BAHIR DAR UNIVERSITY

COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCE

GRADUATE PROGRAM

RESPONSE OF BARELY (*Hordeum vulgare* L.) YIELD AND YIELD COMPONENTS TO LIME AND VERMICOMPOST APPLICATION ON ACIDIC SOIL OF SANKET LIDETA KEBELE BANJA DISTRICT NORTHWESTERN ETHIOPIA

M.Sc Thesis

By

Wubayehu Kidanemariam Beyene

October, 2021

Bahr Dar, Ethiopia.

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A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF COLLAGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES, BAHIR DAR UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (MSC.) IN SOIL SCIENCE

Department: Natural Resource Management

Program: Soil Science

Major-advisor: Getachew Agegnehu (PhD) Lead Researcher

Co-advisor: Eyayu Molla (PhD) Associate professor

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THESIS APPROVAL SHEET

As members of the Board of Examiners of Master of Sciences (M.Sc.) thesis open defense examination, we have read and evaluated this thesis prepared by Miss Wubayehu Kidanemariyam Beyene entitled **Response of Barley (*Hordeum vulgare* L.) Yield and Yield Components to Lime and Vermicompost Application on Acidic Soil of Sanket Lideta Kebele Banja District Northwestern Ethiopia.** We hereby certify that the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Sciences (M.Sc.) in Soil Science.

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DECLARATION

This is to certify that this thesis entitled "**RESPONSE OF BARLEY *(Hordeum vulgare* L.*)* YIELD AND YIELD COMPONENTS TO LIME AND VERMICOMPOST APPLICATION ON ACIDIC SOIL OF SANKET LIDETA KEBELE BANJA DISTRICT NORTHWESTERN ETHIOPIA"** was submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in **"Soil Science"** to the Graduate Program of College of Agriculture and Environmental Sciences, Bahir Dar University by Miss **Wubayehu Kidanemariam Beyene** (ID. No. BDU1206790PR) is an authentic work carried out by her under our guidance.

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ABBREVIATIONS AND ACRONYMS

C: N	Carbon Nitrogen Ratio
CEC	Cation Exchange Capacity
CSA	Central Statistical Agency
CV	Coefficient of Variance
M	Molarity
SAS	Statistical Analysis System
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
TN	Total Nitrogen
VC	Vermicompost
PARC	Pawe Agricultural Research Center
EthioSIS	Ethiopian Soil Information System
LR	Lime Requirement

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Response of Barely (*Hordeum vulgare* L.) Yield and Yield Components to Lime and Vermicompost Application on Acidic Soil of Sanket Lideta Kebele Banja District Northwestern Ethiopia

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ABSTRACT

Soil acidity is the major challenge in the highland areas of Ethiopia which is potentially limiting soil fertility and agricultural productivity. As a result, soil acidity and the associated soil infertility problems are the major challenges to crop production such as barley (Hordeum vulgare L.) in the northwestern highlands of Ethiopia. In response to this problem this study was conducted on acidic soils of Sanket Lideta kebele Banja district northwestern Ethiopia to evaluate the main and/or interaction effects of different rates of lime and vermicompost (VC) application on soil properties and yield and yield components of barley (Hordeum vulgare L.) during the 2020 cropping season. The factorial combinations four rates of lime (0, 50, 100 and 150% or converted to 0, 0.93, 1.86 and 2.79 t ha^{-1}) and three rates of VC (0, 2.5 and 5 ton ha^{-1}) were laid out in randomized complete block design with three replications. Representative soil samples were taken at a depth of 0-15 cm before the application of treatments and after harvesting as well as the agronomic data were collected with the appropriet time. The data were analyzed using SAS computer software version 9.4. The results revealed that the application of lime and VC significantly increased soil pH, total nitrogen (TN), organic carbon (OC), available phosphorus (P), cation exchange capacity (CEC), Exchangeable cations and decreased bulk density, exchangeable acidity and Al^{3+}. The analysis of variance for agronomic data showed that plant height, number of seeds per spike, grain and straw yield, harvest index, 1000 grain weight, and protein content were affected by the interaction effects of lime and VC. While spike length, effective tiller, biomass yield and hectoliter weight were affected by the main effects of lime and vermicompost. Grain yield was positively correlated with pH (0.851^{***}), TN (0.74^{**}), OC (0.57^{*}), available P (0.65^{*}), CEC (0.87^{***}), Ca (0.68^{*}), Mg (0.69^{**}), Na (0.91^{***}), and K (0.59^{*}), but negatively correlated with exchangeable acidity (-0.94^{***}), Al^{3+}(-0.90^{***}) and bulk density (-0.59^{*}). Grain yield was also highly correlated with seed number (0.84^{***}) and biomass yield (0.92^{***}). The lowest grain yield (3635.4 kg) was found from the control plots. But, the highest grain yield (5097.5 kg) was recorded from 1.86 lime and 5 VC t ha^{-1} treatment combinations. The application of (0.93 t ha^{-1}) lime and 5 t ha^{-1} VC was found to be highest net benefit (90997.9 ETB with acceptable MRR for the Sanket Lideta Kebele which improves nutrients of soil and is economically feasible. It is recommended that the experiment needs to be conducted on the same plots at least for one additional season to reach a final conclusion.

Key words: Barley, Grain yield**,** Lime**,** Net benefit**,** Soil acidity, Vermicompost

Chapter 1. INTRODUCTION

1.1. Background and Justification

Soil acidification is a major global problem, especially in the humid tropical region, where high precipitation has been a dominant influence on pedogenic development (Brady and Weil, 2016). It is a multipart process that results in the formation of acidic soil. In the broadest sense, it can be considered as the addition of natural and anthropogenic processes that lower down the pH of the soil solution (Brady and Weil, 2008). Soil acidity is the major cause of soil fertility depletion, which affects approximately 50% of the world's potentially arable soils (Kochian *et al.,* 2004). It is a complex of numerous factors involving nutrient deficiencies and toxicities low activities of beneficial microorganisms and reduced plant root growth, which limits the absorption of nutrients such as P, Ca, K, Mg, and Mo and water (Wang *et al.,* 2006; Fageria and Baligar, 2008). In Ethiopia, Soil acidity is the major problem that is mostly observed in the soils of highlands receiving high rainfall. Acid soils are widespread and occupy 43% of the total land areas in Ethiopia (Getachew Agegnehu *et al.,* 2019). In western part of Ethiopia; sustainable agricultural production becomes low due to soil acidity and low soil fertility. Areas that affected by soil acidity include Ghimbi, Nedjo, Hosanna, Sodo, Chencha, Hagere-Mariam, Endibir, and Awi Zone of the Amara regional state (Lulseged Tamene *et al*., 2017).

Soil acidity can be corrected by the application of liming materials. Lime is an agricultural material capable of increasing soil pH and neutralizing soil acidity. It is the application of calcium and magnesium-rich materials to the soil in various forms, including marl, chalk, limestone, or hydrated lime. It is a desirable practice where the soil is highly acidic and multi-cropping involving acid sensitive crops is adopted. Lime, in its most pure form, is made up largely of Ca. Calcium carbonate is a base, and therefore, has a neutralizing effect of acids (Getachew Agegnehu *et al*., 2019). The addition of lime to acid soils has long been widely adopted as the amelioration strategy for many years to improve crop production which is rarely used in Ethiopia (Hailu Regassa and Getachew Agegnehu, 2011). There is a positive relationship between SOC and pH, implying the strong effect of land management on soil acidity. This further reveals that bad management of soil organic matter can lead to an exacerbation of soil acidity. Effective management of soil acidity in the acidic area includes an integrated approach involving the combined application of organic amendment, liming and application of optimal inorganic fertilizers (Biyensa Gurmessa, 2020).

Vermicompost is a nutrient-rich organic amendment that is microbiologically active, resulting from the interactions between earthworms and microorganisms during the breakdown of organic matter (Edwards and Fletcher, 1988; Sinha *et al*., 2010). Vermicompost is a stabilized, finely divided peat-like material with a low C:N ratio, high porosity and high water-holding capacity, in which most nutrients are present in forms that are readily taken up by crops (Domfnguez, 2004). Vermicompost can restore and improve nutrients for a long time, and has a high water-holding capacity and high porosity compared to conventional compost due to its humus content (Sinha *et al.,* 2010). According to Arancon *et al*. (2006), vermicompost applications can improve soil fertility and agricultural productivity. Demonstration of soil P mobilization can be directly or indirectly affected by vermicompost. According to Guppy *et al.* (2005), vermicompost reduces the P fixation by the soil via its rich organic acids which compete for binding sites with orthophosphates and complexes with metals. Other studies demonstrated that the organic acids in vermicompost effectively slow down the formation of soluble phosphates (Moghimi *et al.,* 2018). Total organic carbon in the vermicompost determines the organic matter. The contents of total nitrogen in the vermicompost varied depending on the types of organic input, and carbon to nitrogen ratio is critical in the processes of vermicompost. (Meena, 2020). Therefore, integrated use of lime, vermicompost, and chemical P fertilizer can improve soil acidity and availability of nutrients (Abdissa Bekele *et al*., 2018).

Barley (*Hordeum vulgare* L.) ranks fifth next to teff (*Eragrostistef*), maize (*Zea mays* L.), sorghum (*Sorghun bicolor* L.), and wheat (*Triticum aestivum* L.) in Ethiopia, and third after teff and wheat in the high altitude areas of Ethiopia (Hailu Regassa and Getachew Agegnehu, 2011). Ethiopia, Algeria, Morocco, Tunisia and South Africa were the top five largest barley producers in the Africa for the year 2019 with estimated production of approximately 2.4, 1.6, 1.2, 0.9 and 0.3 million tons respectively (FAO, 2019). The main advantage of incorporating barley in diets nowadays is due to its potential health benefits among which lowering of blood cholesterol, with b-glucans (Behall *et al*., 2004). Barley is the dominant cereal crop grown in the highlands of Ethiopia where soil acidity is rampant. Barley production covers a total area of 1.02 million ha^{-1} with a national average productivity of 1.87 t/ha (CSA, 2018).

Soil acidity is considered to be one of the major bottlenecks to barley production in the highlands of Ethiopia. The problem still persists and has not been addressed sufficiently. Consequently, many small-scale farmers in the highlands of the country have almost given up barley production due to severe soil acidity. Infact, some farmers practice barley bare fallow oats rotation system to reduce the negative effects of soil acidity and improve soil fertility (Hailu Regassa and Getachew Agegnehu, 2011). Nevertheless, this rotation system is not sustainable and in the long run will degrade the soil resource due to severe soil erosion on the bare fallow. Farmers are not encouraged to apply P fertilizer due to low response of the acidic soils to P application as a result of P fixation. Consequently many parts of the Ethiopian highlands have a problem of acidity which causes a gradual declining of soil fertility and crop productivity. On the otherhand, a significant number of research on the effect of vermicompost (VC) individually and combined with lime and inorganic fertilizers in ameliorating the acidic soils of the country has not been done. Actually few studies has been conducted on the amendments of acidic soils by lime and lime with other organic and inorganic fertilizers other than vermicompost in different areas (Achalu Chimdi, 2012; Asmare Melese *et al.,2015;* Abdissa Bekele *et al*., 2018).

1.2. Statement of the Problem

The study area, Banja district was suitable for the production of several crops including barely, wheat, and other crops. However, soil acidity and fertility depletion is the major problem faced by smallholder farmers in the district and other similar areas of the Amhara region. This problem is primarily resulted from continuous cultivation and crop removal of nutrients, leaching of ions due to high amount of rainfall, and decomposition of organic matter. As a result, large area of the district has low soil fertility and farmers are not food secured. The productivity of the district is declining year after year, and farmers are forced to expand their farm land to marginal areas and grazing lands. Thus, improved soil fertility and acidity management through the use of organic fertilizer and lime amendments could be used as one efficent strategy to improve soil fertility and increase agricultural productivity. Although the problem of soil acidity is well known, so far there are no research reports that showed the effects of vermicompost and lime on acidic soils and barley crop yield in Banja district. Therefore, identifying effective nutrient management method through the combined application of organic fertilizers and lime is needed to replenish the soil nutrients and sustain crop productions in the study area.

1.3. Objectives

1.3.1. General objective

The general objective of this study was to evaluate the main and/or interaction effects of different rates of lime and vermicompost application on soil properties and grain yield and yield components of barley (*Hordeum vulgare* L.) in acidic soil Sanket Lideta Kebele Banja district.

1.3.2 Specific objectives

The specific objectives of this study were

- ✓ To evaluate the main and/or interaction effects of lime and vermicompost on barely grain yield and yield components.
- ✓ To determine the optimum lime and vermicompost requirement of barely grown under acidic soil condition of Banja district.
- ✓ To analyze the effects of lime and vermicompost on selected soil properties

1.4 Research Questions

- ➢ Do the applications of lime and vermicompost affect yield and yield components of barley under acidic soil condition?
- ➢ Do lime and vermicompost applications affect the soil properties under acidic soil condition?

Chapter 2. LITERATURE REVIEW

2.1. Soil pH and Soil Acidity

Soil pH is an important soil chemical property that indicates the quality of the soil. The soil pH varies with the amount of H^+. The more the high H^+ in the soil solution, the higher the acidity while less H^+ influences the soil to be alkaline, and when moderate the soil is said to be neutral (Wanjiru, 2018). The pH less than seven indicates the degree of soil acidity, equals to seven indicates neutral and greater than seven indicates the increase in the soil alkalinity level (Tan, 2010). Soil acidity is one of the major constraints in crop production throughout the world that influences many chemical and biological reactions that control plant nutrient availability and the toxicity of some elements and is a serious limitation for crop production in many regions of the world (Pagani and Mallarino, 2012).

Soils become acidic for several reasons. The reaction of aluminum ions with water is the most common source of hydrogen (pH<4.0 is: $Al^{3+} + H_2O = Al\ (OH)^{2+} + H^+$). The species of aluminum (Al) ions present vary with pH. Potassium chloride extracted Al and Al saturation has an inverse relationship with pH (Kariuki *et al.*, 2007). When soil pH is < 5.5, it affects the growth of crops due to high concentration of Al and manganese (Mn), and deficiency of phosphorus (P), nitrogen (N), sulfur (S) and other nutrients (Abreha Kidanemariam *et al*., 2013). Soil acidification is a gradual process that results from long-term intensive crop production. The rate of soil acidification may be reduced through management (Wortmann *et al*., 2003). In Ethiopia, soil acidity is a problem that has not been addressed in depth. It is observed that most of these soils are found in the highlands of Ethiopia where the rainfall is high (Paoulos Dubale, 2001). The Ethiopian highlands are one of the hotspots on the African continent about food production and in the struggle to preserve the natural resource base (Tilahun Amede *et al*. 2021).

2.2. Soil Acidity and Acid Prone Areas in Ethiopia

In Ethiopia, huge surface areas of the highlands located at almost all regional states of the country are affected by soil acidity especially the western part of the country. According to Eyasu Elias (2016), 80% of the Nitisols and luvisol soils found in the North, central and southwestern highlands of Ethiopia are very strongly acidic soils, predominantly covering most parts of Wollega, Jimma and Ilubabor from the Oromia Region, and Gojjam from the Amhara Region. Even though the soil types of these areas are not well defined and mapped, the dominant is reported to be Nitisols, with a reddish color, deep horizon and a high proportion of clay content. These areas receive higher annual rainfall than other areas in the country (Eyasu Elias., 2017). The strongly acid soils are found in ecologies that receive or have historically received high rainfall and have warm temperatures much of the year. The most strongly acidic soils are found in western and southwestern parts of Ethiopia, the central highlands, and the high rainfall areas of the northwestern part of the country. Nevertheless, moderately acidic soils (pH 5.5-6.5) are distributed throughout much of the rest of the country (Taye Bekele, 2008). Most of the time acidic soil is dominated by Nitisols, and due to leaching of basic cations, more than 80% of the landmasses that originated from Nitisols could be acidic (Eyasu Elias, 2016; Eyasu Elias *et al*. 2020).

2.3. Causes of Soil Acidity

2.3.1. Climate

The main factors giving rise to increased soil acidity in Ethiopia include climatic factors such as high amount of precipitation that exceeds evapotranspiration which leaches appreciable amounts of exchangeable bases from the surface soil (Mesfin Abebe, 2007). High rainfall leaches the soil's profile basic elements (Ca, Mg, Na, and K) that prevent soil acidity. Excessive rainfall leaches soluble nutrients such as Ca and Mg which are specifically replaced by Al from the exchange sites (Brady and Weil, 2016). Theremoval of bases exceeds the rate of their liberation from non-exchangeable forms. Wet climates have a greater potential for acidic soils (Girma Tadesse, 2001).

2.3.2. Acidic parent material

Due to differences in the chemical composition of parent materials, soils will become acidic after different lengths of time. Thus, soils developed from granite material are likely to be more acidic than soils developed from calcareous shale or limestone (Slattery and Hollier, 2002). The inherent fertility of Ethiopian soils developed under different parent materials and climate varies depending on the origin and composition of the materials. Soils developed from sandstones are poor sandy soils, whereas the inherent soil fertility developed over basic parent materials is relatively high (Woldeab Asnake *et al*., 1991). In most cases, soils found in high-altitude areas of the country are acidic in reaction, poor in exchangeable cations, and low in base saturation (Hailu Regassa and Getachew Agegnehu, 2011).

2.3.3. Application of mineral fertilizers

Soil acidity increases through continuous application of inorganic fertilizer without soil test and amendment. The use of N fertilizers in form of ammonia is a source of acidification (Guo *et al*., 2010). Longterm application of nitrogen fertilizer, loss of cations through leaching, and land use change, meaning that continuous cropping without organic inputs is among the anthropogenic factors (Tully *et al*., 2015). The transformation of nitrogen fertilizers into nitrate releases hydrogen ions to create soil acidity. Application of mineral fertilizer containing nitrogen to soil can ultimately lower soil pH and increased soil acidity (Guo *et al*., 2010).

Urea and diammonium phosphate (DAP) are the types of fertilizer as a source of N and P respectively, which were widely used in Ethiopia (World Bank, 2016). Increased level or frequency of application of the same fertilizer can lead to increased soil acidity because it enhances the release of H (Zhu *et al*. 2020). Due to the limitation of N use efficiency in acidic soils, acid soils could require a relatively higher amount of fertilizer to give the intended crop yield (Antoniadis *et al*., 2015). Phosphorous is commonly known as a scarce nutrient. A little amount (15–20%) of applied P is used by crops (Karunanithi *et al*., 2015). The fate of the long-term accumulation of P is uncertain, but there is a high possibility of P to be reused about 46 times (Karunanithi *et al*., 2015). However, this might not be true for all soil types (Tekalgn Mamo and Haque, 1987). The use of optimum fertilizer should be the priority recommendation.

2.3.4. Decomposition of organic matter

The reactive carboxylic, enolic and phenolic groups are found in soil organic matter or humus that behave as weak acids. During their dissociation, they release H^+ ions. In addition, the formation of CO_2 and organic acids during the decomposition also results in the replacement of bases on exchange complex with H^+ ions (Somani *et al*., 1996). Depending on the plant from which the organic matter is derived many forms of organic matter are acidic. Some plants contain some quantities of organic acids. Through their residues are decomposed, the organic acids naturally affect the soil acidity. Other plants are acidifying simply because of the low concentrations of bases they contain. If the plant does not contain enough bases to satisfy microbial needs, the decomposition of the plant debris will not only give off carbon dioxide but will also remove base nutrients such as calcium and magnesium from the soil (Harter, 2007).

2.3.5. Removal of major cations through crop harvest

The most significant role in increasing soil acidity is the harvest of high-yielding crops. To fulfill the requirement of their nutrition, crops absorb basic elements such as Ca, Mg, and K. As crop yields increase, more of these lime-like nutrients are removed from the soil. Compared to the leaf and stem portions of the plant, the grain contains minute amounts of these basic nutrients. Therefore, harvesting high-yielding forages affects soil acidity more than harvesting grain does (Fageria and Baligar, 2008; Rengel, 2011). During the harvesting of crops the mobile Ca^{2+}, Mg^{2+}, K^+ and Na^+ cations are removed from the soil solution, and they are replaced with H_3O and Al^{3+} ions. Both of these species are acids. In conditions where rainfall exceeds leaching during most of the year, the basic soil cations (Ca, Mg, K) are gradually depleted and replaced with cations held in colloidal soil reserves, leading to soil acidity (Slattery and Hollier, 2002; Mesfin Abebe, 2007).

2.3.6. Low buffer capacity of the soil

The low buffer capacity of the soil is the other source of soil acidity and contact exchange between exchangeable hydrogen on root surfaces and the bases in an exchangeable form on soils. Microbial production of nitric and sulfuric acids occurs through leaching. The lime requirement of acid soil is related not only to the soil pH but also to the buffer or CEC. The buffering or CEC is related to the amount of clay and organic matter present, the larger the amount, the greater the buffer capacity and, even if acid, will have low lime requirment (Aboyitu Sisay, 2019; Getachew Agegnehu *et al.*, 2019). Soils with higher buffer capacity like clayey and peats, if acid, have high lime requirements. Coarse textured soils with little or no organic matter have low buffer capacity and will have low lime requirements. The indiscriminate use of lime on coarse-textured soil could lead to over-liming injury (Somani *et al*., 1996). Therefore, due to the higher base saturation requirement to raise the pH to 6 with montmorillonite than with kaolinite the relationship between pH and percent base saturation is important for soils representative of 1:1 and 2:1 clay (Kamprath and Adams, 2010).

2.4. Effect of Acidic Soil on Nutrient Availability

The high concentration of Al^{3+}, Fe^{3+}, and H^+ in acid soil can reduce the soil pH < 4 and cause high P fixation, low organic matter content, and diminish the activity of microorganisms (Fernández and Hoeft, 2009). Effects of high acidity in soil are shortage of available Ca, P and Mo on the one hand, and excess of soluble Al, Mn, and other metallic ions on the other hand (Somani, 1996; Getachew Agegnehu and Sommer, 2000). Soil acidity inhibits the growth of sensitive plant species, though it has little effect on insensitive species. During the deficiency of Ca and Mo the pH effect become low and Al and Mn toxic on soil (Somani, 1996; Baquy *et al*., 2017). The main aluminum toxicity symptom is inhibition of root elongation with simultaneous induction of glucan synthesis, which is apparent even in a short exposure time. Aluminum leads to poor ion and water uptake. Al is known to induce a decrease in mitotic activity in many plants, and the aluminum-induced reduction in the proliferating cells is accompanied by the shortening of the region of cell division in plants

(Krstic *et al*., 2012). The effects of aluminum toxicity are most noticeable in seasons with a dry finish. Roots are unable to effectively grow through acidic subsurface soil which forms a barrier and restricts access to stored subsoil water for grain filling (Gazey and Davies, 2009).

2.5. Management of Acidic Soil

Management of acid soils entails the development of viable and sustainable management techniques to improve food and other agricultural production. Management strategies for efficient crop production on these soils may include the adoption of soil to fit plants and/or adapting plants to fit soils. These strategies may include the use of amendments (lime and gypsum) and also planting tolerant species or cultivars. Evidence from elsewhere show that a combined application of lime and the organic amendment is more effective against soil acidity (Tiritan *et al*., 2016).

Soil acidity can be managed by adding lime, organic matter, and planting acid tolerant crop varieties. Limes are materials containing carbonates, oxides, or hydroxides required to apply in acid soils to raise soil pH and in addition neutralize toxic elements in the soil (TSO, 2010).

2.5.1. Liming

The value of liming to correct soil acidity and enhance agricultural productivity has been well documented (Pagani and Mallarino, 2012). The most common and effective practice for reducing soil acidity is the application of lime. Direct effects of liming increase Ca content and, if dolomitic limestone is used, Mg content in the soil. Increased soil pH results in several changes that might be considered as indirect effects (Fageria and Nascente, 2014). As soil pH increases, P and Mo become more available (Duncan, 2012).

Application of lime containing Ca and/or Mg compounds to acid soil increases Ca^{2+} and/or Mg ions and reduces Al^{3+}, H^{+}, Mn^{2+}, and Fe^{2+} ions in the soil solution. Hence, this leads to increased soil pH and available P due to a reduction in P sorption (Fageria and Baligar, 2008). pH is used to determine the amount of lime to be added to the soil, the higher the buffer capacity of the soil the higher resistance of the soil for change in pH due to CEC and clay content, and the higher CEC and clay content, the larger lime content required. The degree of fineness is equally important in the selection of a liming material since the speed with which the various materials will react is dependent on the surface area that is in contact with the soil. If the soil is fine, the reaction would be extensive; but if coarse, the reaction will be slight. So, for materials such as CaO and $Ca(HO)_2$ that are by nature powdery, no problem of fineness is involved. On the other hand, limestone is entirely a different matter since its reaction is related to particle size (Taye Bekele, 2008). Liming materials or limestone can be ground to any degree of fineness such as ground marble, limestone, and dolomite that are found in the country (Sanchez, 1976).

2.5.2. Addition of organic fertilizers

The use of organic inputs like vermicompost can be very promising and suitable for sustainable organic agriculture for a better future (Reganold *et al*., 2001). Current trends in agriculture are centered on reducing the use of inorganic fertilizers by biofertilizers such as vermicompost (Hadi *et al.*, 2011). Application of vermicompost (VC) to the soil reduces the bulk density, thereby increases the soil porosity and aeration which facilitates the movement of nutrients. It helps in soil aggregate formation and better root development during plant growth. Soil pH is maintained by the humic acid component of vermicompost that acts as a buffer and facilitates the slow release of nutrients. The physical, chemical and biological properties of soils are improved by vermicompost as an organic amendment (Hussain and Abbasi 2018; Yadav *et al*., 2019).

Soil nutrients recycle by adding of organic matter like green manure, compost, farmyard manure, biochar and retention of crop residues (Getachew Agegnehu and Tilahun Amede, 2017; Tilahun Amede *et al*. 2021). To reduce Al toxicity application of manure is the cheapest amendment of soil acidity for smallholder farmers. After mineralization of manure cations released to the soil.

Vermicompost is a nutrient rich, microbiologically active organic amendment created by earthworms and microbes interacting during the decomposition of organic materials.

Vermicompost (VC) is one of the stabilized, finely divided organic fertilizers with a low C: N ratio, high porosity, and high water-holding capacity, in which most nutrients are present in forms that are readily available for plants (Domfnguez, 2004). Vermicompost decreases exchangeable acidity which can support a release of plant nutrients in the acidic soils (Reshid Abafita, 2016). The application of VC promotes growth of plants and have a positive effect on growth and productivity of cereals and legumes. When it is compared, VC contain high nutrients with growth hormones and more powerful growth promotes than all other organic fertilizers and it gives 30-40% higher yield of crops over chemical fertilizers (Sinha *et al*., 2010). Organic matter added in the soil binds the nutrients like calcium, magnesium, and potassium in the form of soil colloids with humic acids that are critical for plant growth (Hussain and Abbasi, 2018).

2.5.3. Use of acid tolerant crop varieties

Acidic tolerant crop depends on genetic variation. There is little attention for selection or breeding to obtain acid soil-tolerant crop varieties in Ethiopia. The collection of germplasm, characterization, and evaluation on the Al toxicity tolerance is another study, the long-run plan is suggested for genetic recombination and progeny evaluation using the available genetic resources (Tenaye Sisay and Tesfaye Balemi., 2014). The assessments of plant that tolerate acid soil stresses include tolerance to high levels of Al or Mn, and to deficiencies of Ca, Mg, P. Species and genotypes within a species have been reported to have considerable variation in their tolerance to Al and Mn (Somani, 1996; Kochian et al., 2004). Plant species have their center of origin in acidic soil regions where adaptation to soil constraints is the evolutionary process (Somani 1996). The variety selections that perform well at high Al saturation levels and thus need only a fraction of the normal lime requirement is the great practical importance (Getachew Agegnehu *et al*.,2021). In the high lands of Ethiopia, most of the time barley is grown on Nitisol, where soil pH is low, and thus barley is already adapted to acidic soil (Aboyitu Sisay, 2019).

2.6 Characteristics of Lime

Calcite and aragonite are the forms of limestone, sedimentary rock composed mainly of calcium carbonate ($CaCO_3$). Lime contains considerable amounts of magnesium carbonate or dolomite as well as minor constituents also commonly present include clay, iron carbonate, feldspar, pyrite, and quartz. Liming is the application of Ca and Mg-rich materials to the soil in various forms, including marl, chalk, limestone, or hydrated lime. Acid-sensitive crops are adopted by the desirable practice of liming. Calcium carbonate is a base, and made up of large calcium, and has a neutralizing effect on acid (Rengel, 2003). Lime improves base saturation and availability of Ca and Mg. Toxicity arising from excess soluble Al, Fe and Mn is corrected and thereby root growth is promoted and uptake of nutrients by plants is improved. It stimulates microbial activity and enhances N fixation and N mineralization and hence, legumes are highly benefited from liming (Fageria and Baligar, 2008). Soil acidity and Al^{3+} toxicity in surface soil can be ameliorated through liming (Fegeria and Baligar, 2008). Increasing the pH of acidic soils via liming improves the plant-availability of some nutrients while reducing the exchangeable acidity (Getahun Dereje *et al*., 2019).

2.7 Characteristics of Vermicompost

Vermicompost is a biofertilizer, it increases useful microorganisms that recycle the organic substances in the soil and release the available nutrients slowly to the plants (Meena *et al*., 2018). Vermicomposting is an efficient process as it is faster than the conventional composting methods that take longer time about three months. Conversion of organic waste results in the superior quality of vermicompost which contains earthworm cast and available nutrients encapsulated in mucus formed through the processing of composting material mixed with fine soil particles when processed through the earthworm gut systems. The plants can absorb the macro and micronutrients easily slowly from the soil in optimum quantity (Meena *et al*., 2015b).

The use of organic inputs has become an essential component of organic agriculture. Without the use of chemical fertilizers vermicomposting plays an important role in realizing agriculture. It is a simple process and has excellent properties without causing any damage to the plants. The process involves the use of earthworms for the degradation of organic waste through vermin. Organic waste is processed by aerobic microorganisms and is consumed by earthworms. The vermicast is free of pathogens and mixed with the composted material. There is a process of thermophilic digestion in the initial phase of composting that utilizes thermophilic microorganisms. The diversity of useful microorganisms increases in the vermicompost (Buragohain *et al*., 2017; Meena *et al*., 2017). Vermicompost is soft light and dark black material like peat with all the properties of standard compost like structure, aeration, and moisture enriched with useful microbes (Meena *et al*., 2015a). The soil pH is directly affecting the form and availability of nutrients and quantity, composition, and activity of the microorganisms (Zhang *et al*., 2020).

2.8 Barley (*Hordeum vulgare* L.)

Barley is the fourth most important cereal crop in the world in production after wheat, maize, and rice (FAO, 2013). Globally, European Union, Russia, Canada, USA and Argentina are the top five largest world barley producers (USDA 2017). Ethiopia, Algeria, Morocco, Tunisia and South Africa were the top five largest barley producers in Africa for the year 2019 with an estimated production of approximately 2.4, 1.6, 1.2, 0.9 and 0.3 million tons, respectively (FAO, 2019). In Ethiopia, among the cereals, barley is the fifth most important crop next to teff (*Eragrostis tef*), maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L.) and wheat (*Triticum aestivum* L.). it is believed to have been cultivated in Ethiopia as early as 300 BC (CSA, 2003). Barley (*Hordeum vulgare* L.) is the major cereal crop grown in the highlands of Ethiopia where soil acidity is rampant. It is one of the most important staple food crops in the highlands of Ethiopia. It has great importance in the food habits of people. It is the staple food grain for Ethiopian highlands who manage the crop with indigenous technologies and utilize different parts of the plant for preparing various types of traditional food such as Kita, Kolo, Beso, Injera, Dabo, and local beverages, such as local beer. The major production of barley still largely depends on the traditional varieties and farming practices, which is also assumed to be one of the constraint accountings for its low yield (Tadesse Moges *et al*.,2018). Many researchers released a lot of barley varieties. Currently, HB-1307 has shown better grain yield than other varieties in addition to logging resistance which might be suitable agro-ecology for the variety (Zeleke Legesse *et al*., 2018). According to Getachew Alemu *et al*. (2017), the chemical properties of the soil and grain yield of barley were improved through the application of lime and P fertilizer. Barley grain yield has increased progressively with higher application of lime and P rates.

Chapter 3. MATERIALS AND METHODS

3.1. Description of Study Area

3.1.1. Location

Geographically, the study area Sanketlideta kebele is located in Banja district, Awi administrative zone, Amhara National Reginal State Northwest Ethiopia. Banja is located at $10^{\circ}47'30''$ to $11^{\circ}4'0''$N latitude and $36^{\circ}40'0''$ to $37^{\circ}10'$E longitude. The district is located 130 km south of the regional city Bahir Dar and 460 km northwest of Addis Ababa (Figure 3.1).

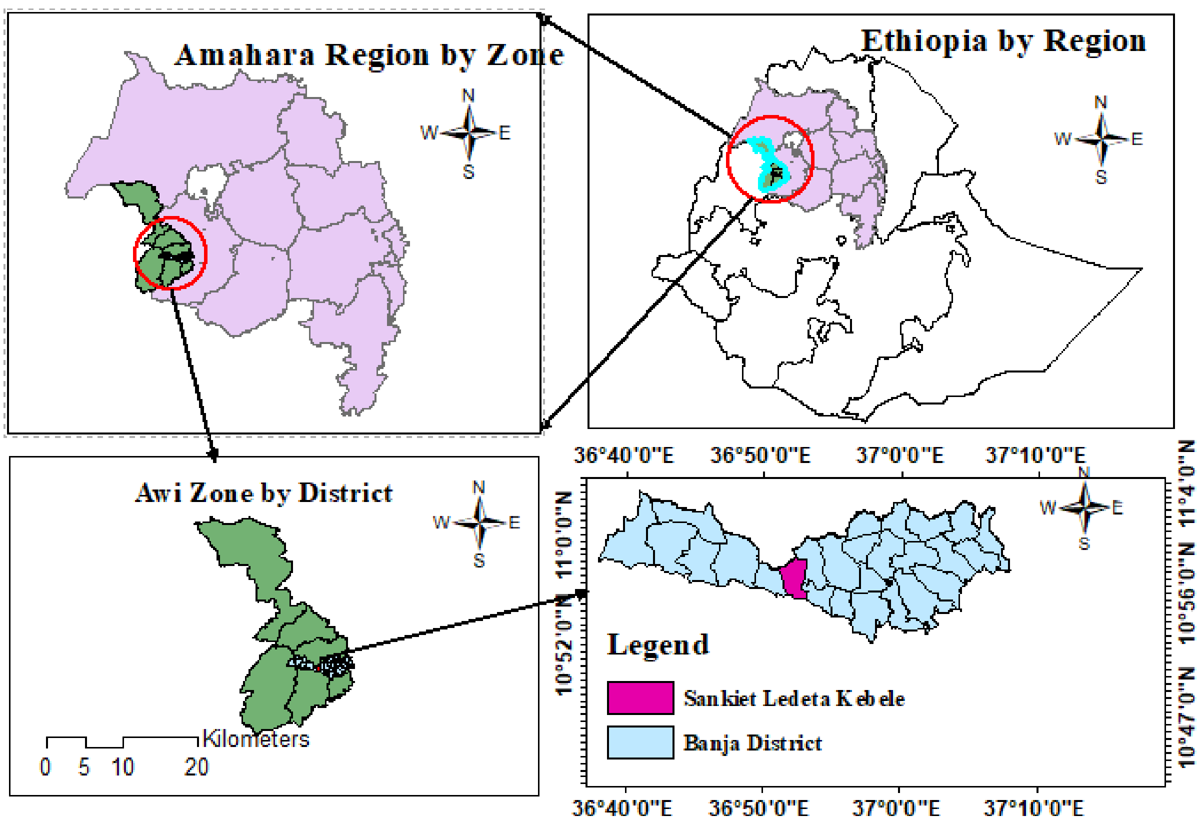

Figure 3. 1: Location map of the study area

3.1.2. Climate

According to National Meteorology Agency of Bahr Dar Metrology Station weather data from 2011 to 2020, the mean minimum and maximum temperatures of the study area were 12.98 and 26.26ºC, respectively. The mean annual rainfall is 1864.13 mm with the main wet season from June to September usually continued with a less pronounced wet period up to November for the main growing season of crops (Figure 3.2).

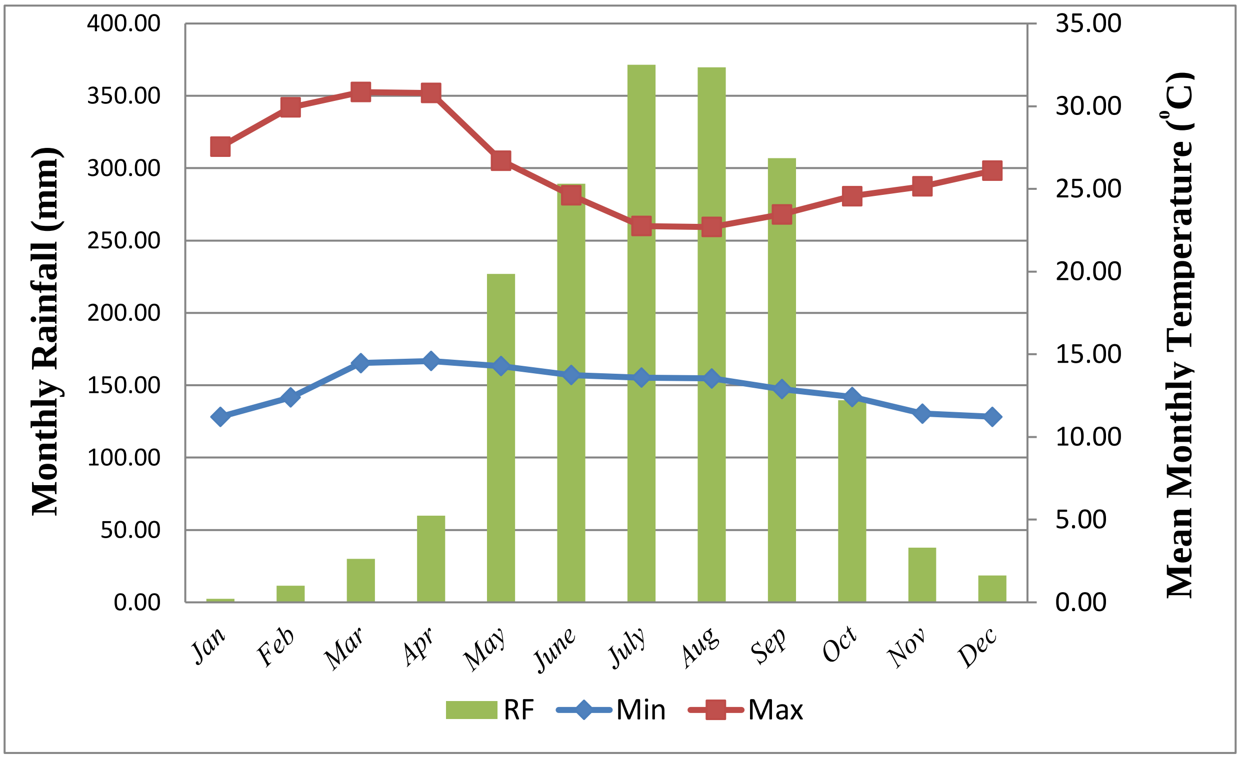

Figure 3. 2. Rainfall and temperature distributions (2011-2020) at the study area

3.1.3. Geology and soil

The parent material of the soil is made up of volcanic rock and quaternary basalts. The major soil types include Andosols, Nitisols, and Cambisols. Generally, the soil types of the study area is Nitosol characterized with shallow, moderate to deep and very deep in depth and sandy clay to clay textural types (Bireda Alemayehu, 2015).

3.1.4. Farming systems

The total area of the distric where the study is conducted 47,915.82 ha. Land use pattern of the district of cultivated land is 12,277 ha, grazing land 21,141.57 ha, forest 12,346 ha and the rest 2151.24 ha for other uses. Crop production, livestock farming and charcoal production from plantations of *Acacia decurrens* and different Eucalyptus species are the main sources of farmers income in the district. The major crops growing in the district include potato, barley, wheat, faba bean, tef, and finger millet. Some farm householdes produce potato through irrigation system and the farming system of the area is mainly characterized by mixed crop-livestock production. About 80% of the district is classified as highland and 20% as mid-highland. The altitude ranges from 1800-2750 m.a.s.l (Melkamu Bazie *et al*., 2017).

3.2. Description of the Experimental Materials

High-yielding food barley (*Hordeum vulgare* L.) variety named HB 1307 was used as a test crop at a seed rate of 150 kg ha^{-1}. The mineral fertilizers applied were Urea and nitrogen, phosphorus, sulfur and boron containing blended fertilizer (NPSB). A high-quality limestone (98 % $CaCO_3$, 99.5 % <250 µm in diameter) and vermicompost were used.

3.3. Experimental Design and Treatments

The experimental design was factorial combinations of four rates of lime (0, 50% of the recommended rates of lime, 100% recommended rate, and 150% the recommended rate of lime based on the exchangeable acidity and bulk density which are 0, 0.93, 1.86, and 2.79 t ha^{-1}) and three rates of vermicompost (0, 2.5, and 5 t ha^{-1}). The mineral fertilizers were applied uniformly to all plots. The treatments (Table 3.1) were laid out in a randomized complete block design (RCBD) with three replications. Thus, there were 4*3 treatment combinations, with 12 treatments. The spacing between rows, plots and blocks was 0.2 m, 1 m, and 2 m respectively. The data were harvested excluding the border row of each plot in each treatments.

Table 3. 1. Treatment setup of the experiment

Treatments	Lime (ton/ha)	Vermicompost(ton/ha)
1	0	0
2	0	2.5
3	0	5
4	0.93	0
5	0.93	2.5
6	0.93	5
7	1.86	0
8	1.86	2.5
9	1.86	5
10	2.79	0
11	2.79	2.5
12	2.79	5

The experiment was conducted at the representative acid soil affected areas, using barley as a test crop, which is the major crop grown in the area. Different rates of limestone ($CaCO_3$) and vermicompost were used as experimental factors to ameliorate soil acidity with recommended mineral fertilizer. The lime and vermicompost were applied a month before planting by broadcasting method and incorporated into the 15 cm soil depth.

The recommended rates of 92 kg N ha^{-1} by Pawe agricultural research center (PARC) and the blanket recommended rates of 100 kg ha^{-1} NPSB (18-39-6-0.1) were applied in a band at planting time uniformly to all treatments. The nitrogen fertilizer was applied half at planting and the rest half after a month of sowing. Barely seeds were planted at the rate of 150 kg ha^{-1} through hand drilling method.

The amount of lime that was applied based on exchangeable Al^{+3} and H^{+1} was calculated on the basis of the mass of soil per 15 cm hectare-furrow-slice and exchangeable Al^{+3} and H^{+} of the study site as follows.

$$LR, CaCO_3\ (kg/ha) = \frac{EA\ (cmol/kg\ of\ soil * 0.15m * 10^4 m^2\ B.D(mg/m^3) * 1000}{2000} * 1.5 \quad Eq.1$$

Where LR = Lime Requirement, EA = Exchangeable acidity, BD = Bulk density, 1.5 multiplication factor was adopted based on a recommendation by Birhanu Agumas, *et al*. (2016).

3.4. Data Collection and Measurements

3.4.1. Soil sampling and analysis

Soil samples were collected randomly from the surface layer of the experimental field at a depth of 15 cm. Initially, one composite soil sample was collected from the experimental site before lime and vermicompost application. Soil samples were also collected after harvesting the barley crop from each plot at a similar soil sampling depth. The collected samples were air dried, sieved to pass through 2 mm sieve and prepared for the chemical and physical analysis of soil pH, exchangeable acidity, exchangeable Al^{3+}, organic carbon, total nitrogen, available phosphorus, cation exchange capacity, exchangeable bases, base saturation, soil texture and bulk density.

Soil pH was measured potentiometrically using a digital pH meter with combined glass in the suspension of 1:2.5 soils to water ratio as described by Carter (1993). Soil organic carbon, total nitrogen (TN) and available P were determined by the Walkley-Black oxidation method (Walkley and Black, 1934), Kjeldahl digestion method (Bremner and Mulvaney, 1982) and standard Bray-II extraction methods (Bray and Kurtz, 1945), respectively. Whereas, total P in soil samples were estimated by the Perchloric acid ($HClO_4$) digestion method as described by Jackson (1967).

Exchangeable acidity and exchangeable Al were determined by saturating the soil samples with 1M KCl solution and the filtrate was titrated with 0.02M NaOH and 0.02M HCl, respectively as described by Rowell (1994). The CEC was determined through distillation and titration of ammonia, after washing down excess ammonium acetate by ethyl alcohol as described by Sahlemedhin Sertsu and Taye Bekele (2000). Exchangeable bases (Ca^{+2}, Mg^{+2},

K^+ and Na^+) were determined using 1M neutral ammonium acetate (NH_4OAc) extraction method. In the extract, exchangeable Na^+ and K^+ were measured by using flame photometry, and exchangeable Ca^{2+} and Mg^{2+} were measured using atomic absorption spectrophotometry (AAS) (Rowell, 1994).

Percent base saturation (PBS) was calculated by dividing the sum of the base forming cations (Ca, Mg, Na and K) by the CEC of the soil and multiplying by 100 at the soil and plant analysis laboratory of Pawe Agricultural Research Center. Soil particle size distribution was analyzed by the hydrometer method (Bouyoucos, 1962), using sodium hexametaphosphate (Calgon) as a dispersing agent. Soil textural class names were determined following the textural triangle of the United States of Department of Agriculture (USDA) system as described by Rowell (1994). The bulk density (core method) value of undisturbed cores is practical significant as it indicates soil aggregation and structure under field conditions. After 24 hours of oven dry, bulk density was calculated by the ratio of the weight of oven dry soil to the volume of soil (Blake G.R. 1965).

3.4.2. Vermicompost preparation and analysis

The vermicompost used for the trial was prepared following the standard vermicompost preparation procedures within few months, 2020 at Pawe Agricultural Research Center using concrete tank material as a pit. First, materials such as cow dung, , straw (soybean, finger millet and groundnut) were collected and chopped into small pieces using a cutter (sickle) and soaked in water for a week. This well-soaked straw material was at the bottom of the bin, followed by a thin layer of forest top soil and then the cow dung was added. Then after, the nationally well-known vermiworms (*Eisenia fetida*) about 2000 in number were added at the top of the pit and covered with well-soaked straw. In each layer, water was sprinkled to maintain 70-80% moisture content of the prepared material. Finally, the vermicompost maturity was judged from eighty to ninety days visually by observing the formation of the granular structure of the compost at the surface of the tank and the vermicompost was separated from the vermiworm manually and the compost was placed in a shade and to be air-dried.

The air-dried vermicompost was grounded and sieved to pass through two mm sieve. Then the chemical properties of the vermicompost such as total N, organic carbon, pH, and total P were analyzed following the standard procedures as described by (Peters, 2003). Total N was determined by digesting the sample with concentrated sulphuric acid (H_2SO_4) in the presence of a catalyst following distillation and titration methods. Organic carbon was determined following the wet digestion and titration procedure. Total P was determined calorimetrically using the ascorbic acid molybdenum-blue color method after extracting with concentrated H_2SO_4, Se powder, salicylic acid ($C_7H_6O_3$), and H_2O_2 mixture. The pH was determined in 1:2.5 (soil/water) suspension using a pH meter.

3.4.3. Agronomic data collection

The yield and yield components of barley that were collected days to 50% heading, days to 90% maturity, spike length, number of effective tillers, plant height, number of grain per spike, aboveground total biomass, grain yield per hectare, straw yield, harvest index thousand-grain weight. The grain quality parameters including hectoliter weight and protein content were also measured.

Days to 50% heading: was determined by counting the number of days from sowing to the time when 50% of the plants started to emerge the tip of spikes through visual observation.

Days to 90% maturity: It was calculated as the number of days of sowing to the date when 90% of the crop matured.

Spike length: was measured from base to the tip of spike by excluding the awns from ten randomly selected spikes from each plot.

Number of effective tillers: Counting of effective tillers in one meter square from net pot area. It was taken at harvesting time.

Plant height (PH)(cm): The height of the plant was taken from the base of the main stem to the tip of the panicle (excluded awns) and recorded as the average of ten randomly selected plants from harvestable rows.

Number of grains per spike: was collected by counting the number of seeds from the random plant.

Aboveground total biomass: This was determined as the weight of sun-dried aboveground parts of the plants that were obtained from harvestable rows.

Grain yield per hectare (GYH): Grain yield in kilogram obtained from the harvestable rows of each plot was converted to kilograms per hectare by adjusting the moisture content at 12.5%.

Straw yield: was determined by subtracting grain yield from the total biomass of each plot.

Harvest Index (%): It was calculated as the ratio of grain yield to the total aboveground total biomass.

$$HI(\%) = \frac{Grain\ yield}{Biological\ yield} * 100$$

Thousand-grain weight (TGW): was recorded in a gram of thousand-grain weight by sensitive balance, using samples taken from bulked grains of each plot and was adjusted by 12.5% seed moisture level.

Hectoliter weight : Hectoliter weight is good indication of grain-soundness. It was measured with hectoliter weight equipment uses 100 ml volume of grain and gave the value in kilogram per hectoliter by using conversion chart (Lee, 2013).

Protein content: was determined by Kjeldahl method described as nitrogen determination converted by multiplying using a conversion factor of 6.25 (AOAC, 2000) according to the formula below: %Crude protein = % Kjeldahl nitrogen *F

Where F= factor to convert nitrogen to protein (6.25).

3.5. Statistical Analysis

All the collected agronomic and soil data were subjected to analysis of variance (ANOVA) using the general linear model (GLM) of SAS computer software version 9.4. Mean separation was done using the least significant difference (LSD) test at 5% probability level (SAS, 2013).

3.7. Partial Budget Analysis

To conduct the cost and benefits associated with different treatments the partial budget technique as described by CIMMYT (1988) was applied to the yield results. The cost of vermicompost analysis was considered preparation and application cost while cost of lime based on price of lime and application cost. All costs and benefits were calculated. The gross field benefit ha^{-1}, a product of a real price and yields of receiving for each treatment after adjusting the grain yield of barley and straw yield downward by 10% to represent the yield obtained by farmers. Total variable cost is a cost incurred due to the application of inputs. Gross income is obtained by multiplying the mean grain yield and straw yield (kg/ha) of each treatment by the price of 1kg of the grain. Net income is calculated by subtracting the total variable cost from the gross income. The dominance analysis procedure, which was used to select potentially profitable treatments, comprised ranking of treatments in an ascending order of total variable cost from the lowest to the highest cost to eliminate treatments costing more but producing a lower net benefit than the next lowest costing treatment was undertaken. For each pair of ranked non-dominated treatments, marginal rate of return was also calculated in percent. The percent marginal rate of return between any pair of undominated treatments denoting the return per unit of investment for crop production was analyzed. The marginal rate of return is a return in (%) that we get from a unit of expenditure.

$$MRR(\%) = \frac{\begin{matrix} Net\ benefit\ from\ superior\ doaminant\ plot - \\ Net\ benefit\ from\ inferior\ dominant\ plot \end{matrix}}{\begin{matrix} Total\ variable\ cost from\ superior\ dominant\ plot - \\ Total\ variable\ cost\ of\ the\ inferior\ dominant\ plot \end{matrix}} * 100$$

According to CIMMYT (1988) for a treatment to be considered a worth while option to farmers, the marginal rate of return needed by taking the acceptable rate of return to be 100%. The values of other materials used fixed for each treatment were not considered in the budget for the partial economic analysis.

Chapter 4. RESULT AND DISCUSSION

4.1. Inherient Soil Physicochemical Properties of the Study Area

Soil texture: The laboratory result indicated that the soil texture of the experimental site is sandy clay loam based on the textural class of the soil, with relative proportions of 28% clay, 12% silt and 60% sand (Table 4.1). It is a basic physical property of the soil that remains less affected by the management practices and it also determines the nutrient status, organic matter content, air circulation and water holding capacity of a given soil (Fageria and Baligar, 2008).

Bulk density: The weight of soil bulk density before planting was 1.37 g cm^{-3} (Table 4.1). It was determined using the core method by weighing undisturbed oven-dried soil samples. According to Hazelton and Murphy (2007), soil bulk density values were very low (<1.0), low (1.0-1.3), moderate (1.3-1.6), high (1.6-1.9), very high (>1.9). Thus, the experimental site was moderate. The rate of lime applied was determined based on the bulk density and exchangeable acidity of the experimental soil.

Soil reaction (pH): The result of laboratory analysis showed that the soil pH value of the experimental site was 4.80 (Table 4.1). According to Hazelton and Murphy (2007), soils with pH > 9.0 are very strongly alkaline, 9.0-8.5 strongly alkaline, 8.4-7.9 moderately alkaline, 7.8-7.4 mildly alkaline, 7.3-6.6 neutral, 6.5-6.1 slightly acid, 6.0-5.6 moderately acid, 5.5-5.1 strongly acidic and 5.0-4.5 is very strongly acidic. EthioSIS (2016) also categorized soil pH as strongly acidic (<5.5), moderately acidic (5.6-6.5), neutral (6.6-7.3) and moderately alkaline (7.4-8.4). Based on both soil pH classification, the soil of experimental site was very strongly acidic and not suitable for the growth of most crops and needs soil amelioration mechanisms. Soil pH or hydrogen ion activity is the most common acidity index used in soil testing programs for assessing lime requirements of crops grown on acid soils (Fageria and Baligar, 2008).

Total nitrogen and organic carbon: The total nitrogen and organic carbon content of the soil before applying lime and vermicompost were found to be 0.197 and 2.78%, respectively

(Table 4.1). The percent total nitrogen (TN%) is rated by Havlin *et al*, (1999) as very low (<0.1), low (0.1 to 0.15), medium (0.15 to 0.25), and high (>0.25). According to Tekalign Tadesse (1991) total nitrogen as very low <0.05%, poor 0.05-0.12%, moderate 0.12-0.25% and high >0.25. As per the interpretation of Hazelton and Murphy (2016), the rating of total nitrogen is very low (<0.05), low (0.05-0.15), medium (0.15-0.25), high (0.25-0.50), and very high (>0.5). So, the result showed that the total nitrogen level in the soil of the experimental site was medium for crop production. According to Tekalign Tadesse (1991), the description of the percentage of soil organic carbon content is very low (<0.5), low (0.5-1.5), moderate (1.5-3.0) and high (>3.0%). So, the organic carbon content of the experimental site was low. Organic matter is calculated from the level of organic carbon in the soil by multiplying with 1.724.

Exchangeable acidity and exchangeable Al^{3+}: The exchangeable acidity of a soil indicates the presence of excess Al^{3+} and H^+ ion in the soil colloid as compared to the total cation exchange capacity of the soil. The exchangeable acidity and Al concentration of the experimental soil before application of the treatments were 1.205 cmol $_{(+)}$ kg^{-1} and 1.124 cmol $_{(+)}$ kg^{-1} respectively(Table 4.1). The exchangeable acidity of the soil was used to determine the lime rate to be applied.

Available phosphorus: The level of phosphorus for the experimental soil before application of the treatments was 11.81 mg kg^{-1} (Table 4.1). The rating of phosphorus is very low (0-7), low (8-19), medium (20-30), high (40-58) and very high (>59) (Sahlemedhin Sertsu and Taye Bekele, 2000). Hence, the available soil P on the experimental site was low, which might be due to fixation. Solomon Dawit *et al*. (2002), reported that the availability of P in most soils of Ethiopia has been declining due to the impacts of fixation as a result of low pH. In order to increase the bioavailability of P in such soil, the increase in soil pH is the best management option to minimize fixation.

Cation Exchange Capacity (CEC): The result showed that the cation exchange capacity of the experimental soil was 24.91 cmol $_{(+)}$ kg^{-1} (Table 4.1). According to the classification of Hazelton and Murphy (2007), the soil CEC isvery low, low, moderate, high, and very high, with a range of <6, 6-12, 12-25, 25-40, and >40, respectively. So, the CEC of the experimental field was rated as moderate. The CEC of a soil is a measurement of the magnitude of the negative charge per unit weight of the soil, or the number of cations a particular soil sample can hold in an exchangeable form. It provides a buffering effect to changes in pH, available nutrients, calcium levels and soil structural changes. Meaning that, it is a major controlling agent of stability of soil structure, nutrient availability for plant growth, soil pH, and the soil's reaction to fertilizers and other ameliorants. A low CEC means the soil has a low resistance to changes in soil chemistry (Thomas and Hargrove, 1984).

Exchangeable bases (Ca, Mg, K and Na): The removal of base cations, especially Ca and Mg, by leaching and erosion results in their replacement by acidic cations of H, Al and Fe on exchangeable sites and in the soil solution (Johnston, 2004). Results of the laboratory analysis indicated that exchangeable Ca, Mg, Na, and K were 3.99, 0.33, 0.22 and 0.52 cmol (+) kg^{-1}, respectively. According to the interpretation of Hazelton and Murphy (2007), the level of basic cations are classified sodium (Na) as very low (0-0.1), low (0.1-0.3), moderate (0.3-0.7), high (0.7-2.0), very high (>2), potassium (K) very low (0-0.2), low (0.2-0.3), moderate (0.3-0.7), high (0.7-2), very high (>2), calcium (Ca) very low (0-2), low (2-5), moderate (5-10), high (10-20), very high (>20), and magnesium (Mg) very low (0-0.3), low (0.3-1), moderate (1-3), high (3-8), very high (>8). Depending on this classification, the level of Ca, Mg and Na are low for the experimental soil, while K is in moderate range.

Base saturation: It is the percentage of cation exchange capacity that is saturated with calcium, magnesium, sodium and potassium ions.

BS (%) = $\frac{(Ca+Mg+Na+K)}{CEC} * 100$ BS (%) = $\frac{3.99+0.33+0.22+0.52}{24.91} * 100$ =20.31

According to the interpretation of Hazelton and Murphy (2016), the result of the base saturation (20.31) indicates low, with the rating of 0 to 20 very low, 20 to 40 low, 40 to 60 moderate, 60 to 80 high and >80 very high. It indicates how closely nutrient status approaches potential fertility.

Table 4. 1. Selected soil physico-chemical properties before application of the treatments

No.	Parameters	Unit	Value
1	pH		4.8
2	BD	g/cm^{-3}	1.37
3	TN	%	0.197
4	OC	%	2.78
5	Ex. Acidity	Cmol (+)/kg	1.205
6	Ex Al	Cmol (+)/kg	1.124
7	Av. P	mg/kg	11.81
8	CEC	Cmol (+)/kg	24.91
9	Ex. Ca^{2+}	Cmol (+)/kg	3.99
10	Ex. Mg^{2+}	Cmol (+)/kg	0.33
11	Ex. Na^{+}	Cmol (+)/kg	0.22
12	Ex K^{+}	Cmol (+)/kg	0.52
13	BS	%	20.31
14	Soil textural class		sand clay loam
	Sand	%	60
	Silt	%	12
	Clay	%	28

4.2. Analysis of Some Selected Chemical Properties of Vermicompost

The laboratory analysis of vermicompost indicated that the total nitrogen, organic matter. and P values were 1.66%, 18.44%, and 0.61%, respectively (Table 4.2). The pH of vermicompost was moderately alkaline (8.45), with a C:N ratio of 6.46**.** The pH of vermicompost varies based on the types of raw materials used in the processes of vermicomposting. The C:N ratio is an important parameter commonly used to see the progression of organic material undergoing the process of vermicomposting process and there is a distinct variation in C:N ratio depending on the starting organic material in the process (Meena, 2020). As reported by Temesgen Chimdssa (2021) the lower acidic nature of vermicompost was desirable in increasing the productivity of acidic soil.

Nitrogen varies from 0.1% to 4% and can be increased further by manipulation of nitrogen rich starting material and is an important parameter in determining the quality of vermicompost in terms of usage for various crop productions (Edwards and Bohlen, 1996).

Table 4. 2. Selected chemical properties of vermicompost

Parameters	pH	OC (%)	OM (%)	TN (%)	CEC Cmol$_{(+)}$ kg	TP (%)	C:N ratio
Value	8.45	10.69	18.44	1.66	65.59	0.61	6.46

pH= power of hydrogen, OC=Organic Carbon, OM=Organic Matter, TN=Total Nitrogen, TP=total phosphorous, C:N ratio=carbon nitrogen ratio

4.3. Effects of Lime and Vermicmpost on Soil Physico-Chemical Properties after Harvesting

4.3.1 Bulk density

Sole application of vermicompost had significant ($p<0.01$) effect on soil bulk density while the main effect of lime and lime by vermicompost interaction were not significant for soil bulk density (Appendix Table 4.1). The application of 5 t ha^{-1} vermicompost decreased bulk density by 6.4% compared to the control (Table 4.3). The bulk density of the soil decreased as the application rate of vermicompost increased, which indicates the decreasing of soil compaction and increasing of soil porosity. Biruk Teshome *et al.* (2017) reported that the dry bulk density was significantly ($p<0.05$) affected due to the addition of compost alone, which contradicts with the study of Temesgen Chimdessa (2021), where the interaction of lime and vermicompost affected soil bulk density.

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Table 4. 3: The main effects of lime and vermicompost on bulk density (BD) of soil

Lime (t/ha)	BD
0	1.33
0.93	1.32
1.86	1.28
2.79	1.29
LSD (0.05)	0.061
Significance level	NS
VC(t/ha)	
0	1.33[a]
2.5	1.33[a]
5	1.25[b]
LSD (0.05)	0.05
Significance level	**
CV (%)	4.57

** significant at p<0.01, NS=no significant

4.3.2. Soil reaction (pH)

The analysis of variance revealed that the main and interaction of lime and vermicompost had highly significant ($p<0.0001$) effect on soil pH (Appendix Table 4.1). The highest (5.55) pH value was obtained from the combined application of 2.79 (t/ha) lime rate with 5 t ha^{-1} of vermicompost. However, the lowest (4.99) pH or acidity indicator was recoreded from the control treatment (Table 4.4). The increase in soil pH might be due to the neutralization of H^+ ion and Al^{3+} because of the presence of Ca^{2+} and Co_3^{2-} contributed by vermicompost and lime. The finding of this study was in agreement with Abdissa Bekele *et al*, (2018), reported the significant effect of application lime at each respective level either alone and or in combination with vermicompost had a significant effect on soil pH. In their study the the highest value of soil pH was obtained from the combined application of lime at the rate of 4 t ha^{-1} and vermicompost at the rate of 5 t ha^{-1}.

Vermicompost raises soil pH due to the presence of high contents of basic cations in it and its buffer capacity because some nutrients like phosphorus become highly available to plants while reducing elements such as Al, Mn, and Fe. According to Getachew Agegnehu *et al*, (2017), the application of lime rates raised soil pH close to the optimum pH requirement of barley while radically decreased the exchangeable Al^{3+} to a minimum level of 0.1 $cmol_{(+)}$ kg^{-1} which enhanced available phosphorus as a result of increased pH and decreased acidity level. Similar finding of Temesgen Chimdessa (2021) indicate that soil amended with lime had higher pH than the unamended soil.

Soil pH was increased in a linear fashion with increasing lime rate. The increase in pH was the highest with applications of the maximum rate of 2.2 t ha^{-1} lime. When lime is added to acid soils containing high Al^{3+} and H^+ concentrations, it dissociates into Ca^{2+} and OH^- ions. The hydroxyl ions react with hydrogen and Al^{3+} ions forming Al^{3+} hydroxide and water, thereby increasing soil pH in the soil solution. The application of the highest rate of lime appreciablly reduces soil exchangeable Al^{3+}, which was 1.32 cmol kg^{-1} at the start of the experiment to a negligible level of 0.12 cmol $_{(+)}$ kg^{-1} after two years of soil analysis in acidic soil in the central highlinds of Ethiopia (Temesgen Desalegn *et al*., 2017).

4.3.3. Organic carbon (%)

The main and interaction effects of lime and vermicompost had significantly increased soil organic carbon (Appendix Table 4.1). The highest (3.17%) soil OC was obtained from the application of 1.86 lime rate with 5 t ha^{-1} vermicompost, while the lowest (2.73%) was recorded from the control treatment (Table 4.4). It might be the improvements of soil through applying of treatments. The findings of a similar study indicated that the application of organic fertilizer significantly improved soil organic carbon from 1.26% to 1.56% (Girma Chala *et al*., 2020).

Table 4. 4. The interaction effects of lime and vermicompost on soil pH and organic carbon (OC)

Lime(t/ha)	VC (t/ha)	pH	OC (%)
0	0	4.99^{h}	2.73^{d}
0	2.5	5.18^{g}	2.95^{bc}
0	5	5.20^{g}	2.78^{cd}
0.93	0	5.25^{fg}	2.63^{d}
0.93	2.5	5.42^{bcd}	3.04^{ab}
0.93	5	5.30fe	3.00^{ab}
1.86	0	5.44^{bc}	2.98^{b}
1.86	2.5	5.36^{cde}	3.05^{ab}
1.86	5	5.46^{b}	3.17^{a}
2.79	0	5.35^{de}	2.97^{b}
2.79	2.5	5.46^{b}	3.07^{ab}
2.79	5	5.55^{a}	3.05^{ab}
Mean		5.33	2.952
Significance level		***	*
LSD (0.05)		0.080	0.172
CV (%)		0.787	3.207

* Significant at $p \leq 0.05$, *** significant at $p < 0.001$

4.3.4. Total nitrogen

The solitary application of lime ($P<0.05$) and vermicompost ($P<0.001$) showed a significant effect on the amount of total N. However, the interaction effect showed insignificant difference (Apendix Table 4.1). The highest TN values of 0.239% and 0.234% were obtained from the application of 2.79 (t/ha) and 1.86 (t/ha) lime respectively. While the lowest (0.216%) was recorded from the control (untreated) plots (Table 4.5). The increase in soil N due to the application of lime might be owing to mineralization of the nutrients and direct relation of soil water pH and OC. Fageria and Baligar (2008), reported that addition of lime on acidic soil improves the soil environment for plant growth by increasing soil pH. A more favorable root environment may be a consequence of desirable soil pH, decreasing the toxicity of Al and Mn, increasing Ca and Mg supplies, enhancing the availability of P and Mo, improving the mineralization of organic compounds, thereby improved soil nitrogen, phosphorus and sulphur uptake, improved soil biological activity (Bikila Takala, 2019).

Similarly, the highest (0.243%) TN obtained from the application of 5 t ha^{-1} vermicompost, whereas the lowest (0.213%) TN was recorded from the control (Table 4.5). It might be the residual effects of vermicompost. According to Abdissa Bekele *et al,* (2018), The application of vermicompost on the acidic soil increases the organic matter and total nitrogen contents of the soil. The application of organic fertilizers (vermicompost and farmyard manure) significantly improved soil nitrogen from 0.14% to 0.23% on Nitisols of Central Ethiopian Highlands (Girma Chala *et al*., 2020). The application rate of lime and vermicompost solely or in combination form increased the mineralization of nitrogen (Temesgen Chimdessa, 2021).

Table 4. 5. The main effects of lime and vermicompost on, total nitrogen, exchangeable acidity and aluminum

Lime (t/ha)	Total N (%)	Exchangeable Acidity (cmol (+) kg^{-1})	Exchangeable Al^{3+} (cmol (+) kg^{-1})
0	0.216^{b}	1.499^{a}	1.004^{a}
0.93	0.226^{ab}	0.893^{b}	0.620^{b}
1.86	0.234^{a}	0.687^{c}	0.469^{c}
2.79	0.239^{a}	0.455^{d}	0.292^{d}
Significance level	*	***	***
LSD (0.05)	0.124	0.175	0.12
VC(t/ha)			
0	0.213^{c}	0.956^{a}	0.669^{a}
2.5	0.230^{b}	0.939^{a}	0.598^{ab}
5	0.243^{a}	0.756^{b}	0.522^{b}
Significance level	***	*	*
LSD (0.05)	0.012	0.152	0.104
CV (%)	6.796	20.78	20.93

* Significant at $p \leq 0.05$, *** significant at $p<0.001$

4.3.5. Exchangeable acidity and aluminum

The main effect of lime ($p<0.001$) and vermicompost ($p<0.05$) showed significantly decreased soil exchangeable acidity and Al. However, their interaction effect showed no significant ($p>0.05$) difference (Appendix Table 4.1). Accordingly, the application of 2.79 t ha^{-1} lime lowered the soil exchangeable acidity by 69.6% and aluminum 70.9 % from the control (Table 4.5). Exchangeable acidity decreased with increasing lime rate. The reduction of exchangeable acidity with increasing lime rates might be associated with the replacement of H^+ and Al^{3+} by Ca ions from lime on the soil colloides which subsequently increased the soil pH. The result is consistent with the findings of Temesgen Chimdessa (2021), reported that exchangeable acidity was significantly influenced by the effects of different lime rates. Similarly, Achalu Chimdi *et al*, (2012), reported that the application of lime at the rate of 10-ton ha^{-1} decreased the soil exchangeable acidity from 2.80 cmol $_{(+)}$ kg in the control to 0.26 cmol $_{(+)}$ kg^{-1}, with the decrease in exchangeable acidity by 90.7%. Temesgen Desalegn *et al*, (2017) reported that the application of lime and its residual effect highly decreased exchangeable aluminum from the initial level of 1.32 to 0.12 cmol $_{(+)}$ kg^{-1} as the level of applied lime rates increased.

Similarly, the exchangeable acidity was significantly ($p<0.05$) decreased by 1.77% and 20.9% after the application of 2.5 and 5 t ha^{-1} vermicompost (VC), respectively. In the same way, the level of exchangeable Al^{3+} declined by 10.6 and 21.97% after the application of 2.5 and 5 t ha^{-1} of VC respectively (Table 4.5). This showed that increased rates of VC caused a decline in soil exchangeable acidity and Al^{+3} due to the increasing of soil pH as well as the improvement of available nutrients. The lime at each respective application level alone or in combination with vermicompost had a significant ($p<0.001$) effect on soil exchangeable acidity and aluminum (Abdissa Bekele *et al*., 2018).

4.3.6. Available phosphorus

The interaction effect of lime and vermicompost on available phosphorus was not significant while the main effect of lime was highly significant ($p<0.01$) and the effect of vermicompost was significant ($p<0.05$) on the availability of phosphorus (Appendix Table 4.1). The highest available P (16.49 mg kg^{-1}) was recorded from the the application of 1.86 t ha^{-1} lime rate, whereas the lowest available P (12.69 mg kg^{-1}) was recorded from the control treatment (Table 4.6). According to Achalu Chimdi *et al*. (2012), the application of lime increased soil pH and enhanced the release of phosphate ions which was fixed by Al and Fe ions in the soil solution. The available phosphorus increased through the application of lime due to decreased soil acidity (Kisinyo, 2016). Similarly, Bolan *et al*. (2003), reported that in soils high in exchangeable acidity, liming might increase plant phosphorus uptake by declining of Al, rather than by increasing P availability. Lime contributed to the release of some amount of fixed P in the soil, which will be available for plant growth. Therefore, liming materials added to the soil improve soil additive and it hydrolyzes Al and Fe ions that precipitated with P. Hence, the precipitated phosphate ion is released in to the soil solution thereby rendering the phosphate ion available for plant uptake. Thus liming raises the pH of acidic soil and generally provides more favorable environments for microbial activities and possibly results in the net mineralization of soil organic phosphorus. It can increase phosphate availability by stimulating mineralization of soil organic phosphorus (Tolossa Ameyu, 2019).

Vermicompost application also increased the availability of phosphorus compared with the control one. The highest available P (15.54 mg kg^{-1}) was obtained from the application of 5 t ha^{-1}, while the lowest (13.27 mg kg^{-1}) was recorded from the control (Table 4.6). By itself VC contains high amount of phosphorus, due to this applying in the soil significantly increase the availability of phosphorus. The application of organic fertilizer significantly improved soil phosphorous from 7.84 mg kg^{-1} to 12.59 mg kg^{-1} on Nitisols of Central Ethiopian Highlands (Girma Chala *et al*., 2020). Phosphorus is commonly bound to iron and Aluminium oxides and hydroxides through chemical precipitation or physical adsorption (Kochian *et al.*, 2004).

4.3.7. Cation exchange capacity (CEC)

The cation exchange capacity of the soil represents the total quantity of negative charge available to attract cations in the soil solution. CEC values are usually associated with humus compared to those exhibited by the inorganic clays, especially kaolinite and Fe and Al oxides (Brady and Weil, 2016).

The analysis of variance showed that the interaction effect of lime and vermicompost did not have significant difference on soil CEC. While the main effect of lime rate and vermicompost significantly ($p<0.01$ and $p<0.05$) influenced soil cation exchange capacity (Appendix Table 4.1). The highest CEC value of 29.95 cmol $_{(+)}$ kg^{-1} was obtained from the application of 1.86 t ha^{-1} lime rate, but it was at par with 2.79 t ha^{-1} and 0.93 t ha^{-1} lime and the lowest CEC value of 27.68 cmol $_{(+)}$ kg^{-1} was recorded from the control (Table 4.6). The result concurs with findings of Adane Buni (2014), reported the highest (33.34 cmol$_{(+)}$ kg^{-1}) and the lowest (19.18 cmol $_{(+)}$ kg^{-1}) CEC values were observed from the highest lime treated and the control, respectively in Sodo Zuria Woreda, Kutosorpela kebele on Nitisol. The increase in CEC due to liming could be attributed to the change in pH and the release of the interlayer substitutional negative charge by deprotonation of the variable charge minerals and functional groups of humic compounds caused by Ca^{2+}. The greater amount of negative charge available on the surfaces of these minerals results in the increase in CEC (Pionke and Corey, 1967). Liming acidic soil indirectly increases the effective cation exchange capacity of soils that contain organic matter or variably charged clay minerals (Bohn *et al*., 2001).

In the same way, application of 5 t ha^{-1} vermicompost resulted in the highest (29.42 cmol $_{(+)}$ kg^{-1}) CEC, while the lowest (28.21 cmol $_{(+)}$ kg^{-1}) was recorded from the control (Table 4.6). However, it contradicts with the result of Temesgen Chimdessa (2021), where the change in soil CEC due to lime and vermicompost application is minimum and statistically insignificant. It might be due to the addition of lime and vermicompost which facilitates organic matter decomposition that may decrease soil CEC.

Table 4. 6. The main effects of lime and vermicompost on soil available P (phosphorus), CEC (cation exchange capacity)) and K (potassium).

Lime rate (t/ha)	Av. P	CEC	K
0	12.69^{c}	27.68^{b}	0.643^{b}
0.93	14.10^{bc}	29.03^{a}	0.851^{b}
1.86	16.49^{a}	29.95^{a}	0.843^{b}
2.79	15.58^{ab}	29.47^{a}	1.086^{a}
Significance level	**	**	**
LSD (0.05)	2.01	0.96	0.22
VC(t/ha)			
0	13.27^{b}	28.21^{b}	0.729
2.5	15.34^{a}	28.72^{ab}	0.89
5	15.54^{a}	29.42^{a}	0.948
Significance level	*	*	NS
LSD (0.05)	1.74	0.83	0.192
CV $_{(\%)}$	13.02	3.65	25.80

* Significant at $p \leq 0.05$, ** significant at $p<0.01$, *** significant at $p<0.001$, NS=no significant

4.3.8. Exchangeable cations

The main effect of lime had a significant ($p<0.05$) effect on the soil potassium, whereas the main effect of vermicompost and the interaction effect of lime with vermicompost were nonsignificant on soil potassium (Appendix Table 4.1). The highest (1.09 cmol $_{(+)}$ kg^{-1}) soil K was obtained from the application of 2.79 t ha^{-1} lime ha^{-1}, while the lowest K values of 0.85, 0.84, and 0.64 cmol $_{(+)}$ kg^{-1} were recorded from the application of 0.93 t ha^{-1}, 1.86 t ha^{-1} , and 0 lime rate, respectively (Table 4.6). According to Abdissa Bekele *et al.* (2018), the availability of exchangeable bases (Ca, Mg, Na and K) were increased due to the application of lime, which might be attributed to the increase in soil pH.

The analysis of variance revealed that exchangeable soil calcium, magnesium, and sodium were highly significantly ($p<0.001$) influenced by the interaction effects of lime and vermicompost (Appendix Table 4.1). The highest (14.36 cmol $_{(+)}$ kg^{-1}) exchangeable calcium was measured from the application of 2.79 t ha^{-1} lime rate with 5 t ha^{-1} vermicompost, while the lowest (4.34 cmol $_{(+)}$ kg^{-1}) exchangeable Ca was recorded from the control plot. Similarly, the highest (1.49 and 1.47 cmol $_{(+)}$ kg^{-1}) exchangeable soil magnesium values were recorded from the application of 1.86 t ha^{-1} lime with 5 t ha^{-1} vermicompost, followed by 0.93 t ha^{-1} lime with 2.5 t ha^{-1} vermicompost respectively. While the lowest (0.31 $cmol_{(+)}$ kg^{-1}) exchangeable Mg was recorded from the control. The highest (0.577 $cmol_{(+)}$ kg^{-1}) exchangeable sodium was obtained from the application of 2.79 t ha^{-1} lime rate with 5 t ha^{-1} of vermicompost, while the lowest (0.19 and 0.203) exchangeable Na was recorded from the control and 0 lime with 2.5 t ha^{-1} vermicompost (Table 4.7). Kisinyo (2016) reported that application of lime to acidic soils increased Ca^{2+} and/or Mg^{2+} ions and reduced Al^{3+}, H^{+}, Mn^{2+}, and Fe^{2+} ions in the soil solution. Soil calcium and magnesium were sharply increased by liming and vermicomposting. Increasing lime with vermicompost application rates resulted in the increase in soil calcium and magnesium.

Table 4. 7. Interaction effects of lime and vermicompost on selected soil properties

Lime (t/ha)	VC (t/ha)	Ex. Ca	Ex. Mg	Ex. Na
0	0	4.34^{f}	0.313^{e}	0.190^{c}
0	2.5	4.78^{ef}	0.320^{e}	0.203^{c}
0	5	6.745^{de}	1.347^{ab}	0.46^{ab}
0.93	0	4.965^{ef}	0.680^{de}	0.483^{ab}
0.93	2.5	8.05^{cd}	1.473^{a}	0.447^{b}
0.93	5	8.76^{bcd}	1.073^{bc}	0.487^{ab}
1.86	0	10.05^{bc}	1.387^{ab}	0.473^{ab}
1.86	2.5	9.99^{bc}	1.387^{ab}	0.467^{ab}
1.86	5	10.45^{b}	1.493^{a}	0.493^{ab}
2.79	0	5.37^{ef}	0.727^{cd}	0.493^{ab}
2.79	2.5	10.75^{b}	1.34^{ab}	0.467^{ab}
2.79	5	14.355^{a}	1.427^{ab}	0.577^{a}
Mean		8.216667	1.08	0.437
Significance level		**	***	*
LSD (0.05)		2.34	0.39	0.124
CV (%)		16.99	21.51	15.78

* Significant at p≤0.05, ** significant at p<0.01, *** significant at p<0.001, VC=vermicompost, Exchangeable (Ca=calcium, Mg=magnesium, Na=sodium)

4.4. Effects of Lime and Vermicompost on Yield and Yield Components of Barley

4.4.1. Days to 50% heading and 90% maturity

The analysis of variance showed that the main and the interaction effects of lime and vermicompost were not significant for days to 50% heading. This might be due to the use of one variety only and the slow release of nutrients from lime and vermicompost .The main effect of vermicompost as well as the interaction effect of lime rates with vermicompost were not significant for days to 90% maturity. However, statistically significant ($p<0.01$) differences were observed on days to 90% maturity due to the main effect of applied lime rates (Appendix Table 4.2). Lime applied with high rate 2.79 t ha^{-1} matured later than those with lower rates (1.86 and 0.93 t ha^{-1}) and the untreated (control) (Table 4.8). The sole application of lime had significant ($p\leq0.05$) effect on days to maturity (Tadesse Moges *et al.*, 2018).

4.4.2. Spike length per plant

The main effect of lime and vermicompost was significant ($p<0.01$ and $p<0.05$) for spike length. However, the interaction effect of lime and vermicompost was not significant for the spike length of barley (Appendix Table 4.2). The maximum spike height (6.1 cm) was recorded from the application of 1.86 t ha^{-1} lime rate, but it is at part with 2.79 t ha^{-1} and 0.93 t ha^{-1} of lime rate. While the minimum mean spike height (5.64 cm) was recorded from the control plot (Table 4.8). The spike length of barely was significantly increased with the application of lime up to the optimum level. The increase in spike length with increasing lime rates on acidic soils is highly likely related to the increase in concentration of exchangeable cations and soil fertility, and the reduction of the toxic concentration of Al and H concentration of exchangeable cations might be increased. In line with this result application of different rates of agricultural lime significantly improve spike length of wheat (Kamaruzzaman *et al*., 2013).

In the same way, the maximum (6.08 cm) spike length was recorded from the application of 5 t ha^{-1} vermicompost, whereas the lowest spike length of 5.78 cm was recorded from 2.5 t ha^{-1} vermicompost (Table 4.8). The spike length increased due to the application of high vermicompost. According to Getachew Agegnehu *et al.* (2016), organic amendments significantly ($p<0.01$) improved spike length of barley. The finding of Girma Chala *et al.* (2020), also indicated that application of organic and inorganic nutrient sources either alone or in combination significantly ($p<0.05$) improved spike length of barley.

4.4.3. Effective Tillers M^{-2}

The analysis of variance showed that the main effect of lime and vermicompost significantly ($P<0.001$ and $P < 0.05$) increased effective barley tiller numbers m^{-2}. While the interaction effect of lime and vermicompost was not significant for tiller numbers (Appendix Table 4.2). The highest effective tiller numbers (447.56 m^{-2}) were obtained from the application of 2.79 t ha^{-1} lime, but it was at par with 1.86 t ha^{-1} lime rate which recorded 435.78 tillers m^{-2}, with 34.8% increase in the number of tillers over the control treatment (Table 4.8). According to Getahun and Bobe (2017), reported highest number of tillers were recorded from the plots in which the soil was amended with lime. The highest number of tillers was recorded in the lime amended plots (Temesgen Desalegn *et al*., 2016). Accordingly, the highest mean effective tiller numbers (428.83) were obtained from the application of 5 t ha^{-1} vermicompost, while the lowest number of effective tillers (388.83) was obtained from the control treatment (Table 4.9). Hence, the application of 5 t ha^{-1} increased the number of effective tillers by 10.29% as compared to the control.

Table 4. 8. The main effects of lime and vermicompost on days to to 90% maturity, spik length per spike, and number of effective tillers m^{-2} of barley

Lime rate (t/ha)	Days to 90% maturity	SLPP	ETM^{-2}
0	133^{b}	5.64^{b}	353.11^{b}
0.93	133^{b}	5.99^{a}	378.67^{b}
1.86	134^{b}	6.1^{a}	435.78^{a}
2.79	136^{a}	5.99^{a}	447.56^{a}
Significance level	**	**	*
LSD (0.05)	1.97	0.24	36.28
Vermicompost (t ha^{-1})			
0	133	5.93^{ab}	388.83^{b}
2.5	134	5.78^{b}	393.67^{b}
5	134	6.08^{a}	428.83^{a}
Significance level	NS	*	*
LSD (0.05)	1.71	0.208	31.42
CV (%)	1.69	4.05	8.36

* Significant at $p \leq 0.05$, ** significant at $p<0.01$, NS=no significant

4.4.4. Plant height (PH)

The analysis of variance revealed that plant height (PH) was affected significantly ($p<0.05$) by the main effect of VC, lime and their interaction (Appendix Table 4.2). The combined application rates of 1.86 t ha^{-1} lime with 5 t ha^{-1} of vermicompost recorded the tallest PH (108.61 cm), but it was at par (108.01 cm) with 2.79 t ha^{-1} lime with 5 t ha^{-1} VC rate, while the shortest PH (96.61 cm) of barley was recorded from the control treatment (Table 4.9). According to Getahun Bore and Bobe Bedadi (2016), there was a consistent significant increase of plant height in response to the increase in applied lime rate. The significant barley plant height increment in response to the increasing lime rates on acidic soils over the control is because of the lime's ability to neutralize soil acidity and the reductions of its toxicity effect on plant growth and the subsequent increase in soil nutrient availability by enhancing mineralization. The increments related to the increase in soil fertility and improvement in plant growth is most likely resulted from the reduction of the the toxic concentration of acidic cations hinders, and also helps in raising the pH of the soil which reduces the effects of acidity on the performance of the crop (Tolossa Ameyu, 2019).

Liming might have reduced the detrimental effect of soil acidity on plant growth due to high concentration of H^+ and Al^{3+} ions in the acidic soil (Achalu Chimdi *et al*., 2012). Similarly, the combined application of integrated organic and inorganic fertilizers was highly significant ($p<0.01$) for plant height of food barley (Girma Chala, *et al*., 2020). Liming of acidic soil increased the plant height of barley (Achalu Chimdi *et al*., 2012).

4.4.5. Number of grains per spike

The potential of barley spike is determined by the number of grains $spike^{-1}$ which is an important yield component of grain yield. The main and interaction effect of lime and vermicompost was highly significant ($p<0.001$) for number of grains per spike (Appendix Table 4.2). The highest number of grains per spike (36.83) was recorded from the combined application of of 1.86 t ha^{-1} lime rate with 5 t ha^{-1} vermicompost, whereas the lowest number of grains per spiket (28.47) was recorded from the untreated (control) treatment (Table 4.9).

The number of grain per spike was increased due to the application of optimum lime rate and high rate of vermicompost, as well as it depends on the length of spike. This indicates that the combined use of lime with vermicompost might increase the available nutrients like nitrogen, phosphorus, potassium, soluble calcium, nitrate (NO_3^-) and other necessary elements for plant growth and reduction of toxic concentration of Aluminium and Hydrogen. Similarly, Temesgen Desalegn *et al.* (2017) reported that limed soil provided higher mean seeds per plant compared to the un-treated soil. The number of grains per spike showed significant variation due to the different liming treatments (Kamaruzzaman *et al*., 2013).

Table 4. 9. The interaction effect of lime and vermicompost on plant height and number of seed per spike of barley

Lime	VC	PH (cm)	NSPS
0	0	96.61[d]	28.47[e]
0	2.5	103.40[bc]	29.03[de]
0	5	100.09[cd]	29.07[de]
0.93	0	103.26[bc]	29.07[de]
0.93	2.5	102.33[bc]	32.10[bc]
0.93	5	106.04[ab]	32.93[b]
1.86	0	102.16[c]	31.67[bc]
1.86	2.5	101.76[c]	30.73[cd]
1.86	5	108.61[a]	36.83[a]
2.79	0	102.55[bc]	32.37[bc]
2.79	2.5	105.98[ab]	32.57[bc]
2.79	5	108.01[a]	33.50[b]
Mean		103.4	31.53
Significance level		*	**
LSD (0.05)		3.74	2.1
CV (%)		2.17	4.09

* Significant at $p \leq 0.05$, ** significant at $p<0.01$, PH=plant height, NGPS=number of grain per spike and ETM^{-2}=effective tiller per square meter.

4.4.6. Aboveground total biomass

The analysis of variance showed that the interaction effect of lime rates and vermicompost had no significant ($p>0.05$ effect on sun dried aboveground total biomass. In contrast, the main effect of lime and vermicompost was highly significant ($p<0.001$) for total biomass of barley (Appendix Table 4.2). The highest barley total biomass of 11759.3 kg ha^{-1} was obtained from the application of 2.79 t ha^{-1} lime kg ha^{-1}, while the lowest total biomass of 9319.4 kg ha^{-1} was recorded from the control (zero treatment) (Table 4.10). The increase in the total biomass of barley due to liming of acidic soils may be attributed to the reduction in H^+ and Al^{3+} ions and the increase in the availability of Ca and P by raising soil pH. Achalu Chimdi *et al*. (2012) reported that increasing lime application on acidic soil significantly increased the total biomass of the barley.

Similarly, the highest total biomass (11174) kg ha^{-1} was recorded from the application of 5 tones ha^{-1} of vermicompost, while the lowest mean total biomass of 10607.6 and 10618.1 kg ha^{-1} were recorded from the rate of 2.5 t ha^{-1} and the control and vermicompost, respectively (Table 4.10). The combined application of organic and inorganic fertilizers was highly significant ($p<0.01$) for the total biomass of food barley (Girma Chala *et al*., 2020).

Table 4. 10. The main effect of lime and vermicompost on total biomass yield (BY) of barley

Lime rate	BY(kg/ha)
0	9319.4^{c}
0.93	10995.8^{b}
1.86	11125^{b}
2.79	11759.3^{a}
significancelevel	***
LSD (0.05)	378.78
Vermicompost	
0	10618.1^{b}
2.5	10607.6^{b}
5	11174^{a}
significance level	**
LSD (0.05)	328.03
CV(%)	3.48

** significant at $p<0.01$, *** significant at $p<0.001$

4.4.7. Grain yield

The analysis of variance showed that the main and interaction effect of lime and vermicompost application on soil had significant ($p<0.01$) effect on grain yield of barley (Appendix Table 4.2). The result showed that the maximum grain yield of 5097.5 kg ha^{-1} was obtained from the application of 1.86 t ha^{-1} lime rate with 5 t ha^{-1} vermicompost, while the minimum grain yields of 3635.4 and 3713.4 kg ha^{-1} were recorded from control and 0 lime with 2.5 t ha^{-1} vermicompost respectively (Table 4.11). Grain yield is the result of other parameters and the application of optimum lime rate with high vermicompost increased barley grain yield. This might be due to the reduction of soil acidity (Al^{3+} and exchangeable acidity) and the increase in the available nutrients like Ca, N, available P. The trend in grain yield increase was also related with plant height and seed number as well as spike length. A similar study has also shown that the combined application of organic and inorganic fertilizers was highly significant ($p<0.01$) for grain yield of food barley (Girma Chala *et al*., 2020).

The increase in crop yield through application of lime may be attributed to neutralization of Al^{3+}, supply of Ca^{2+} and increased availability of some plant nutrients. Also, increase in grain yield with the application of lime is ascribed to its favorable effect on chemical, physical, and microbial properties of soil (Achalu Chimdi *et al*., 2012). Similarly, Temesgen Desalegn *et al*. (2017) reported that the effect of lime on acidic soil amelioration and barley grain yield was the highest during the initial four years, but in the final year grain yield was decreased significantly. This yield reduction in the final year may indicate the need for reliming of the soil. Lime raised soil pH that increased the availability of soil P by unlocking the soil fixed P in to available P for crop use and basic cations especially calcium which forms plant structure (Waluchio and Othieno, 2015).

4.4.8. Thousand grain weight (TGW)

The main effects of lime and interaction effect of lime and vermicompost were significant ($p<0.05$) on thousand grain weight while the main effects of vermicompost was no significant (Appendix Table 4.2). The maximum thousand grain weight (53.72 g) was obtained from the combined application of 2.79 t ha^{-1} lime with 5 t ha^{-1} vermicompost, while the minimum TGW (50.09 g) was recorded from the control treatment (Table 4.11). The finding of a similar study indicated that the combined application of lime and P had significant ($p<0.05$) effect on thousand grain weight of barley (Tadesse Mogess *et al*., 2018). Kamaruzzaman*et et al*. (2013) also reported that liming had significant effects on thousand grain weight of wheat. The 1000-grain weight of wheat varied from 29.0 g to 72.67 g, where the highest (72.67 g) thousand grain weight was from application of lime at 1.5 ton ha^{-1} and the lowest was from the control treatment (29.0 g). Getachew Agegnehu *et al*. (2016) reported that the integrated application of organic and inorganic fertilizers was significant for thousand grain weight.

4.4.9. Straw yield per hectare and harvest index (%)

The analysis of variance showed that the interaction effect of lime rate with vermicompost were significant ($p<0.05$) for straw yield of barley (Apendix Table 4.2). Accordingly, the highest straw yield of 7541.7 kg ha^{-1} was obtained from the combined application of the highest lime rate 2.79 t ha^{-1} and VC (5 t ha^{-1}), while the minimum number of straw yields of 5434, 5522.7, and 5402.8 kg ha^{-1} were recorded from the control (untreated), 0-2.5, and 0-5 LR-VC t ha^{-1} respectively (Table 4.11). The application of 4 and 6 ton lime ha^{-1} increased straw yield by 22.59% and 22.96% as compared to the control (Moges Tadesse, 2018). According to Getachew Agegnehu *et al*. (2016), the application of organic materials on the soil significantly ($p<0.01$) improved straw yields of barley.

Table 4. 11. Interaction effects of soil ammendments on some yield and yield components of barley

Lime	VC	GY (kg/ha)	SY (kg/ha)	HI (%)	TGW (g)
0	0	3635.4^{g}	5434^{c}	40.18^{de}	50.09^{d}
0	2.5	3713.4g	5522.7c	40.21^{de}	51.59^{bc}
0	5	4250^{f}	5402.8^{c}	44.08^{ab}	50.87^{cd}
0.93	0	4548.6^{de}	6423.6^{b}	41.45^{cde}	51.93^{bc}
0.93	2.5	4538.2^{de}	6225.7^{b}	42.18^{bcd}	51.70^{bc}
0.93	5	4888.9^{bc}	6362.5^{b}	43.49^{abc}	51.07^{bcd}
1.86	0	4744.5^{dc}	6436.1^{b}	42.45^{bcd}	51.89^{bc}
1.86	2.5	4457.3^{ef}	6445.5^{b}	40.88^{de}	52.20^{b}
1.86	5	5097.5^{a}	6194.1^{b}	45.16^{a}	51.95^{bc}
2.79	0	4864^{bc}	6386^{b}	43.24^{abc}	51.07^{bcd}
2.79	2.5	4791.7^{bc}	6736.1^{b}	41.6^{cde}	51.78^{bc}
2.79	5	4958.3^{ab}	7541.7^{a}	39.67^{e}	53.72^{a}
Mean		4540.66	6259.23	42.05	51.65
Significance Level		**	*	**	*
LSD (0.05)		208.44	554.95	2.33	1.25
CV (%)		2.59	5.36	3.36	1.497

* Significant at $p\leq0.05$, ** significant at $p<0.01$, GY= grain yield, SY=straw yield, HI=harvest index, TGW=thousand grain weight

The analysis of variance showed that harvest index (HI) of barley were significantly ($p<0.01$) influenced by the interaction effect of lime with vermicompost as well as main effects of vermicompost rates. However, sole application of lime not affect harvest index (Appendix Table 4.2). The combined application of 1.86 t ha^{-1} lime with 5 t ha^{-1} vermicompost gave the highest HI (45.16) percentage, while the lowest HI of 39.67% was obtained from the application of 150% lime with 5 t ha^{-1} vermicompost (Table 4.11). It might be high amount of lime with vermicompost takes long time for Morphological growth and the biomass becomes high. Liming of acidic soil increased the harvest index of barley (Achalu Chimdi *et al*., 2012).

4.4.10. Grain protein and hectoliter weight

The main effects of vermicompost and combined application of lime and vermicompost significantly ($p<0.01$) affected the grain protein of barley while the main effects of lime had no significant effect (Appendix Table 4.2). Grain protein of content barley ranged from 8.05% to 9.04% (Table 4.12); where protein content is mainly related to the level of soil nitrogen available to the plant and type of crop variety. Grain protein content is an important quality component of cereals (Xu *et al*., 2012). Since food barley is a major source of protein in the highland areas of Ethiopia, increasing grain yield and quality of barley is important. The highest grain N concentrations attained (1.69% at Holetta and 1.58% at Robgebeya) are equivalent to the respective grain protein contents of 9.9% and 9.1%, respectively (Getachew Agegnehu *et al*., 2016).

Liming increases the availability of cations which act as catalysts in protein synthesis. The content of protein after physiological maturity stage was lower than after harvest, which explained that at grain filling stages the plants were still actively absorbing nitrogen from the soil. The amount of available soil nitrogen, soil moisture status and temperature conditions determine the level of grain protein. High rates of nitrogen and limited soil moisture results in a protein content above acceptable malting level for malting barley (Waluchio and Othieno, 2015).

Table 4. 12. Interaction effects of soil ammendments on grain protein

Lime	VC	Protein (%)
0	0	8.16cd
0	2.5	8.62ab
0	5	8.17cd
0.93	0	8.51bc
0.93	2.5	8.52bc
0.93	5	8.47bcd
1.86	0	8.05d
1.86	2.5	9.04a
1.86	5	8.14cd
2.79	0	8.55bc
2.79	2.5	8.26cd
2.79	5	8.37cd
Mean		8.4
Significance Level		**
LSD (0.05)		0.43
CV (%)		3.003

** significant at $p<0.01$

The ANOVA revealed that the main effect of lime and vermicompost were highly significant ($p<0.01$) for barley hectoliter weight, while their interaction was non-significant (Appendix Table 4.2). Accordingly, the highest hectoliter weight (629.3 g/l) was obtained from the application of 2.79 t ha^{-1} lime rate, but it was at par with 1.86 t ha^{-1} and 0.93 t ha^{-1} of lime rate. The lowest (606.1 g/l) hectoliter weight was recorded from the control (Table 4.13). The result showed that the increase in lime rate from 0.93 to 2.79 t ha^{-1}, the hectoliter weight also increased. Temesgen Desalegn *et al*. (2017), also reported that all the liming treatments had higher mean HLW values relative to the control (un-limed). Similarly, the analysis of hectoliter weight showed that application of 5 t ha^{-1} of vermicompost gave the highest (629.1 g/l) hectoliter weight,while the control treatment gave the lowest (611.2 g/l) HLW (Table 4.14). It might be due to the content of high organic matter and nutrients in the vermicompost .

Table 4. 13. Main effect of lime and vermicompost on hectoliter weight (HLW)

Lime rate	HLW (g/l)
0	606.1[b]
0.93	619.2[a]
1.86	624.4[a]
2.79	629.3[a]
significancelevel	**
LSD (0.05)	1.231
Vermicompost	
0	611.2[b]
2.5	619.1[ab]
5	629.1[a]
Significance level	**
LSD (0.05)	1.066
CV(%)	2.12

** significant at $p<0.01$

4.5. Correlation among Barley Grain Yield and Yield Components

Grain yield had positively correlated with days to maturity (0.63*), plant height (0.76**), spike length per plant (0.78**), number of grains per spike (0.84***), number of effective tillers per square meter (0.71**), biomass yield (0.92***), straw yield (0.75**), and hectoliter weight (0.79**) (Table 4.14). However, grain yield had no significant ($p>0.05$) correlation with days to heading, harvest index, thousand grain weight and protein content. Similarly, Temesgen Desalegn *et al*. (2017) reported that the yield components of barley such as number of tillers, number of grains per spike and total biomass were highly correlated with grain yield. According to Getachew Agegnehu *et al*. (2012), barley grain yield was significantly and positively correlated with total biomass, number of productive tillers, spike size and plant height. Grain yield was strongly correlated with total biomass, followed by spike length and number of productive tillers, plant height and spike size. However, grain yield was not significantly correlated with harvest index and thousand grain weight. Hence, based on the results of the study, high total biomass, taller plant height and large spike size are the traits associated with good performance of barley.

Table 4. 14. Correlation of grain yield and yield components of barley

Parameters	GY	HD	MA	PLH	SLPP	NSPS	ETM^{-2}	BY	SY	HI	TGW	HLW
HD	0.48^{NS}											
MA	0.63^{*}	0.51^{NS}										
PLH	0.76^{**}	0.46^{NS}	0.64^{*}									
SLPP	0.78^{**}	0.46^{NS}	0.28^{NS}	0.69^{*}								
SNPS	0.84^{***}	0.47^{NS}	0.57^{NS}	0.80^{**}	0.72^{**}							
ETM^{-2}	0.71^{**}	0.80^{**}	0.71^{**}	0.73^{**}	0.74^{**}	0.65^{*}						
BY	0.92^{***}	0.62^{*}	0.73^{**}	0.75^{**}	0.78^{**}	0.72^{*}	0.84^{***}					
SY	0.75^{**}	0.66^{*}	0.72^{**}	0.67^{*}	0.69^{*}	0.56^{NS}	0.84^{***}	0.95^{***}				
HI	0.49^{NS}	-0.14^{NS}	-0.01^{NS}	0.22^{NS}	0.25^{NS}	0.49^{NS}	-0.05^{NS}	0.11^{NS}	-0.20^{NS}			
TGW	0.52^{NS}	0.72^{*}	0.57^{NS}	0.68^{*}	0.65^{*}	0.44^{NS}	0.80^{NS}	0.73^{**}	0.82^{**}	-0.29^{NS}		
HW	0.79^{**}	0.63^{*}	0.70*	0.89^{***}	0.66^{*}	0.87^{***}	0.78^{**}	0.81^{**}	0.74^{**}	0.18^{NS}	0.63^{*}	
Protein	-0.1^{NS}	0.43^{NS}	0.05^{NS}	-0.02^{NS}	-0.22^{NS}	-0.19^{NS}	0.07^{NS}	0.03^{NS}	0.13^{NS}	-0.34^{NS}	0.21^{NS}	-0.07^{NS}

*, **, *** Significant at $p \leq 0.05, 0.01, 0.001$ probability level: NS: Not significant; AGY= grain yield, HD=heading, MA=maturity. PLH=plant height, SLPP, spike length per plant, NSPS=number of seed per spike, ETM^{-2}=effective tiller per square meter, BY= biomass yield, SY=straw yield, HI=harvest index, TSW= thousand seed weight, HLW=hectoliter weight.

4.6. Correlation between Grain Yield of Barley and Selected Soil Properties

Grain yield in cereals is the product of optimum soil nutrients. The correlation indicates that grain yield was strongly significantly ($p<0.001$) and positively correlated with soil pH ($r=0.85$), TN($r=0.74$), CEC ($r=0.87$), Mg ($r=0.69$), and Na ($r=0.91$). Grain yield was also significantly ($p<0.05$) and positively correlated with OC ($r=0.57$), Ca ($r=0.68$) and K ($r=0.59$). On the other hand, grain yield was highly significant ($p<0.001$) and negatively correlated with bulk density ($r=-59$), exchangeable acidity ($r=-0.939$) and exchangeable Al ($r=-0.90$). Increasing soil pH also increases grain yield and decreases exchangeable acidity and Al^{3+}(Table 4.15), which may indicate that grain yield and available nutrients had direct relationship and invers relation with toxic nutrients. A similar finding by Getachew Alemu *et al*., (2017) indicated barley grain yield was significantly ($P < 0.01$) positively correlated with some soil properties such as soil pH and available P, but significantly ($P<0.01$) negatively correlated with exchangeable acidity and Al^{3+}.

Similarly, correlation among soil properties positively and significant correlation coefficient were observed pH was positively correlate with TN ($r=0.85$), OC (0.75), available P ($r=0.80$), CEC (0.78), Ca ($r=0.84$), Mg ($r=0.79$), Na ($r=0.80$) and K ($r=0.69$). Inversely and significantly correlated with bulk density ($r=-0.62$) exchangeable acidity ($r=-0.91$) and Al^{+3} ($r=-0.93$) Table (4.15). Increasing the amendments of lime and organic matter rate on the soil positively improves availability of nutrients. According to Temesgen Chimdessa (2021) soil pH is significantly ($P<0.01$) and positively correlated with available P.

Table 4. 15. Relation between grain yield of barley and selected soil properties

Parameters	GY	pH	BD	TN	OC	Ex. Acidity	Ex. Al^{3+}	Av. P	CEC	Ex. Ca	Ex. Mg	Ex. Na
pH	0.85***											
BD	-0.59*	-0.62*										
TN	0.74**	0.85***	-0.82**									
OC	0.57*	0.75**	-0.45NS	0.78**								
Ex. acidity	-0.94***	-0.91***	0.54NS	-0.73**	-0.69**							
Ex. Al^{+3}	-0.90***	-0.93***	0.50NS	-0.76**	-0.71**	0.99***						
Av. P	0.65*	0.80**	-0.39NS	0.75**	0.86***	-0.72	-0.73**					
CEC	0.87***	0.78**	-0.56NS	0.83 ***	0.72**	-0.85***	-0.85***	0.65*				
Ex. Ca	0.68*	0.84***	-0.68*	0.90***	0.70*	-0.73**	-0.80**	0.71**	0.74**			
Ex. Mg	0.69**	0.79***	-0.61*	0.85***	0.61*	-0.64*	-0.69**	0.68*	0.72**	0.81***		
Ex. Na	0.91***	0.80***	-0.64*	0.72**	0.37NS	-0.81***	-0.81***	0.47NS	0.77**	0.67*	0.77**	
Ex. K	0.59*	0.69*	-0.44NS	0.69*	0.50NS	-0.68*	-0.75**	0.45NS	0.70**	0.83***	0.48NS	0.61*

*, **, *** Significant at $p \leq 0.05, 0.01, 0.001$ probability level: NS: Not significant. GY= grain yield, pH=power of hydrogen, BD=bulk density, TN=total nitrogen, OC=organic carbon, Ex. acidity=exchangeable acidity, Ex. Al3+=exchangeable aluminum, Av. P=available phosphorus, CEC=cation exchange capacity, Ex. (Ca, Mg, Na, K) = exchangeable (calcium, magnesium, sodium, potassium).

4.7. Partial Budget Analysis

The vermicompost preparation needs raw material (straw & cow dung). Raw materials for one ton vermicompost preparation 168 ETB labor cost 35 ETB man per day. The costs of raw material per ton became double but labor cost not double because it increased only amount. Cost of 2.5 t ha^{-1} needs were 420 ETB and labor 35 ETB man day^{-1} by using interval days 1400 ETB total 1820 ETB, and for 5 t ha^{-1} needs straw and cow dung cost were 940 ETB labor cost 2100 total 3040 ETB. The transport and application cost of vermicompost was 200 and 250 ETB for 2.5 and 5 t/ha respectively. The price of 100 kg lime was 240 ETB during the 2020 cropping season and cost of transport and application 175, 200 and 225 ETB for 0.93, 1.86 and 2.79 t ha^{-1} respectively.

According to the partial budget analysis, the highest net benefit (92569.8 Birr) was obtained from the application of 1.86 t ha^{-1} lime rate with 5 t ha^{-1} vermicompost followed by net benefit (90997.9 Birr) obtained from application of 0.93 t/ha lime and 5 t/ha vermicompost. While the lowest net benefit (72377) was recorded from the control treatment (Table 4.16). However, the highest marginal rate of return (644.8%) was obtained from the application of 0.93 t ha^{-1} lime individually, while the net benefit (87897.5) was low. Therefore, the application of 0.93 t ha^{-1} lime with 5 t ha^{-1} vermicompost resulted in economically the optimum net benefit and total variable cost with acceptable MRR (159.39%) for barley grain yield due to the increment of soil nutrients and residual effects.

Table 4.16. Partial budget analysis for lime and vermicompost effects on barley yield

Lime	VC	GY	SY	AGY	ASY	CLM	CVC	TVC	GFB	NB	MRR
(t/ha)	(kg/ha)					(Birr/ha)					(%)
0	0	3635.4	5434	3271.86	4890.6	0	0	0	72377.0	72377	-
0	2.5	3713.4	5522.7	3342.06	4970.43	0	2020	2020	73911.1	71891.1	D
0.93	0	4548.6	6423.6	4093.74	5781.24	2407	0	2407	90304.5	87897.5	644.8
0	5	4250.0	5402.8	3825	4862.52	0	3290	3290	83971.9	80681.9	D
0.93	2.5	4538.2	6225.7	4084.38	5603.13	2407	2020	4427	89974.3	85547.3	D
1.86	0	4744.5	6436.1	4270.05	5792.49	4664	0	4664	94015.4	89351.4	64.42
0.93	5	4888.9	6362.5	4400.01	5726.25	2407	3290	5697	96694.9	90997.9	159.39
1.86	2.5	4457.3	6445.5	4011.57	5800.95	4664	2020	6684	88593.7	81909.7	D
2.79	0	4864.0	6386	4377.6	5747.4	6921	0	6921	96240.2	89319.2	D
1.86	5	5097.5	6194.1	4587.75	5574.69	4664	3290	7954	100524	92569.8	69.64
2.79	2.5	4791.7	6736.1	4312.53	6062.49	6921	2020	8941	95110.0	86169.0	D
2.79	5	4958.3	7541.7	4462.47	6787.53	6921	3290	10211	98802.5	88591.5	D

VC=vermicompost, GY=grain yield, SY=straw yield, AGY= adjusted grain yield, ASY=adjusted straw yield, CLM= cost of lime, CVC= cost of vermicompost, TVC=total variable cost, GFB=gross field benefit, GB=gross benefit, NB=net benefit, MRR=marginal rate of return Cost of 1 kg grain=21 ETB, cost of straw=0.75ETB

Chapter 5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Soil acidity is the major constraint to agricultural productivity. Since study area is affected by soil acidity application of lime and vermicompost showed a significant effect in decreasing soil acidity and increasing soil pH. Based on the results of the study, the application of lime and vermicompost significantly increased soil pH, TN, OC, available P, CEC, exchangeable Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}. This implies that the application of lime and vermicompost significantly decreased soil acidity and improved soil fertility and nutrient availability. The agronomic data of plant height, number of seed per spike, adjusted grain yield, straw yield, harvest index, and thousand grain weight were significantly improved by the main and interaction effects of lime and vermicompost. In contrast, spike length per plant, effective tillers, total biomass and hectoliter weight were significantly affected by the main effects of lime and vermicompost. Sole application of lime affected maturity date. Days to heading was not affected by the treatment application. Barley grain yield and yield components of barley were significantly increased due to the improvement of soil fertility and availability of nutrients.

Grain yield also highly and positively correlated with seed number, biomass yield, followed plant height, spike length, effective tiller, straw yield, and hectoliter weight. Soil pH was positively and strongly correlated with TN, CEC, Ca, Mg, Na, followed by available P, OC, and K. Soil pH was strongly and negatively correlated with bulk density, exchangeable acidity and Al^{3+} which implies that amending soil acidity through the application of lime and organic fertilizer could decrease soil acidity greatly. Grain yield was significantly and positively correlated with soil pH, TN, OC, available P, CEC, Ca, Mg, Na, and K, but significantly and negatively correlated with bulk density, exchangeable acidity and Al^{3+}. This indicates that amelioration of soil acidity through the application of lime and organic (vermicompost) amendments, that eliminates soil acidity and toxicity of Al, Mn, and H, and improves the availability of Ca, P, Mo, and Mg, pH as well as soil aeration. As a result, the improvement of available nutrients will increase the production and productivity of barley in acid soil areas.

The correlations between heading, harvest index, thousand grain weight, and grain protein were not significant. The application (0.93 t ha^{-1}) lime rate and the highest rate (5 t ha^{-1}) vermicompost improved soil fertility and resulted in economically profitable yield. Overall, the integrated use of lime with organic fertilizer could ameliorate soil acidity, improve soil nutrients and increase yield of barley compared to the separate use of these amendments.

5.2. Recommendations

From this study, despite only one-season study results, the integrated application of lime at the rate of 0.93 t ha^{-1} and vermicompost at the rate 5 t ha^{-1} were found to be optimum rates which could be recommended to reclaim soil acidity and improve soil fertility for improved growth and yield of barley.

Further research is also needed to investigate the main and interaction effects of three factors, including organic and mineral fertilizers, and lime on acidic soils to improve soil fertility and determine the requirement of inorganic fertilizer for increased barley yield.

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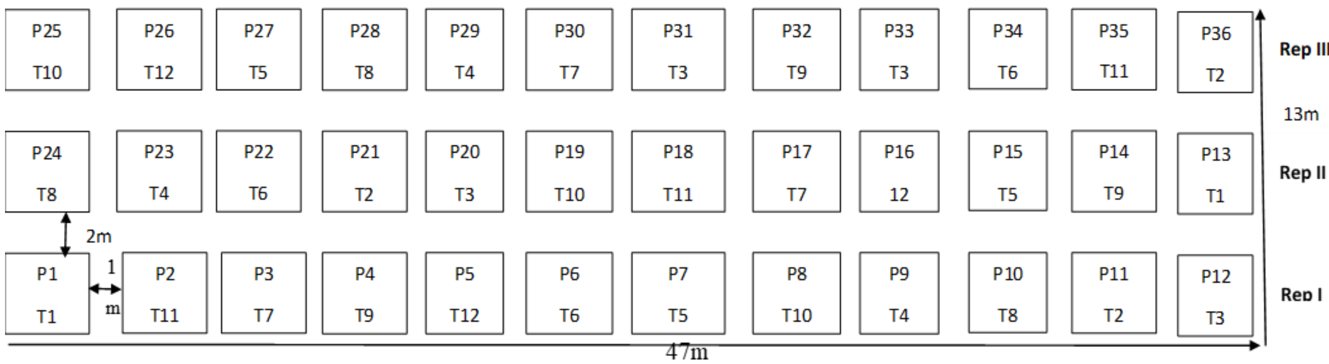
7. APPENDICES

Appendix Table 3. 1. Field experimental layout



Appendix Table 4. 1. ANOVA tables of selected soil properties

		mean squares				
Source	DF	pH	TN (%)	OC (%)	Ex. acidity	EX. Al^{3+}
Rep	2	0.0159*	0.00034^{NS}	0.0265NS	0.0245NS	0.0004NS
LM	3	0.5796***	0.00096*	0.122***	1.804***	0.8281***
VC	2	0.1011***	0.0029***	0.139***	0.1465*	0.0647*
LM*VC	6	0.1110***	0.00007^{NS}	0.029*	0.0302NS	0.015NS
Error		0.0018	0.00024	0.009	0.0337	0.0156
CV (%)		0.787	6.796	3.207	20.78	20.93

				Mean squares			
Source	DF	Av. P	CEC	Ca	Mg	Ex. Na	K
Rep	2	0.741^{NS}	5.410*	1.682^{NS}	0.049^{NS}	0.0125^{NS}	0.0354^{NS}
LM	3	25.077**	5.304*	51.14***	0.902***	0.0955***	0.294**
VC	2	18.935*	4.395*	45.85***	0.957***	0.0416**	0.1546^{NS}
LM*VC	6	6.802^{NS}	0.551^{NS}	10.935**	0.341***	0.0133*	0.0668^{NS}
Error		3.67	1.103	1.948	0.054	0.0048	0.0488
CV (%)		13.017	3.648	16.99	21.507	15.78	25.804

Appendix Table 4. 2. ANOVA tables of yield and yield components of barley

Source	DF	mean squares					
		50% HD	90%MA	PLH	SLPP	NSPS	ETPP
Rep	2	50.25^{NS}	12.86^{NS}	3.90^{NS}	0.039^{NS}	0.385^{NS}	0.009^{NS}
LM	3	29.81^{NS}	27.21^{**}	49.89^{***}	0.352^{**}	33.649^{***}	0.371^{*}
VC	2	23.25^{NS}	3.44^{NS}	61.91^{***}	0.285^{*}	23.319^{***}	0.489^{*}
LM*VC	6	14.36^{NS}	0.63^{NS}	17.04^{*}	0.077^{NS}	7.644^{**}	0.106^{NS}
Error	22	17.10	5.13	5.03	0.058	1.67	0.115
CV (%)		5.62	1.69	2.17	4.05	4.09	13.2

Source	DF	mean squares						
		BY (kg/ha)	AGY (kg/ha)	strow yield	HI	TSW	HLW	Protein
Rep	2	145582.27^{NS}	31664.79^{NS}	65007.45^{NS}	1.007^{NS}	0.048^{NS}	0.864^{NS}	0.0975^{NS}
LM	3	9768610.29^{***}	1887070.34^{***}	3182843.36^{***}	3.985^{NS}	3.233^{**}	9.005^{**}	0.0497^{NS}
VC	2	1259708.91^{**}	615204.67^{***}	132927.72^{NS}	11.08^{*}	1.536^{NS}	9.674^{**}	0.3795^{**}
LM*VC	6	201143.76^{NS}	56513.32^{**}	341314.87^{*}	10.29^{**}	2.162^{*}	1.250^{NS}	0.267^{**}
Error	22	140972.57	13811.26	112396.78	1.9998	0.598	1.73	0.064
CV (%)		3.48	2.59	5.36	3.36	1.497	2.12	3.003

Appendix Table 4.3. Laboratory results of some selected parameters

Issue date____________

Test report No---------------

Request No------------------

Name of laboratory	PARC agricultural and nutrition research laboratory
Address	Pawe
	Tel: 0585500360

Sample type-soil and vermicompost

Date and place of sampling 22/09/2012

Sample condition air dried

Sampled and submitted by Wubayehu K/mariam

Date of sample received __________

Date of test performed 07/10/2012-15/10/2012

Customer ID	pH 1:2.5	BD ($g\ cm^{-3}$)	TN (%)	OC (%)	Ex. Ac ($Cmol_{(+)}\ kg^{-1}$)	Ex. Al ($Cmol_{(+)}\ kg^{-1}$)	Av.P (mg kg^{-1})	CEC ($Cmol_{(+)}\ kg^{-1}$)	Soil textural class	sand clay loam
WB	4.80	1.37	0.197	2.78	1.205	1.120	11.81	24.91	Sand (%)	60
									Silt (%)	12
									Clay (%)	28

NO.	Customer ID	pH (1:2.5)	TN (%)	OC (%)	OM (%)	C:N ratio	Total P (%)	CEC ($Cmol_{(+)}\ kg^{-1}$)
1	WV	8.45	1.66	10.69	18.44	6.46	0.61	65.59

Remark: Available phosphorus (mg kg^{-1}) for soil and total phosphorus (%) for vermicompost were analyzed

Prepared by Solomon B.__________ Approved by ____________

Mesfin Kuma Megersa
Natural Resource Management Research Process Representative

	Name of institute ETHIOPIAN INSTITUTE OF AGRICULTURAL RESEARCH	Doc. number: EIAR/RL/F5.10-2	Version No: 2 Page 1 of 3
Document Title:	TEST REPORT	Effective date:	June 2021

Issue date--------------------.

Test report No----------------

Request No------------------

Name of laboratory	PARC agricultural and nutrition research laboratory
address	Pawe
	Tel: 0585500360

Sample type-soil, hectoliter weight and grain protein

Date and place of sampling 01/05/2013

Sample condition air dried

Sampled and submitted by Wubayehu K/mariam

Date of sample received ___________

Date of test performed 26/07/2013-15/09/2013

Customer ID	pH (1:2.5)	BD (g cm^{-3})	OC (%)	TN (%)	Ex. Ac (Cmol$_{(+)}$ kg^{-1})	Ex. Al (Cmol$_{(+)}$ kg^{-1})	Av. P (mg kg^{-1})	CEC (Cmol$_{(+)}$ kg^{-1})	HLW (kg hl^{-1})	Protein (%)
WP1	4.96	1.42	2.73	0.19	1.700	1.158	13.57	29.26	58.50	8.55
WP2	5.46	1.36	2.96	0.25	0.482	0.201	16.83	29.50	63.20	8.34
WP3	5.45	1.32	2.95	0.22	0.643	0.442	12.36	28.98	62.00	8.05
WP4	5.52	1.25	3.16	0.26	0.321	0.320	18.56	28.79	64.40	8.42
WP5	5.53	1.22	3.05	0.27	0.482	0.201	16.50	28.32	64.80	8.75
WP6	5.37	1.24	3.04	0.25	0.643	0.442	11.07	29.34	60.80	8.46
WP7	5.42	1.36	3.04	0.25	0.964	0.442	17.47	29.40	61.60	8.49
WP8	5.37	1.34	2.96	0.23	0.241	0.286	16.44	27.96	60.80	8.24
WP9	5.30	1.42	2.69	0.18	1.150	0.894	14.09	28.59	62.40	8.62
WP10	5.38	1.27	3.21	0.24	0.995	0.659	15.79	27.45	61.20	8.90
WP11	5.30	1.37	3.00	0.23	1.644	1.038	13.58	28.06	59.30	8.67
WP12	5.23	1.19	2.93	0.22	1.606	1.004	12.64	27.89	61.20	8.60
WP13	5.01	1.37	2.83	0.20	1.573	1.050	10.54	26.73	62.00	7.94
WP14	5.46	1.25	3.36	0.24	0.482	0.462	19.57	29.53	63.60	8.05
WP15	5.44	1.40	3.09	0.26	0.884	0.643	16.30	29.28	62.40	8.31
WP16	5.60	1.18	3.12	0.25	0.241	0.161	14.07	30.04	63.20	8.09
WP17	5.46	1.21	3.02	0.23	0.884	0.623	16.89	26.99	61.20	8.08
WP18	5.47	1.31	3.06	0.23	0.321	0.161	18.14	28.65	62.40	8.34

Prepared by Solomon B.___________ Approved by ______________

Mesfin Kuma Megersa
Natural Resource Management Research Process Representative

WP19	5.32	1.32	3.05	0.22	0.482	0.406	14.12	28.94	60.40	8.39
WP20	5.21	1.31	2.64	0.24	0.964	0.723	14.48	26.96	59.70	7.94
WP21	5.12	1.41	2.90	0.21	1.422	0.994	15.12	26.28	60.80	8.78
WP22	5.24	1.31	3.03	0.23	0.884	0.723	13.65	29.62	63.20	8.39
WP23	5.20	1.34	2.62	0.23	1.070	0.763	10.86	26.43	61.60	8.69
WP24	5.33	1.30	3.05	0.23	0.773	0.444	13.93	28.98	64.00	9.07
WP25	5.35	1.28	2.89	0.22	0.723	0.487	11.85	30.25	63.20	9.03
WP26	5.51	1.19	2.98	0.25	0.402	0.241	18.30	30.71	64.00	8.27
WP27	5.41	1.22	2.99	0.19	0.643	0.482	14.79	28.79	60.80	8.75
WP28	5.36	1.40	2.90	0.23	0.883	0.544	16.12	29.60	60.80	9.15
WP29	5.25	1.33	2.58	0.21	0.993	0.632	12.47	28.49	59.70	8.23
WP30	5.40	1.22	2.98	0.22	0.562	0.341	14.63	29.94	60.80	8.02
WP31	4.99	1.42	2.64	0.20	1.446	0.945	11.43	26.00	60.80	7.99
WP32	5.40	1.30	2.99	0.24	0.643	0.382	20.57	30.27	64.00	7.94
WP33	5.17	1.27	2.77	0.24	1.606	1.044	10.83	30.23	61.20	7.97
WP34	5.28	1.25	2.93	0.23	0.803	0.562	16.24	31.32	64.80	8.55
WP35	5.44	1.37	3.18	0.23	0.723	0.482	13.95	30.87	64.40	8.09
WP36	5.13	1.20	2.94	0.21	1.533	1.082	12.05	27.75	62.00	8.42

Remark		attachment		Next page	
✓ the report is only for the sample submitted to the laboratory		Yes		Yes	
		No		No	

Prepared by Solomon B.________ Approved by ------------

Mesfin Kuma Megersa
Natural Resource ...search
Man... ...tative
Proces...

Amhara Design & Supervision Works Enterprise
Laboratory Servise
Soil Chemistry & Water Quality Section

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Soil Analysis of Laboratory Report

Client : Wubayehu Kidanemariam (BDU)

Sr. No.	Lab. No.	Client Code	Ex.Ca	Ex.Mg	Ex.Na	Ex.K
			Cmol (+) / Kg			
1	0201/21	WP1/1	3.495	0.02	0.23	0.73
2	0202/21	WP2/11	9.675	1.26	0.52	0.93
3	0203/21	WP3/7	7.92	1.18	0.49	0.53
4	0204/21	WP4/9	10.485	1.18	0.52	0.87
5	0205/21	WP5/12	16.695	1.58	0.59	1.87
6	0206/21	WP6/6	9.63	1.18	0.54	0.68
7	0207/21	WP7/5	5.575	1.32	0.52	0.68
8	0208/21	WP8/10	5.805	0.82	0.53	0.73
9	0209/21	WP9/4	4.585	0.64	0.51	0.8
10	0210/21	WP10/8	9.675	1.26	0.42	1.13
11	0211/21	WP11/2	4.33	0.26	0.15	0.73
12	0212/21	WP12/3	6.235	1.38	0.54	0.73
13	0213/21	WP13/1	4.515	0.4	0.11	0.6
14	0214/21	WP14/9	10.86	1.54	0.54	0.73
15	0215/21	WP15/5	8.98	1.62	0.41	0.8
16	0216/21	WP16/12	14.475	1.86	0.57	0.97
17	0217/21	WP17/7	11.19	1.5	0.46	0.6
18	0218/21	WP18/11	10.935	1.42	0.53	1
19	0219/21	WP19/10	5.745	0.74	0.51	0.89
20	0220/21	WP20/3	4.72	1.04	0.41	0.47
21	0221/21	WP21/2	4.825	0.28	0.24	0.67
22	0222/21	WP22/6	7.635	0.88	0.51	1.23
23	0223/21	WP23/4	4.765	0.74	0.42	0.73
24	0224/21	WP24/8	9.96	1.38	0.64	0.87
25	0225/21	WP25/10	4.56	0.62	0.44	0.68
26	0226/21	WP26/12	11.895	0.84	0.57	1.23
27	0227/21	WP27/5	9.595	1.48	0.41	0.87
28	0228/21	WP28/8	10.335	1.52	0.34	0.93
29	0229/21	WP29/4	5.545	0.66	0.52	0.8
30	0230/21	WP30/7	11.025	1.48	0.47	1.13
31	0231/21	WP31/1	5.01	0.52	0.23	0.53
32	0232/21	WP32/9	10.005	1.76	0.42	0.8
33	0233/21	WP33/3	9.28	1.62	0.43	0.73
34	0234/21	WP34/6	9.015	1.16	0.41	1.07
35	0235/21	WP35/11	11.64	1.34	0.35	1.47
36	0236/21	WP36/2	5.185	0.42	0.22	0.6
37	0237/21	WPS	3.99	0.33	0.22	0.52
38	0238/21	WV	46.64	14.2	0.81	11.45

Name of Chemist Abel Ayale
Date 25/09/2013
Sign

Checked by
Date 25/9
Sign Hailu Getahun Yimer
Soil Chemistry & Water Quality Team Leader

Approved by
Date 25/9
Sign Hailu Getahun Yimer
Soil Chemistry & Water Quality Team Leader

BIOGRAPHICAL SKETCH

The author was born in October 1987 E.C in Tarmaber wereda of North Shewa. She attended elementary education (grade 1-4) at shotelamba and (grade 5-8) Armaniya primary and secondary school from 1996-2003 E.C. After completing elementary education, she was pursued secondary school at Debre Sina preparatory school. Then she join Debre Berhan University college of agriculture from 2008 to 2010 graduated with Bachelor degree of science in natural resource management in June 2010 E.C. From October 2011 E.C still now she is employed at EIAR as a junior researcher in pawe agricultural research center. Then after, in 2012 joined the school of graduate studies of Bahir Dar University, college of agriculture and environmental science, department of natural resources management in the regular programs as a candidate for Master of Science degree in Soil Science.