond more rapidly to the changing soil conditions than either the chemical or physical properties (Korwaljow and Mazzarino, 2007). Enzymatic activities, microbial biomass and rate of CO_2 releases markedly improved through organic amendment. Soil enzymatic activities have been used as indicators of soil fertility, while they are the reflections of soil properties improvement (Corstanje *et al.,* 2007). Furthermore, soil enzyme and microbial biomass, especially in combination with an activity parameter such as CO_2 production rate, are very sensitive to both natural and anthropogenic disturbances and show a quick response to the induced changes (Hernández *et al.,* 2007). Greater soil enzyme activities and larger microbial biomass were also reported following the application of green manure and crop residue (Wale *et al.,* 2005).

Research has shown that FYM application greatly increased soil microbial biomass and soil enzyme activities, while inorganic fertilizers had relatively less effect (Chu *et al.*, 2007). In a long-term field trial, Mando *et al.*, (2005) found that the application of liquid pig manure increased activities of soil urease, acid phosphates and alkaline phosphates. Greater soil enzyme activities and larger microbial biomass were also reported following the application of green manure and crop residue (Bohme *et al.*, 2005).

Apart from soil properties improvement, farmyard manure are widely known in improving the yield of many garden and field crops. According to Karazija *et al.* (2015), application of farmyard manure at 40 t/ha significantly increased the tuber yield of potato (40 t/ha) by four folds over the yield (10.5 t/ha) on the unfertilized control. Similarly, Ali and Al-Juthery (2015) reported that application of well prepared organic fertilizer at the optimal rate of 20 t/ha gave an equivalent tuber yield of potato as that of 100% mineral fertilizer. In addition, Sayed, *et al.* (2014) indicated that organic production of potato using 23.8 t/ha of compost could be an alternative to the conventional production with commercial inorganic fertilizers without significant reduction in yield and quality. Furthermore, Zha *et al.*, (2015) reported that long-term organic manure fertilization at the rate of 10 t/ha attributed to elevating wheat grain yield to 4.58 t/ha as compared to 2.02 t/ha grain yield obtained from unfertilized control. Similarly, Der *et al.*, (2013) showed that organic manure increased grain yield of wheat by 23.2% over that of unfertilized treatment. Besides, Muhammad *et al.* (2008) showed that application of organic manure increased the wheat yield by 105 % over the control. All other growth parameters such as plant height, number of tillers, spike length, straw yield, grain yield and thousand grain weight of wheat grown after incorporation of manure into the soil were statistically different from that of the control (Muhammad *et al.*2008).

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The other important source of organic fertilizer is green manure (GM). Growing of green manure as a part of a crop rotation is an important source of organic soil fertilization. GM improves the general properties of the soil and ultimately the yield of crops. According to Diver (1999) green manures are plants grown to accumulate nutrients for the main crop. Certain principles should follow on the use of green manure for soil fertilization. Firstly, a given green manure hold maximum biomass accumulation with good balance of carbon and nitrogen at flowering stage, and incorporating it into the soil at this stage releases nutrients quickly within a short period of time (Eyhorn, 2004). The gap between digging of the green manure and planting of the next crop is the other important consideration during manure amendment. Shorter gap prevents nutrient leaching before taken up by the crop (HDRA, 1998). Similarly Eyhorn, (2004) showed that plowing of manure should not be longer than 2 to 3 weeks before planting.

Legumes applied as green manure remains as an important source of nitrogen in many crop production systems (Janzen and Radder, 1989; Becker *et al.*, 1995). It does not only serve as a direct source of plant available nitrogen but also have a great potential for increasing the availability of soil nitrogen to subsequent crop plants (Ashraf *et al.*, 2004). Legumes also known to increase the mineralization of soil native nitrogen, which might be an important mechanism, through which green manures enhance soil productivity (Fox *et al.*, 1990). Similarly, Caporali *et al.* (2004) reported that the amount of nitrogen contributed by the green manure depending upon the species and the weather trend that determine vigor and duration of the green manure growth cycle.

Apart to soil improvement, GM in pure stand or in undersown culture of a crop rotation improved the yields of ranges of crops and ameliorating soil physical properties of the cultivated lands (Malihe *et al*. (2015). According to Eugenija *et al.* (2014), the greatest tuber yield of potato obtained after clover than barley rotation system. Similarly, Malihe *et al*. (2015) found that potato plants grown in plots following common vetch and faba bean produced 12.7% and 15 % more tuber yield, respectively, over that of potato grown after winter wheat. Stefano *et al*. (2010) indicated that clover green manure and farmyard manure substantially increased the total yield by 22.5% and 25.1%, respectively, over the untreated control. In addition, the effect of including legume in the rotation system in improving wheat yield is quite tremendous. According to Talgre *et al.* (2009), the yield of spring wheat on wheat to wheat rotation system was only 2.12 t/ha but an extra yield of 1.45 t/ha was recorded after *Lucerne* as a preceding crop. Similarly, Garofalo *et al*. (2009) reported that the yield increment of wheat following faba bean was above 12 percent but this effect went up to 135 percent in drier years. In line with these reports, Dayegamiye *et al.*

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*(*2015) demonstrated that legumes have significantly increased yields of wheat by 35 percent. Ali and Abbas (2015) showed that legumes as preceding crop had significantly elevated grain yield (5.1 t/ha) compared to wheat-wheat (3.18 t/ha) rotation systems. Furthermore, Hayat and Ali (2010) demonstrated that legumes certainly increased the biomass and grain yield of succeeding wheat by 18% over non-legume sorghum.

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Meanwhile, multiple organic fertilizers sources are wildly available in the highlands of Awi Zone. Dung from higher animals (cattle, sheep, horse, donkey and mule) and litter from chicken are available with the significant amount in quantity. Crop residues and shrubs of green manure (tree lucerne, clover and sesbania) also found in a measurable amount. However, the organic materials are miss-utilized and caste arbitrarily undermining their wider importance in the agricultural sector. Furthermore, continuous cereal cropping system dominating the area without integration of legume crops in the rotation system which is further dwindling the physico-chemical properties of cultivated lands. Hence, re-directing current trends of inorganic soil fertility management systems to organic soil fertility management strategies is absolutely essential in the highlands of Awi Zone. In addition, there is no consolidated information available regarding the effect of manure of different sources on soil quality parameters in the study district. The effect on physico-chemical and biological properties of the soil; ultimately on yield growth of many crops are not widely recognized. Instead, growers heavily depend on chemical soil fertilization which is not widely acknowledged on the sustainability and cost-benefit ratio. Hence, the objective of the study was to evaluate the effect of long-term application of organic fertilizer and sound rotation pattern on productivities of crops and soil quality parameters needed for crop growth.

1.2 Hypothesis

Long-term application of farmyard manure and legume-based crop rotation improves soil physico-chemical properties and crop productivity sustainably.

1.3 Objectives

1.3.1 General objective

The aim of the study was to generate pertinent information on the influences of organic manuring and crop rotation inputs on productivities of different crops and on some soil properties, which could be useful alternative to commercial fertility management systems. The overall goal is thus to promote organic soil fertilization among smallholders in the highlands of Awi-Zone. In general, this research is looking at how the different components of organic fertilization could benefit smallholder farmers in improving food security, profitability and sustainability.

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1.3.2 Specific objectives

- To evaluate the effect of manuring and crop rotation on potato productivity
- To assess the effect of organic treatments and crop rotation on growth and yield of bread wheat
- To estimate the growth and biomass yield response of clover to the preceding crop and organic treatment
- To investigate the effec of long-term organic soil fertilization and crop rotation on soil physico-chemical properties

1.4 Organization of the Dissertation

The dissertation is organized in the manuscript format that contains six different Chapters. The first Chapter addresses the general introduction followed by four research Chapters organized as complete publishable papers. The last and sixth chapter dwells the summary, conclusion, recommendations and suggestions for future studies. The chapters briefly overviewed as the follows.

Chapter 1 introduces the theoretical details of the subject of the study as well as the general methodology. The introduction part focuses on discussing the extent of nutrient depletion in the high lands of Ethiopia due to unsustainable soil fertility management and others. Furthermore, the benefits of organic soil fertilization in replenishing of the degraded soil and the improvement achieved on the productivities of crops also presented. The biological, chemical and physical impact of organic material in the arable lands is widely discussed. It also shows how organic fertilization needs to be adapted to local conditions. Possible challenges such as improper management of organic manure clearly explained. The methods followed and site descriptions for experimentation properly mentioned in this chapter.

Chapter 2 provides a description of the effects of manuring and crop rotation system on the tuber yield of potato in the highlands of Ethiopia. The effect of repeated application of manures and the effects of preceding crop examined on the potato plant.

Chapter 3 presents the influence of different sources of manure on growth and yield of bread wheat in the highlands of Ethiopia.

Chapter 4 describes the growth and biomass yield response of clover to the preceding crop and organic treatment in the highlands of Awi Administrative Zone, Ethiopia.

Chapter 5 underlines the effect of three-year organic soil fertilization and crop rotation on soil physico-chemical properties in the highlands of Ethiopia.

Chapter 6 presents the summary, conclusion and recommendations for future research works. The summary of results of each chapter is clearly discussed and present conclusion regarding the study as a whole, the implications of this research and some suggestions for future studies.

1.5 General Materials and Methods

1.5.1 Description of the study area

The present study was carried out both on station and on-farm in Gusha Shinkurta rural village of Amhara region from 2013 to 2015. Geographically, Gusha Shinkurta is located in northwestern Ethiopia in the ranges of 11°91' to 11°92' N latitude and 28°61' to 28°87' E longitude. The altitude of the area ranges from 2451 to 2537 meters above sea level (masl) with a slope of 2.6 to 3.7% (Figure 1.1).

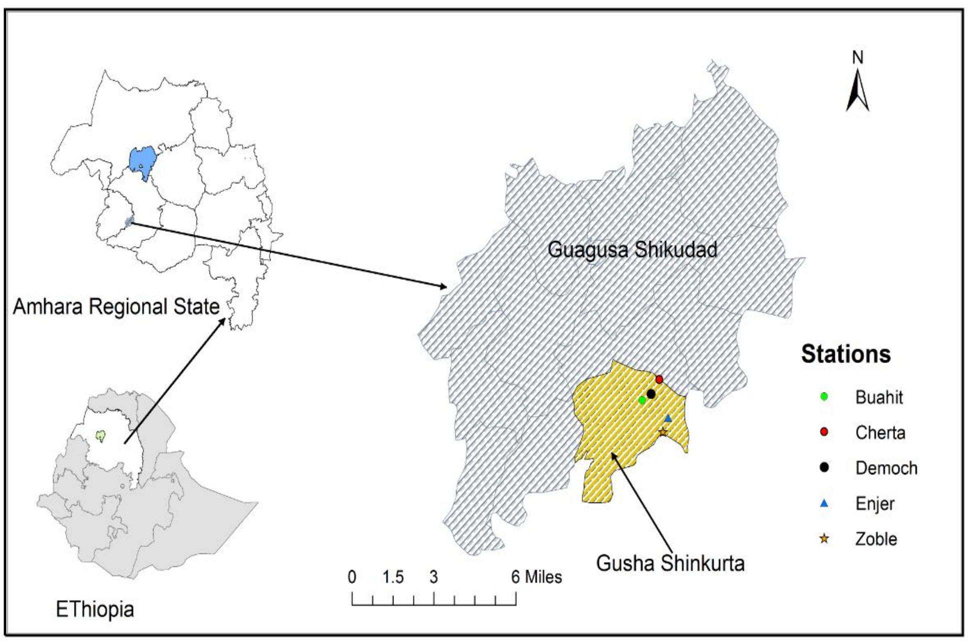


Figure 1.1: Location map of the study site

The temperature of the area is cool with average night and day temperature of 10.2°C and 22.4°C, respectively. Its average mean annual rainfall is 2491.9 mm with mono-modal system, extended from March to the end of October while the peak is in July and August (Figure 1.2).

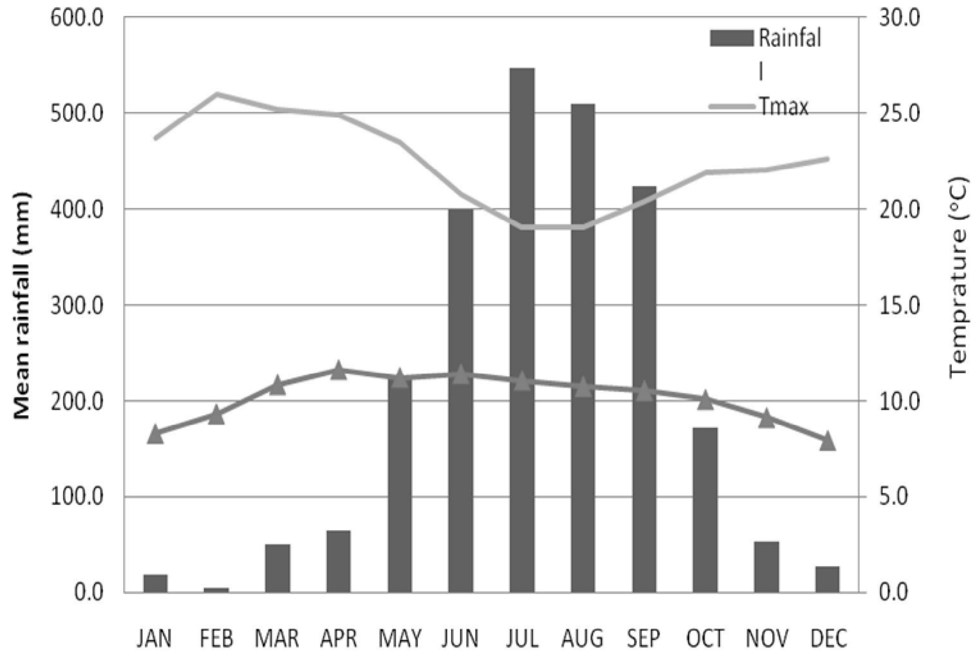


Figure 1.2: Average monthly rainfall and minimum and maximum temperatures of the study area from 2006 to2015

However, rainfall during these months is erratic in distribution. The soil of the area is low in nutrient contents. According to Yihenew (2002), the dominant soil category is Acrisols with soil pH of 4.81, total N of 0.03 %, organic carbon of 3.5% and C: N of 9.5.

The farming system of the area is characterized by mixed type of farming system. Both crop production and livestock managements are integrally conducted side by side. Potato, wheat, barley, maize, field pea and faba bean are the dominant crops grown and accounts 90 % of the cultivated area. Whereas, cattle, sheep, horse, mule and poultry husbandry are dominantly found in the study zone (ANRS-BoFED, 2006). Physiographical, plateaus, mountains, hills, plains and valleys characterize the area. The average farmland holding of a household is as small as 0.7 ha with fragmented distribution. Availability of small land size leads to intensive and continuous cultivation in arable lands and consequently aggravate to resource degradation.

1.5.2 Planting materials

Wheat and potato are the two most important crops in Awi Administrative Zone. Both cover over 70% of the arable lands (ANRS-BoFED, 2006). Recently released varieties of *Belete* and *Tay* of potato and wheat, respectively, were used as a planting material for the study. Both verities were selected on the bases of their importance. The two varieties are capable of sustained high yields, easy to manage, highly adaptable and resistant to major pests and diseases. In addition, clover, one of the most important wildly grown fodder crop was also used for the study. Clover can serve both as a green manure and as animal feed to the locality.

1.5.3 General treatments, design and procedures

The experiment generally followed a mother-baby trial set up approach whereby one big full set of a trial was placed at on–station. Similarly, additional four on-farm sites were selected at individual farmers' site and used each site as replication. The purpose of such arrangements of experimental setup was to capture the variability of treatment effects at the different location.

Six levels of rotation pattern and four levels of organic fertilizer were factorial combined as 5 X 4 factorial experiments. The rotation treatments consists of R1 = wheat-clover-potato; R2 = clover -wheat under sown lupine-potato; R3 = potato-clover-wheat; R4 = wheat under sown lupine- potato under sown lupine-wheat; R5 = lupine-potato under sown lupine-wheat and R6 = wheat- faba bean-potato as farmers practice. The organic treatments consists of V1 = 0 t/ha farmyards manure (FYM); V2 = 2.5 t/h fresh *Sesbania* biomass (FSB); V3 = 5 t/ha FYM; and V4 = 5 t/ha FYM + 2.5 t/ha FSB. The design of an experiment was Randomized Complete Block Design (RCBD) with four replications. Well-fermented FYM were applied to the soil two weeks prior to planting whereas, the green manures applied on experimental site at 50% flowering.

The size of the plots were 3 X 3 meter width and length, respectively. The distance between plots and replications were 50 cm and 1 m, respectively. Seed potatoes were planted at the spacing of 30 cm and 70 cm between plants and rows, respectively. Similarly, lupine was sowed with the spacing of 20 cm between plants and 40 cm between rows where faba bean was sowed with 10 X 40 cm between plants and rows, respectively. Diller planting were employed for clover and wheat with row spacing of 20 cm.

1.5.4 Agronomic and soil data collections and analysis

The data of plant height and grain yield of wheat; marketable and unmarketable yield of potato and fresh and dry biomass yield of clover were collected and analyzed using standard measuring techniques. In addition, important physico-chemical properties of experimental soils including cation exchange capacity (CEC), soil reaction (pH), total nitrogen (N), avialable posphorus (P), soil organic carbon (SOC) and bulk density were collected and analyzed in the soil laboratory of Adet Agricultural Research Center following their respective standard methods and procedures. The data were further subjected to analysis of variance (ANOVA) using general linear model (GLM) procedures SAS version 9.1 (SAS Institute, 2002). Whenever there were statistical differences between treatments for a parameter, further mean separation were done using the Least Significant Difference (LSD) test at 1% or 5% level of significance depending on the ANOVA results. Homogeneity test also performed before combined over locations.

CHAPTER 2. THE EFFECTS OF ORGANIC MANURE AND CROP ROTATION ON POTATO (*Solanum tuberosum* L.) TUBER YIELD IN THE HIGHLANDS OF AWI ZONE

ABSTRACT

Lack of sustainable soil fertility management is a critical challenge in the highlands of Awi Zone. Moreover, important physico-chemical properties of the soil are below the critical level to support crop growth. Hence, a study conducted with the aim of improving the yield of potato through organic treatments and sound crop rotation system. Two rotation systems and four levels of organic treatments were factorially arranged and laid out in RCBD with four replications. The organic treatments were V1 = 0 t/ha farmyards manure (FYM); V2 = 2.5 t/h fresh *Sesbania* green manure (FSB); V3 = 5 t/ha FYM; and V4 = 5 t/ha FYM + 2.5 t/ha FSB applied in fixed plots for three years. Indeed, the rotation systems were varied from year to year to estimate the changes in potato tuber yields due to the differences in crop rotation systems. In the second year R1 = wheat under sown lupine-potato and R2 = lupine-potato were the rotation patterns whereas R_3 = wheat-clover- potato and R_4 = clover-wheat under sown lupine-potato were the rotations in the third year. The rotation pattern wheat-faba bean-potato and 1t/ha FYM was also used as farmers practice without factorial combination. Tuber yields of potato were showed increasing trend over the period of the three years. Among all, the highest total potato tuber yield (35.15 t/ha) was obtained at the combined application of 5 t/ha FYM + 2.5 t/ha FSB and wheat-clover-potato rotation system in the third year. This treatment combination were increased the total potato tuber yield by 140% and 41% over that of the first and the second years and recommended as ecologically sound option in improving the productivity of potato.

Keywords: cropping system, farmyard manure, green manure, sustainable soil management

Comment [D11]: C

2.1 Introduction

The highlands of Ethiopia account only 44% of the total area of the country, although 90% of the human and 75% of the livestock population of the country is found in these highlands (Mohammed Gedefaw and Teshome Soromessa, 2015). The unbalanced livestock and human population pressure resulted in severe land degradation and soil nutrient depletion that has attributed to low agricultural productivity (Amare Haileslasie *et al.*, 2006). Similarly, in the highlands of Awi Zone exploitative conventional agricultural practices such as continuous cropping with the entire removal of crop residues, abandoning of fallowing, reduced use of manure and crop rotation are further impoverishing soil resources of the region (Yazie Chanie, 2009). Tilahune Amedie *et al*. (2007) indicated that the use of dry animal manure and crop residues for the household energy source is also partly responsible for the declining of soil fertility in the highlands of Awi Zone.

Comment [D12]: *

Potato (*Solanum tuberosum* L.) is a very important crop in the highlands of Awi Zone. It has been widely renowned for improving the livelihood of smallholder farmers and sustains their food security at the household level (Glidermacher *et al*., 2009). However, the average national productivity of potato (11.07 t/ha) remains stagnant which is far below that of the world's average productivity of 17.67 t/ha (FAOSTAT, 2013). Lack of sustainable soil fertility management is partly responsible for the lower productivity of potato in the country in general and in Awi Zone in particular (Tilahune Amedie *et al.*, 2007; Glidermacher *et al.*, 2009; Hirpa Adane *et al.*, 2010).

Attempts to optimize sustainable nutrient supply in potato fields need diverse approaches of using organic inputs (Najme *et al*., 2013). Focusing on utilizing organic inputs are the key solution to reverse the declining trend of soil fertility, environmental threat and ultimately improve the profitability and the yield quality of potato (Goffart and Olivier, 2008). In cultivated lands, the primary organic input sources are the *in-situ* maintenance of crop residues and addition of farmyard manure to the soil. Another potential source of organic fertilizer in the present study area is using green manure such as clover and lupine under sown with cereals or grown in pure stands in the rotation system. The important soil quality parameters such as the organic matter of the soil, soil nutrients, soil aeration and water holding capacity would be improved that in turn make the crop production more sustainable (Ndayegamiye *et al.*, 2017). Hence, complementing of organic fertilizers with sound crop rotation systems would make the cropping systems more sustainable over the use of synthetic fertilizers.

Several research results underscore the importance of adding organic fertilizer in improving the yield of potato. Malihe *et al.* (2015) showed that application of farmyard manure at 40 t/ha significantly increased the tuber yield of potato (40 t/ha) by four folds over the yield (10.5 t/ha) on the unfertilized control. Similarly, Nooruldeen and Hiawe (2015) reported that application of well-prepared organic fertilizer at the optimal rate (20 t/ha) gave an equivalent tuber yield of potato to that of 100% mineral fertilizer. In addition, Sayed *et al*. (2014) indicated that organic production of potato using 23.8 t/ha of compost could be an alternative to the conventional production with commercial organic fertilizers without significant reduction in yield and quality.

Like that of farmyard manure, green manure in pure stand or in under sown culture improved the tuber yield of potato by improving the fertility and ameliorating soil physical properties of the cultivated lands (Malihe *et al*., 2015). Eugenija *et al*. (2014) reported that the greatest tuber yield of potato obtained after clover than barley rotation system. Similarly, Malihe *et al*. (2015) found that potato plants grown in plots following common vetch and faba bean produced 12.7% and 15.0% more tuber yield, respectively, compared with that of winter wheat. Stefano *et al*. (2010) also reported that the clover green manure and farmyard manure substantially increased the total yield by 22.5% and 25.1%, respectively, over the untreated control.

In the same way, farmyard manures and green manure crops are widely available in Awi Administrative Zone. Clover, lupine and sesbania have long been grown for years and can easily used as green manure for potato production. Due to their very deep root penetration nature, high root biomass and ability to fix nitrogen biologically, inclusion of clovers in crop rotation schemes can play a great role in improving the properties of soils (Ruser *et al.,* 2008). In low input cropping systems in general, using organic fertilizers and sound crop rotation system may remarkably be improving crop productivity including potato on a more sustainable way. However, due to lack of awareness and intensive promotion of mineral fertilizer by extension system, the organic sources of fertilizers are not properly functioning in Awi Zone. Organic fertilizers commonly used for other purposes such as fuel wood and plastering of houses than as source of nutrients. In addition, mono and continuous cropping are the dominant cropping systems in the study area, which further diminish the fertility status of this area. In general, farmers of the locality have little experience in cultivating potato using their own farm resources.

They rather rely on commercial sources of fertilizer, which has a bearing on the sustainability of potato production.

In view of these backgrounds, the present study was initiated to assess the potential of organic treatments and sound crop rotation system for improving the productivity of potato in the highlands of Awi Agro-Ecological Zone.

2.2 Materials and Methods

2.2.1 Descriptions of the study area

The present study was carried out both on-station and on-farm in Gusha Shinkurta rural village of Guagusa District, Awi Zone from 2013 to 2015**.** The detail biophysical characteristics of the area described in chapter I, sub-sub section 1.5.1.

2.2.2. Experimental treatments and design

The treatment set up for the experiment was varied from year to year to estimate the change in potato tuber yield of each year. Thus, in the first year potato was planted with four different levels of organic treatments (V1= 0 t/ha FYM; V2 = 2.5 t/ha FSB; V3 = 5 t/ha FYM and V4 = 5 t/ha FYM + 2.5 t/ha FSB) in a randomized complete block design (RCBD) with four replications. In the second year, factorial combinations of four level organic treatments (V1 = 0 t/ha FYM; V2 = 2.5 t/ha FSB; V3 = 5 t/ha FYM and V4 = 5 t/ha FYM + 2.5 t/ha (FSB) and two rotation systems (R1 = wheat under sown lupine-potato and R2 = lupine-potato) were laid out in a completely randomized block design (RCBD) with four replications. In the third year, four different levels of organic treatments (V1 = 0 t/ha FYM; V2 = 2.5 t/ha FSB; V3 = 5 t/ha FYM and V4 = 5 t/ha FYM + 2.5 t/ha FSB) and two rotations (R3 = wheat-clover-potato and R4 = clover-wheat under sown lupine-potato) were laid out in the same design and replications indicated above. The rotation pattern wheat-faba bean-potato and 1t/ha FYM was also used as farmers practice without factorial combination.

The gross size of the experimental plots was 3 x 3 m (9 m^2) with net harvesting plot area of 1.6 x 2.4 m (3.84 m^2). Adjacent plots within replications were separated with 0.5 m wide paths, while the spacing between adjacent replications was 1 m. *Sesbania* branches and leaves were cut and chopped before incorporated into the soil. As per the treatments and the design, fresh *Sesbania* green manure and farmyard manure were uniformly broadcasted on the surface of the plots and incorporated immediately within 20 cm soil depth two weeks before planting. Clover as well as under sown lupine in wheat and potato plots were also chopped and incorporated into the soil at their 50% flowering growth stages. Seed tubers of recently released potato variety "*Belete*" were used with recommended inter-row and intra-row spacing of 70 x 30 cm, respectively, (Bikila kassahun *et al.,* 2014)

2.2.3. Data collection and analysis

Data of marketable, unmarketable and total tuber yields of potato were collected following their respective standard methods and procedures. The data were further subjected to analysis of variance (ANOVA) using General Linear Model (GLM) procedures of SAS version 9.1 (SAS, 2002). For parameters whose ANOVA results showed significant differences between treatments, mean separation was done using Least Significant Difference (LSD) test at their respective level of error. Homogeneity test also performed before combined over locations.

2.3 Result and Discussion

Potato tuber yield was varied significantly (*$P<0.01$*) in response to the main effects of organic treatments and crop rotation systems. Similarly, it was significantly influenced by the interaction of organic treatment and crop rotation in each site and in combined over sites from 2013-2015.

Organic treatments were significantly (*$P<0.05$*) affected the potato tuber yield in 2013 (Table 2.1). The highest marketable and total potato tuber yields were recorded at 5 t/ha FYM + 2.5 t/ha FSM at both sites and in combined over sites. The marketable tuber yield (14.32 t/ha) was maximum on station plots. Similarly, application of 5 t/ha FYM + 2.5 t/ha FSM showed maximum marketable yield of 14.09 t/ha and 14.20 t/ha at on-farm conditions and in combined over the sites, respectively (Table 2.1). The marketable tuber yield in the station is a bit higher than that of on-farm condition due to the variation in initial soil conditions. In addition, the total tuber yields of potato were increased with the same scenario as the marketable yield. FYM at 5 t/ha + 2.5 t/ha FSM was showed the highest total potato tuber yield (14.69 t/ha) on the station. Similarly, the total tuber yields of 14.49 and 14.59 t/ha were also superior at on-farm and in combined over sites, respectively. Following this treatment, FYM at 5 t/ha showed better potato tuber yield with 11.32 t/ha at on-station; 13.49 t/ha at on-farm and 12.04 t/ha in combined over sites. The unfertilized control showed the minimum total potato tuber yield of 4.26, 6.71 and 5.49 t/ha at the station, on-farm and in combined over sites, respectively. The total tuber yield at a combination of manure increased by 165% compared to that of the unfertilized control.

The increase in potato tuber yield at 5 t/ha FYM + 2.5 t/ha FSM was due to the availability of more concentration of soil nutrients at the maximum level of organic treatments. The combination of manure contained the greatest quantity of 121, 40.5 and 73 t/ha of NPK, respectively, of soil nutrients compared to the lower levels (Appendix Table 1). The lowest yield on unfertilized control showed that the initial soil conditions were poorer to achieve modest potato tuber yield in Gusha soil conditions (Table 2.1).

Similarly, the increasing level of organics treatments and crop residue were measurably increased the marketable and total tuber yield of potato in 2014 (Table 2.1). Thus, application of 5 t/ha FYM + 2.5 t/ha FSM resulted in the highest marketable tuber yield of 22.4, 24.4 and 23.36 t/ha at the station, on farm and in combined over sites, respectively. Like ways, the highest total potato tuber yields of 23.5 t/ha at station; 25.5 t/ha at on-farm and 24.52 t/ha in combined over sites were recorded at 5 t/ha of FYM + 2.5 t/ha FSB. Following this treatment, FYM at 5 t/ha that have 60, 33 and 50 t/ha of NPK, respectively, showed greater total potato tuber yield of 22.60 t/ha at station; 23.30 t/ha at on-farm and 22.92 t/ha in combined over sites. The unfertilized control showed the lowest total tuber yield of 11.2, 10.8 and 10.8 t/ha potatoes at station, on-farm and in combined over sites, respectively.

Furthermore, the variation in levels of organic treatments significantly ($P<0.05$) affected the tuber yield of potato at both sites and in combined over sites in 2015. Farmyard manure at 5 t/ha + 2.5 t/ha of FSB demonstrated the highest marketable tuber yield (29.52 t/ha) at the station. Similarly, the marketable yield of 29.64 t/ha was the greatest at on-farm conditions. The markatab1e yield (29.57 t/ha) recorded was also highest in combined over sites compared to other treatments in previous year. The trends of total potato tuber yields were similar to the marketable yield of potato. Total potato tuber yield of 31.43 t/ha was the largest at the station. In the same way, the total tuber yield of 31.55 t/ha was the biggest at the on-farm condition. Similarly, total tuber yield of 31.49 t/ha was the greatest in combined over sites. However, the unfertilized control showed the minimum marketable tuber yields of 11.9, 12.16 and 12.01 t/ ha at the station, on-farm and in combined over sites, respectively.

Table 2.1: Main effects of organic treatments on potato tuber yields (t/ha) over sites and years in Gusha Shinkurta Rural Village, Awi Zone, Northwest Ethiopia

Year	Organic treatments	On-station			On-farm			Over sites combination		
		MTY	UMTY	TTY	MTY	UMTY	TTY	MTY	UMTY	TTY
2013	V1	3.64^{d}	0.63^{a}	4.26^{c}	6.14^{c}	0.58	6.71^{c}	$4.89d^{d}$	0.60^{a}	5.49^{d}
	V2	6.59^{cd}	0.15^{d}	6.74^{c}	10.34^{b}	0.50	10.84^{b}	8.47^{c}	0.32^{c}	8.79^{c}
	V3	10.97^{b}	0.35^{c}	11.32^{b}	13.01^{a}	0.48	13.49^{a}	11.98^{b}	0.41^{bc}	12.40b
	V4	14.32^{a}	0.38^{c}	14.69^{a}	14.09^{a}	0.40	14.49^{a}	14.20^{a}	0.39^{bc}	14.59^{a}
	SL	**	**	**	**	ns	**	**	**	**
	SE (d)+	0.83	0.06	0.81	0.88	0.04	0.88	1.04	0.08	1.04
	CV (%)	14.57	13.93	13.47	11.94	14.1	11.33	15.86	17.71	15.11
2014	V1	9.60^{c}	1.60^{a}	11.20^{c}	8.60^{c}	1.76^{a}	10.4^{d}	9.11^{d}	1.69^{ab}	10.8^{d}
	V2	14.90^{b}	1.80^{a}	16.70^{b}	14.50^{c}	1.86^{a}	16.4^{c}	14.71^{c}	1.83^{a}	16.5^{c}
	V3	21.10^{a}	1.50^{b}	22.60^{a}	21.60^{b}	1.73^{a}	23.3^{b}	21.30^{b}	1.61^{b}	22.92^{b}
	V4	22.40^{a}	1.20^{c}	23.50^{a}	24.40^{a}	1.15^{b}	25.5^{a}	23.36^{a}	1.16^{c}	24.52^{a}
	SL	*	**	**	*	**	*	**	**	**
	SE (d) $\underline{+}$	1.18	0.18	1.22	0.89	0.14	0.92	1.07	0.16	1.12
	CV (%)	9.80	16.70	9.30	7.30	12.30	6.90	9.10	14.7	9.60
2015	V1	11.9^{d}	2.18^{a}	14.08^{c}	12.16^{d}	2.13^{a}	14.27^{d}	12.01^{d}	2.14^{a}	14.18^{d}
	V2	17.66^{c}	1.96^{ab}	19.70^{c}	15.82^{c}	2.02^{ab}	17.85^{c}	16.73^{c}	2.01^{b}	18.77^{c}
	V3	23.44^{b}	2.03^{b}	25.41^{b}	22.46^{a}	2.01^{ab}	24.47^{b}	22.95^{b}	1.96^{bc}	24.94^{b}
	V4	29.52^{a}	1.91^{b}	31.43^{a}	29.64^{a}	1.90^{b}	31.55^{a}	29.57^{a}	1.90^{c}	31.49^{a}
	SL	**	**	**	*	**	**	*	**	*
	SE (d) +	0.09	0.76	0.80	0.09	0.53	0.51	0.10	0.36	0.52
	CV (%)	6.73	9.46	5.00	6.38	6.95	3.44	6.76	5.73	7.02

V1= 0 t/ha FYM; V2 = 2.5 t/ha FSB; V3 = 5 t/ha FYM; V4 = 5 t/ha FYM + 2.5 t/ha FSB; MTY= marketable tuber yield; UMTY = unmarketable tuber yield; TTY = total tuber yield; SL = Significant level; ns = non-significant; ** = highly significant at *P<0.01*; * = significant at P<0.05

In general, the total tuber yields of potato were the highest at the highest level of organic treatments and the lowest at the lowest level of organic treatments. This was because of the availability of high amount of soil nutrients from the combination manure. The combination of manure at 5 t/ha FYM + 2.5 t/ha FSM contains the highest amount of soil nutrients with 121, 40.5 and 73 t/ha of NPK, respectively, than other treatments (Appendix Table 1). Several research reports supported the importance of organic fertilizer in replenishing the degraded soil in potato yield. According to Swadija (2013) the highest total tuber yield of 23.49 t/ha was obtained by application of 6.5 t/ha of FYM.. Similarly, Amir *et al.* (2012) argue that the tuber yield of potato was increased by increasing the level of FYM, but increasing the application above 20.9 t/ha did not increase the tuber yield. This is also supported by Najm *et al.* (2013) who showed that potato tuber yields of 20 t/ha were the highest at 15 t/ha of FYM. Amber *et al. (*2011) also showed the yield attributing characters of potato significantly augmented by annual application of organic treatments and showed the highest increase at higher rate of organic fertilizer compared to unfertilized control. Furthermore, Amir *et al*. (2006) also suggested that maximum tuber yield of 35.34 t/ha was recorded at maximum rates of farmyard manure (20 t/ha) whereas amounts of tuber yields of 25 t/ha were the minimum at the lower rate of FYM at 5 t/ha. Consistent with this suggestion, Stefano *et al.* (2010) confirmed that potato preceded by clover showed 35% yield increase than winter wheat.

Unlike the main effect of organic treatment, crop rotation system did not bring about significant (*P<0.05*) difference on the marketable and total yield of potato in 2014 (Table 2.2). However, relatively higher total potato tuber yields of 18.8 t/ha and 18.9 t/ha of potato were recorded when potato followed after sole lupine (R2) at on-station and on-farm, respectively. The same rotation system recorded 18.85 t/ha in ccombined over sites. However, the rotation system of potato after wheat under sowing lupine showed the lowest total tuber yield of 18.2.18.8 and 18.55 t/ha at the station, on farm and in combined over sites, respectively. A similar scenario was recorded on the unmarketable yield of potato (Table 2.2). Potato after sole lupine has showed the highest total tuber yield at both sites and in combined over sites.

Table 2.2: Main effects of crop rotation on potato tuber yields (t/ha) over sites and years in Gusha Shinkurta Rural Village, Awi Zone, Northwest Ethiopia

Year	Crop rotation system	On-station			On-farm			Over sites combination		
		MTY	UMTY	TTY	MTY	UMTY	TTY	MTY	UMTY	TTY
2014	R1	16.69	1.52	18.2	17.28	1.60	18.80	17.00	1.56	18.55
	R2	17.27	1.53	18.8	17.25	1.65	18.90	17.26	1.59	18.85
	SL	**	**	**	**	*	**	*	**	**
	SE (d) ±	1.18	0.18	1.22	0.89	0.14	0.92	1.07	0.16	1.12
	CV (%)	9.80	16.70	9.30	7.30	12.30	6.90	9.10	14.7	9.60
2015	R3	22.00[a]	2.03	24.02[a]	21.81[a]	2.04	23.81[a]	21.9[a]	2.00[a]	23.91[a]
	R4	19.25[b]	2.01	21.29[b]	18.21[b]	1.99	20.26[b]	18.73[b]	2.04[a]	20.77[b]
	SL	*	ns	**	*	ns	**	*	*	*
	SL	**	**	**	*	**	**	*	**	*
	SE (d) ±	0.09	0.76	0.80	0.09	0.53	0.51	0.10	0.36	0.52
	CV (%)	6.73	9.46	5.00	6.38	6.95	3.44	6.76	5.73	7.02

R1 = wheat under sown lupine-potato; R2 = lupine-potato, R3 = wheat-clover-potato; R4 = clover-wheat under sown lupine-potato; MTY = marketable tuber yield; UMTY = unmarketable tuber yield; TTY = total tuber yield; SL = significance level; ns = non-significant; ** = highly significant at *P<0.01*; * = significant at *P<0.05*

However, crop rotation system significantly (*P<0.01*) influenced the tuber yield of potato in 2015 (Table 2.2). Potato after clover and wheat (R3) showed the highest marketable and total potato tuber yields than potato after wheat under sown lupine and clover. At the station, the highest marketable potato tuber yield (22 t/ha) was recorded when potato was after clover and wheat. Similarly, the marketable yield (21.81 t/ha) recorded at R3 was maximum at on-farm conditions. Tuber yields in combined over sites showed similar trends as the individual sites where the marketable yield (21.9 t/ha) was higher than other treatments. However, the lowest marketable yields of 19.25 18.21 and 18.73 t/ha were recorded when potato was after wheat under sown lupine and clover (R1) at the station, on-farm and combined over sites, respectively. Similar scenario was observed on total tuber yield of potato. Potato after clover and wheat rotation system showed the highest total potato tuber yields of 24.02, 23.81 and 23.91 t/ha at station, on-farm and combined over location, respectively. However, potato after wheat under sown lupine and clover (R1) showed the lowest total tuber yields of 21.29, 20.26 and 20.77 t/ha at station, on-farm and in combined over sites, respectively.

The results indicate that planting of green manure crops especially clover as preceding crop enhances soil nutrients and improves potato yield tremendously. This is in agreement with the research results of Malihe *et al*. (2015) who reported that green manure as preceding crop improved the tuber yield of potato by improving the fertility and ameliorating soil physical properties. Similarly, Eugenija *et al.* (2014) reported that maximum tuber yield of potato was obtained after clover than barley rotation system. Malihe *et al*. (2015) also found that potato plants grown in plots following common vetch and faba bean produced 12.7% and 15.0% more tuber yield, respectively, compared with that of winter wheat. Similarly, Stefano *et al* .(2010) indicated that clover green manure and farmyard manure substantially increased the total yield by 22.5% and 25.1%, respectively, over the untreated control. Similarly, Sanderson and Macleod (1993) reported that tuber yields were the lower following barley than following lupine green manure.

Like the main effects of organic treatment, the interaction effect of organic treatment and crop rotation system showed significant (*P<0.001*) difference on tuber yields of potato in 2014 and 2015 (Table 2.3). The highest marketable and total tuber yield of potato were recorded at the combination of 5 t/ha of FYM + 2.5 t/ha FSB with potato after sole lupine (R2V4) compared to all other treatment combinations in 2014. The total tuber yields of 24.2, 25.4 and 24.8 t/ha at on-station, on-farm and in combined over locations, respectively, were the highest by any standards compared to other treatment combinations. Marketable yield also showed similar trend to the total yield of potato (Table 2.3). However, the interaction of unfertilized control and wheat under sown lupine showed the smallest tuber yield in both sites and in combined over sites. The total tuber yields of 10, 11 and 10.5 t/ha at station, on-farm and combined over location, respectively, were lower by any standards. In general, an increase in potato tuber yield due to variation in cropping system and rate of manure indicted that soil properties improved by the system of soil fertilization. This was because of the availability of the highest amount of soil nutrients from the interaction of 5 t/ha of FYM + 2.5 t/ha FSB and due to the fact that potato was after sole lupine with superior quantity of 179, 50.3 and 99.4 kg/ha of NPK, respectively, than other treatments (Appendix Table 2).

Table 2.3: Interaction effects of organic treatments and crop rotation on potato tuber yields (t/ha) over sites in Gusha Shinkurta Rural Village, Awi Zone, and Northwest Ethiopia

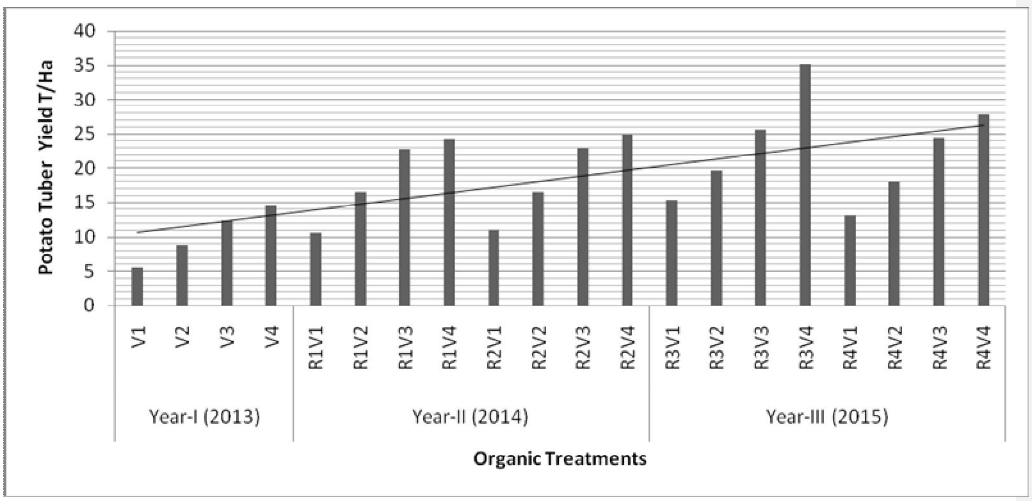
Year	Crop rotation system	Organic Treatment	On-station			On-farm			Over sites combination		
			MTY	UMTY	TTY	MTY	UMTY	TTY	MTY	UMTY	TTY
	R1	V1	9.40^{c}	1.60^{a}	11.00^{c}	8.20^{d}	1.60^{a}	10.00^{d}	8.80^{d}	1.60^{ab}	10.50^{d}
		V2	14.80^{b}	1.90^{a}	16.60^{b}	14.60^{c}	1.80^{a}	16.40^{c}	14.72^{c}	1.80^{a}	16.50^{c}
		V3	20.80^{a}	1.40^{ab}	22.30^{a}	21.80^{b}	1.40^{ab}	23.40^{b}	21.40^{b}	1.50^{b}	22.80^{b}
		V4	21.60^{a}	1.40^{b}	22.90^{a}	24.40^{a}	1.20^{b}	25.50^{a}	23.00^{a}	1.17^{c}	24.20^{ab}
2014	R2	V1	9.70^{c}	1.60^{a}	11.40^{c}	8.90^{d}	1.70^{a}	10.70^{d}	9.30^{d}	1.70^{ab}	11.00^{d}
		V2	15.00^{b}	1.70^{a}	16.80^{b}	14.40^{c}	1.80^{a}	16.30^{c}	14.70^{c}	1.80^{a}	16.55^{c}
		V3	21.20^{a}	1.50^{ab}	22.80^{a}	21.30^{b}	1.50^{a}	23.10^{b}	21.30^{b}	1.60^{ab}	22.90^{b}
		V4	23.00^{a}	1.10^{b}	24.20^{a}	24.30^{a}	1.10^{b}	25.40^{a}	23.60^{a}	1.15^{c}	24.80^{a}
		SL	**	**	**	**	*	**	*	**	**
		SE (d) ±	1.18	0.18	1.22	0.89	0.14	0.92	1.07	0.16	1.12
		CV (%)	9.80	16.70	9.30	7.30	12.30	6.90	9.10	14.7	9.60
	R3	V1	12.7^{e}	2.16^{a}	15.07^{f}	13.50^{g}	2.06^{ab}	15.60^{g}	13.2^{g}	2.12^{ab}	15.31^{e}
		V2	18.67^{d}	2.02^{a}	20.70^{d}	16.55^{e}	1.97^{abc}	18.52e	17.61^{e}	2.04^{abc}	19.61^{d}
		V3	23.92^{bc}	1.95^{bc}	25.87^{c}	23.19^{c}	2.02^{abc}	25.22^{c}	23.55^{c}	1.98^{abc}	25.53^{c}
2015		V4	32.54^{a}	1.90^{c}	34.45^{a}	34.02^{a}	1.87^{c}	35.90^{a}	33.28^{a}	1.87^{c}	35.15^{a}
	R4	V1	10.90^{e}	2.20^{a}	13.10^{g}	10.77^{h}	2.14^{ab}	12.95^{h}	10.83^{h}	2.17^{a}	13.02^{f}
		V2	16.64^{d}	2.05^{abc}	18.70e	15.09^{f}	2.07^{abc}	17.17f	15.87^{f}	1.96^{abc}	17.92^{d}
		V3	22.97^{c}	1.97^{bc}	24.95^{c}	21.72^{d}	2.00^{abc}	23.72^{d}	22.34^{d}	1.98^{abc}	24.32^{c}
		V4	26.5^{b}	1.92^{bc}	28.42^{b}	25.28^{b}	1.93^{bc}	27.17^{b}	25.88^{b}	1.91^{bc}	27.81^{b}
		FP	15.29^{de}	2.10^{ab}	17.40^{e}	12.93^{g}	2.12^{b}	16.95^{f}	15.06^{c}	2.11^{ab}	17.17^{e}
		SL	**	**	**	*	**	**	*	**	*
		SE (d) ±	0.09	0.76	0.80	0.09	0.53	0.51	0.10	0.36	0.52
		CV (%)	6.73	9.46	5.00	6.38	6.95	3.44	6.76	5.73	7.02

R1 = wheat under sown lupine-potato; R2 = lupine-potato; R3 = wheat-clover-potato; R4 = clover-wheat under sown lupine-potato; FP = wheat-fababean-potato;V1= 0 t/ha FYM; V2 = 2.5 t/ha FSB; V3 = 5 t/ha FYM; V4 = 5 t/ha FYM +2.5 t/ha FSB; MTY = marketable tuber yield; UMTY = unmarketable tuber yield; TTY = total tuber yield; SL = significance level; ns = non significant; ** = highly significant at *P<0.01*; * = significant at *P<0.05*

Similarly, during 2015 growing season, the interaction (M x T) effects of organic treatment and crop rotation system showed significant (*P<0.001*) difference on tuber yield of potato (Table 2.3). Maximum marketable and total tuber yield were recorded at the highest levels of organic treatment and sound crop rotation system and become the minimum on unfertilized control and less sound rotation systems. The highest marketable potato yield (32.5 t/ha) was recorded at the interaction effects of 5 t/ha FYM + 2.5 t/ha FSM and potato after clover and wheat at the station. Incoherent with the station, marketable yield (34.02 t/ha) was also highest at on-farm conditions. Similarly, the marketable yield (33.28 t/ha) was the peak in combined over sites. Following this treatment, the interaction effects of 5 t/ha FYM + 2.5 t/ha FSM and potato after wheat under sown lupine and clover showed the highest marketable yield of 26.5, 25.28 and 25.88 t/ha at the station, on farm and combined over sites, respectively. However, minimum marketable tuber yield was recorded on the interaction effects of unfertilized control and potato after wheat under sown lupine and clover rotation system (Table 2.3).

The total tuber yield of potato also varied with the same trend to the marketable yield of potato. The highest total potato tuber yield (34.45 t/ha) was recorded at the interaction effects of 5 t/ha FYM + 2.5 t/ha FSM and potato after clover and wheat (R3V4) in the station. In the same way, the total tuber yield (35.90 t/ha) recorded was maximum at on-farm conditions. The combined over sites still showed the highest total tuber yield (35.15 t/ha) compared to other treatment combinations. Following the above treatment, the interaction effects of 5 t/ha FYM + 2.5 t/ha FSM and potato after clover and wheat (R4V4) showed greater total potato tuber yield next to R3V4. The total tuber yields were 28.42, 27.17 and 27.81 t/ha at the station, on-farm and combined over sites, respectively. However, the interaction effects of unfertilized control and potato after wheat under sown lupine and clover (R2V1) rotation systems showed the lowest total tuber yield of 13.1, 12.95 and 13.02 t/ha at the station, on-farm and combined over sites, respectively. The harvesting of the highest yield at the higher rate of organic treatment and potato immediately after clover enriched the soil with nitrogen and other nutrients to fulfill the nutrient demand of the crop (Appendix Table 3).

In general, the yield of potato showed increasing trends in response to organic treatments and crop rotation system year after year (Figure 2.1). Tuber yields of potatoes were the lowest in the first year, intermediate in the second and hit the highest in the third year across each treatment. For example, the maximum level of organic treatment that showed the highest potato tuber yield across all years produced the lowest potato tuber yield (14.59 t/ha) in the first year. An intermediate potato tuber yield (24.8 t/ha) when preceded by sole lupine in the second year and showed maximum potato tuber yield (35.15 t/ha) when integrated with potato after clover and wheat rotation system in the third year. The yield advantage of the third season increased by 140% and 41% compared with the yield of potato in the first and the second year, respectively.



V1= 0 t/ha FYM; V2 = 2.5 t/ha FSB; V3 = 5 t/ha FYM; V4 = 5 t/ha FYM +2.5 t/ha FSB; R1= wheat under sown lupine-potato; R2 = lupine-potato, R3 = wheat-clover-potato; R4 = clover-wheat under sown lupine-potato

Figure 2.1: The total tuber yield trend of potato (t/ha) in response to organic treatments and rotation system from 2013 to 2015

The appreciable increasing trend of potato yield over the three years arguably generalized due to the carryover effects of the annual application of organic inputs and residue from rotation system. This results is in line with Manoj *et al. (*2013) who reported that long-term organic treatment either from the preceding crop or FYM improves steadily potato yield over the years with the lowest at the beginning of project phase and the highest at the end of the fifth year. Similarly, Fan *et al.* (2005) showed that long-term additions of organic materials definitely arrested potato yield declines and improved yield year after year. Furthermore, Amber *et al.* (2010) reported that tuber yield of potato significantly increased year after year through applications of composted dairy manure and proper rotation system. Comparable yield trend also observed in many of field and garden crops including wheat. Mando *et al.* (2005) demonstrated greater grain and straw yields of wheat recorded on long-term manure input than on the unfertilized control. Similarly, Hatch *et al.* (2008) in their long-term study demonstrated that maize straw and grain yield showed the largest increase at the end of long term manure fertilization.

2.4 Conclusion and Recommendations

The variation in the level of organic manure and crop rotation system and their interaction effects showed strong influence on tuber yield of potato. Application of different levels of organic treatments influenced the yield of potato differently. Potato tuber yield was the highest at the maximum level of organic treatments and the smallest at the lowest level of organic treatments.

Similarly, growing of green manures as a preceding crop substantially improved the yield of potato. Potato tuber yield was greater when potato was planted after clover and sole lupine than under sown of them. In addition, the interaction effects of a combination of manure and sound crop rotation system synergistically improved the tuber yield of potato. Maximum potato tuber yield was recorded by the combination of 5 t/ha FYM + 2.5 t/ha FSB with wheat-clover-potato (R3) rotation system. This was certainly due to the high level of soil nutrient replenishing rate at the maximum level of organic treatments and sound rotation system. Hence, it could be concluded that even though, separate application of organic treatment and rotation system has a positive effect on yield performance of potato, their combined use has more beneficial effect in improving the potato yield.

CHAPTER 3. EFFECTS OF ORGANIC TREATMENTS AND CROP ROTATION ON GROWTH AND GRAIN YIELD OF WHEAT (*Triticum aestivum L.*) IN THE HIGHLANDS OF ETHIOPIA

Agegnehu Shibabaw[1], Getachew Alemayehu[2], Enyew Adgo[2], Folkard Asch[3]and Bernhard Freyer[4]

[1]Adet Agricultural Research Center, [2]Bahir Dar University, College of Agriculture and Environmental Sciences, Ethiopia, [3]University of Hohenheim, Germany, [4]University of Natural Resources and Life Sciences, Austria

ABSTRACT

Concerns on soil fertility degradation were resonating for decades in wheat growing highlands of Ethiopia. Important physico-chemical properties of the soil have been below the critical level to support crop growth. Thus, an experiment was initiated to improve the productivity of wheat through organic treatments and crop rotation systems. Four levels of organic treatments and annually varied crop rotation systems were arranged factorially and laid out in a completely Randomized Block Design (RCBD) with four replications. The organic treatments were V1= 0 t/ha farmyard manure (FYM); V2 = 2.5 t/ha fresh sesbania biomass (FSB); V3 = 5 t/ha FYM and V4 = 5 t/ha FYM + 2.5 t/ha FSB. Indeed, the planting system of wheat varies from year to year to investigate the change in wheat yield over years. Thus, in the first year, wheat was planted with different level of organic treatments in under sown lupine (R1) and along with a sole wheat (R2) treatment. In the second year, wheat was also planted with different levels of organic treatments only. In the third year, the rotation systems were R3 = potato-clover-wheat; R4 = wheat under sown lupine-potato under sown lupine-wheat and R5 = lupine-potato under sown lupine-wheat. Data on plant height, thousand seed weight and grain yield of wheat were recorded and analyzed using SAS system. The results demonstrated that grain yields of wheat showed increasing trends over the period of the three years. Among all, the highest grain yield of wheat (4.48 t/ha) was recorded at the interaction effect of 5 t/ha FYM + 2.5 t/ha FSB and potato-clover-wheat rotation system in the third year and could be recommended as alternative soil fertility management system to attain optimum yield in the high lands of Ethiopia.

Keywords: cropping pattern, natural fertilizer, soil fertility, productivity

Comment [D13]: C

3.1 Introduction

Wheat is one of the most important staple crops in Ethiopia. It ranks fourth after tef, maize and sorghum in area coverage and the third in total production (CSA, 2016). Annually production reaches 1.63 million hectare with a total production of 4.2 million tons (CSA, 2016). This makes the country to be the largest wheat producer in Sub-Saharan Africa. However, the productivity of wheat (1.8 t/ha) have been by far very low from world average yields of 2.5 t/ha (FAOSTAT, 2013). In Ethiopia, under improved production management, grain yield ranges from 3-6 t/ha at farmers' field and went up from 5-7 t/ha at research levels (Bekele Hundie *et al.*, 2000). This indicates the existing gap between potential yield and yield at farmer's management level. Quite a lot of production challenges are responsible for the lowest mean national yield of wheat. Poor agronomic practice, soil fertility depletion, lack of adaptable variety, poor diseases and weed control measures are responsible for the lower yield of wheat (Schneider and Anderson, 2010).

Among all, depletion of soil fertility emerged as a critical challenge in wheat grown highlands of Ethiopia (Tanner and Hulluka, 1991). Similarly, Taye Belachew and Yifru Abera (2010) confirmed that soils of the highlands of Ethiopia were inherently low in cation exchange capacity, organic matter, pH, total nitrogen and available phosphorus that requires quite reasonable intervention options. Furthermore, Mulualem Twodros and Yebo Belay (2015) showed that the extent of soil fertility problem of the country is accepted without question with low level of micro and macro nutrients, organic matter, CEC and soil reaction.

Long-term organic soil fertility management and sound rotation system resolve the challenges of poor soil quality and lower yield of wheat for many years in the various part of the world. According to Moharana *et al.* (2012) organic manure input unquestionably sustains crop production, maintaining soil quality and should be involved in the nutrient management of intensive cropping system. Different research outputs have showed that the long-term organic amendment definitely improving wheat yield. According to Zha *et al.* (2015), long-term organic manure fertilization of 10 t/ha elevated wheat yield to 4.58 t/ha while it was 2.02 t/ha on unfertilized control. Similarly, Der *et al.* (2013) showed that organic manure increased grain yield of wheat by 23.2%, compared to unfertilized treatment. Besides, Muhammad *et al.* (2008) showed that organic manure`s application increased the wheat yield by 105 % relative to the control. All other growth parameters such as plant height, number of tillers, spike length, straw yield, grain yield and a thousand grain weights all were statistically different from that of control.

In addition, the effect of including legume in the rotation system in improving wheat yield is quite tremendous. According to *Talgre et al.* (2009) the yield of spring wheat on wheat to wheat rotation system was only 2.12 t/ha but an extra yield of 1.45 t/ha was recorded after lucerne as a preceding crop. Similarly, Garofalo *et al.* (2009) reported that the yield increase of wheat following faba bean was above 12% but this effect was went up to 135 % in drier years. In line with these reports, Dayegamiye *et al. (*2015) demonstrated that legumes have significantly increased yields of wheat by 35 %. Ali and Abbas (2015) also showed that legumes as preceding crop had significantly elevated grain yield (5.1 t/ha) from wheat-wheat (3.18 t/ha) rotation systems. Furthermore, Hayat and Ali (2010) demonstrated that legumes certainly increased the biomass and grain yield of succeeding wheat by 18% over non-legume sorghum.

Despite, the community of the study locality strongly suffered from reduced level of wheat yield owing to the low-level soil nutrients. Inorganic fertilizer sources believed stereotypically as a means to achieve modest yield of wheat in the district. However, over-relaying on inorganic fertilizers further dwindle the important soil physico-chemical properties and grain yield of wheat. Only mean wheat yield of 2 t/ha has been recorded in the district using inorganic fertilizer (CSA, 2007). To fill the gap, numerous alternative techniques can be adapted and integrated at smallholder farmers' condition. Organizing sound rotation system that includes legume and careful use of locally available organic manure could be the best alternatives options at Awi Administrative Zone. Hence, the objective of the study was to evaluate the effect of organic manures and sound crop rotation system on the productivity of wheat in the high lands of Awi Zone of Ethiopia.

3.2 Materials and Methods

3.2.1 Descriptions of the study area

The present study was carried out both at on-station and on-farm in Gusha Shinkurta rural village of Guagusa District, Awi Zone from 2013 to 2015**.** The biophysical characteristics are described in chapter I, sub-sub section 1.5.1.

3.2.2 Treatments, design and procedures

Four levels of organic treatments and annually varied crop system were arranged factorially and laid out in a completely Randomized Block Design (RCBD) with four replications. The organic treatments include V1 = 0 t/ha FYM; V2 = 2.5 t/ha FSB; V3 = 5 t/ha FYM and V4 = 5 t/ha FYM + 2.5 t/ha FSB. Indeed, the planting system of wheat varies from year to year to investigate the change in wheat yield over years. Thus, in the first year, wheat was planted with different level of organic treatments in under sown lupine (R1) and sole wheat (R2) forms. In the second year, wheat also planted with different levels of organic treatments only. In the third year, the rotation systems include R3 = potato-clover-wheat; R4 = wheat under sown lupine-potato under sown lupine-wheat and R5 = lupine-potato under sown lupine-wheat. Bread wheat variety "*Tay*" was drilled at seeding rates of 150 kg/ha in 20 cm distant between rows and covered with thin layer of soil (Dawit Dalga *et al.*, 2014). Gross size of experimental plots was 3 X 3 m (9 m^2) with net plot area of 2.6 X 2.8 m (7.28 m^2). Adjacent plots within replications separated with 0.5 m wide paths, while distance between replications was 1 m. As per the treatments and the design, manures were uniformly surface broadcasted and then incorporated within 20 cm soil depth two weeks before planting. The biomasses of clover and lupine were also incorporated into the soil at their 50% flowering growth stages. Samples of the different sources of manure were taken and analyzed to determine at least their NPK contents and the results presented in Table 5.2.

3.2.3 Agronomic data collection and analysis

Data on plant height, thousand seed weight and grain yield of wheat were measured timely following their respective standard methods and subjected to analysis of variance (ANOVA) using General Linear Model (GLM) procedures SAS version 9.1 (SAS, 2002). For parameters whose ANOVA results showed significant differences between treatments, mean separation done using Least Significant Difference (LSD) test at their respective level of significance used for analysis of variance. Homogeneity test also performed before combined over locations.

3.3 Result and Discussion

The main effect of organic treatment and crop rotation system as well as their interaction significantly (*$P<0.01$*) influenced the growth parameter and grain yield of wheat in each site and combined over sites (Table 3.1;Table 3.2 and Table 3.3).

3.3.1 The effect of organic treatments on wheat

The main effects of organic treatments showed significant difference (*$P<0.01$*) on plant height, thousand-seed weight and grain yield of wheat in 2013. Increasing the level of organic treatment undoubtedly increased the plant height (PH), thousand-seed weight (TSW) and grain yield (GY) of wheat (Table 3.1). The greatest PH, TSW and GY of wheat were recorded at the 5 t/ha FYM + 2.5 t/ha FSB (V4) in each site and combined over sites. The tallest PH of 72.5, 67.81 and 69.15 cm were recorded at on-station, on-farm and in combined over sites, respectively. Similarly, TSW of wheat were the maximum at on-station (39.50 g), on-farm (42.12 g) and in combined over sites (40.82 g) compared to all other treatments. The grain yields of wheat were also following similar trend like PH and TSW of wheat. The grain yield of 1.73 t/ha was the maximum at on-station conditions (Table 3.1). Similarly, the grain yields of 1.41 t/ha was the greatest at on-farm conditions. Like to the individual sites, the grain yield of 1.59 t/ha was also the maximum in combined over sites. However, the smallest PH, TSW and GY of wheat recorded on the unfertilized control (V1). The PH, TSW and GY of wheat of the rest treatments lay between V4 and V1.

The increment in PH, TSW and GY of wheat in response to increased rates of organic treatments attributed to the availability of optimum nitrogen, phosphorus and other nutrients for maximum growth of wheat. As depicted in Appendix Table 4, the nutrients obtained from the highest level of organic treatment were by far greater compared to the lower levels and unfertilized control.

Table 3.1: The main effects of organic treatments on the growth and grain yield of wheat over sites and years in Gusha Shinkurta Rural Village, Awi Zone/Northwest Ethiopia

Year	Organic treatments	On-station			On-farm			Over sites combination		
		PH (cm)	TSW (g)	GY (t/ha)	PH (cm)	TSW (g)	GY (kg/ha)	PH (cm)	TSW (g)	GY (kg/ha)
2013	V1	48.12^{d}	32.12^{d}	0.96^{d}	40.50^{d}	32.87^{d}	0.74^{d}	43.31 ^{d}	32.5^{d}	0.85^{d}
	V2	55.75^{c}	35.75 ^{c}	1.06^{c}	53.12^{c}	36.12^{c}	1.08^{c}	53.93^{c}	35.93^{c}	1.07^{c}
	V3	62.75^{b}	37.62^{b}	1.26^{b}	58.87^{b}	38.75^{b}	1.25^{b}	60.81^{b}	38.18^{b}	1.26^{b}
	V4	72.50^{a}	39.50^{a}	1.73^{a}	67.81^{a}	42.12^{a}	1.41^{a}	69.15^{a}	40.81^{a}	1.59^{a}
	SL	**	**	**	*	**	**	*	*	**
	SE (d) ±	2.96	1.28	58.72	2.66	1.98	22.47	3.17	1.9	40.2
	CV (%)	7.5	5	8	6.98	7.41	7.59	8.1	7.3	11.02
2014	V1	60.00^{c}	35.25^{c}	1.71^{e}	52.85^{c}	40.00^{b}	1.53^{e}	56.42^{c}	37.62^{c}	1.62^{e}
	V2	71.27^{b}	40.25^{ab}	2.52^{c}	62.85^{d}	41.25^{ab}	2.04^{c}	67.06^{b}	40.75^{bc}	2.28^{c}
	V3	78.15^{ab}	43.00^{a}	2.97^{b}	70.75^{a}	44.75^{a}	2.65^{b}	74.45^{a}	43.87^{a}	2.81^{b}
	V4	80.80^{a}	43.50^{a}	3.22^{a}	77.07^{bc}	45.50^{a}	3.18^{a}	78.93^{aa}	44.50^{a}	3.20^{a}
	SL	**	**	**	**	**	**	**	*	**
	SE (d) ±	2.96	1.28	58.72	2.66	1.98	22.47	3.17	1.9	40.2
	CV (%)	7.5	5.0	8.0	6.98	7.41	7.59	8.1	7.3	11.02
2015	V1	77.50^{c}	37.92^{c}	1.80^{d}	68.89^{c}	37.29^{c}	1.69^{d}	73.20^{c}	37.61^{c}	1.74^{d}
	V2	81.59^{c}	41.48^{b}	2.48^{c}	75.15^{b}	39.66^{b}	2.54^{c}	78.37^{b}	40.58^{b}	2.48^{c}
	V3	83.07^{b}	42.48^{b}	3.48^{b}	76.84^{b}	40.91^{b}	3.03^{b}	79.96^{b}	41.70^{b}	3.23^{b}
	V4	87.82^{a}	48.42^{a}	4.27^{a}	83.87^{a}	46.75^{a}	3.67^{a}	85.85^{a}	47.59^{a}	4.00^{a}
	SL	**	**	**	**	**	**	**	**	**
	SE (d) ±	2.6	1.28	81.89	3.7	1.7	1.093	3.62	1.06	68.34
	CV (%)	6.61	4.25	4.13	6.78	5.83	5.68	6.7	5.07	4.95

V1 = 0 t/ha FYM; V2 = 2.5 t/ha FSB; V3 = 5 t/ha FYM; V4 = 5 t/ha FYM +2.5 t/ha FSB; PH = plant height; TSW = thousand seed weight; GY = grain yield; SL = significant level; ns = non-significant; ** = highly significant at *P<0.01* and * = significant at *P<0.05*

Similarly, the main effects of organic treatments significantly (*P<0.01*) influenced the PH, TSW and GY of wheat in the second year (2014). Increasing the levels of organic treatments was tremendously increasing the grain yield and other growth parameters of wheat. Maximum grain yield and other growth parameters of wheat recorded from V4 at both sites and in combined over sites (Table 3.1). Thus, PH of 80.80 cm was the maximum at station conditions. Similarly, PH of 77.07 cm was the highest at on-farm conditions. Aligned with the sites, the PH of 78.93 cm was the maximum in combined over sites. Thousand-seed weights were also highest as plant high of wheat. The highest TSW recorded at V4 in all sites and combined over sites (Table 3.1). Grain yield of wheat was also acting similarly to the plant height and a thousand-seed weight of wheat. The GY of 3.22, 3.18 and 3.20 t/ha were the maximum at the station, on-farm and in combined over sites, respectively. However, the lowest grain yield and other growth parameters of wheat recorded on unfertilized control.

This attributed to the availability of the highest quantity of soil nutrients from the combination of manure and previous year carryover effects. The combination of manure contained the greater quantity of 147.5, 44.4 and 84.5 kg/ha of NPK, respectively, than other treatments (Appendix Table 5). In addition, FYM at 5 t/ha (V3) showed greater grain yield of wheat following the combination of manure following (V4). Highest wheat grain yield of 2.97 t/ha was recorded at station conditions. Unweaving with the station, the wheat grain yield of 2.65 t/ha produced was relatively higher at on-farm conditions. The grain yield of 2.81 t/ha was also superior in combined over sites. This owing to the availability of the greater amount of soil nutrients of 82.78, 35.86 and 59.1 kg/ha of NPK' respectively, following V4 (Appendix Table ***5***). However, the unfertilized control showed the lowest grain yield of 1.71, 1.53 and 1.62 t/ha, at the station, on-farm and in combined over sites, respectively. The highest PH, TSW and GY of wheat observed from V4 were attributable to the continuous supply of high level of soil nutrients throughout the developmental stages of the crop.

Furthermore, the main effect of organic treatments significant (*P<0.01*) affected the grain yield and other growth parameters of wheat in 2015. Grain yield and other growth parameters of wheat increased as the level of organic treatments increased (Table 3.1). Hence, V4 showed the highest level of grain yield as other growth parameters of wheat. Thus, the GY (4.27 t/ha), PH (87.82 cm) and TSW (48.42 g) were the highest at the on-station conditions. Similarly, to the station, the GY (3.67 t/ha), PH (83.87 cm) and TSW (46.75 g) of wheat were the highest at on-farm conditions. As to the individual sites, the GY (4.00 t/ha), PH (85.85 cm) and TSW (47.59 g) of wheat were the highest in combined over sites. However, the unfertilized control demonstrated the lowest GY (1.74 t/ha), PH (73.20 cm) and TSW (37.61 g) of wheat in combined over sites.

The increase in grain yield and other growth parameters were due to the availability of the greatest level of soil nutrients of 120.50, 40.5 and 73.0 kg/ha of NPK, respectively. The results demonstrated that organic manures from either of the sources benefit the wheat plant to stay without nutrient deficiency throughout the growing period and resulted in enhancing the grain and biological yield of wheat. The result is consistent with that of Zha *et al.* (2015) who found that long-term organic manure fertilization has elevated wheat yield to 4.58 t/ha while it was 2.02 t/ha on unfertilized control. Similarly, Der *et al.* (2013) showed that organic manure increased grain yield of wheat by 23.2% compared to unfertilized treatment. In addition, Muhammad *et al.* (2008) showed that organic manure at 30 t/ha application resulted 28% more grains of wheat over control. Hayat and Ali (2010) reported that higher yield of wheat on green manure is due to the improvement in soil properties and high nitrogen recovery from manures. Besides, Ram *et al.* (2014) showed that the highest increase in productivity, grain quality and nutrient uptake were recorded with the combined application of green and farmyard manure at 4.5 t/ha in rice-wheat cropping system.

In general, plant height, thousand-seed weight and grain yield of wheat were showed an increasing trend from year to year. The yield and growth parameters of wheat were the lowest in 2013, intermediate in 2014 and placed the highest in 2015. The highest level of yield increment was recorded at V4 which were 1.59, 3.20 and 4.00 in 2013, 2014 and 2015, respectively, in combined over locations. The yield advantage of the third season were increased by 101.25% and 25% compared with the yield of wheat in the first and the second year, respectively.

3.3.2 The effect of rotation on wheat

The main effect of cropping patterns significant (*P<0.01*) affected the PH, TSW and GY of wheat at both sites and in combined over sites in 2013. PH, TSW and GY of wheat were greater in sole wheat (R1) than wheat under-sowing lupine (R2) planting pattern (Table 3.2). R1 was showing the highest PH (60.56 cm) at the station. Similar to the station, PH (56.84 cm) and (58.7 cm) were the highest at on-farm and in combined over sites, respectively. Similar to PH, the highest GY demonstrated in R1 than R2. The GY of 1.32, 1.16 and 1.24 t/ha were the highest at the station, on-farm in combined over sites, respectively. However, the GY of wheat in R2 of 1.19, 1.09 and 1.14 t/ha at the station, on-farm and in combined over sites, respectively, were the minimum compared to its contestant. A thousand-seed weight of wheat was also highest as other growth parameters in each site and combined over sites (Table 3.2). TSW of wheat were the highest at R1 than R2 planting pattern. The increased in PH, TSW and GY of wheat at R1 were that a competition for farm resource among plants was definitely lower on sole lupine than in under sown forms. The present finding supported by the results of Prasad and power (1991) who reported competition for light water and nutrients was severe in mixed crop communities than sole crops.

Table 3.2: Main effects of crop rotation on the growth and grain yield of wheat over sites and years in Gusha Shinkurta Rural Village, Awi Zone/Northwest Ethiopia

Year	Rotations	On-station			On-farm			Over sites combination		
		PH (cm)	TSW (g)	GY (t/ha)	PH (cm)	TSW (g)	GY (kg/ha)	PH (cm)	TSW (g)	GY (kg/ha)
	R1	60.56^{a}	37 .00^{a}	1.32^{a}	56.84^{a}	38.19^{a}	1.16^{a}	58.70^{a}	37.59^{a}	1.24^{a}
2013	R2	57.50^{b}	35.50^{b}	1.19^{b}	53.313^{b}	36.75^{b}	1.09^{b}	55.40^{b}	36.12^{b}	1.14^{b}
	SL	**	**	**	*	**	**	*	*	**
	SE (d) $\pm$	2.96	1.28	58.72	2.66	1.98	22.47	3.17	1.9	40.2
	CV (%)	7.5	5	8	6.98	7.41	7.59	8.1	7.3	11.02
	R3	84.65a	44.00^{b}	3.26^{a}	79.21^{a}	42.81^{a}	3.02^{a}	81.93^{b}	43.41^{a}	3.14^{a}
2015	R4	80.33b	41.44^{b}	2.73^{c}	74.40^{b}	39.93^{b}	2.51^{c}	77.37^{b}	40.69^{b}	2.62^{c}
	R5	72.50c	42.28^{a}	2.99^{b}	74.95^{b}	40.71^{b}	2.66^{b}	78.73^{a}	41.50^{b}	2.83^{b}
	SL	**	**	**	**	**	**	**	**	**
	SE (d) $\pm$	2.6	1.28	81.89	3.7	1.7	1.093	3.62	1.06	68.34
	CV (%)	6.61	4.25	4.13	6.78	5.83	5.68	6.7	5.07	4.95

R1 = sole wheat; R2 = wheat under sown lupine; R3 = potato-clover-wheat; R4 = wheat under sown lupine-potato under sown lupine lupine-wheat; R5 = lupine-potato under sown lupine-wheat; PH = plant height; TSW = thousand seed weight; GY = grain yield; SL = significance level; ns = non-significant; ** = highly significant at *$P<0.01$*; * = significant at *$P\geq0.05$*

Similarly, the variation in crop rotation systems (T) significantly (*P<0.05*) influenced the grain yield and other growth parameters of wheat in 2015. The highest grain yield and other growth parameters of wheat were recorded at potato-clover-wheat (R3) (Table 3.2). Thus, R3 has shown the highest GY (3.26 t/ha) at station conditions. In the same way to the station, the GY of 3.02 and 3.14 t/ha were the highest at on-farm and in combined over sites, respectively. Plant heights of wheat were also showed similar fashion like the grain yield of wheat. The PH of 84.65, 79.21 and 81.93 cm were also the tall est at station, on-farm and in combined over sites, respectively, at R3. In the same way, TSW and PH were also the highest at R3. This is because of the harvesting of an additional level of soil nutrients from preceding crop. Wheat after clover and potato (R3) offer additional soil nutrients of 149.22, 38 and 73 kg/ha of NPK, respectively. However, the lowest grain yield and other growth parameters of wheat was recorded at wheat after potato under sown lupine and wheat under sown lupine rotation patterns (R4). The difference in grain yield and other growth parameters between rotations patterns were showed that the influence of the rotation patterns was greater to bring significant change on wheat grain yields. This is particularly true when clover immediately after wheat. Clover was providing additional nutrient benefits to the succeeding crop.

Several studies showed that wheat planted following sole legume significantly increased the grain yield and all other crop growth parameters of wheat. According to Talgre *et al.* (2009) the yield of spring wheat was greater by 1.45 t/ha when preceded by clover than rotated by cereals. Similarly, Dayegamiye and Tran (2001) were demonstrated the greater wheat yield and N nutrition from clover green manure. Furthermore, Garofalo *et al.* (2009) reported that the yield increase of wheat when following a faba bean crop was on average 12%, but this effect was amplified in drier years up to 135%. Besides, Ali *et al.* (2015) showed that clover as preceding crop showed the greater grain yield (5.10 t/ha) than the yield (3.18 t/ha) on unfertilized control. Studies also showed that legumes with and without P fertilization increased the biomass and grain yield of succeeding wheat with an increase of 18% over non-legume sorghum (Hayat and Ali, 2010). In addition, Babulicová (2016) showed that the significantly higher grain yield of winter wheat was recorded after preceding crop of field pea (6.18 t/ha) by comparison with winter barley as preceding crop (5.19 t/ha).

3.3.3 The effects of rotation and organic treatments on wheat

The interaction effects of organic treatments and cropping systems significantly (*P<0.01*) influenced the PH, TSW and GY of wheat in 2013. The highest grain yields and other growth parameters were recorded at the interaction effects of maximum level of organic treatments and sole wheat (R1V4). However, the interaction effects of the unfertilized control and wheat under-sowing lupine (R2V1) cropping pattern were the lowest level of grain yield and other growth parameters. Thus, R1V4 showed the maximum GY, PH and TSW in each site and in combined over sites. The GY (1.85 t/ha), PH (73.00 cm) and TSW (40.50 g) were the maximum at the on-station. Similar to the station, the GY (1.55 t/ha), PH (72.12 cm) and TSW (43.25 g) were the greatest at on-farm conditions (Table 3.3). As to the individual sites, maximum GY (1.68 t/ha), PH (72.56 cm) and TSW (41.87 g) were the maximum in combined over sites. However, the lowest GY (0.82 t/ha), PH (43.87 cm) and TSW (32.12 g) were recorded on the interaction effects of unfertilized control and sole wheat in combined over sites. The sudden reduction in GY, PH and TSW of wheat were due to the intense competition of wheat and lupine for farm resources in mixed communities. The present finding supported by the results of Prasad and power (1991) competition for light, water and nutrients were severe in mixed crop communities than sole crops.

The interaction of organic treatment and crop rotation pattern also significantly influenced the grain yield and other growth parameters of wheat in 2015 (Table 3.3). Grain yield and other growth parameters of wheat were the highest at the interaction effects of the maximum level of organic treatments and sound rotation patterns. Thus, the highest grain yield and other growth parameters of wheat were recorded at the interaction effect of FYM at 5 t/ha + 2.5 t/ha FSB and potato-clover-wheat (R3V4) compared to other treatments. The GY (4.83 t/ha), PH (92.52 cm) and TSW (52.12 g) were the highest at the station. In a similar way, the GY (4.14 t/ha), PH (92.67 cm) and TSW (52.00 g) were the highest at on-farm conditions. As its sites, the highest GY (4.48 t/ha), GY (91.60 cm) and TSW (52.06 g) were maximum in combined over sites. Following this treatment, the interaction of FYM at 5 t/ha + 2.5 t/ha FSB and lupine-potato under-sowing lupine-wheat have shown greater grain yield, plant height and a thousand seed weight in each site and in combined over sites (Table 3.3). However, the lowest wheat grain yield, plant height and a thousand-seed weight were recorded at the interaction effect of the unfertilized control and wheat under sown lupine-potato under sown lupine-wheat in combined over location.

Table 3.3: Interaction effects of organic treatments and crop rotation system on the growth and grain yield of wheat over sites and years in Gusha Shinkurta Rural Village, Awi Zone/Northwest Ethiopia

Year	Rotations	Organic treatments	On-station			On-farm			Over sites combination		
			PH (cm)	TSW (g)	GY (kg/ha)	PH (cm)	TSW (g)	GY (kg/ha)	PH (cm)	TSW (g)	GY (kg/ha)
	R1	V1	48.75^{f}	32.75^{de}	0.96^{e}	40.75^{e}	33.00^{d}	0.80^{de}	44.75^{f}	32.87^{de}	0.98^{f}
		V2	56.00^{de}	36.75^{bc}	1.14^{d}	54.50^{cd}	38.00^{bc}	1.09^{c}	$55.25d^{e}$	37.00^{bc}	1.11^{d}
		V3	64.50^{bc}	38.00^{ab}	1.32^{c}	60.00^{bc}	40.25^{ab}	1.26^{b}	$62.25b^{c}$	38.75^{b}	1.29^{c}
		V4	73.00^{a}	40.50^{a}	1.85^{a}	72.12^{a}	43.25^{a}	1.55^{a}	72.56^{a}	41.87^{a}	1.68^{a}
2014	R2	V1	47.50^{f}	31.50^{f}	0.95^{e}	40.25^{e}	32.75^{d}	0.69^{e}	43.87^{f}	32.12^{e}	0.82^{h}
		V2	53.50^{ef}	34.75^{dc}	0.99^{d}	51.75^{d}	37.00^{bcd}	1.07^{c}	52.62^{e}	36.87^{bc}	1.03^{e}
		V3	61.00^{dc}	37.25^{bc}	1.21^{cd}	57.75^{bc}	39.50^{abc}	1.24^{b}	59.37^{cd}	37.62^{bc}	1.23^{cd}
		V4	68.00^{ab}	38.50^{ab}	1.61^{b}	63.50^{b}	41.00^{ab}	1.37^{a}	65.75^{b}	39.75^{ab}	1.49^{b}
		SL	**	**	**	**	**	**	**	*	**
		SE (d) ±	2.96	1.28	58.72	2.66	1.98	22.47	3.17	1.9	40.2
		CV (%)	7.5	5.0	8.0	6.98	7.41	7.59	8.1	7.3	11.02
	R3	V1	79.92^{bc}	39.15^{de}	1.97^{h}	70.27^{bc}	37.75^{de}	2.01^{h}	75.10^{cde}	38.45^{de}	1.99^{j}
		V2	82.17^{bc}	41.62^{cd}	2.65^{f}	75.35^{bc}	40.00^{cde}	2.77^{ef}	78.76^{bcd}	40.81^{c}	2.76^{g}
		V3	84.00^{b}	43.12^{c}	3.61^{d}	78.55^{bc}	41.50^{bcd}	3.15^{c}	81.27^{b}	42.31^{c}	3.38^{d}
2015		V4	92.52^{a}	52.12^{a}	4.83^{a}	92.67^{a}	52.00^{a}	4.14^{a}	91.60^{a}	52.06^{a}	4.48^{a}
	R4	V1	74.17^{c}	36.07^{f}	1.54^{i}	68.17^{d}	36.50^{e}	1.46^{i}	71.17^{e}	36.28^{e}	1.50^{l}
		V2	80.50^{bc}	41.40^{dc}	2.25^{g}	75.00^{bc}	39.25^{de}	2.29^{g}	77.75^{bcd}	40.32^{cd}	2.27^{i}
		V3	82.25^{bc}	42.05^{c}	3.26^{e}	75.75^{bcd}	40.50^{cd}	2.91^{de}	79.00^{bcd}	41.27^{c}	3.08^{f}
		V4	84.42^{b}	46.25^{b}	3.87^{c}	78.67^{bc}	43.50^{bc}	3.39^{c}	81.55^{b}	44.87^{b}	3.63^{c}
	R5	V1	82.10^{bc}	38.55^{fe}	1.89^{h}	68.22^{d}	37.62^{ed}	1.60^{i}	73.32^{de}	38.08^{e}	1.74^{k}
		V2	82.97^{bc}	41.42^{dc}	2.38^{g}	75.10^{bcd}	39.75^{ed}	2.55^{f}	78.60^{bcd}	40.58^{cd}	2.47^{h}
		V3	84.42^{b}	42.27^{c}	3.41^{e}	76.22^{bcd}	40.75^{cd}	3.03^{cd}	79.60^{bcd}	41.51^{c}	3.22^{e}
		V4	86.52^{ab}	46.90^{b}	4.28^{b}	80.27^{b}	44.75^{b}	3.47^{b}	83.40^{b}	45.82^{b}	3.88^{b}
		SL	**	**	**	**	**	**	**	**	**
		SE (d) ±	2.6	1.28	81.89	3.7	1.7	1.093	3.62	1.06	68.34
		CV (%)	6.61	4.25	4.13	6.78	5.83	5.68	6.7	5.07	4.95

R1 = sole wheat; R2 = wheat under sown lupine; R3 = potato-clover-wheat; R4 = wheat under sown lupine-potato under sown lupine-wheat; R5 = lupine-potato under sown lupine-wheat; V1 = 0 t/ha FYM; V2 =2.5 t/ha FSB; V3 = 5 t/ha FYM; V4 = 5 t/ha FYM +2.5 t/ha FSB, PH = plant height; TSW = thousand seed weight; GY = grain yield; SL = significance level; ns = non significant; ** = highly significant at *P<0.01*; * = significant at *P<0.05*

The increment in grain yield and other growth parameters of wheat in response to interaction effects of organic treatment and crop rotation may be the synergism of the components in providing optimum nitrogen, phosphorus and other soil properties, which led to high grain yield and other growth parameters of wheat. For example, FYM at 5 t/ha + 2.5 t/ha FSB and wheat after clover and potato showed the greatest level of soil nutrient compared to other treatment combinations (Appendix Table 6). Study showed that the higher wheat grain yields harvested following legume manures.

The result is consistent with results of Babulicová, (2016) who showed that thousand grain weight of wheat were significantly influenced by levels of organic treatment and higher (51.2 g) when preceded by legume than after preceding crop of winter barley (48.6 g). Besides, Nawab and Ali (2006) has showed that the highest biological (9.43 t/ha) and grain yields (3.19 t/ha) were produced by wheat fallowing mung beam. Similarly, Hayat and Ali (2010) demonstrated that maximum wheat grain yield of 9.97 t/ha was observed in the plots which were previously under legume and increase by 31% over non-legume sorghum. In additions, Babulicová, (2016) showed that significantly higher grain yield of winter wheat was observed after field pea (8.38 t/ha) in comparison to winter barley (7.29 t/ha). Farmyard manure also markedly improved the yield and other growth parameters of wheat owing to its rich nutrient content. According to Ram *et al.* (2014) the highest increase in productivity, grain quality and nutrient uptake was recorded with the combined application of green and farmyard manure at 4.5 t/ha organic farming of the rice-wheat cropping system. Similarly, Zaghloul (2010) showed that plant height and a thousand seed weight of wheat were increased with the use organic matter application. In addition, Muhammad *et al.* (2008) also noted that organic manure’s application increased the wheat yield by 105 % relative to the control.

3.4 Conclusion and Recommendations

The type of preceding crop and the levels of organic treatment showed the greatest influence on grain yield and other growth parameters of wheat. The main effect of organic treatment significantly affects the grain yield and other growth parameters of wheat with the highest yield at the highest level of organic treatments and low at the unfertilized control. In addition, the main effect of crop rotation system significantly affects the grain yield and other growth parameter of wheat. Grain yields were the highest when wheat was immediately after clover and being low when wheat was after other crops. Finally, the interaction of organic treatment and crop rotation system were significantly influenced the grain yield and other growth parameters of wheat.

Grain yield and other growth parameters of wheat were the highest at the interactions of maximum level of organic treatments and sound rotation systems. Thus, the highest grain yield (4.48 t/ha) was recorded at the interaction effect of FYM at 5 t/ha + 2.5 t/ha FSB and potato-clover-wheat compared to other treatments. However, the lowest grain yield (1.50 t/ha) recorded at the interaction effect of the unfertilized control and wheat under sown lupine-potato under sown lupine-wheat. Hence it could be concluded that although individual effect is useful in increasing the grain yield of wheat, it is advisable to use the interaction effects of FYM at 5 t/ha + 2.5 t/ha FSB and potato-clover-wheat rotation system to achieve optimum yield of wheat in the study area.

CHAPTER 4. GROWTH AND BIOMASS YIELD RESPONSE OF CLOVER (*Trifolium decorum L.*) TO PRECEDING CROP AND ORGANIC TREATMENT IN THE HIGHLANDS OF AWI MINISTRATIVE ZONE

Agegnehu Shibabaw[1], Getachew Alemayehu[2], Enyew Adgo[2], Folkard Asch[3]and Bernhard Freyer[4]

[1]Adet Agricultural Research Center, [2]Bahir Dar University, College of Agriculture and Environmental Sciences, Ethiopia, [3]University of Hohenheim, Germany, [4]University of Natural Resources and Life Sciences, Austria

ABSTRACT

Low soil fertility status is a dominant challenge in Ethiopian agriculture for decades. Organic amendment from different sources could help to rebuild the soil fertility status of the country. Hence, an experiment was conducted to evaluate the outcome of organic treatment and preceding crops on growth and biomass yield of clover. Four levels of organic treatments (V1= 0 t/ha FYM; V2 = 5 t/ha FYM; V3 = 2.5 t/ha FSB and V4 = 5 t/ha FYM + 2.5 t/ha FSB) and two levels of crop rotation patterns (R1 = wheat-clover and R_2 = potato-clover) were factorially arranged and laid out in a randomized complete block design (RCBD) with four replications. Plant heights, number of tillers per plant number of nodules per plant, root biomass per plant and above ground biomass of clover were recorded and analyzed using SAS system. The overall experimental results showed crop rotation as well as the interaction with organic treatments were not significantly influenced the biomass yield of clover. Whereas the main effect of organic treatments were significantly influenced the growth and biomass yield of clover. The highest total dry biomass (5.6 t/ha) of clover was recorded at 5 t/ha FYM + 2.5 t/ha FSB. The unfertilized control gave the lowest mean dry biomass (3.06 t/ha) of clover compared to all other treatments. Thus 5 t/ha FYM + 2.5 t/ha FSB could be recommended for better biomass yield of clover.

Keywords: crop rotation, succeeding crop, farmyard manure, ecological farming

4.1 Introduction

Declining of soil fertility and food security status are recurrent problems in Sub-Saharan Africa. Continuous cultivation without or limited application of organic inputs into the soil and conventional rotation system are the causes of soil fertility and productivity decline (Zingore, 2011). In addition, limited incorporation of organic matter inputs into soil during the past 50 years has led to a deterioration in soil structure and health (Carl *et al.,* 2007). Hence, proper application of organic matter into the soil advised to enhance soil fertility, which increases crop productivity.

Organic matter amendments are essential for the sustainability of long-term productivity of agroecosystems through improving the physical, chemical and biological properties of the soil. Organic amendment improves soil nutrients level, soil water holding capacity, soil reaction (pH), movement of water and air, activities of soil microbes, soils tilth, root growth and penetration of crops, all of which ultimately improve the productivity of crop (Scotti, 2015).

The effect of organic matter application on growth and yield of legume crops and forages were reported by several researchers. For instance, application of farmyard manure at 7.5 t/ha produced a higher dry pod yield (3510 kg/ha) of faba bean as compared to the applications of recommended dose of NPK fertilizers that gave 2970 kg/ha dry pod yield (Sulfab, 2010). Similarly, Yolcu *et al*. (2010) reported that cattle manure at 40 t/ha gave higher yield, quality and mineral content of common vetch compared to the control. Hellal and Zewainy (2014) showed that organic fertilizer application in combination with bio-fertilizers not only improved the yield, nutrient availability and uptake of faba bean markedly, but also improved maize productivity in the succeeding season more stable than the application of mineral fertilizer. Sulfab (2010) recommended that application of organic fertilizers at 15 t/ha with Rhizobium seed inoculation significantly increased groundnut pod and hay yields over the control. Tarkalson *et al*. (1998) recommended that application of manure at 10 t/ha would facilitate mycorrhizal colonization in dry bean roots, which might in turn improve the availability of phosphorous and its uptake by plants. Konthoujam *et al.* (2013) identified that the number of nodules per plant influenced significantly by the different combination of organic materials and Rhizobium inoculants. Generally, recent studies showed that organic matter applications give tremendous yield advantage on ranges of tropical and temperate crops.

In addition, to organic matter application, preceding crops have widely been recognized as an important alternative method in improving the potential yield of the succeeding crops. According to Angus *et al*. (2001), Dalal and Mayer (1990) the yield of wheat increased by an average of 40 to 50 % following pulses as preceding crops. Kumar and Hiremath (2015) reported that 39% yield increment in maize was recorded using chickpea as a preceding crop. Similarly, Armstrong *et al*. (1999) also reported that grain protein and yield of sorghum increased by up to 5% and 70%, respectively, following mung bean as a preceding crop.

This article examined the impact of different organic amendments and of preceding crops on the biomass yield of clover (*Trifolium decorum*) in the climatic and soil conditions of the highland area of Awi Administrative Zone. The research aimed to assess the contribution of clover to solve the key challenges of agriculture in many agro-ecological zones of Sub-Saharan Africa. Clover provides high quality and quantity feed, restoration of soil fertility due to the improvement in carbon sequestration, deep root penetration, high root biomass and its ability to fix nitrogen biologically. However, due to poor agronomic management practices and improper soil management system, biomass yield of clover varies considerably from region to region. Farmers of the locality have little experience in cultivating clover with the use of organic inputs. They rather grow clover in their pastureland and between farmlands as a source of feed and green manure. In view of these, the present study initiated to determine the effect of a preceding crop and different level and type of organic matter applications on growth parameters and biomass yield of clover in the highlands of Awi Administrative Zone.

4.2 Materials and Methods

4.2.1 Descriptions of the study area

The present study was carried out both at on-station and on-farm in Gusha Shinkurta rural village of Guagusa District, Awi Zone from 2013 to 2015**.** The biophysical characteristics are described in chapter I, sub-sub section 1.5.1.

4.2.2 Treatments and design

Four levels of organic treatment and two levels of proceeding crop factorially were arranged in randomized complete block design (RCBD) with four replications. The organic matter treatments include V1= 0 t/ha farmyard manure; V2 = 5 t/ha farmyard manure; V3 = 2.5 t/ha fresh sesbania biomass and V4 = 5 t/ha farmyard manure + 2.5 t/ha fresh sesbania biomass. The rotation patterns include R_1 = wheat-clover and R_2 = potato-clover. Manure was uniformly surface broadcasted and then incorporated within 20 cm soil depth two weeks before planting. The size of the plot was 3 X 3 m with a net plot size of 2.6 X 2.8 m. The distance between plots and replications was 50 and 100 cm, respectively. The seed of the most adaptive Ethiopian clover (*Trifolium decorum*) with seed rate 3 kg/ha was used with drill planting and row spacing of 20 cm.

4.2.3 Agronomic data collection and analysis

The growth and biomass yield parameters of clover (*Trifolium decorum*) such as plant height, number of nodules, number of tillers, root and above ground biomass of clover were measured and recorded regularly. The root and above ground biomass of clover were recorded after dried with 75 ^oC for 24 hours in an oven. The data subjected to analysis of variance (ANOVA) using General Linear Model (GLM) procedures, SAS version 9.1. Means of data separated using the Least Significant Difference (LSD) test at 5% level of significance.

4.3 Results and Discussion

4.3.1 Growth parameter and biomass yield improvement

The overall combined experimental results indicated that the main effect of preceding crops (factor B) and the interaction effects of organic matter application and preceding crop (AXB) did not show any significant effect on the growth and biomass yield of clover. Nor did plant height, number of tillers, number of nodules, dry root and shoot biomass show significant variation in response to the variation of either the preceding crop or their interactions with organic treatments. A similar trend was followed in all other parameters except in the interaction (A X B) effects of the root and shoot biomass at station condition. However, the main effect of organic matter applications (factor A) showed a significant effect on the growth and biomass yield of clover at both sites and combined over sites. Statistically, significant differences observed among these treatments with respect to all the parameters measured. Generally, application of 5 t/ha FYM + 2.5 t/ha FSB was found superior in almost all parameters measured after 5 t/ha FYM, 2.5 t/ha FSB and the unfertilized control. The control showed the lowest in all the growth parameters and biomass yield compared to all other treatments (Table 4.1; Table 4.2 and Table 4.3)

4.3.2 Growth parameter

Plant height (PH) was not significantly affected by preceding crops and their interaction with organic matter application in all sites and the combined over sites. However, statistically significant ($P<0.01$) plant height was recorded in response to the main effect of different levels of organic matter application. The tallest plant height of 57.05 and 51.00 cm was recorded by the application of 5 t/ha FYM + 2.5 t/ha FSB at station and on-farm conditions, respectively. The unfertilized control showed the shortest plant height of 39.25 and 37.38 cm at station and on-farm conditions, respectively. The combined over sites data also showed that the tallest plants height (54.02 cm) was recorded at 5 t/ha FYM + 2.5 t/ha FSB compared to all other treatments (Table 4.3). The increases in plant height attributed to increased level of nutrients, organic carbon and microbial activity from mixed sources of organic treatments. This is in agreement with the findings of Adeoye *et al*. (2011) such that combination of green and FYM resulted in better plant height than the unfertilized control did. Malligawad (2010) also noted that application of manure brought about significantly better plant height of fodder than unfertilized control did.

Like plant height, number of tillers (TN) per plant not significantly affected by the preceding crops and their interaction with organic matter application. However, statistically significant responses were recorded in response to different levels of organic treatments at both sites and the combinations over sites. Application of FYM at 5 t/ha + FSB 2.5 t/ha were showed superior numbers of tillers per plant of 4.5 and 4.6 at station and on-farm conditions, respectively than all other treatments did. Consequently, the lowest mean numbers of tillers were recorded on unfertilized control. The combined over site data also showed that FYM at 5 t/ha + FSB 2.5 t/ha gave superior number of tillers (4.57) than the rest of treatments. Following this treatment, 5 t/ha FYM also demonstrated greater number of tillers per plant (4) in combined over sites (Table 4.3). The unfertilized control provided the least number of tillers per plant (1.94) compared with the rest of treatments. This is due to the improvements of soil physical and chemical properties up on the use of organic treatments. The current result has parallels information with the previous study of Bilal (2000) in that application of FYM increased the number of tillers of motto grass over control. Yolcu *et al*. (2011) also suggested that the combination of manure at 40 t/ha gave higher tiller number, biomass yield, quality and mineral content of common vetch compared to the control. Sulfab (2013) reported that application of organic fertilizers at 15 t/ha significantly increased the tillering capacity and hay yields of groundnut over the control.

4.3.3 Number of nodules

The number of nodules (NN) was not significantly affected by the preceding crops and their interaction with organic matter application. However, statistically significant (*P<0.01*) difference was recorded in response to the main effect of the different levels of organic matter application (Table 4.1; Table 4.2 and Table 4.3). Application of 5 t/ha FYM + 2.5 t/ha FSB led to significantly greater effective number of nodule per plant of 28 and 28.25 at station and on-farm conditions, respectively. Similarly, the combined over site data showed that the highest number of nodule per plant (28.13) was recorded from the combined application of 5 t/ha FYM + 2.5 t/ha FSB. Following this treatment, 5 t/ha of FYM showed more number of nodule (27.01) following the highest level of organic treatment. The lowest number of nodules per plant (20.3) recorded by untreated checks (Table 4.3). FSB at 2.5 t/ha lead to an intermediate number of nodules per plant (21.82) which slightly higher compared to the unfertilized control.

The highest number of nodule per plant was due to the increased level of phosphorous and other soil nutrients upon the use of organic amendments. This is in line with previous reports of Madukwe *et al*. (2008) in that organic manure positively influenced the nodulation of the cowpea varieties. Consequently, poultry manure gave the highest number of nodules per plant (15.9) which was significantly different from the mean values of 12.2 and 10.3 nodules per plant observed from cow dung-treated plots and untreated plots, respectively. Abebe Zerihun *et al*. (2011) reported that greater number of nodules of cowpea recorded upon the use of integrated soil fertility management than the unfertilized control. According to Otieno *et al*. (2009) application of manure improved the nodulation number per plant of cowpea in the short rainy seasons. Tarkalson *et al*. (1998) suggested that application of manure to subsoils would facilitate mycorrhizal colonization in dry bean roots grown compared with untreated control. Konthoujam *et al*. (2013) also found out that the number of nodules per plant was influenced significantly by the different combination of organic materials and that nodulation increased depending on the type of organic amendments.

Table 4.1: Station growth and biomass performance of clover in response to the main and interaction effects of the preceding crops and organic matter applications in the highland of Guagusa District, Awi Administrative Zone, Ethiopia in 2014

Treatment		Plant height (cm)	No. of tiller per plant	No. of nodules per plant	Root dry biomass (mg per plant)	Shoot dry biomass (t/ha)
Preceding crop						
	Wheat	48.66	3.38	24.19	225.75	4.54
	Potato	46.5	3.19	24.75	216.15	4.34
	SL	ns	ns	ns	ns	ns
Organic treatment						
	0 t /ha OM	39.25^{c}	2.00^{c}	20.88^{c}	152.13^{d}	3.09^{d}
	5 t/ha FYM	48.52^{b}	3.63^{b}	27.25^{a}	245.06^{b}	4.92^{b}
	2.5 t/ha FSB	45.51^{b}	3.00^{b}	21.75^{bc}	176.51^{c}	3.53^{cd}
	5 t/ha FYM + 2.5 t/ha FSB	57.05^{a}	4.50^{a}	28.00^{a}	310.10^{a}	6.22^{a}
	SL	**	**	**	**	**
Preceding crop*organic treatment						
Wheat	0 t/ha OM	41.24^{d}	2.00^{d}	19.00^{d}	153.18^{d}	3.13^{d}
	5 t/ha FYM	47.88^{b}	3.75^{b}	28.00^{b}	243.75^{b}	4.90^{b}
	2.5 t/ha FSB	46.08^{c}	3.00^{c}	21.25^{c}	171.99^{c}	3.43^{c}
	5 t/ha FYM + 2.5 t/ha FSB	59.43^{a}	4.75^{a}	28.50^{a}	334.08^{a}	6.70^{a}
Potato	0 t/ha OM	37.25^{d}	2.00^{d}	22.75^{d}	151.08^{d}	3.05^{d}
	5 t/ha FYM	49.16^{b}	3.50^{b}	26.50^{b}	246.36^{b}	4.93^{b}
	2.5 t/ha FSB	44.93^{c}	3.00^{c}	22.25^{c}	181.03^{c}	3.62^{c}
	5 t/ha FYM + 2.5 t/ha FSB	54.67^{a}	4.25^{a}	27.50^{a}	286.12^{a}	5.74^{a}
	SL	**	**	**	*	*
	SE±	2.46	0.28	1.19	9.30	0.19
	CV (%)	10.37	17.16	9.66	8.42	8.56

OM = organic matter; FYM = farmyard manure; FSB = chopped fresh sesbania biomass; SL = significance level; ** = highly significant at *$P<0.01$*; * = significant at *$P<0.05$*; ns = not significant at *$P\geq0.05$*; CV = coefficient of variation; SL= significant level

Table 4.2: On-farm growth and biomass performance of clover in response to the main and interaction effects of the preceding crops and organic matter applications in the highlands of Guagusa district Awi Administrative Zone, Ethiopia in 2014

Treatments		Plant height (cm)	No. of tiller per plant	No. of nodules per plan	Root dry biomass (mg per plant)	Shoot dry biomass (t/ha)
Preceding crop						
	Wheat	44.04	3.50	23.50^{b}	196.60	3.93
	Potato	44.95	3.38	24.88^{a}	199.06	3.99
	SL	ns	ns	*	ns	ns
Organic treatment						
	0 t/ h OM	37.38^{b}	1.88^{c}	19.88^{c}	150.03^{c}	3.02^{b}
	5 t/ha FYM	49.27^{a}	4.38^{a}	26.75^{a}	222.55^{b}	4.45^{a}
	2.5 t/ha FSB	40.33^{b}	2.88^{b}	21.88^{b}	169.67^{c}	3.39^{b}
	5 t/ha FYM + 2.5 t/ha FSB	51.00^{a}	4.63^{a}	28.25^{a}	249.09^{a}	4.99^{a}
	SL	**	**	**	**	**
Preceding crop*organic treatment						
Wheat	0 t/ha OM	37.25^{d}	2.00^{d}	22.75^{c}	151.08^{d}	3.05^{d}
	5 t/ha FYM	49.16^{b}	3.50^{b}	26.50^{b}	246.36^{b}	4.93^{b}
	2.5 t/ha FSB	44.93^{c}	3.00^{c}	22.25^{c}	181.03^{c}	3.62^{c}
	5 t/ha FYM + 2.5 t/ha FSB	57.05^{a}	4.25^{a}	27.50^{a}	286.12^{a}	5.74^{a}
Potato	0 t/ha OM	39.75^{d}	1.75^{d}	20.25^{c}	144.28^{d}	2.91^{d}
	5 t/ha FYM	48.46^{b}	4.00^{b}	27.75^{b}	230.03^{b}	4.60^{b}
	2.5 t/ha FSB	39.58^{c}	3.00^{c}	22.00^{c}	166.06^{c}	3.32^{c}
	5 t/ha FYM + 2.5 t/ha FSB	52.00^{a}	4.75^{a}	29.50^{a}	255.89^{a}	5.12^{a}
	SL	*	*	**	**	*
	SE$\pm$	3.00	0.31	62	9.08	0.18
	CV (%)	13.46	17.72	5.17	9.18	9.34

OM = organic matter; FYM = farmyard manure; FSB = chopped fresh sesbania biomass; SL = significance level ** = highly significant at *P<0.01*; * = significant at *P<0.05*; ns = not significant at *P≥0.05*; CV = coefficient of variation; SL= significant level

Table 4.3: Combined station and on-farm growth performance of clover in response to the main and interaction effects of the preceding crops and organic matter applications in the highland of Guagusa district Awi Administrative Zone, Ethiopia in 2014

Treatments		Plant height (cm)	No. of tiller per plant	No. of nodules per plant	Root dry biomass (mg plant)	Shoot dry biomass (t/ha)
Location						
	Station	47.60^{a}	3.28	24.47	220.95^{a}	4.44^{a}
	On-farm	44.49^{b}	3.44	24.19	197.83^{b}	3.96^{b}
	SL	*	ns	ns	**	**
Preceding crop						
	Wheat	46.35	3.44	23.84	211.17	4.24
	Potato	45.72	3.28	24.81	207.6	4.16
	SL	ns	ns	Ns	ns	ns
Organic treatment						
	0 t/ha OM	38.31^{d}	1.94^{c}	20.38^{b}	151.08^{c}	3.06^{c}
	5 t/ha FYM	48.89^{b}	4.00^{a}	27.01^{a}	233.80^{b}	4.68^{b}
	2.5 t/ha FSB	42.92^{c}	2.94^{b}	21.82^{b}	173.09^{c}	3.46^{c}
	5 t/ha FYM + 2.5 t/ ha FSB	54.02^{a}	4.57^{a}	28.13^{a}	279.59^{a}	5.60^{a}
	SL	**	**	**	**	**
Preceding crop*organic treatment						
Wheat	0 t/ha OM	39.24^{c}	2.00^{d}	20.85^{c}	152.13^{d}	3.09^{d}
	5 t/ha FYM	48.52^{b}	3.62^{b}	27.25^{b}	245.40^{b}	4.91^{b}
	2.5 t/ha FSB	45.5^{c}	3.00^{c}	21.75^{c}	176.54^{c}	3.52^{c}
	5 t/ha FYM + 2.5 t/ ha FSB	57.05^{a}	4.5^{a}	27.25^{a}	310.12^{a}	6.22^{a}
Potato	0 t/ha OM	38.50^{c}	1.88^{d}	21.50^{c}	147.28^{d}	2.98^{d}
	5 t/ha FYM	48.81^{b}	3.75^{b}	27.13^{b}	238.19^{b}	4.76^{b}
	2.5 t/ha FSB	42.26^{c}	3.00^{c}	22.13^{c}	173.54^{c}	3.47^{c}
	5 t/ha FYM + 2.5 t/ ha FSB	53.33^{a}	4.50^{a}	28.50^{a}	271.00^{a}	5.43^{a}
	Sig. difference	**	**	**	**	**
	SE±	1.91	0.21	0.71	8.27	0.17
	CV (%)	11.73	17.86	8.26	11.18	11.19

OM = organic matter; FYM = farmyard manure; FSB = chopped fresh sesbania biomass; SL = significance level; ** = highly significant at *P<0.01*; * = significant at *P<0.05*; ns = not significant at *P≥0.05*; CV = coefficient of variation; SL= significant level

4.3.4 Shoot and root dry biomass

Unlike other growth parameters, the shoot and root dry biomass of clover showed significant difference due to the interaction effects of organic matter application and preceding crop at station conditions (Table 4.2). The highest shoot and root dry biomass of 6.7 t/ha and 334.08 mg per plant of clover, respectively was recorded using 5 t/ha FYM + 2.5 t/ha FSB and clover following wheat (Table 4.3). The lowest shoot and dry root biomass of 3.05 t/ha and 151.08 mg per plant, respectively, was recorded when clover was preceded by potato and by the addition of 0 t/ha of FYM. This might due to the larger amount of wheat biomass returned to the soil in previous years. However, the combined over site data showed that the shoot and dry root biomass of clover significantly varied in response only to the different level of organic treatment. The highest shoot and dry root biomass of 5.6 t/ha and 279.59 mg per plant, respectively of clover were recorded at 5 t/ha FYM + 2.5 t/ha FSB in combined over sites. FYM at 5 t/ha showed shoot and root biomass of 4.68 t/ha and 233.80 mg/plant of, respectively, following the highest level. The lowest shoot and root dry biomass (3.06 t/ha and 151.08 mg per plant, respectively) were recorded on the untreated check (Table 4.3). FSB at 2.5 t/ha showed slightly higher dry shoot and root biomass of 3.46 t/ha and 233 mg per plant, respectively, compared to the control. The increase in biomass yield of clover was due to the increases of soil nutrient at higher rate of organic treatment.

The result is in agreement with previous studies that application of combinations of different manures sources improves the biomass yield of several crops. Farhad and Saleem (2009) observed that combinations of manure that holds 3 t/ha of cow manure and 2 t/ha of chicken manure significantly increased the dry weight of cowpea. Singh and Sinha (2001) identified that fresh and dry biomass yield of menthol mint increased by 23.4 % with green manure. Malligawad (2010) noted that application of organic manure significantly yielded higher fodder dry matter of 9.3 t/ha than the untreated control (7.1 t/ha).

4.3.5 Correlations

Correlation analysis also made between agronomic traits of clover (Table 4.4). Shoot dry biomass yield showed positive and significant correlation with plant height (r = 0.75**), number of nodules per plant (r = 0.78**), root biomass (r = 0.99**) and the number of tillers per plant (r = 0.75**). These results confirmed that growth parameters such as plant height, root dry weight, the number of nodules and tillers are best indicators to estimate total biomass production of clover. Strong correlation between nodule number and shoot dry biomass magnifies the contribution of bacterial association for better dry matter accumulation in legume species. The higher root dry matter also helps the plant to acquire ample nutrient and water for better biomass production. However, there is weak and none significant correlation between days to 50 % flowering (r = 0.07) and stand count (r = 0.23). The probable reason may be less number of stand count might compensated by an increase in number of tiller.

Table 4.4: Correlation coefficients between agronomic parameters of clover

Growth parameter	PH	TN	NN	RDW	SDBY
PH	1	0.60*	0.64*	0.75*	0.75*
TN		1	0.72*	0.76*	0.75*
NN			1	0.78**	0.78**
RDW				1	0.99**
DBY					1

PH = plant height; TN = tiller number; NN = number of nodules; RDW = root dry weight; SDBY = shoot dry biomass yield; ** = highly significant at *P<0.01* and * = significant at *P<0.05*.

The study summarized that plant height, the number of nodules per plant, root dry weight and tiller number per plant were the most important variables considered to estimate the biomass yield of clover in Guagusa District Administrative Zone.

4.4 Conclusion and Recommendations

The variation in levels of organic treatments showed significant effect on the biomass yield of clover. Only the main effect of organic treatment significantly affected the biomass yield of clover. Biomass yield was highest at the highest level of organic treatment, intermediate at intermediate level of organic treatment and low on unfertilized control. Thus the highest total dry biomass (5.60 t/ha) clovers was recorded at 5 t/ha FYM + 2.5 t/ha FSB whereas the unfertilized control showed the lowest mean dry biomass (3.06 t/ha) of clover compared to all other treatments. FYM at 5 t/ha showed shoot biomass (4.68 t/ha) of clover following the highest level of treatments. In addition, plant height and the number of modules per plant and of tillers per plant were highest at the highest level of organic treatment. In general, the result demonstrated that the combination of manure improved the biomass yield of clover without reduction in yield potential. Maximum yield achieved by application of high level of organic treatment. The finding also solves the challenges of over relying of the community on synthetic fertilizer. Growers experience escalating price, diminishing farm returns, soil acidity and water quality deterioration upon heavy use of synthetic fertilizer for decades. However, tending to organic soil amendment solves the challenges of synthetic fertilizer that farmers currently face. Organic fertilizer is less costly, environmentally less hazardous and more profitable compared to synthetic fertilizer. Hence, the results of this study suggest that combination of manure, FYM at 5 t/ha + FSB at 2.5 t/ha could be recommended for better biomass yield of clover for Awi Administrative Zone and other similar agro-ecological areas.

CHAPTER 5. LONG-TERM ORGANIC MANURE APPLICATION AND CROP ROTATION ON SELECTED SOIL PHYSICO-CHEMICAL PROPERTIES IN THE HIGHLANDS OF AWI ZONE

Agegnehu Shibabaw[1], Getachew Alemayehu[1], Enyew Adgo[1], Folkard Asch[2]and Bernhard Freyer[3]
[1]Bahir Dar University, College of Agriculture and Environmental Sciences, Ethiopia
[2]University of Hohenheim, Germany
[3]University of Natural Resources and Life Sciences, Austria

ABSTRACT

Soil fertility degradation is the critical challenge in the cultivated lands of Ethiopia. Low level of organic carbon, soil nutrients, soil reaction and porosity are the dominant soil related problems in the region. Thus, an experiment was initiated with the objective of testing the effects of repeated application of organic soil amemneds along with crop rotation patterns on physico-chemical properties of the soil. Four levels of organic treatments and five levels of rotation pattern were factorially combined and laid in a randomized complet block design (RCBD) with four replications. The organic treatments were: V1 = 0 t/ha FYM; V2 = 2.5 t/ha FSB; V3 = 5 t/ha FYM and V4 = 5 t/ha FYM + 2.5 t h^{-1} FSB. Tested rotation patterns were: R1 = wheat-clover-potato; R2 = clover-wheat under sown lupine-potato; R3 = potato-clover-wheat; R4 = wheat under sown lupine-potato under sown lupine-wheat and R5 = lupine-potato under sown lupine-wheat. The rotation pattern wheat-faba bean-potato and 1 t/ha FYM was also used as farmers practice without factorial combination. The experimental result showed that the interaction effects of 5 t/ha FYM + 2.5 t/ha FSB and wheat-clover-potato rotation system (R1V4) were markedly influenced the physico-chemical properties of soil with the highest level of organic carbon (2.26%), cation exchange capacity (25.28 cmol (+) kg^{-1} soil), total nitrogen (0.28%), phosphorus (15.85 ppm), potassium (0.81 cmol (+) kg^{-1} soil) and pH (6.17) and the lowest level of bulk density (1.11 g/cm^3) and could be recommended as a sustainable soil soil quality improvement needed to sustain crop productivity.

Keywords: soil quality parameter,organic soil fertilization, sustainable agiculture

5.1 Introduction

Depletion of soil nutrients is the leading causes of food insecurity in Sub-Saharan Africa including Ethiopia (FAO, 2015). Majorities of cultivated lands have poor soil quality parameters due to continuous cultivation, a low level of replenishing rate of the organic residue, mono-cropping and irrational use of commercial soil fertilization (Jastrow *et al.* 2007). Quite a large number of research reports adequately addressed the issues poor soil quality of the region. According to Meseret Muchie *et al*. (2015) continuous cultivation leads to nutrient depletion, high bulk density, low pH and soil organic carbon in the highlands of Ethiopia. Similarly, Habtamu Eyasu *et al*. (2014) also confirmed that over-relying on chemical soil fertilization and continuous cropping system negatively altered the physico-chemical properties of cultivated land and brings a low level of N, P, S, CEC and porosity.

Similarly, in northwestern Ethiopia, soil nutrient depletion is a critical challenge due to crop harvest, leaching and low inputs applied to the soil (ATA, 2013). Many research outputs raised their concern about soil health issues of agricultural lands of the region. Yihinew Gebresselasie (2015) showed that low level of nitrogen (0.12%), organic matter (2.57%), CEC (26.08 cmol (+) kg^{-1} of soil and available phosphorus (6.18 ppm) were recorded in most cropping lands of northeast Ethiopia. In addition, Taye Belachew and Yifru Abera (2010) have indicated that cropping land has shown high bulk density, low total porosity, pH and organic carbon (OC) than any other land use types. Furthermore, Yihenew Gebresselasie (2002) more specifically has reported that low level of soil pH (4.81), nitrogen (0.03%) and available phosphorus (9.5 ppm) in highlands of Awi Zone.

However, long-term organic soil fertilization and sound rotation pattern could solve the poor soil quality status of the arable lands. Organic soil fertilization profoundly improves the physico-chemical and biological properties of arable lands and the yield of crops. Major properties such as soil aeration, structure, water holding capacity, nutrient availability and microbial ecology were widely enhanced through organic amendment (Carl and Rosen, 2007). A Similar result also reported by Fondere *et al*. (2015) that long-term organic soil amendment substantially increase soil quality needed for optimum crop production. In addition, Manna *et al*. (2005) showed that the higher value of microbial population, dehydrogenate activity, organic carbon, available nitrogen (N), phosphorus (P), potassium (K) and lower bulk density were observed at farmyard manure applied equivalently to 120 kg N/ha. Furthermore, Tamos *et al*. (2015) reported in his long-term studies that farmyard manure leads to an increase in exchange capacity and leads to a decrease in soil bulk density. The outhor has also confirmed that the humus content in soil was enhanced by 0.50% at 30 t/ha farmyard manure with every 5 years of application and with leguminous crops. Finally, Johann and Ulrich (2004) have shown that plots which received either prepared or non-prepared FYM at 30 t/ha per yearhad significantly increased soil pH, P, K concentrations and other soil biological properties.

In the someway, use of sound crop rotation has many agronomic, economic and environmental benefits like organic soil amendment. Appropriate crop rotation improves organic matter, soil structure, soil nutrients, grain yields and profitability in the long run. According to Dhull *et al.* (2005) soil organic matter and soil nutrients increased using three-year rotation by including clover in the rotation system. In addition, microbial biomass C and dehydrogenises activity was the highest in a millet-clover rotation system and was the lowest in millet-wheat conditions (Dhull *et al.*, 2005). Similarly, Ryan and Masri (2007) concluded that rotation of wheat has significantly influenced mean soil organic matter level, the order being fallow with lowest and wheat-vetch-potato recording the highest. Similarly, Rosen and Allan (2007) in his cropping system study confirmed that cropping systems that contained alfalfa had the highest soil nutrients and SOC stocks, whereas the continuous corn cropping system had the lowest nutrient levels. Furthermore, Mahdi (2005) summarized the long-term impact of different crop rotations on soil nutrients and concluded higher rate of soil nutrient decline observed on continuous corn compared to corn-clover-oat rotations.

Meanwhile, multiple sources of organic fertilizers are wildly available in the highlands of Awi Zone. Dung from higher animals (cattle, sheep, horse, donkey and mule) and litter from chicken are available with the significant amount in quantity. Crop residues and shrubs of green manure (lucerne, clover and sesbania) also found in a measurable amount. However, the organic materials are miss-utilized and caste arbitrarily undermining their wider importance in the agricultural sector. Furthermore, continuous cereal cropping system is dominating the area without integration of legume crops in the rotation system which further is dwindling the physico-chemical properties of cultivated lands. Hence, re-directing the current trends of inorganic soil fertility management systems to organic soil fertility management strategies is absolutely essential in the highlands of Awi Zone. In addition, there is no consolidated information available regarding the effect of organic fertilizer and sound rotation pattern on soil quality parameters in the study district. The effect on physico-chemical and biological properties of the soil; ultimately on yield growth of many crops are not widely recognized. Instead, growers heavily depend on chemical soil fertilization which is not widely acknowledged on the sustainability of the environment and cost-benefit ratio. Hence, the objective of the study was to evaluate the effect of long-term application of organic fertilizer and sound rotation pattern on soil quality parameters needed for crop growth.

5.2 Materials and Methods

5.2.1 Description of the study area

The present studies were carried out both at on-station and on-farm in Gusha Shinkurta rural village of Guagusa District, Awi Zone from 2013 to 2015**.** The biophysical characteristics described in chapter I, sub-sub section 1.5.1.

5.2.2 Treatments, design and procedures

Both on station and on-farms expement were stablished at Awi Adminestrative Zone. Five rotation patterns and four levels of organic treatments were factorial combined and laid out in a randomized complet block design (RCBD) with four replications. The rotation patterns were: R1 = wheat-clover-potato; R2 = clover-wheat under sown lupine-potato; R3 = potato-clover-wheat; R4 = wheat under sown lupine-potato under sown lupine-wheat; R5 = lupine-potato under sown lupine-wheat. The organic treatments were: V1= 0 t/ha FYM; V2 = 2.5 t/ha FSB; V3 = 5 t/ha FYM; V4 = 5 t/ha FYM + 2.5 t/ha FSB. The rotation pattern wheat-faba bean-potato and 1t/ha FYM was also used as farmers practice without factorial combination. Manure was uniformly surface broadcasted and then incorporated within 20 cm soil depth two weeks before planting. The potatoes were planted with a spacing of 30 X 70 cm between plants and rows, respectively, and wheat was drilled at seeding rates of 150 kg/ha in 20 cm distant between rows. Similarly, the seeds of clovers were drilled at seeding rates of 3 kg/ha in 20 cm distant between rows and lupine were planted with the spacing of 20 and 40 cm between plants and rows, respectively. Gross sizes of experimental plots were 3 X 3 m (9 m^2). Adjacent plots within replications were separated with 0.5 m wide paths, while the distance between replications was 1 meter. The biomasses of clover and lupine were also incorporated into the soil at their 50% flowering growth stages.

5.2.3 Methods of soil analysis

The soil sample was taken at plow depth (0-20 cm) using an auger as discribed in chapter I, subsection 1.6.4. It was subjected to drying, grinding, mixing, partitioning and sieving before went to physico-chemical analysis. The physical and chemical properties of the soil were analyzed using different methods. Particle size distribution was determined in hydrometer method (Bouyoucos, 1962). Soil pH was measured using a digital pH meter in a 1:2.5 soil-water suspension. Organic carbon (OC) was determined by wet digestion method (Walkley, 1934). Determination of total N of the soil was carried out through Kjeldahl digestion method (Black and Allison, 1965). Available phosphorus was determined by calorimetrically using Olsen's method (Olsen *et al.,* 1954). Exchangeable potassium was determined by flame photometer as described by (McLean, 1965). CEC were determined using amonium acetate method and the bulk density of the soil was determined by weighting oven dried soil (at 105 ^{O}C for 24 hrs) dividend by the core volume (98.123 cm^3) and the result of initial soil analysis is depicted in Table 5.1.

Table 5.1: Initial physico-chemical properties of the experimental soil before planting

Soil parameters	On-station	On-farm	Means	Category
Total nitrogen%	0.13	0.11	0.12	low
Available P (ppm)	9. 54	8.64	8.64	low
Exc. K cmol(+) kg^{-1} soil	0.68	0.67	0.68	low
Organic carbon (%)	1.30	1.25	1.26	low
Organic matter (%)	2.25	2.21	2.23	low
pH (H_2O)	5.36	5.15	5.19	moderate
CEC cmol(+) kg^{-1} soil	16.10	15.52	15.64	moderate
Bulk density g/cm^3	1.36	1.37	1.37	compacted
Sand	27.00	29.50	29.00	
Clay	38.00	36.25	36.60	
Silt	35.00	34.25	34.40	
Textural class	Clay-loam	Clay-loam	Clay-loam	

CEC = cation exchange capacity; P = phosphorus; K = potassium; ppm = part per million and pH = potential of hydrogen

5.2.4 Manure preparation and chemical concentrations

Farmyard manures were produced with mixtures of fresh cow dung (55%), sheep (35%), chicken waste (5%) and tree lucerne(5%) as bedding material. At maturity the organic manure was analyzed for the nutrient concentration by collecting composite samples of all depths of top, middle and base of the pit and the result is depicted in Table 5.2

Table 5.2: Chemical composition of different manure sources

Manure type	pH	CEC mol(+) kg^{-1} soil)	OC (%)	OM (%)	N (%)	P (%)	K (%)
Farmyard manure	7.44	44.2	16.31	28.12	1.20	0.65	1.1
Sesbania (*Sesbania sesban*)	-	-	-	-	2.42	0.32	0.91
Lupine (*lupine alba*)	-	-	-	-	1.95	0.31	0.88
Clover (*Trifolium decoriom*)	-	-	-	-	2.17	0.43	0.89

Key: CEC = cation exchange capacity; N = nitrogen; P = phosphorus; K = potassium; pH = potential of hydrogen; OM = organic matter and OC= organic carbon

5.2.5 Data collection and analysis

Soil samples were taken from 0-20 cm depth of soil and analyzed for soil quality parameters. Important physico-chemical properties such as the bulk density (BD), organic carbon (OC), soil reaction (pH), cation exchange capacity (CEC) and NPK were analyzed at the end of the third year. Data were subjected to analysis of variance (ANOVA) using General Linear Model (GLM) procedures SAS version 9.1 (SAS, 2002). Means of data were separated using the Least Significant Difference (LSD) test at 5% level of significance.

5.3 Result and Discussion

5.3.1 Soil improvement

The main effects, as well as the interaction effects of crop rotation system and long-term organic treatments significantly ($P<0.01$) influenced the physico-chemical properties of the experimental soil at both sites and in combined over sites. The soil organic carbon (OC), cation exchange capacity (CEC), total nitrogen (N), phosphorus (P) and potassium (K) were significantly ($P<0.01$) influenced by the main and interaction effects of crop rotation system (T) and organic treatment (M) while the bulk density (BD) and soil reaction (pH) showed significant effect by the main effects of organic treatments and the interaction effect with crop rotation system.

5.3.2 Effects of crop rotation on soil physico-chemical properties

The main effect of crop rotation system showed significant ($P<0.01$) difference on the physico-chemical quantity of the experimental soil. The OC, CEC, N, P and K were significantly affected by the system of crop rotation, while BD and pH of the soil didn't showed any significant ($P<0.05$) change in response to the type of crop rotation. The highest levels of OC, CEC, N, P and K were recorded at wheat-clover-potato (R1) rotation system at both site and in combined over sites without a statistical difference to clover-wheat under sown lupine-potato (R2) rotation system. Maximum nutrient concentration of 2.19 % OC, 24.66 cmol (+) kg^{-1} soil CEC, 0.24% N, 15.98 ppm P and 0.92 cmol (+) kg^{-1} soil K were recorded at on-station. Similarly, 1.94% OC, 21.76 cmol (+) kg^{-1} soil CEC, 0.19% N, 14.53 ppm P and 0.75 cmol (+) kg^{-1} soil K were the highest at on-farm conditions. In the same way, 2.07% OC, 23.21 cmol (+) kg^{-1} soil CEC, 0.21% N, 15.26 ppm P and 0.84 cmol (+) kg^{-1} soil K were the maximum in combined over sites. Clover-wheat under sown lupine-potato (R2) rotation system was providing better soil nutrient level closely following the highest manure rates. However, the lowest level of 1.72% OC, 21.24 cmol (+) kg^{-1} soil of CEC, 0.17% N, 14.03 ppm P and 0.72 cmol (+) kg^{-1} soil K were recorded at wheat under sown lupine-potato under sown lupine-wheat (R4) rotation system in combined over sites (Table 5.3, Table 5.4 and Table 5.5). The OC, CEC and N, P and K were higher in R1 by 36.5%, 35.8%, 41.66%, 62.38% and 16%, respectively, from R4 rotation systems. In addition, R1 was greater by 64.28% OC, 48.40% CEC, 75%N, 76.62% P, 23.52% k, 14.06% pH from the initial soil physico-chemical properties. The better levels of physico-chemical properties on R1 were owing to the incorporation of the maximum amount of biomass over the three years (Appendix 1). When legume crops are regularly part of a rotation system, their residues increase soil organic matter. The result is in accordance to Perez-brandan *et al*. (2014) who showed that OC, N, P and K were, respectively, higher by 144%, 121%, 56% and 178% in soybean rotation than mono-cropping systems. Similarly, Campbelll *et al.* (1991) have shown that inclusion of legume in the rotation system improves OC, N and C: N ration of experimental soil. Furthermore, Muthoni and Kabira (2010) showed soybean-maize rotation exhibited the highest amounts of OC, total N, P, K, Mg, Ca and water holding capacity increased by the rotation. Similar,studies also showed that percent total nitrogen was adequate for potato production at soybean rotation system over cereal rotation system (Yusuf *et al.*, 2009).

However, BD and pH were not significantly (*P<0.05*) influenced by the main effects of the rotation system. But, relatively lower BD and higher pH was recorded at R1 rotation system like other soil properties. The lowest BD of 1.13 g/cm^3 and the highest pH of 5.98 were recorded at on-station conditions. Similarly, BD of 1.21 g/cm^3 and pH of 5.87 were the minimum and the highest at on-farm conditions. Like the individual sites, the bulk density of 1.17g/cm^3 and 5.92 of pH were the minimum and the highest in combined over sites. However, the highest bulk density and the lowest soil reaction were recorded at R4 at both sites and in combined over sites (Table 5.3; Table 5.4 and Table 5.5). The relative reduction in the values of bulk density is due to the improvement of total soil porosity up on the organic amendment. This is in agreement with Perez *et al.* (2014) who reported pH was slightly greater on legume rotation but not significantly affected by the different rotation pattern. Yusuf *et al.* (2009) also reported that cropping sequence has slightly changed soil pH and BD of the soil. This might be due to the amount of biomass may not be sufficient enough to bring significant change to pH and BD of the soil.

Table 5.3: On-station physico-chemical properties of the soil in response to the main and interaction effects of the preceding crops and organic matter applications

Treatments		BD (g/cm$^{3)}$	OC (%)	CEC cmol (+) kg^{-1} soil)	N (%)	P (ppm)	K cmol (+) kg^{-1} soil)	pH
Rotation								
R1		1.13	2.19^a	24.66^a	0.24a	15.98^a	0.92^a	5.98
R2		1.16	2.14^a	24.37^a	0.22b	15.52^a	0.90^a	5.90
R3		1.15	1.94^b	22.45^b	0.20^b	14.74^b	0.81^b	5.91
R4		1.20	1.85^b	21.83^b	0.19^b	14.27^b	0.78^b	5.85
R5		1.16	1.89^b	22.27^b	0.20^b	14.47^b	0.79^b	5.88
Sig. difference		ns	*	*	*	*	*	ns
Organic treatments								
V1		1.25^a	1.63^d	20.74^c	0.13^d	13.94^d	0.75^c	5.64^c
V2		1.19^b	1.97^c	22.68^b	0.17^c	14.67^c	0.82^b	5.83^c
V3		1.15^c	2.13^b	23.63^b	0.25^b	15.45^b	0.82^b	5.98^b
V4		1.05^d	2.28^a	25.39^a	0.27^a	16.85^a	0.97^a	6.15^a
Sig. difference		**	**	**	**	**	*	**
Rotations	Organic treatment							
R1	V1	1.22^{abcd}	1.67^f	21.56^{def}	0.17^e	14.00^{fg}	0.83^{bcde}	5.65^d
	V2	1.17^{bcde}	2.24^{bc}	24.55^{abc}	0.20^d	15.60^{abcdef}	0.88^{abcde}	5.94^{abcd}

	V3	1.14^{cdef}	2.37^{ab}	25.62^{ab}	0.25^{c}	16.98^{a}	0.93^{abcdd}	6.09^{abc}
	V4	1.02^{h}	2.50^{a}	26.90^{a}	0.33^{a}	17.35^{a}	1.05^{a}	6.23^{a}
R2	V1	1.24^{abc}	1.60^{b}	21.43^{def}	0.14^{efg}	13.88^{fgh}	0.81^{cdef}	5.60^{ab}
	V2	1.18^{abcde}	2.23^{bc}	24.32^{abc}	0.20^{d}	15.13^{abcdef}	0.88^{cde}	5.80^{bcd}
	V3	1.16^{bcdef}	2.26^{abc}	25.34^{ab}	0.24^{c}	15.96^{abcde}	0.92^{cdef}	6.09^{abc}
	V4	1.07^{efgh}	2.49^{a}	26.41^{a}	0.28^{b}	17.13^{a}	1.01^{ab}	6.13^{ab}
R3	V1	1.26^{abc}	1.67^{f}	20.38^{ef}	0.13^{gh}	12.80^{ghi}	0.72^{f}	5.72^{cd}
	V2	1.18^{abcde}	1.84^{ef}	21.56^{def}	0.16^{ef}	14.33^{cd}	0.75^{ef}	5.82^{bcd}
	V3	1.13^{defgh}	2.06^{cde}	23.03^{bcde}	0.25^{bc}	14.94^{efg}	0.79^{ef}	5.95^{abcd}
	V4	1.03^{gh}	2.20^{bcd}	24.83^{def}	0.27^{bc}	16.90^{ab}	1.01^{ab}	6.17^{ab}
R4	V1	1.29^{a}	1.61^{f}	20.03^{f}	0.10^{i}	11.98^{i}	0.69^{f}	5.58^{d}
	V2	1.24^{abcd}	1.72^{f}	21.47^{def}	0.14^{fgh}	14.12^{efg}	0.80^{def}	5.81^{bcd}
	V3	1.16^{bcde}	1.97^{de}	21.62^{def}	0.25^{c}	14.60^{def}	0.74^{ef}	5.87^{abcd}
	V4	1.12^{defgh}	2.10^{cd}	24.20^{abcd}	0.26^{bc}	16.40^{abcd}	0.88^{bcde}	6.13^{ab}
R5	V1	1.27^{ab}	1.62^{f}	20.33^{ef}	0.12^{hi}	12.33^{ih}	0.71^{f}	5.67^{d}
	V2	1.20^{abcd}	1.82^{ef}	21.54^{def}	0.16^{efg}	14.20^{efg}	0.81^{cdef}	5.82^{bcd}
	V3	1.13^{defg}	2.02^{cde}	22.56^{abcd}	0.25^{c}	14.86^{cdef}	0.78^{def}	5.91^{abcd}
	V4	1.04^{fgh}	2.12^{cd}	24.65^{abc}	0.26^{bc}	16.50^{abc}	0.95^{abc}	6.13^{ab}
	FP	1.2^{abcd}	1.77^{de}	21.25^{ef}	0.16^{e}	14.8^{f}	0.88^{cde}	5.68^{d}
	SL	**	**	**	**	**	**	**
	SE +	0.05	0.1	1.19	0.01	1.09	0.53	0.16
	CV%	6.19	7.73	7.25	8.1	7.54	10.77	4.01

Means followed with the same letter are not significantly different; R1= wheat-clover-potato; R2 = clover-wheat under sown lupine-potato; R3 = potato-clover-wheat; R4 = wheat under sown lupine-potato under sown lupine-wheat; R5 = lupine-potato under sown lupine-wheat; FP = wheat-fababean-potato; V1 = 0 t/ha: V2 =2.5 t/ha FSB; V3 = 5 t/ha FYM; V4 = 5 t/ha FYM + 2.5 t/ha FSB;SL= significance level ** = highly significant at *$P<0.01$*; * = significant at *$P<0.05$*; ns = not significant at *$P\geq0.05$*; CV = coefficient of variation; SE = standard error; BD = bulk density; OC = organic carbon; TN = total nitrogen; CEC = cation exchange capacity; P = phosphorous; pH = power of hydrogen; K = potassium

5.3.3 Effects of organic treatments on soil physico-chemical properties

Like the crop rotation system, the main effect organic treatment showed significant *($P< 0.01$)* effect on the physico-chemical quantity of the experimental soil. Generally, increasing the rates of farmyard manure decreased BD and increases OC, CEC, N, P, K and pH of experimental soil at both sites and in combined over the site (Table 5.3; Table 5.4 and Table 5.5).

Over the period of three-year, application of 5 t/ha FYM + 2.5 t/ha FSB (V1) was observed the lowest levels of bulk density and the highest levels OC and CEC, N,P,K and pH at both sites and in combined over sites. Hence 2.28% OC, 25.39 cmol (+) kg^{-1} of soil CEC, 0.27% N, 16.85 ppm P, 0.97 cmol (+) kg^{-1} of soil K and 6.15 pH were the highest at station condition. Similarly, 2.09% OC, 24.33 CEC cmol (+) kg^{-1} of soil, 0.23% nitrogen, 16.31 ppm phosphorus, 0.80 cmol (+) kg^{-1} of soil potassium and 6.00 of pH were the highest at on-farm condition. Like the individual sites, 2.18% OC , 24.86 cmol (+) kg^{-1} of soil CEC, 0.25% N, 16.58 ppm P,0.88 cmol (+) kg^{-1} of soil K and 6.07 pH were the highest in combined over sites. Farmyard manure at 5 t/ha (V2) has shown better soil nutrient level following V4. In contrast, the lowest 1.51% OC, 19.66 cmol (+) kg^{-1} of soil CEC, 0.12% N, 12.36 ppm P, 0.70 cmol (+) kg^{-1} of soil K and 5.53 pH were recorded on unfertilized control (V1) in combined over sites. The OC, CEC and N, P and K were higher in V4 by 44.37%, 26.44%, 108.33%, 33.81%, 25.71% and 4.83%, respectively, from V1. In addition, R1 was greater by 73.01% OC, 58.95% CEC, 108.33% N, 91.89% P 29.41% k, 16.95% pH from initial soil physico-chemical properties. The highest levels of physico-chemical quantity on R1 were owing to the harvesting of the maximum amount of biomass over the three years (Appendix Table 7).

The increased in chemical quantity is due to the increase of organic matter at the higher rate of organic treatment. Organic matter is widely proven as a store house of different soil nutrients. The study is in accordance to Manna *et al*. (2005) who showed the higher value of organic carbon, available nitrogen, phosphorus, potassium and lower bulk density at farmyard manure equivalent to 120 kg N/ha compared to the lower levels. Similarly, Fonderer *et al.* (2015b) reported annual organic soil amendment increase soil quality needed for optimum crop production. Furthermore, Johann and Ulrich (2004) showed that plots which received either prepared or non-prepared FYM at 30 t/haper yearhad significantly increased soil pH, P and K concentrations and altered earthworm's population.

Meanwhile, the main effect of organic treatment showed a significant difference in bulk density of experimental soil. The bulk density (BD) was showing positive and opposite effect to the level of organic treatments. The bulk densities of the experimental soil were drastically reduced as the level of organic treatment increased and the vice versa. Hence the lowest bulk densities of 1.05, 1.12 and 1.08, respectively, was recorded at-stations, on-farm and in combined over sites at V4. However, the highest bulk of 1.25, 1.31 and 1.28 were recorded, respectively, at-station, on-farm and in combined over sites at V1. The bulk densities at V4 were reduced by 15.62%, 21.16%, respectively, from V1 and initial soil conditions. The bulk densities of the rest of treatments were located between the maximum level of organic treatments and the unfertilized control. In general, BD was negatively associated with the levels of soil OM. This reduction in the values of bulk density is due to the improvement of total soil porosity up on the organic amendment. The result is in line with Hunt and Gilkes (1992) who showed the highest rate of manure amendment decreases the bulk density by 0.19 g/cm^3 form unfertilized control.

Table 5.4: On-farm physico-chemical properties of the soil in response to the main and interaction effects of the preceding crops and organic matter applications

Treatments		BD (g/cm$^{3)}$	OC (%)	CEC cmol (+) kg^{-1} soil	N (%)	P (ppm)	K cmol (+) kg^{-1} soil	pH
Rotations								
R1		1.21	1.94^{a}	21.76	0.19^{a}	14.53	0.75^{a}	5.87
R2		1.22	1.88^{a}	21.34	0.17^{b}	13.97	0.73^{a}	5.79
R3		1.19	1.69^{b}	20.96	0.18^{a}	14.19	0.70^{b}	5.76
R4		1.23	1.59^{b}	20.65	0.16^{b}	13.78	0.67^{b}	5.65
R5		1.21	1.64^{b}	20.80	0.17^{b}	13.98	0.68^{b}	5.70
Sig. difference		ns	*	ns	*	ns	*	ns
Organic								
V1		1.31^{a}	1.39^{d}	18.57^{c}	0.11^{d}	11.78^{c}	0.64^{c}	5.41^{c}
V2		1.23^{b}	1.65^{c}	20.28^{b}	0.15^{c}	13.82^{b}	0.66^{c}	5.71^{c}
V3		1.19^{b}	1.87^{b}	21.22^{b}	0.21^{b}	14.45^{b}	0.73^{b}	5.89^{ab}
V4		1.12^{c}	2.09^{a}	24.33^{a}	0.23^{a}	16.31^{a}	0.80^{a}	6.00^{a}
Sig. difference		**	**	**	**	**		**
Rotations	Organic treatments							
R1	V1	1.30^{ab}	1.51^{fg}	19.98^{ef}	0.12^{ij}	12.85^{efg}	0.69^{cdef}	5.50^{cde}
	V2	1.25^{abc}	1.84^{bcd}	20.20^{ef}	0.17^{g}	14.35^{bcdef}	0.72^{bcde}	5.68^{abcde}
	V3	1.19^{bcd}	2.07^{ab}	21.60^{abcd}	0.21^{e}	15.10^{abcd}	0.79^{ab}	6.05^{ab}
	V4	1.11^{dc}	2.26^{a}	25.28^{a}	0.26^{a}	15.85^{ab}	0.81^{a}	6.17^{a}
R2	V1	1.31^{ab}	1.45^{g}	19.28^{ef}	0.12^{ij}	12.58^{fg}	0.68^{def}	5.45^{cde}
	V2	1.23^{abcd}	1.84^{cde}	20.18^{ef}	0.18^{g}	13.41^{def}	0.70^{cde}	5.75^{abcde}
	V3	1.22^{abcd}	2.05^{abc}	21.24^{cde}	0.18f^{g}	14.53^{bcde}	0.75^{abcd}	5.93^{abc}
	V4	1.14^{cd}	2.17^{ab}	24.65^{a}	0.21^{de}	15.35^{abc}	0.80^{a}	6.05^{ab}
R3	V1	1.32^{ab}	1.40^{g}	17.95^{f}	0.12^{ij}	11.63^{gh}	0.62^{fg}	5.42^{de}
	V2	1.19^{bcd}	1.49^{fg}	20.43^{ef}	0.14^{h}	14.08^{cdef}	0.66^{efg}	5.75^{abcde}
	V3	1.18^{bcd}	1.82^{de}	21.27^{cde}	0.23^{bcd}	14.24^{bcdef}	0.72^{bcde}	5.85^{abcd}

	V4	1.09^{d}	2.06^{abc}	24.20^{ab}	0.24^{ab}	16.85^{a}	0.81^{a}	6.05^{ab}
R4	V1	1.34^{a}	1.28^{g}	17.80^{f}	0.10^{j}	10.75^{h}	0.60^{g}	5.33^{e}
	V2	1.25^{abc}	1.44^{g}	20.22^{ef}	0.13h^{i}	13.46^{cdef}	0.62^{fg}	5.63^{bcde}
	V3	1.19^{bcd}	1.68^{ef}	20.93^{ed}	0.20^{ef}	14.19^{bcdf}	0.68^{def}	5.80^{abcde}
	V4	1.14^{cd}	1.98^{bcd}	23.65^{abcd}	0.23^{bcd}	16.73^{a}	0.77^{abc}	5.85^{abcd}
R5	V1	1.32^{ab}	1.34^{g}	17.87^{f}	0.11i^{j}	11.12^{gh}	0.61^{fg}	5.42^{abc}
	V2	1.23^{abcd}	1.48^{fg}	20.39^{ef}	0.13^{hi}	13.80^{cdef}	0.62^{fg}	5.70^{abcde}
	V3	1.18^{bcd}	1.78^{de}	21.06^{cde}	0.22^{cde}	14.23^{bcdef}	0.71^{bcde}	5.82^{abcd}
	V4	1.12^{cd}	2.00^{bcd}	23.88^{abc}	0.24^{bc}	16.78^{a}	0.79^{ab}	5.90^{abc}
	FP	1.19^{bcd}	1.7d^{e}	20.06^{ed}	0.15^{b}	14.68^{bcd}	0.86^{bc}	5.65^{cd}
	SL	**	**	**	**	**	**	**
	SE +	0.06	0.12	1.39	0.01	1.09	1.01	0.21
	CV%	6.99	8.63	8.36	7.46	8.04	6.99	4.94

Means followed with the same letter are not significantly different; R1 = wheat-clover-potato; R2 = clover-wheat under sown lupine-potato; R3 = potato-clover-wheat; R4 = wheat under sown lupine-potato under sown lupine-wheat; R5 = lupine-potato under sown lupine-wheat; FP = wheat-fababean-potato;V1 = V1 = 0 t/ha; V2 = 2.5 t/ha FSB; V3 = 5 t/ha FYM; V4 = 5 t/ha FYM + 2.5 t/ha FSB; SL= significance level ** = highly significant at *$P<0.01$*; * = significant at *$P<0.05$*; ns = not significant at *$P\geq0.05$*; CV = coefficient of variation; SE = standard error; BD = bulk density; OC = organic carbon; TN = total nitrogen; CEC = cation exchange capacity; P = phosphorous; pH = power of hydrogen; K = potassium

5.3.4 The interaction effects of rotation and organic treatment on soil physico-chemical properties

The interaction effects of organic treatment and crop rotation system were showed significant (*$P<0.001$*) difference on the physico-chemical quantity of the experimental soil. The OC, CEC, N, P, K, BD and pH were markedly varied in response to treatment combinations.

The OC, CEC and pH of the soil were significantly (*$P< 0.01$*) influenced by the interaction effects of organic treatment and crop rotation system. The interaction effects of the maximum organic treatment and sound crop rotation system were showed the highest level of OC, CEC and pH of the soil. Hence, the highest level of OC, CEC and pH of the soil were recorded from R1V4 at both sites and in combined over sites. The 2.5% OC, 26.90 cmol (+) kg^{-1} of soil CEC and 6.23 of pH were the maximum at on-station. Similarly, 2.26% OC and 25.28 cmol (+) kg^{-1} of soil CEC and 6.17 of pH were the highest at on-farm condition. In the same way, 2.38% OC and 26.09 cmol (+) kg^{-1} of soil CEC and 6.20 of pH were the highest in combined over sites. The treatment combination of R2V4 showed greater OC, CEC and pH closely following R1V4. However, the lowest level of 1.61% OC, 20.03 cmol (+) kg^{-1} of soil CEC and 5.58 pH and were recorded on R4V1 treatment combinations (Table 5.2). The OC, CEC and N, P and K, pH were higher in R1V4 by 65.27%, 37.96%, 190%, 46.12% and 45.31%, 13.76, respectively, from R4V1 rotation systems. In addition, R1V4 was greater by 88.88% OC, 66.81% CEC, 141.66%N, 92.12% P 36.76% k, 19.46% pH from initial soil physico-chemical properties. The highest levels of physico-chemical quantity on R1V4 were due to the incorporation of the maximum amount of biomass over the three years (Table 5.5). The concentration achieved at the maximum rates of manure of 2.38% OC, 6.14 of pH and 25.81cmol (+) kg^{-1} of soil CEC categorized as moderate levels (Murphy, 1968a).

In general, increasing the rates of farmyard manure increased the levels of OM, pH and CEC of the experimental soil. This was due to the increase in soil organic matter accumulation in the experimental soil as the result of three-year application of organic manure, above and below ground organic residues accumulated over the years. When cover crops are regularly part of a rotation, their residues increase soil organic matter (Perez-brandan *et al*., 2014). The result is in agreement with Trevor *et al.* (2015) who reported that long-term compost amended soils had a positively influenced the SOC, CEC and pH of the soil than unfertilized control and inorganic soil fertilization. The outhor has also confirmed that the humus content in soil was enhanced by 0.50% at 30 t/ha farmyard manure with every 5 years of application and with leguminous crops than on field without legumes and without farmyard manure. Similarly, Kuz and Mina (2011) showed that fertilization with farmyard manure leads to an increase in exchange capacity, increases soil pH and improve the organic carbon level of the soil.

Table 5.5: Combined on-station and on-farm physico-chemical properties of the soil in response to the main and interaction effects of the crop rotation and organic matter applications

Treatments		BD ($g/cm^{3)}$)	OC (%)	CEC cmol (+) kg^{-1} soil	N (%)	P (ppm)	K cmol (+) kg^{-1} soil	pH
Rotations								
R1		1.17	2.07^{a}	23.21^{a}	0.21^{a}	15.26^{a}	0.84^{a}	5.92^{a}
R2		1.19	2.01^{a}	22.86^{ab}	0.19^{b}	14.74^{ab}	0.82^{a}	5.85^{ab}
R3		1.17	1.82^{b}	21.70^{bc}	0.19^{b}	14.47^{ab}	0.75^{b}	5.84^{ab}
R4		1.22	1.72^{b}	21.24^{bc}	0.17c	14.03^{b}	0.72^{b}	5.75^{b}
R5		1.19	1.77^{bc}	21.53^{bc}	0.18^{bc}	14.23^{b}	0.74^{b}	5.79^{b}
Sig. difference		ns	*	*	*	*	*	**
Organic treatment								
V1		1.28^{a}	1.51^{d}	19.66^{d}	0.12^{d}	12.39^{d}	0.70^{c}	5.53^{d}
V2		1.21^{b}	1.80^{c}	21.49^{c}	0.16^{c}	14.25^{c}	0.74^{b}	5.78^{c}
V3		1.17^{c}	2.00^{b}	22.43^{b}	0.23^{b}	14.96^{b}	0.78^{b}	5.93^{b}
V4		1.08^{d}	2.18^{a}	24.86^{a}	0.25^{a}	16.58^{a}	0.88^{a}	6.07^{a}
Sig. difference		**	**	**	**	**	*	**
Rotations	Organic treatments							
R1	V1	1.26^{abcde}	1.59^{ghi}	20.77^{hig}	0.14^{hi}	13.43^{fg}	0.76^{cdef}	5.58^{figh}
	V2	1.21^{bcdef}	2.09^{bcd}	22.38^{defg}	0.19^{g}	14.98^{cde}	0.80^{bcdef}	5.86^{cde}
	V3	1.17^{efgh}	2.22^{ab}	23.61^{cdef}	0.23^{def}	16.04^{abcd}	0.86^{abc}	6.07^{abcd}
	V4	1.06^{j}	2.38^{a}	26.09^{a}	0.29^{a}	16.60^{a}	0.93^{abcd}	6.20^{a}
R2	V1	1.27^{abcd}	1.52^{ghi}	20.35^{hij}	0.13^{ij}	13.23^{gh}	0.75^{defg}	5.53^{ih}
	V2	1.19^{defg}	2.16^{ab}	23.29^{cdefg}	0.21^{f}	15.24^{bcd}	0.83^{abcde}	6.01^{abcde}
	V3	1.20^{cdef}	2.04^{cde}	22.25^{bcd}	$0.19c^{g}$	14.27^{def}	0.79^{bcdef}	$5.78c^{defg}$
	V4	1.10^{ij}	2.33^{a}	25.53^{a}	0.25^{bc}	16.24^{ab}	0.90^{ab}	6.09^{abc}
R3	V1	1.29^{abc}	1.53^{ghi}	19.16^{ij}	0.13^{ij}	12.21^{hi}	0.67^{h}	5.57^{fghi}
	V2	1.19^{defgh}	1.67^{g}	20.99^{ghi}	0.15^{h}	14.20^{def}	0.70^{gh}	5.78^{cdefg}
	V3	$1.15f^{hgi}$	1.94^{efg}	22.15^{efgh}	0.24^{bcd}	14.59^{def}	0.75^{efgh}	5.90^{abcde}
	V4	1.06^{j}	2.13^{bc}	24.51^{abc}	0.26^{b}	16.88^{a}	0.91^{ab}	6.11^{a}
R4	V1	1.32^{a}	1.44^{i}	18.91^{j}	0.10^{k}	11.36^{i}	0.64^{h}	5.45^{de}
	V2	1.25^{abcdef}	1.58^{ghi}	20.85^{igh}	0.13^{i}	13.79^{efg}	0.70^{fgh}	5.72^{bcde}
	V3	1.18^{efgh}	1.82^{f}	21.28^{gh}	0.22^{ef}	14.40^{defg}	0.71^{efgh}	5.84^{abc}
	V4	1.13^{ghi}	2.04^{dec}	23.93^{cde}	0.24^{bc}	16.56^{a}	0.82^{bcdf}	5.99^{abcde}
R5	V1	1.29^{ab}	1.48^{ih}	19.10^{ij}	0.12^{jk}	11.73^{i}	0.65^{h}	5.54^{hig}
	V2	1.22^{bcdefg}	1.65^{gh}	20.96^{hig}	0.14^{hi}	14.00^{defg}	0.71^{efgh}	5.76^{efgh}
	V3	1.16^{figh}	1.90^{ef}	21.81^{fgh}	0.23^{cde}	14.54^{def}	0.75^{cdef}	5.86^{bcde}
	FP	1.2^{hi}	1.7^{f}	20.7^{ig}	0.12^{jk}	14.74^{de}	0.87^{bcd}	5.5^{ig}

V4	1.08[ij]	2.06[bcd]	24.26[abcd]	0.25[cb]	16.64[a]	0.87[abc]	6.01[bcde]
SL	**	**	**	**	**	**	**
SE +	0.05	0.10	1.21	0.01	0.80	0.05	0.18
CV%	6.62	7.94	7.78	7.75	7.82	8.64	4.48

Means followed with the same letter are not significantly different; R1 = wheat-clover-potato; R2 = clover-wheat under sown lupine-potato; R3 = potato-clover-wheat; R4 = wheat under sown lupine-potato under sown lupine-wheat; R5 = lupine-potato under sown lupine-wheat; FP= wheat-fababean-potato; V1 = 0 t/ha; V2 =2.5 t/ha FSB; V3 = 5 t/ha FYM; V4 = 5 t/ha FYM + 2.5 t/ha FSB; SL= significance level ** = highly significant at *P<0.01*; * = significant at *P<0.05*; ns = not significant at P≥0.05; CV = coefficient of variation; SE = standard error: BD = bulk density; OC = organic carbon; TN = total nitrogen; CEC = cation exchange capacity; P = phosphorous; pH = power of hydrogen; K = potassium

In the meantime, the interaction effects of organic treatment and crop rotation system significantly influenced the concentration of NPK content of the experimental soil. The highest level NPK concentration was recorded at the interaction effect of the maximum level of the organic treatment and sound rotation system. Then the highest levels of NPK concentration were recorded at R1V4. The 0.30% N, 17.24 ppm P and 1.03 cmol (+) kg^{-1} of soil K were the maximum at on-station. Similar trends was observed at on-farm conditions with the highest nutrient levels of 0.23% N, 15.60 ppm P and 0.81 cmol (+) kg^{-1} soil K compared to other treatments. As to the individual sites, nutrients concentration of 0.27% N, 16.42 ppm P and 0.92 cmol (+) kg^{-1} of soil K were the highest in combined over sites. The interaction effect of farmyard manure at 5 t/ha + 2.5 t/ha FSB and clover-wheat under sown lupine-potato provides better soil nutrient level closely following the highest manure rates. In contrast, R4V1 showed the lowest level of 0.14% N, 13.33 ppm P and 0.75 cmol (+) kg^{-1} of soil K in combined over sites. Slight improvment obtained in NPK concentration compared to the concentration on initial soils. There is an improvement by 2% N, 6.49 ppm P and 0.07cmol (+) kg^{-1} of soil K compared to the initial soil conditions.

This is due to the effect of previous improved management practice employed on the experimental soil. Generally, after three-years of application, the highest rates of manure and sound rotation system provide an optimum concentration of N, P and K levels for plant growth (Appendix Table ***7***). This result is in agreement with Fula *et al.* (2015) who reported the long-term application of manure substantially increased plant nutrients and ultimately improves crop productivity. In addition, Johann and Ulrich (2004) showed that higher available nitrogen (N), phosphorus (P) and potassium (K) observed in farmyard manure applied equivalently to 120 kg /ha N for subsequent years. Furthermore, Manna *et al.* (2005) showed that plots which receive manure at 30 t/ha per year annually significantly increased soil nitrogen, phosphorus and potassium concentrations.

The bulk densities of the experimental soil showed a statistically significant variation on the interaction effects of organic treatment and crop rotation system. In general, the bulk density of experimental soil was lower at the interaction effects of maximum level of organic treatment and sound rotation system and higher on unfertilized control and less sound crop rotation system. Therefore, the lowest level of BD was recorded from R1V4 at both sites and in combined over sites. The BD of 1.12 and 1.11 g/cm^3 were the lowest at on-station and on-farm conditions, respectively. Likewise, the bulk density of 1.08 g/cm^3 was the lowest in combined over sites. The treatment R2V4 was showed lower BD after the R1V4. However, the interaction effects of unfertilized control and wheat under sown lupine-potato under sown lupine-wheat rotation system (R4V1) showed the highest bulk density of 1.29, 1.34 and 1.32 g/cm^3 at station, on-farm and in combined over sites, respectively. Generally, soils having low-level of bulk density exhibit favorable soil physical conditions and create a suitable condition for crop growth. The result is in line with the study of Hunt and Gilkes (1992) that the bulk density (1.08 g/cm^3) recorded at highest rates of manure amendment was low and satisfactory for crop growth. This reduction in the values of bulk density is due to dilution effect organic components in lowering bulk density.

The current result is similar to Manna *et al.* (2005) who noted the lowest bulk density was observed when manure applied equivalently to 120 kg/ha of Nitrogen. Similarly, Tamos *et al.* (2015) reported that long-term organic soil fertilization leads to a decrease in soil bulk density compared to unfertilized control. Furthermore, Ronky and Mishra (2009) confirmed that organic manure decreases soil bulk density by 12.6% compared with unfertilized control. Similarly, Kuz and Mina (2011) showed that fertilization with farmyard manure leads to a decrease of soil bulk density and farmyard manure at 20 t/ha resulted in the lowest soil bulk density of 1.19 g/cm^3 compared to control. In addition, Manna *et al.* (2005) indicated the lower bulk densities were observed in farmyard manure applied equivalently to 120 kg/ha nitrogen.

5.4 Conclusion and Recommendations

The variation in the level of organic manure and the type of crop rotation system and their interaction effects influenced the physico-chemical properties of experimental soil. Application of different level of organic treatments influenced the physico-chemical properties of experimental soil. Physico-chemical properties of experimental soil were the highest at the maximum level of organic treatments and the smallest at the lower level of organic treatments. Similarly, crop rotation system could substantially improve the physico-chemical properties of experimental soil. Physico-chemical properties of experimental soil were greater at potato-clover-wheat than other rotation systems. In addition, the interaction effects of a combination of manure and sound crop rotation system synergistically improved physico-chemical properties of experimental soil. Maximum physico-chemical properties of experimental soil were recorded at the interaction effects of 5 t/ha FYM + 2.5 t/ha FSB and potato-clover-wheat compared to other treatments combinations. This was certainly due to the high level of soil nutrient replenishing rate on the maximum level of organic treatments and sound rotation system. Hence, it could be concluded that even though the separate application of organic treatment and crop rotation system have a positive effect on physico-chemical properties of experimental soil their combined use has more beneficial effect in improving physico-chemical properties of experimental soil

CHAPTER 6. GENERAL SUMMARY, CONCLUSION, RECOMMENDATIONS AND FUTURE RESEARCHCH DIRECTIONS

Inorganic soil amendment has been exercised for long years in the highlands of Ethiopia. The terrible incident appears due to over relaying of inorganic fertilizer and disregard to the beneficial effects of organic fertilizer. The disadvantage of synthetic fertilizer outweighs the advantages and lead to acidity, nutrients depletion, soil compaction, ground and surface water contamination, hardpan and salt formed in the upper layer of cultivated land of Ethiopia. Hence, changing the conventional systems to sustainable soil fertility management essentially appears important to maintain a high level of soil quality and sustain crop productivity. In this regard, selecting organic manure from an inorganic form of soil fertilization could bring sustainability in the agriculture sector. Organic fertilizers contribute a lot to sustain crop production through the beneficial effects of physical, chemical and biological properties of the soil. It improves soil aggregation, soil nutrient level, water retention and reduces soil compaction. However, the organic matter level of the soil controlled by the balance between additions of plant and animal biomasses and losses by decomposition. Both additions and losses directly affected by management practices on a given cultivated land. For example, addition of farmyard and green manure maintain soil organic matter content while burning of farmyard manure and crop residue reduces the organic matter of the soil.

Thus experiments were initiated with the objective of improving the productivity of different crops and the physico-chemical properties of experimental soil through long-term organic treatments in combination with sound rotation pattern. The field experiments conducted in various locations under several cropping systems in Gusha Shinkurta village, Awi Administrative Zone. All experiments were conducted according to an agreed protocol, but the design allowed flexibility to adjust treatments and management practices. Data of plant height and grain yield of wheat; marketable and unmarketable yield of potato and fresh and dry biomass yield of clover were recorded to measure the agronomic performance of each crop. In addition, the cation exchange capacity (CEC), soil reaction (pH), total nitrogen (N), avialable posphorus (P), soil organic carbon (SOC) and bulk density of experimental soil were analyzed and recorded following the standard methods before commencing and at the end of the experiment. The data was subjected to analysis of variance (ANOVA) using General Linear Model (GLM) procedures

SAS version 9.1 (SAS Institute, 2002). The means of the data were separated using the Least Significant Difference (LSD) test at 5% level of significance.

The experimental results showed that the type of preceding crop and the levels of organic treatments greatly influenced the performance of each crop and properties of experimental soil. The productivity of potato, wheat and clover showed incredible variation to the variation of the level farmyard manure and crop rotation pattern. The yield of potato, wheat and clover were increased three to four times in response to sound rotation pattern and organic treatments compared with respective untreated soil and less sound rotation pattern as follows:

1. The tuber yields of potato showed increasing trend over the period of the three years with the lowest in the first year, intermediate in the second year and being the highest in the third year across all treatments. In the first year, maximum potato tuber yield (14.59 t/ha) was recorded at 5 t/ha FYM + 2.5 t/ha FSB, while the lowest tuber yield of 5.4 t/ha was recorded on unfertilized control plots. In the second year, the highest total tuber yield of 24.8 t/ha was recorded at the interaction of 5 t/ha FYM + 2.5 t/ha FSB and potato after sole lupine, while the lowest potato tuber yield (10.5 t/ha) was recorded at the interaction of unfertilized control and potato followed after wheat under sown lupine. In the third year, the highest total tuber yield (35.15 t/ha) was obtained at the interaction of 5 t/ha FYM + 2.5 t/ha FSB and clover-wheat-potato rotation and the lowest tuber yield (13.02 t/ha) was recorded at the interaction of unfertilized control and wheat under sown lupine-clover-potato rotation. Application of 5 t/ha FYM + 2.5 t/ha FSB to potato plots in the third year after clover and wheat attributed to increase tuber yield by 69% and 41% over that of the first and the second years, respectively. In other words, annual application of the maximum rate of farmyard manure and the longest length of rotation with sound rotation pattern gave the maximum potato tuber yield. Hence, application of 5 t/ha FYM + 2.5 t/ha FSB and potato-clover-wheat rotation would be recommended as ecologically sound alternative option to the inorganic soil fertility management system to improve the productivity of potato in the studied area.

2. Similarly, the grain yields of wheat showed increasing trend over the period of the three years with the lowest in the first year, intermediate in the second year and being the highest in the

third year across all treatments. In the first year, the highest grain yield (1.68 t/ha) was recorded at 5 t/ha FYM + 2.5 t/ha FSB and sole lupine. Similarly, the highest grain yield (3.20 t/ha) was recorded at 5 t/ha FYM + 2.5 t/ha FSB and rotation system sole lupine-wheat in the second year. In the third year, the highest grain yield (4.48 t/ha) was recorded at 5 t/ha FYM + 2.5 t/ha FSB and wheat followed by clover and potato. However, the lowest grain yield and other growth parameters recorded on unfertilized control and unsound rotation patterns. The increment in grain yield and other growth parameters of wheat is due to the ability of the systems in providing optimum nitrogen, phosphorus and other nutrients. Hence, 5 t/ha FYM + 2.5 t/ha FSB and potato-clover-wheat rotation pattern could be recommended to achieve optimum yield and profitability of wheat in the high lands of Ethiopia.

3. Furthermore, the biomass yield of clover showed variation in response to treatments. The main effects of preceding crop and the interaction effects of preceding crop and organic matter application did not have a significant effect in most of the growth parameter except the root and shoot dry biomass at on-station conditions. However, the main effect of applications of organic matter applications showed a significant effect on the growth parameters and biomass yield of clover. Statistically significant differences were observed among treatments with respect to all the parameters measured. Plant height, number of nodules, number of tillers, root and shoot biomass of clover were varied in response to organic matter applications. Generally, application of 5 t/ha of FYM combined with 2.5 t/ha of FSB was found superior in almost all parameters measured followed by FYM at 5 t/ha, FSB at 2.5 t/ha and the unfertilized control. The highest total dry biomass of clover (5.6 t/ha) was recorded on FYM at 5 t/ha combined with FSB at 2.5 t/ha followed by FYM at 5 t/ha (4.68 t/ha). The unfertilized control showed the lowest mean dry biomass (3.06 t/ha) of clover compared to all other treatments. FYM at 5 t/ha combined with FSB at 2.5 t/ha showed as much as 86.6% biomass yield advantage over the unfertilized control. Thus, it is advisable to use the FYM at 5 t/ha combined with FSB at 2.5 t/ha for better biomass yield of clover. In addition, correlation within agronomic traits of clover indicated that dry biomass demonstrated positive and significant correlation with plant height, the number of nodule, root and shoot plant biomasses and the number of tillers. In contrast, weak correlations exist for days of 50% flowering and to the stand count of clover.

4. Finally, the variation in crop rotation and organic treatments showed different effects on the physico-chemical property of experimental soil. Thus, the main effects as well as the interaction effects of organic treatment and crop rotation system significantly ($P< 0.01$) influenced the physico-chemical properties of the soil at both sites and in combined over sites. Among all, the interaction effects of wheat-clover-potato rotation pattern and 5 t/ha FYM + 2.5 t/ha FSB markedly influenced the physico-chemical properties of soil. The organic carbon (2.26%), cation exchange capacity (25.28 cmol (+) kg-1 soil), total nitrogen (0.28%), phosphorus (15.85 ppm), potassium (0.81 cmol (+) kg-1 soil) and pH (6.17) were the highest compared to other treatments. Similarly, the lowest level of bulk density (1.11 g/cm3) recorded at this treatment combination. This is because of the incorporation of more crop residue from the system of soil fertilization. Hence, the interaction effects of wheat-clover-potato rotation system and 5 t/ha FYM + 2.5 t/ha FSB recommended for improve soil quality parameters needed to sustain crop productivity.

Generaly, this serious of experiment provides useful information for producers and users about the use of manure in the agriculture sector. Manure not only provide nutrient for plant growth and development but also a beneficial effect on soil properties. These results were a good example to encourage farmers to use farmyard manure and green manure instead of inorganic soil amendments. However, the research has also generated a number of questions which could be addressed in the future to optimize the use of manure for agriculture purposes.

1. In this research, only a few types of manure were used for the study. However, it is well known that manure effect on crop yield and soil properties varies with the source material used. Therefore, it would be important to conduct a similar experiment with manure from different sources.
2. The field experiment was conducted only for three years. Thus, the more longer-term experiment should be established to obtain concrete information on the effects of manure and crop rotation on crop yield and soil properties.

3. Farmers have recognized the importance of organic inputs on crop yield since ancient times,. However, the demand of manure for other purposes is very strong. The farming community use farmyard manure for plastering local house and energy source. This practice highly aggravated the negative nutrient balance in the agricultural fields. Hence, further study must be suggested on alternative energy sources and house making systems.
4. The way of handling organic matter is full of difficalties in the highlands of Awi Zone. Pits and heaps of manure are not well technically fit with scientific standards. The collected manures subjecteed to open sunshine and rainfall that volatilize nitrogen and wash out nutrients. Hence, strong intervention in the teaching of the local community must be suggested.
5. The experimental plan was not able to give the maximum yield of potato, wheat and clover. Hence some revisions should be done on levels of farmyard manure.
6. The calendar of sowing date of green manure should be revisited in order to allow adequate time span to have adequate time between incorporation and planting of the main crop.
7. Finally, selection of different types of green manure that better fit with the agro-ecosystem of the district could be an intervention in the future for better soil and yield improvement.

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APPENDIXES

Appendix Table 1: The nutrient levels applied in the form of organic matter for potato in 2013

Treatment	Manure (t/ha)	Nutrient (kg/ha)		
		N	P	K
0 t/ha FYM (V1)	0.00	0.00	0.00	0.00
2.5 t/ha FSB (V2)	2.50	60.50	8.00	23.00
5 t/ha FYM (V3)	5.00	60.00	32.50	50.00
5 t/ha FYM + 2.5 t/ha FSB (V4)	7.50	121.00	40.50	73.00

FYM = farmyard manure; FSB = fresh sesbania biomass; N = nitrogen; P = phosphorus; K = potassium

Appendix Table 2: Nutrient levels applied in the form of organic matter for potato in 2014

TRT	LB (t/ha)	Nutrient LB (kg/ha)			FYM (t/ha)	Nutrient FYM (kg/ha)			Total nutrient (kg/ha)		
		N	P	K		N	P	K	N	P	K
R1V1	3.00	58.50	9.30	26.40	0.00	0.00	0.00	0.00	58.50	9.30	26.40
R1V2	3.00	58.50	9.30	26.40	2.50	60.50	8.00	23.00	119.00	17.30	49.40
R1V3	3.00	58.50	9.30	26.40	5.00	60.00	33.0	50.00	118.50	42.30	76.40
R1V4	3.00	58.50	9.30	26.40	7.50	120.5	41.0	73.00	179.00	50.30	99.40
R2V1	3.00	58.50	9.30	26.40	0.00	0.00	0.00	0.00	58.50	9.30	26.40
R2V2	3.00	58.50	9.30	26.40	2.50	60.50	8.00	23.00	119.00	17.30	49.40
R2V3	3.00	58.50	9.30	26.40	5.00	60.00	33.00	50.00	118.50	42.30	76.40
R2V4	3.00	58.50	9.30	26.40	7.50	120.50	41.00	73.00	179.00	50.30	99.40

TRT = treatment; V1= 0 t/ha FYM; V2 = 5 t/ha FYM; V3 = 2.5 t/ha FSB; V4 = 5 t/ha FYM +2.5 t/ha FSB; R1= wheat US lupine; R2 = lupine; LB = lupine biomass; N = nitrogen; P = phosphorus and K = potassium

Appendix Table 3: Nutrient levels applied in the form of organic matter for potato in 2015

TRT	Green Manure (t/ha)		Nutrient LB/CB (kg/ha)			FYM (t/ha)	Nutrient FYM (kg/ha)			Total nutrients (kg/ha)		
	LB	CB	N	P	K		N	P	K	N	P	K
R3V1	0.00	2.90	62.93	12.47	25.81	0.00	0.00	0.00	0.00	62.93	12.40	25.81
R3V2	0.00	3.40	73.78	14.62	30.26	2.50	60.50	8.00	23.000	134.208	22.62	53.26
R3V3	0.00	4.70	101.99	20.21	41.83	5.00	60.00	32.50	50.00	161.99	52.71	91.83
R3V4	0.00	5.40	117.18	23.22	48.06	7.50	121.00	40.50	73.00	238.18	63.72	121.01
R4V1	0.79	0.00	15.40	2.449	6.95	0.00	0.00	0.00	0.00	15.40	2.44	6.952
R4V2	0.85	0.00	16.57	2.635	7.48	2.50	60.50	8.00	23.00	77.07	10.63	30.48
R4V3	1.15	0.00	22.42	3.565	10.12	5.00	60.00	32.50	50.00	82.42	36.06	60.12
R4V4	1.29	0.00	25.15	3.999	11.352	7.50	121.00	40.50	73.00	146.15	44.49	84.35

TRT = treatment; V1= 0 t/ha FYM; V2 = 5 t/ha FYM; V3 = 2.5 t/ha FSB; V4 = 5 t/ha FYM +2.5 t/ha FSB; R3 = wheat-clover-potato; R4 = clover-wheat under sown lupine-potato; LB = lupine biomass; CB = clover biomass; FYM = farmyard manure; N = nitrogen; P = phosphorus; K = potassium

Appendix Table 4: Nutrient levels applied in the form of organic matter for wheat in 2013

Organic treatment	FYM (t/ha)	Nutrient (kg/ha)		
		N	P	K
0 t/ha FYM (V1)	-	-	-	-
2.5 t/ha FSB (V2)	2.50	60.50	8.00	23.00
5 t/ha FYM (V3)	5.00	60.00	32.50	50.00
5 t/ha FYM + 2.5 t/ha FSB (V4)	7.50	120.50	40.50	73.00

FYM = farmyard manure; FSB = fresh sesbania biomass; N = nitrogen; P = phosphorus; K = potassium

Appendix Table 5: Nutrient levels applied in the form of organic matter for wheat in 2014

Treatment	Clover (t/ha)	Nutrient from Clover (kg/ha)			FYM (t/ha)	Nutrient from FYM (kg/ha)			Total nutrient (kg/ha)		
		N	P	K		N	P	K	N	P	K
V1	0.63	13.70	2.00	5.10	-	-	-	-	13.70	2.00	5.10
V2	0.91	19.76	2.90	8.30	2.50	60.50	8.00	23.00	80.26	10.9	31.3
V3	1.05	22.78	3.36	9.10	5.00	60.00	32.50	50.00	82.78	35.86	59.1
V4	1.23	26.75	3.90	11.50	7.50	120.50	40.50	73.00	147.25	44.4	84.5

V1 = 0 t/ha FYM; V2 = 2.5 t/ha FSB; V3 = 5 t/ha FYM; V4 = 5 t/ha FYM + 2.5 FSB; FYM = farmyard manure; FSB = fresh sesbania biomass; N = nitrogen; P = Phosphorus; K = potassium

Appendix Table 6: Nutrient levels applied in the form organic matter for wheat in 2015

Treatment combinations	GM (t/ha)		Nutrient from LB/CB (kg/ha)			FYM (t/ha)	Nutrient from FYM (kg/ha)			Sum of nutrients (kg/ha)		
	LB	CB	N	P	K		N	P	K	N	P	K
R1v1	-	2.900	62.93	12.47	25.81	-	-	-	-	62.90	12.50	25.80
R1v2	-	3.40	73.78	14.62	30.26	2.50	60.50	8.00	23.000	134.30	22.60	53.30
R1v3	-	4.70	101.99	20.21	41.83	5.00	60.00	32.50	50.00	162.00	52.70	91.80
R1v4	-	5.40	117.18	23.22	48.06	7.50	120.50	41.00	73.00	237.70	64.20	121.10
R2V1	0.809	-	17.355	27.59	7.92	0.00	-	-	-	17.40	27.60	7.90
R2v2	1.18	-	23.01	36.58	10.50	2.50	60.50	8.00	23.00	83.50	44.60	33.50
R2v3	1.63	-	31.785	50.53	14.51	5.00	60.00	32.50	50.00	91.80	83.00	64.50
R2v4	2.24	-	43.68	69.44	19.94	7.50	120.50	40.50	73.00	164.20	110.40	92.90
R3v1	1.18	-	23.01	36.58	10.50	0.00	-	-	-	23.00	36.60	10.50
R3v2	1.24	-	24.18	38.44	11.04	2.50	60.50	8.00	23.00	84.70	46.40	34.00
R3v3	1.79	-	34.90	55.49	15.93	5.00	60.00	32.50	50.00	94.90	88.00	65.90
R3v4	2.25	-	43.87	69.75	20.03	7.50	120.50	41.00	73.00	164.40	110.80	93.00

R1 = Potato-clover-wheat; R2 = wheat under sown lupine-potato under sown lupine-wheat; R3 = lupine-potato under sown lupine -wheat; V1 = without any addition; V2 = 2.5 FSB; V3 = 5 t/ha FYM; V4 = 5 t/ha FYM + 2.5 FSB; FYM = farmyard manure; GM = green manure; LB = lupine biomass; CB= clover biomass; N = nitrogen; P = Phosphorus; K = potassium

Appendix Table 7: The total sum of organic matter harvested from the preceding crop and FYM from 2013-2015 in t/ha on both wheat and potato field

	year I	year II				year III				
TC	FYM	FYM	CB	LB	WB	FYM	CB	LB	WB	TB
R1V1	-	-	-	-	1.23	-	3.14	-	-	4.37
R1V2	2.50	2.50	-	-	1.51	2.50	4.46	-	-	13.47
R1V3	5.00	5.00	-	-	1.73	5.00	4.6	-	-	21.33
R1V4	7.50	7.50	-	-	2.62	7.50	5.76	-	-	30.88
R2V1	-	-	0.61	-	-	-	-	0.79	1.37	2.77
R2V2	2.50	2.50	0.95	-	-	2.50	-	0.85	2.8	12.10
R2V3	5.00	5.00	1.08	-	-	5.00	-	1.15	4.45	21.78
R2V4	7.50	7.50	1.18	-	-	7.50	-	1.29	5.13	30.10
R3V1	-	-	-	-	-	-	2.96	-	-	2.90
R3V2	2.50	2.50	-	-	-	2.50	3.47	-	-	10.9
R3V3	5.00	5.00	-	-	-	5.00	4.76	-	-	19.70
R3V4	7.50	7.50	-	-	-	7.50	5.42	-	-	27.9
R4V1	-	-	-	2.00	0.74	-	-	0.89	-	3.63
R4V2	2.50	2.50	-	2.00	0.91	2.50	-	1.18	-	11.59
R4V3	5.00	5.00	-	2.00	1.13	5.00	-	1.63	-	19.76
R4V4	7.50	7.50	-	2.00	1.14	7.50	-	2.24	-	27.88
R5V1	-	-	-	3.00	-	-	-	1.18	-	4.18
R5V2	2.50	2.50	-	3.00	-	2.50	-	1.24	-	11.74
R5V3	5.00	5.00	-	3.00	-	5.00	-	1.79	-	19.79
R5V4	7.50	7.50	-	3.00	-	7.50	-	2.25	-	27.75

TC = treatment combination; R1= wheat-clover-potato; R2 = clover-wheat under sown lupine-potato; R3 = potato-clover-wheat; R4 = wheat under sown lupine-potato under sown lupine-wheat; R5= lupine-potato under sown lupine-wheat. V1= 0 t/ha: V2 = 2.5 t/ha FSB; V3 = 5 t/ha FYM; V4 = 5 t/ha FYM + 2.5 t/ha FSB; LB = lupine biomass; CB = clover biomass; WB = wheat biomass;TB = total biomass; FYM = farmyard manure