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EFFECT OF MICRO DOSING OF LIME ON SELECTED SOIL CHEMICAL PROPERTIES AND YIELD AND YIELD COMPONENTS OF POTATO (Solanum tuberosum L.) IN ACIDIC NITISOLS OF BANJA DISTRICT, AMHARA REGION, ETHIOPIA

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MSc Thesis

By

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June, 2018

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SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (MSc) IN LAND RESOURCE MANAGEMENT

MSc Thesis

By

Selomon Afework Yenesew

Department: Natural Resources Management

Program: Land Resources Management

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June, 2018

Bahir Dar, Ethiopia

THESIS APPROVAL SHEET

As the Board of Examiners of the Master of Sciences (MSc) thesis open defense examination, we have read and evaluated this thesis prepared by Mr. Selomon Afework Yenesew entitled "**Effect of Micro-Dosing of Lime on Selected Soil Chemical Properties and Yield and Yield Components of Potato (*Solanum tuberosum* L.) in Acidic Nitisols of Banja District, Amhara Region, Ethiopia**". We hereby certify that; the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Sciences (MSc) in Land Resource Management.

Board of Examiners

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Name of Chairman	Signature	Date

DECLARATION

This is to certify that this thesis entitled "**Effect of Micro-Dosing of Lime on Selected Soil Chemical Properties and Yield and Yield Components of Potato (*Solanum tuberosum* L.) in Acidic Nitisols of Banja District, Amhara Region, Ethiopia**" submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in **Land Resources Management** to the Graduate Program of the College of Agriculture and Environmental Sciences, Bahir Dar University by Mr. **Selomon Afework Yenesew** (ID.NO. BDU0906213PR) is an authentic work carried out by him under our guidance. The matter embodied in this project work has not submitted earlier for award of any degree or diploma to the best of our knowledge and belief.

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LIST OF ABBREVIATIONS/ACRONYMS

ANOVA	Analysis of Variance
BDOARD	Banja District Office of Agriculture and Rural Development
CASCAPE	Capacity Building for Scaling up of Evidence Based Best Practices in Agricultural Production in Ethiopia
CEC	Cation Exchanges Capacity
CIMMYT	International maize and wheat improvement center
CSA	Central Statistics Agency
DMRT	Duncan’s Multiple Range Test
ECEC	Effective Cations Exchanges Capacity
FAO	Food Agricultural Organization
ha	Hectare
ICRISAT	International Crops Research Institute for the Semi-arid Tropics
LR	Lime Requirement
LSD	Least Significance Different
MRR	Marginal rate of return
MOARD	Ministry of Agriculture and Rural Development
MTY	Marketable Tuber Yield
NMS	Number of Main Stems
PH	Plant Height
RCBD	Randomized complete block design
ROPNE	Regional Office of Planning in Northwestern Ethiopia
SAS	Statistical Application System
SMP	Shoemaker, McLean and Pratt
SPSS	Statistical Package for Social Sciences
SSA	Sub-Saharan Africa
TDR	Tuber Dry Matter
$t\ ha^{-1}$	tons per hectare
WRB	World Reference Base

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ABSTRACT

Liming of acidic soil on smallholder farms is one of the major challenges to enhance crop yields in Ethiopian highlands. This may be attributed to the additional investment cost for liming. The study was carried out to investigate the effects of micro-dosing of lime on selected soil chemical properties and yield and yield components of potato on farmers' field in Banja district, Awi Zone, Amhara Region in 2017/2018. Three methods of lime rate determination and eight treatments on lime rate application were used in the field experiment. The experiment was laid out in RCBD with four replications. Soil samples were collected from 0.15m depth and analyzed before planting and after harvesting of crops and analyzed to assess the effect of lime on soil chemical properties. Crop samples were also collected and analyzed to evaluate the effect of treatments on yield and yield components of potato. Data were analyzed with SPSS version 22.0 and SAS 9.3. The result showed that application of lime significantly ($p<0.01$) affected selected soil chemical properties and yield parameters. However, the emergence date of potato was not affected by application of lime. Liming significantly increased water pH from 5.26 to 7.21, available P from 8.58 to 19.32 mg kg $^{-1}$, total nitrogen from 0.11 to 0.14 % and CEC from 23.2 to 38.4 $Cmol_{(+)}kg^{-1}$. Due to lime application, exchangeable acidity and exchangeable Al decreased from 3.87 to 0.23 and 2.64 to 0.00 $Cmol_{(+)}$ kg $^{-1}$, respectively. There were strong positive correlations among soil pH parameters while strong negative correlations were obtained between exchangeable acidity and soil pH parameters (buffer pH, pH-H_2O, pH-$CaCl_2$ and pH-KCl). The water pH was linearly regressed with buffer and salt solution pH. Similarly, exchangeable acidity was linearly associated with exchangeable aluminum. The lime recommendation equations showed a curvilinear trend and the lime rates curvilinear decreased as values of soil pH parameters increased and the same curvilinear increased as exchangeable acidity values increased. The lime rates applied in rows did not show a significant difference in soil parameters as well as yield and yield components defense from the lime applied in broadcast method. Among the eight treatments, the highest tuber yield of potato was obtained from the application of 15 t ha^{-1} lime. However, the cost of 15 t ha^{-1} lime was 22,500 Birr ha^{-1}, while the cost of micro-dozed lime (0.06 t ha^{-1}) was 90 Birr ha^{-1}. Application of micro-dosing lime was found to be economically feasible with net benefit of 92,352 Birr ha^{-1}. Therefore, micro-dosing application of lime was an efficient and economically affordable method for small scale farmers.

Keywords: Soil acidity, Liming, Micro-Dosing, Banja District, Potato

Chapter 1. INTRODUCTION

1.1 Background and Justification

Soil acidity is one of the main factors that limit and prevent profitable and sustained agricultural productivity in many parts of the world (Sumner and Noble, 2003). It is estimated that approximately 50% of the worlds' arable soils are acidic and may be subjected to the effect of aluminum (Al) toxicity of which the tropics and subtropics account for 60% of the acid soils in the world (Sumner and Noble, 2003). In Ethiopia, about 40.9 % of the total arable land is affected by soil acidity, out of which 27.7 % are moderately to weakly acidic (pH of 5.5 - 6.7) and 13.2 % is strongly to moderately acidic (pH< 5.5) (Mesfin Abebe, 2007). In the Amhara National Regional State 24% of the soil are affected by acidity (ROPNE, 1985). Leaching of cations in soils is mostly responsible for increased soil acidity (Schlede, 1989). Acidic soil often found in Oxisols, Nitisols and Ferralsols (Taye Bekele, 2008).

Soil acidity is responsible for low nutrient use efficiency by crop plants (Fageria and Baligar 2004). In acid soils, aluminum (Al) toxicity constrains root elongation and hence plant growth (Scott *et al.,* 2001). The poor root growth leads to reduced water and nutrient uptake, and consequently crops grown on acid soils are confronted with poor nutrients and water availability. The net effect of which is the reduced growth and yield of crops (Wang *et al*., 2006). The negative effect of high levels of soluble aluminum on plant growth has also been reported by Marschner (1986).

Liming is an important practice to achieve optimum yields of all crops grown on acid soils. According to Kaitibie *et al.* (2002), liming is the most widely used long-term methods of soil acidity amelioration, and its success is well documented. The practice of liming of acid soils is not common in Sub-Saharan Africa (SSA), probably because of limited knowledge on lime usage and its effectiveness, availability and high hauling costs of liming materials (Okalebo *et al*., 2009).

Micro-dosing technology was developed and promoted by ICRISAT and partner institutions over a decade ago to promote the use of fertilizers in the semi-arid tropics (Chianu and Tsujii, 2005; Hayashi *et al*., 2008; Twomlow *et al*., 2010). The technology was developed after realizing that crop yields in the semi-arid areas of Sub-Saharan Africa has been declining over time due to a decline in soil fertility resulting from mono-cropping, lack of fertilizer, unfavorable climatic conditions and low fertilizer use driven by the belief that inorganic fertilizers "burn crops". It provides sufficient nutrients, especially on poor soils or degraded lands in amounts that are not too costly and are not damaging to the environment (Twomlow *et al*., 2010). Even though micro-dosing has the above advantages its limitations are frequent application and it applied during the planting time. Adequate amounts of liming do long last period of time (Fageria and Baligar, 2008). According to the finding of Endalkachew Fekad *et al.* (2017) liming of acidic soil before 40 to 60 days to planting would allow decomposition and chemical reaction of lime.

Potato (*Solanum tuberosum* L.) is the most important vegetable crop, constituting the fourth most important food items in the world (Mattoo, 2006; Douches, 2013). Similarly, it is a very important food and cash crop in Ethiopia, especially in the highland and mid altitude areas (Berga *et al*., 1992a; Berga *et al*., 1992b). It is one of the most economically important tuber crops in Ethiopia that play key roles as a source of food and cash income for smallholder farmers (Agaje *et al*., 2008). As a result, the country has about 70% of the available agricultural land suitable for potato production (Gebremedhin *et al*., 2008). It is also an important food and cash crop in Amhara regional state, particularly in the high land areas where it plays tremendous role in ensuring food security. Over half of a million rural households are involved in potato production in the region (Ermias, 2010). In Banja district potato production is also one of the widely grown food as well as income generating crop. The farmers were grown three times a year: the main season, residual moisture and using irrigation practices (Yazie Chanie *et al*., 2017). Even though the practice is common the yield is very low due to drought (FAO, 2010), frost, hail, pests, diseases (Bekele and Eshetu, 2008), poor production practices and limited access to high quality seed (Hirpa *et al*., 2010). The soil acidity also another challenges the low productivity of potato crop in the district not only caused nutrient deficiency but also it contributes the bacteria wilt. According to Prior and Fegan (2006) bacterial wilt was found in soils of pH 5-5.5.

In general, the high lands of Ethiopia are subjected to strong acid due to high incidence of rainfall (Nigussie Abebe *et al*., 2013). In addition, potato requires a considerable amount of nutrients, and the continued widespread use of the ammonium or urea based N fertilizers with high rainfall regime contributes to the acceleration of the soil acidification (Brett *et al.,* 2005).

Acidity affects the fertility of soils through nutrient deficiencies (P, Ca and Mg) and the presence of phototoxic nutrients such as soluble Al and Mn (Awad *et al.,* 1976). This can be overcome by lime application which can reduce Al toxicity, improve pH, Ca, Mg and increase both P uptake in high P fixing soil and plant rooting system (Black, 1993). Reduction of acidity in soils also improves the microorganisms' proliferation and hence their activity in soils (Onwonga *et al.,* 2010). The soils of Banja district were characterized to be moderately to strongly acidic (EthioSIS, 2016). Therefore, this study was aimed to investigate the effects of micro dosing of lime on selected soil chemical properties, and improving yield and yield components of potato in acidic Nitisols of Banja district.

1.2 Statement of the Problem

Soil acidity is expanding both in scope and magnitude in Ethiopia, severely limiting crop production. The increasing trend of soil acidity and exchangeable Al^{3+} in arable and abandoned lands are attributed to intensive cultivation and continuous use of acid forming inorganic fertilizers (Heluf Gebrekidan and Wakene Negassa, 2006). Soil acidity limits or reduces crop production primarily by impairing root growth there by reducing nutrient and water uptake (Marschner, 1995). Moreover, low pH or soil acidity converts available soil nutrients in to unavailable form. Acidic soils are also poor in their basic cations such as Ca, K, Mg and some micronutrients which are as essential to crop growth and development (Wang *et. al.,* 2006). The soil of the study sites was characterized by strongly acidic very high in exchangeable aluminum very low in available phosphorous and low in its carbon and total nitrogen content to alleviate such types of problems soil amendment techniques crucial from these amendments liming is preferable technique.

Application of lime at an appropriate rate brings several chemical and biological changes in the soils, which are beneficial or helpful in improving crop yields on acid soils. Adequate liming eliminates soil acidity and toxicity of Al, Mn, and H; improves soil structure (aeration); improves availabilities of Ca, P, Mo, and Mg, and N_2 fixation; and reduces the availabilities of Mn, Zn, Cu, and Fe and leaching loss of cations. For several crops, liming results in some chemical changes in the soil such as, increase in pH, effective cation exchange capacity (ECEC), and exchangeable Ca, decrease in toxic elements, for example Al^{3+} and Mn^{2+} and changes in the proportion of basic cations in CEC sites (Ezekiel, 2006). The effects of lime do last long than those of most other amendments but not permanent. When values of exchangeable Ca $^{2+}$, Mg $^{2+}$, and pH fall below optimum levels for a given crop species, liming should be repeated (Fageria and Baligar, 2008).

According to Twomlow *et al*. (2010) micro-dosing results in higher nutrient use efficiency and ultimately improve productivity. Earlier studies have shown that micro dosing is one technology that can be affordable to farmers higher returns to farmers from the fertilizer quantities that they are able to purchase (Chianu and Tsujii, 2005; Twomlow *et al*., 2010).

Remediation of acidic soil with application of lime has been widely practiced and recommended by several researchers to reduce the negative effects of soil acidity on soil fertility and crop productions (Rowell, 1994; Anetor and Ezekiel, 2007 and Brady and Weil, 2008). As a result, many researches have been conducted in different parts of Ethiopia with large amounts of lime (Anteneh Abewa *et al*., 2013; Asmare Melese and Markku, 2016 and Endalkachew Fekad *et al.*, 2017) who reported that large amounts of lime had tremendous role in the change of soil chemical properties of acidic soils. Some researchers such as, Jafer Dawid and Gebresilassie Hailu (2017) recommend spilt application of lime application because of without a significant yield loss and harming soil health, splitting lime into one third and half and applying in three and two consecutive years, give similar yield with the full rate of lime applied once in the first year.. However, there is no much scientific research conducted on the application of lime in small amount (micro dosing) in Ethiopia. In addition, Smallholder farmers are not using lime widely because of the following limiting factors such as; lack of awareness among farmers on its use, lack of appropriate recommended rates and high cost. Capacity Building for Scaling up of Evidence Based Best Practices in Agricultural Production in Ethiopia (CASCAPE) project is working to support the Ethiopian Government to increase agricultural productivity in a sustainable way in order to enhance agricultural growth and to achieve food security, for supporting the project mission bridging the gap of available research, present study on application of micro-dosing of lime in the vicinity of potato tuber instead of mixing in whole fields.

1.3 Objectives of the Study

1.3.1 General Objective

The overall objective of this research was to investigate the effect of micro-dosing of lime on selected soil chemical properties, yield and yield components of potato in acidic Nitisols of Banja District.

1.3.2. Specific Objectives

- ❖ To investigate the effect of micro-dosing of lime on selected soil chemical properties;
- ❖ To investigate the association between soil acidity indices;
- ❖ To develop a lime recommendation equation;
- ❖ To investigate the effect of micro-dosing of lime on yield and yield components of potato.

1.4 Research Questions

- ✓ What are the effects of micro-dosing of lime on selected soil chemical properties?
- ✓ What is the correlation between soil acidity indices of buffer pH, pH-H_2O, pH-$CaCl_2$ pH-KCl and exchangeable acidity?
- ✓ What are the lime recommendation equation using soil acidity indices?
- ✓ What is the effect of micro-dosing of lime on yield and yield components of potato?

Chapter 2. LITERATURE REVIEW

2.1. Soil Acidification

Soil acidification is a naturally occurring process in many soil environments, anthropogenic contributions such as agricultural practices and pollution from industrial, mining, and other human practices, has accelerated the process (McBride, 1994). According to Foy (1984) and Thomas and Hargrove (1984) natural pedogenic processes generally are marked by depressed cation exchange capacity, lower potential for alkaline earth and alkali metal (base) cation releases, and increased influence of acidic cations, particularly. In natural ecosystems, the inputs of acid are nearly balanced by the neutralizing process, such that any change in pH as a result of a dominance of acid addition must be measured over several hundred years. Accelerated acidification occurs as a result of Addition of fertilizers, especially N based, accumulation of organic matter, not rich in basic-cations, largely of plant origin removal of organic anions in plant and animal products and leaching of nitrate (Donald, 2011). On the other hand, Fey *et al.* (1990) stated that the rate of soil acidification may potentially be the highest in agriculture due to the liberal use of ammoniacal fertilizers and the production of legumes. Basic cation levels can also be altered through various agricultural management practices that increase water infiltration and concomitant leaching. The major processes which accelerate agricultural soil acidification include: i) net H^+ excretion by plant roots due to excess uptake of cations over anions; ii) removal of alkalinity in farm products such as grain, hay, meat, and wool; iii) accumulation of organic anions in the form of soil organic matter; iv) mineralization of organic matter, nitrification of ammonium, and subsequent leaching of nitrate; v) input of acidifying substances such as NH^+ based fertilizers (Tang and Rengel, 2003). Nevertheless, the resultant decrease in soil pH associated with agricultural practices may be sufficient to cause moderate to severe Al^{3+} and Mn^{2+} toxicity (Sumner and Noble, 2003). This in turn affects the long-term economic feasibility of farming practices, and in some cases may lead to the permanent dilapidation of the resource base (Sumner and Noble, 2003).

2.2. The effect of liming on selected soil chemical properties

Soil chemical properties are the most important among the factors that determine the nutrient supplying power of the soil to the plants and microbes. The chemical reactions that occur in the soil affect processes leading to soil development and soil fertility build up. Minerals inherited from the soil parent materials over time release chemical elements that undergo various changes and transformations within the soil (Wang *et al*., 2007).

Liming acid soils has significant impact on physical, chemical and biological properties through its direct effects on the amelioration of acidity and indirect effects on the mobilization of plant nutrients, immobilization of toxic heavy metals and improvement in soil structure (Haynesd and Naidu, 1998). Liming is an effective and widespread practice for improving crop production on acid soils (Fageria and Baligar, 2003). Usually, liming acidic soils improve soil physical and chemical properties and biological activities (Fageria and Baligar, 2005).

Soil pH controls solubility, ionic concentration, reactions intensity of the in the soil, and modulates the intensity of sorption processes (Carmo *et.al.*, 2016). It is the most important master chemical soil parameter and reflects the overall chemical status of the soil and influences a whole range of chemical and biological processes occurring in the soils (Bloom 2000). Since pH is a conditioning factor of all processes, soil properties it regulates the availability of nutrients and other chemical elements to plants (Mcbride and Błasiak, 1979), as well as on microbial activity (Robson and Abbott, 1989). Application of lime increase in soil pH is known under the many soil, crops- lime situations (Gupta *et al*., 1989) The increments of soil, water pH associated with the presence of basic cations and anions (CO_3^{-2}) in lime that are able to exchange H^+ from exchange sites to form $H_2O + CO_2$. Cations occupy the space left behind by H^+ on the exchange leading to the rise in pH (Fageria *et al*., 2007). Lime has been attributed to an increase in degree of base saturation and a decrease in exchangeable H^+ and Al^{3+} (Bishnoi *et al.*, 1988). Sahu and Patnaik (1990) observed that lime and organic matter additions in highly weathered acid and laterite soils resulted in an increase in the CEC and pH values, which are essential for higher crop productivity. Studies made by, Pradhan and Mishra (1982) showed by increasing the lime level, there was a rise in soil pH.

Exchangeable acidity is described as the amount of acidity present at the pH of a soil, and varies with the nature of the soil and the percentage base saturation as a proportion of the total acidity (Coleman and Thomas, 1967). In acid soils, biological activities decline, soil aggregation becomes poorer and availability of nutrients to plants is affected. These soils usually have lower contents of calcium and magnesium, and in extreme conditions, the supply of these nutrients to plants may be deficient (Wild, 1993). The most common problem in acid soils is the toxicity of aluminum (Al^{3+}) to plants and for some species the toxicity of manganese (Nekesa *et al.,* 2005). Acid soils are also associated with Phosphorous fixation because of increased iron, aluminum and manganese in the soils. All these factors contribute to severe reduction of potato crop yields (Mujaya and Mereki, 2010). Iron and manganese contents decreased significantly due to application of liming materials like $CaCO_3$ (Mukhopadhya and Das 2001). On the other hand, liming can decrease exchangeable acidity, this may be attributed to the neutralization of exchangeable Al^{3+} and H^+ whereas, the reduction in pH dependent and total acidity would be due to neutralization of hydroxyl-Al and Fe-polymer (Mclean *et al.,* 1964). Other reasons may be that on liming Al^{3+}, Fe^{3+} and Mn^{2+} which are dominant in acid soil get reduced and consequently, decreased the different forms of acidities thereby improving soil pH and base saturation (Haldar and Mandal, 1987). The reduction of exchangeable acidity of the soil due to the increased replacement of Al by Ca in the exchange site and by the subsequent precipitation of Al as $Al(OH)_3$ (Havlin *et al.,* 2005). Lime application had a vital role to decrease the exchangeable acidity and exchangeable aluminum. For example, Endalkachew Fekad *et al*. (2017) reported that application of 10 t ha^{-1} of lime reduced exchangeable acidity from 4.04 to 0.07 $Cmol_{(+)}kg^{-1}$and the exchangeable aluminum minimized 1.77 to 0.00 $Cmol_{(+)}kg^{-1}$. Similarly, Asmare Melese and Markku (2016) also stated that addition of 11.2 an d 9.2 t ha^{-1} of lime reduced the exchangeable acidity of a very strong acid soil from 2.31 to 0.23 and 0.14 $Cmol_{(+)}kg^{-1}$, respectively and exchangeable aluminum from 1.50 to 0.07 $Cmol_{(+)}kg^{-1}$. Anteneh Abewa *et al.* (2013) also reported that application of 2 t ha^{-1} reduces exchangeable acidity from 0.6 to 0.44 $Cmol_{(+)}kg^{-1}$.

Cation exchange capacity is the capacity of the soil to hold and exchange cations. It provides significant a buffering effect to increase in pH, available nutrients, calcium levels and soil structural changes. CEC is a crucial factor in the determination of soil fertility for two fundamental reasons. The first reason is that, the total quantities of nutrients available to plants as exchangeable cations depend on it. The second reason is that, it can influence the degree to which hydrogen and aluminum ions occupy the exchange complex and thus, affect the pH of soils (Sahle medihn and Taye, 2000). Lime has been attributed to an increase in degree of base saturation and a decrease in exchangeable H^+ and Al^{3+} (Bishnoi *et al.*, 1988). Sahu and Patnaik (1990) observed that lime and organic matter additions in highly weathered acid and laterite soils resulted in an increase in the CEC and pH values, which are essential for higher crop productivity. Studies made by, Pradhan and Mishra (1982), liming could be attributed to the change in pH and the release of the initially blocked is amorphous and interlayer substituional 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. The positive effects of lime on CEC, reported by Buni Adane (2014) stated that application of 3.75 t ha^{-1} increases CEC from 17 to 33.34 $Cmol_{(+)}kg^{-1}$. Anteneh Abewa *et al*. (2013) also reported that application of 2 t ha^{-1} increase CEC of soil by 41.1 % from unlimed plot.

Phosphorus is a major plant nutrient essential for initial plant root development, energy transfer, photosynthesis, water use efficiency, nodulation, seed formation, size and number (Tisdale *et al*., 1985) availability of P was affected by soil pH Maximum Phosphorus is among the most limiting nutrients for food production in the sub humid and humid tropical highlands of East Africa (Sanchez, 1976). Availability of phosphorus generally occurs in a pH range of 6.0 to 7.0 (Miller and Donahue, 1997). Furthermore, Tisdale *et al*. (2002) also described that P availability is at maximum in the pH range 5.5-6.0. The effect of lime on acidic soil had on the released of P fixation by Al and Fe and the direct relation of soil pH. (Tisdale *et al.*, 2002; Bolan and Hedley 2003; Achalu Chimdi *et al*. (2012)).

Nitrogen (N) is the fourth plant nutrient taken up by plants in higher quantity next to carbon, oxygen and hydrogen. C, O and H are available naturally whereas, N has to be supplied by organic and inorganic fertilizer. However, it is one of the most deficient elements in the tropical soils for crop production (Sanchez, 1976; Mengel and Kirkby, 1987; Mesfin Abebe, 1998) under continuously, intensively cultivated and highly weathered soils of the humid and sub humid tropics (Tisdale *et al*., 1995; Wakene Negassa, 2001). Nitrogen is a macro nutrient also known as vegetative nutrient and mostly used by the plants (Brady and Weil, 2008). However, availability of N is highly affected by soil acidity and leaching. Acidity tends to reduce microbial mediate processed that results in poor organic matter decomposition, mineralization of nitrogen and consequently the low N availability. Application of soil acidity amendments may improve soil conditions for mineralization take place and increase N availability in the soil, its uptake and finally positive influence on increasing crop yield (Jahangir *et al*., 2009). Bolan *et al.* (2003) reported that, the accumulation of organic matter in acidic soils which could be exploited by liming to release nutrients including nitrogen. Anteneh Abewa *et al.* (2013) reported that, application of 2 t ha^{-1} lime increase TN from 0.17 to 0.19 % that of no amendment plots.

Similarly, liming of acidic soil has been a tremendous role in creating favorable condition for soil microbes to decompose crop residues, thus it also increases soil organic carbon (Achalu chimdi *et al.*, 2012). Anteneh Abewa *et al.* (2013) showed that, application of 2 t ha^{-1} of the lime increase OC from 1.66 to 1.91 % that of no amendment plots.

2.3. Soil acidity indices and their relation

Soil pH has been used to assess the extent of soil acidification (Tamm and Haubacken, 1986; Sjostrom and Qvarfort, 1992), to estimate the susceptibility of a soil to further acidification (van Breemen *et al.,* 1993) and to evaluate the availability or toxicity of elements for plant growth (Sumner *et al.*, 1991). It influences soil chemical and biological processes such as the retention and release of ions at the solid: liquid interface (Barrow, 1987), the rate of mineral dissolution (Cronan 1985), the aqueous speciation of metals (Lindsay, 1979), the decomposition of organic debris (Krug and Isaacson,1984) and the activity of micro-organisms (Wong-Chong and Loehr, 1978). The pH of the soil can be determined by water (pH-H_2O), KCl (pH-KCl) and $CaCl_2$ (pH-$CaCl_2$); however, low pH values are reported from KCl and $CaCl_2$. The low soil pH with pH$CaCl_2$ and KCl determination indicates the presence of substantial quantity of exchangeable hydrogen and aluminum ions because of the displacement (and subsequent hydrolysis) of exchangeable Al and Fe by Ca^{2+} from the pH of mineral soils inferences are made on the nature and cause of the hydrogen ion activity (Buol *et al.,* 1980). According to Mekaru and Uehara (1972 high soil acidity with KCl solution determination showed the presence of high potential acidity and weather able minerals. The soil pH measured in pH-H_2O and pH-KCl had a strong positive association between each other Kabala *et al.* (2016). According to Marcin *et al.* (2005) the other soil acidity indices exchangeable acidity and exchangeable aluminum their relation with soil pH was reported by exchangeable aluminum negatively correlated with soil water pH. Matzher *et al.* (1998) and Hinrich *et al.* (2001) reported that exchangeable acidity is a function of soil pH composed of compounds such as $Al(OH)^{2+}$ or Al $(OH)_2{}^{+}$, and weak organic acid ions held on the colloidal surfaces of the soil. Furthermore, the concentration of the H^+ to cause acidity is pronounced at pH values below 4 while the excess concentration of Al^{3+} is observed at pH below 5.5 (Nair and Chamuah, 1993).

2.4 Liming materials

Lime refers to CaO or quick lime and the commonly used liming materials are calcium hydroxide, calcium carbonate (Pure calcitic limestone), calcium magnesium carbonate (Dolomitic limestone) and calcium silicate. The effectiveness of agricultural lime stone in neutralizing soil acidity is governed by its Ca and Mg content, particle size, moisture content, neutralizing value and unit cost (Sims 1996). The amount of liming required to neutralize soil acidity depends on the neutralizing value of liming material, pH and the buffering capacity of the soils. The time of application, the methodology adopted and the other agro management practices also influence the efficiency of the liming programme. Liming should be cost effective and recommendation should be made in small doses. Reducing Al toxicity in the subsoil is a major but difficult management task in many areas of the tropics. Direct mixing of lime with the subsoil is costly and mechanically infeasible. Phosphogypsum gypsum, which have higher solubility than $CaCo_3$ have been used to ameliorate subsoil acidity in highly weathered soils (Ritchey *et al.*, 1980). Besides lime, some other materials are also used as acid soil amendment, such as gypsum, phosphate rocks and some industrial byproducts like basic slag (Bhat *et al.*, 2007).

2.5. Lime requirement determination methods

The lime requirement (LR) is the amount of limestone ($CaCO_3$) needed to increase the pH of the plough layer of acid soil to a desired level (McLean, 1970). However, in economic terms, lime requirement can be defined as the quantity of liming material required to produce the maximum economic yield of crops cultivated on acid soils (Ruganzu, 2010).

2.5.1. SMP single buffer pH method

The Shoemaker, McLean and Pratt (SMP) (Shoemaker *et al.* 1961) single-buffer procedure has been widely adopted and found particularly accurate in soils with high LR and trivalent Al (Mclean *et al*. 1966). The relationship between SMP soil-buffer pH (X) and LR (Y) is not linear but curvilinear. Curvilinearity increases with the increasing difference between initial buffer pH and the target pH (Tran and van Lierop, 1981). The principal reason for curvilinearity is that buffer-pH procedures measure a greater proportion of soil acidity from low than from high LR soils. Superfluous pH-dependent acidity is measured when soil-buffer pH is higher than the target pH. The SMP buffer contains p-Nitro-phenol, potassium chromate, calcium chloride dihydrate, calcium acetate and Triethanolamine.

2.5.2. SMP double buffer-pH method

The SMP buffer was adapted by McLean *et al.* (1977, 1978) to a double-buffer methodology similar to that proposed by Yuan (1974). This approach was selected for improving the accuracy of LR determination for low-buffering capacity soils. McLean *et al.* (1977, 1978) concluded that double buffer procedures do not measure all the acidity neutralized by $CaCO_3$ either, if we believe in the $CaCO_3$ incubation methods. They therefore, included a proportionality factor into the SMP-double buffer calibration similar to that needed for single-buffer calibrations. This factor which is derived from incubation data using regression techniques corrects for partial acidity displacement. Indirect LR-determination procedures rely on estimating a LR from soil properties without directly measuring acidity. The SMP buffer test is widely used throughout much of the United States for determining LR (Shoemaker *et al.* 1961; Sims 1996). This method uses p-nitrophenol and potassium chromate, a carcinogen. All waste generated by this test method must also be disposed as a hazardous waste. Studies have been conducted to develop alternative buffer methods for making lime recommendations without the use of hazardous chemicals. Recently Sikora (2006) developed the Sikora buffer (SB), which produces the same pH as the SMP buffer but without hazardous chemicals. Sikora (2006) used 2-(N-morpholino) ethane sulfonic acid monohydrate (MES) and imidazole as replacements for chromium and p-nitrophenol in developing the SB. He reported the bench life for this buffer as 150 days. He compared the SMP buffer with SB from samples collected from Kentucky and from other regions using samples from North American Proficiency Testing program. He concluded the SMP buffer and SB produced the same buffer pH, allowing the SB to replace SMP buffer without any effect on agronomic interpretations and recommendations for Kentucky soils (Sikora 2006).

2.5.3. Simplified Ca(OH)2 and Ca(OH)2-CaCl2 equilibration method

According to Samanta (2013) lime requirement of the soils increased in the order of LR determined by $Ca(OH)_2$ equilibration method ‹ LR determined by $CaCl_2$ -$Ca(OH)_2$ equilibration method ‹ LR determined by modified Woodruff buffer method. A linear relationship existed between increase in pH and OH- added in both $Ca(OH)_2$ and $CaCl_2$ -$Ca(OH)_2$ equilibration methods. On the basis of this linearity, a simple and rapid method was tried to develop to determine the LR of the soils by adding $Ca(OH)_2$ solutions of a selected concentrations instead of adding $Ca(OH)_2$ solutions of several concentrations. It was observed that LR determined by adding saturated Ca(OH)2 solutions of 0 & 4 ml in $Ca(OH)_2$ equilibration method and 0 & 8 ml in $CaCl_2$-$Ca(OH)_2$ equilibration method were close to the LR determined by full equilibration studies. These two methods are referred to as the simplified $Ca(OH)_2$ equilibration and the simplified $CaCl_2$ -$Ca(OH)_2$ equilibration method respectively.

2.5.4. Exchangeable acidity method

Lime requirement (LR) was determined following the method as outlined by Kamprath (1970) due to its ability to neutralize all extractable Al in soil. In this method LR is determined by multiplying the factor by extractable Al ($Cmol_{(+)}$ kg^{-1}). The factor depends on the amount of organic matter in the soil for soils with 4 to 5% organic matter, content, lime application rates should be increased by 20 % (David *et al.*, 2011).

According to Kamprath (1984), the amount of lime needed to calculate on the basis of the mass of soil per 15 cm hectare-furrow-slice, soil sample density and exchangeable Al^{+3} and H^{+} of the site. Assuming that one mole of exchangeable acidity would be neutralized by equivalent mole of $CaCO_3$.

2.6. Effect of soil acidity on crop productivity

Soil pH affects crops in many ways and its effects are mostly indirect, through its influence on chemical factors and biological processes. Chemical factors include aluminum (Al) toxicity, calcium (Ca) and phosphorus (P) and magnesium (Mg) deficiencies (Uchida and Hue, 2000). Optimum nutrient uptake by most crops occurs at a soil pH near 7.0. The nutrient availability such as nitrogen, phosphorus and potassium is generally reduced as soil pH decreases. Phosphorus is particularly sensitive to pH and can become a limiting nutrient in strongly acid soils. Thus, reduced fertilizer use efficiency and crop performance can be expected when soil acidity is not properly controlled (McFarland *et al.*, 2005). Hardy *et al.* (1990) reported exchangeable Al to affect crops by shallow rooting, poor use of soil nutrients, and Al toxicity. Soil acidification causes crop yield reduction, which is rapid on sandy soils with low absorption capacity. If exchangeable Al occupies more than 60% of the CEC, toxic levels of Al in soil solution appeared (Nye *et al.*, 1961; Evans, 1968).

2.7. Irish potato (*Solanum tuberosum* L.) growing requirement and response to liming

Potato (*Solanum tuberosum L.*) is one of the most important widely cultivated crops which can grow from sea level to over 4,000 meters' elevation and from the equator to more than 400 South and North. It has a wider range of agro climatic adaptation each local environment, presenting a specific set of opportunities for and constraints on its production (Tesfaye, 2007). The optimum soil temperature for initiating tubers is 16-19°C.Tuber development declines as soil temperatures rise above 20°Cand tuber growth practically stops at soil temperatures above30°C (Van der Zaag, 1992). Potato requires a temperature of 18-22^{0}cwith a day time temperatures of less than 25^{0}c, night time temperatures of less than 200c, a rainfall amount of 500-700mm (Tesfaye, 2007). Well drained, fertile loamy sand, sandy loam soil rich in organic matter (Ermias, 2010) deep friable good water retaining capacity (Tesaye, 2007) The ideal pH for Potato ranges stated by different authors from 5.2 to 6.5 (Adams, 1984 and Biswas et. *al.,* 1991). Adequate moisture is required for steady growth and maximum yield of potato (Ermias, 2010).

Irish potato needs heavier amounts of fertilizers and tuber yields are seriously affected in soils with shortages of P and K. Excessive N on the other hand sharply diminishes tuber yields (Kanzikwera *et al*., 2001). Therefore, potato production requires strict management regimes Yamoah *et al.* (1992). The growth of potato was observed to be more vigorous in the high lime plots than in the low lime plots (Yamoah *et al.,* 1992). Hester (1936) reported 25 to 29% increase in potato yield due to small applications of lime on soil with a pH of 5.2. Plant nutrients are most available at soil pH levels near 6.5; potatoes grown in soils near pH 6.5 produce higher yields with less fertilizer (Rosemary, 1991). According to Khandakhar *et al.* (2004) application of lime affects yield and yield components of potato.

Chapter 3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

The study was conducted in, Banja district, Awi Administrative Zone, Amhara National Regional State, Ethiopia in 2017. Geographically, Banja District lies within 10^0 52'to 11^0 3'N latitude and 36^0 38'to 37^0 8'E longitudes at a distance of 440 km Northwest of Addis Ababa and 120 Km South of Bahir Dar, the capital of Ethiopia and Amhara regional state, respectively (Figure 3.1).

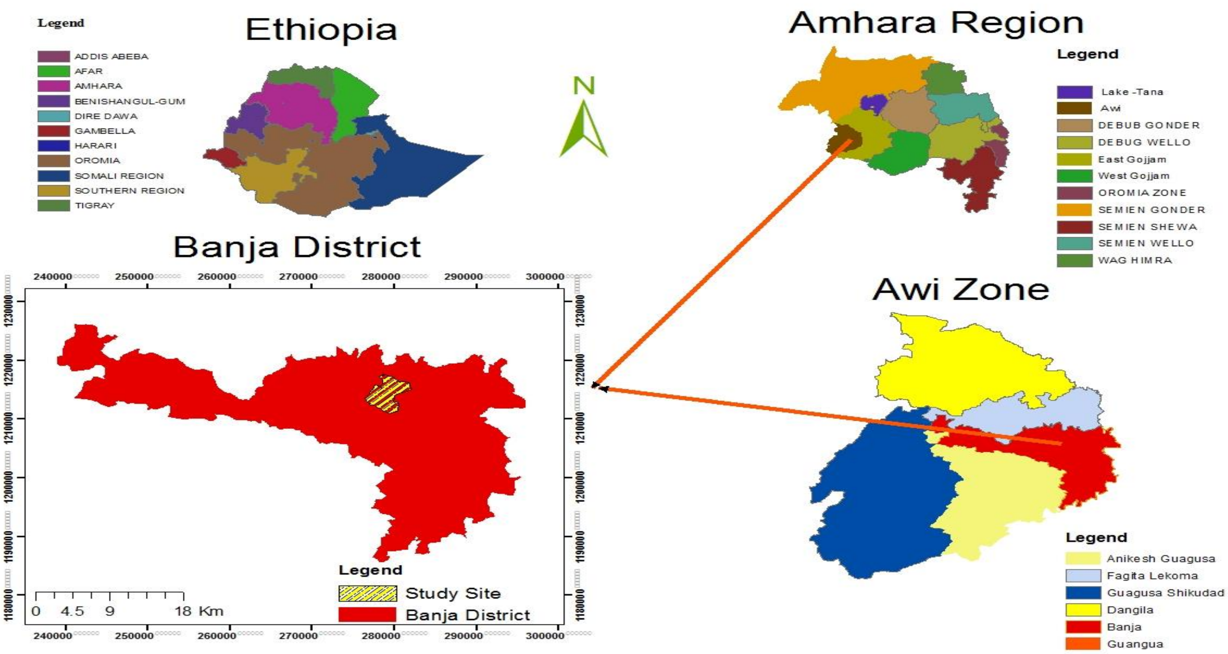

Figure 3.1 Location Map of the study area, Amhara Region, Ethiopia.

3.1.2 Topography, Climate and Soils

The latitude of the study site ranges from 2502 to 3000 meters above sea level. According to the District Office of Agriculture, the total area of the district is 47,915.8 ha. As indicated in Figure 3.3 the district has Nitisols, Fluvisols, Acrisols, Gleysols, Vertisols and Luvisols with respective coverage of 63.4, 21.1, 13.0, 1.2, 0.6 and 0.6 % (FAO 1984). According to National Metrological Service Agency, the mean annual rainfall of was 2521.4 mm while the mean, minimum and maximum air temperatures were 17.95, 11.7 and 24.2 °C (Figure 3.2). Soil erosion, land degradation, deforestation, increase rainfall variability and low soil fertility (soil acidity) commonly mentioned environmental problems (BD-OARD, 2010).

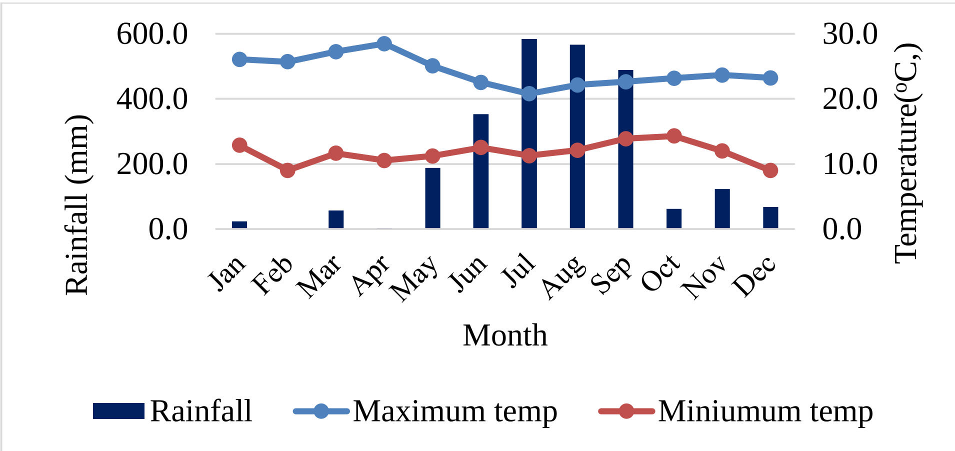

Figure 3.2 Mean monthly rainfall, minimum and maximum temperature of the study area at the Injibara Meteorological Station.

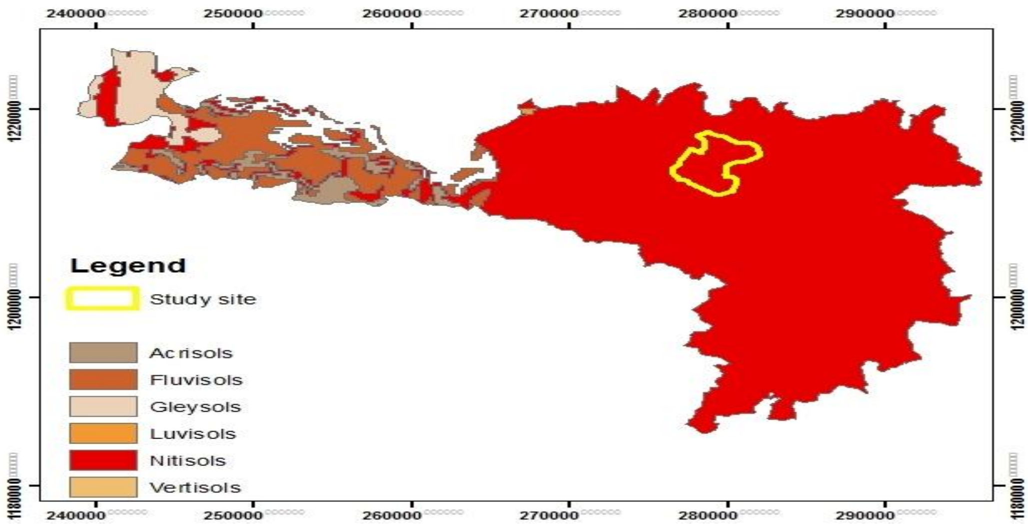

Figure 3.3 Soil map of the study area

3.1.3 Population

Based on 2007 National Census conducted by CSA, the total population of the district was 111,975, out of which, 55,611 males and 56,364 are females. From the total population, 22,473 (20.07%) are urban inhabitants and the rest are rural dwellers.

3.1.4 Farming systems

Farming system of the study area is crop livestock mixed production system. Farmers in the study area rear animals, grow crops and practice charcoal production from plantations of *Acacia decurrens* and different *Eucalyptus* spp as sources of income for their livelihood. Bamboo production and making of different house and furniture as a source of income is a common practice in the area. According to the District office of Agriculture, the main crops grown are potato *(Solanum tuberosum* L.*)*, barley *(Hordeum vulgate)*, wheat (*Triticum aestivum* L.*)*, field pea (*Pisum sativum*), faba bean (*Vicia faba*), teff (*Eragrostis tef*) and the like. Crop rotation, row planting, fallowing, shifting cultivation, livestock rearing and animal fattening are common agricultural practices as a mixed crop-livestock production system (BD-OARD, 2010).

3.2. Experimental Materials

The local variety of potato (*Solanum tuberosum* L.) was used for this study. This variety is chosen for this study due to lack of improved verities, availability and widely grown in the area by smallholder farmers.

Liming material ($CaCO_3$) made by Abyssinia limestone crushing factory was used as sources of liming material with the purity of 94 % with fineness of pass through a 60-mesh. 195 NPS and urea 165 kg ha^{-1} fertilizers were used as a source of phosphorous and nitrogen, respectively.

3.3 Methods

3.3.1 The effect of micro dosing of lime on selected soil chemical properties

Soil sampling before planting and after harvesting

To investigate the effect of micro dosing of lime on selected soil parameters, representative soil samples were collected before planting and after harvesting. Pre-planting composite soil samples were collected in a diagonal pattern from at a depth of 0-15 cm. Uniform volumes of soil were obtained from each sub-sample by vertical insertion of auger. Then the samples were packed in a plastic bag with inside and outside labeling and were taken to Amhara Design and Supervision Works Enterprise and Regional Soil Laboratory for analysis. After harvesting, another soil samples were also collected from each plot of all replications. The composite soil samples were obtained by mixing the samples taken from the replication plots of all treatments.

Soil sample analysis

The samples were air-dried on the shelve of a shaded room until the weight becomes constant after which the samples were ground using pestle and mortar and sieved through a 2 mm sieve for analysis of soil pH, EA, CEC, available phosphorous, OC while for TN a soil passed through 0.5mm sieve was used.

Soil pH (pH-H_2O, pH-$CaCl_2$ and pH-KCl) was measured in a 1:2.5 (soil: liquid). Then buffer pH was measured by adding 20 ml SMP buffer solution in the soil water solution. Exchangeable acidity was determined by saturating the soil samples with a potassium chloride solution and titrating with sodium hydroxide as described by McLean (1965). For the estimation of exchangeable Al^{3+}, 10 ml of 1*M* NaF was added and titrated with 0.1*M* HC1 until the pink color was disappeared (Thomas, 1982). Cation exchange capacity (CEC) was measured after saturating the soil with 1*N* ammonium acetate (NH_4OAc) and displacing it with 1*N* NaOAc (Chapman, 1965). Available P was determined by Olsen methods (Olsen, 1965); organic matter was determined using the method developed by Van Reeuwijk (1992) and Total N was determined by Kjeldahl method (Jackson, 1958).

3.3.2 Investigating the association between soil acidity indices

Correlation and regression analysis were carried out to assess the association between various soil acidity indices, namely pH-H_2O, pH-$CaCl_2$, pH-KCl, buffer pH, exchangeable acidity and exchangeable aluminum.

3.3.3 Developing lime recommendation equation for soil acidity

Lime requirement based on buffer method: Lime requirement was obtained from the SMP soil-buffer pH. Shoemaker *et al*. (1961) calibrated the SMP soil-buffer pH to the lime requirement for achieving a target soil-water pH of 6.5. The initial buffer pH of the soil was 5.4.

LR (t ha^{-1}) = 1.867 (Buffer pH)^2 - 31.82 (Buffer pH) + 131.23……………………Equation 1

Lime requirement based on Exchangeable Acidity: The amount of lime was applied and calculated on the basis of the mass of soil per 15 cm hectare-furrow-slice, soil bulk density and exchangeable Al^{3+} and H^{+} of the site. Assuming that one mole of exchangeable acidity would be neutralized by equivalent mole of $CaCO_3$. The amount of lime consumed was determined by using the formula given by Kamprath (1984).

$$LR, CaCO_3\ (kg/ha) = \frac{EA * 0.15\, m * 10^4\ m^2 * B.D. * 1000}{2000}$$ …….Equation 2

Where LR = Lim requirement, EA= Exchangeable acidity BD= Bulk density.

EA = 3.87 Cmol $_{(+)}$ kg $^{-1}$ and BD = 1.316 Mg m^{-3}, Bulk density was determined from undisturbed soil samples using core samplers.

The lime requirement determination of both the SMP and exchangeable acidity methods were used due to the SMP method is used for appreciable amounts of aluminium (Shoemaker *et al.*,1961). The two methods are widely used and their determination method in the laboratory were available than other lime determination methods.

Developing Lime Recommendations Equation

After determining pH-H_2O, pH-$CaCl_2$, pH-KCl buffer pH, and exchangeable acidity, lime recommendation equations (LR) were developed for each soil acidity indices. With its critical value of lime requirements needs with pH-H_2O below 5.5, pH-$CaCl_2$ below 4.7, pH-KCl below 4.5 and buffer pH of below 7.0; and exchangeable acidity value of above 0.5 Cmol $_{(+)}$ kg^{-1}. The equation was developed based on Shoemaker *et al*. (1961).

$$Y=ax^2+bx + c$$

Where; Y= amount of lime applied, x= soil acidity indices parameters

3.4 Treatments and Experimental Design

The treatments were: full doses of lime using buffer and exchangeable acidity method, ½ full doses of lime using buffer and exchangeable acidity method, ¼ using buffer and exchangeable acidity method by drilling along the row of buffer and exchangeable acidity method, micro-dosing in basal application (0.060 t ha^{-1}) and control. The field experiment was conducted for one cropping season of 2017 by rain fed system of production on acidic Nitisols of Banja District (Figure 3.3). The design was randomized complete block design (RCBD) with four replications (Figure 3.4). A gross plot size was 3 m x 3.75 m = (11.25 m^2). One border row from each side of potato plants and two plants each from the end of the row were left for destructive sampling. The net plot size was 3 rows x 0.75 m x 8 plants *0.3 m=5.4 m^2. The spacing between blocks and plots were 1 m and 1 m, respectively.

Figure 3.4 Field experimental layout in the research area

Legend

FB =	Full doses of buffer method, (15 t ha^{-1})	½ B =	½ full doses of lime buffer method, (7.5 t ha^{-1})
¼ B =	Drilling along the row buffer method, (3.75 t ha^{-1})	½ E =	½ full doses of lime exchangeable acidity, (2.032 t ha^{-1})
FE =	Full doses of exchangeable acidity, (4.064 t ha^{-1})	MD =	Micro-dosing with basal application, (60 kg ha^{-1} = 0.06 t ha^{-1})
¼ E =	Drilling along the row exchangeable acidity, (1.016 t ha^{-1})	LO =	Control

3.5 Land preparation, planting and inputs application

The land was prepared by ploughing four times. Based on the amounts required, finely powdered lime was thoroughly incorporated into the plot and mixed with furrow slices depth of soil to ensure higher reactivity (full reaction) with the soil before 15 days of planting for six treatments, but for the 7^{th} treatment (micro dosing) of lime, 1.35 g of lime for each plant with basal application was applied. While full NPS (4.38 g per tuber) and one-third (1.23 g per tuber) of urea fertilizers were applied during sowing with placement application. The rest urea fertilizer was applied two times for each potato tuber as a top-dressing application immediately after the first and the second cultivation. The inter and intra-row spacing was 0.75 m and 0.3 m respectively, other cultural practice and fertilizer application were constant for all treatments.

3.6 Data Collection

3.6.1 Crop data collection

Days to 50% emergence: was recorded as the number of days from sowing to the date when 50% of the plants emerged in each plot.

Days to 50% flowering: refers to the time required to attain 50% of the plant to flower.

Plant height (cm): refers to the height from the base to the apex of the plant. It was determined by measuring the height of 5 randomly taken plants using a ruler from the central three rows of flowering.

Number of main stems per hill: was determined by counting the stems that originated from the tuber from 5 randomly taken hills, and taking the average.

Tuber dry matter content (%): Five fresh tubers were randomly selected from each plot and weighed. The tubers were then sliced and dried in an oven at 65 ^{0}C until a constant weight was obtained and the dry weight was recorded. The dry matter percent was calculated according to the following formula (Williams, 1968).

$$\% \text{ of tuber dry matter} = \frac{\text{weight of sample after dring (g)}}{\text{Initial weight of sample (g)}} * 100$$

Marketable tuber yield (t ha^{-1}): the weight of tubers free from diseases, insect pests, and greater than or equal to 25 g in weight were recorded.

Unmarketable tuber yield (t ha^{-1}): the weight of tubers diseased and/or rotted ones and smaller-sized (less than 25 g in weight) were recorded.

Total tuber yield (t ha^{-1}): the sum of tuber yield weights of marketable and unmarketable tubers.

3.7 Statistical Data Analysis

The collected data were subjected to analysis of variance (ANOVA) by using SPSS version 22.0 and SAS version 9.3. Least Significance Difference (LSD) test at 1% and 5% probability levels were used for mean comparison. When treatments show significant differences, mean separation were accomplished by using DMRT.

Economic Analysis: marketable tuber yield of the selected treatment was used in the marginal rate of return analysis. The field price of 1 kg of potato that farmers receive from the sale of the crop was taken as the market price of potato at Injibara near the experimental site, 120 km from Bahir Dar. $CaCO_3$, Urea and NPS were applied as a source of lime, nitrogen and P fertilizers, respectively. The price of lime and mineral fertilizers was based on a 2017 sale in Birr kg^{-1}. The Gross benefit was calculated as marketable tuber yield (kg ha^{-1}) multiplied by the field price that farmers receive for the sale of the marketable tuber yields. Total variable cost is the sum of the cost that was variable or specific to a treatment against the control. Net benefit was calculated by subtracting total variable cost from the gross benefit. Then the marginal rate of return was calculated using the procedures described by CIMMYT (1988) as follows:

$$\text{MRR} = \frac{\text{NI from superior dominant plot} - \text{NI from preceding inferior dominant plot}}{\text{TVC of a superior dominant plot} - \text{TVC of the preceding inferior dominant plot}}$$

Where, MRR = marginal rate of return, NI = net income and TVC = total variable cost

Chapter 4. RESULTS AND DISSCUSSION

4.1. Selected Soil Chemical Properties (before planting)

4.1.1. Soil pH

Pre-planting results showed that soil pH values in pH-H_2O, pH-$CaCl_2$, pH-KCl and buffer pH were 5.26, 4.49, 4.27 and 5.4, respectively (Table 4.1). Results exhibited that the soil was strongly acidic according to the EthioSIS (2016). Landon (1991) and Tisdale *et al.* (1993) reported that, most nutrients for field crops are available at pH values of above 5.5. The optimum pH-H_2O range for potato production is 5.2 to 6.5 (Biswas *et al*., 1991) and any pH below these value affects growth of potato crops.

Table 4.1 Status of selected soil chemical properties of experimental plots before planting of potato

Soil Parameters	Results	Ratings	References
pH-H_2O	5.26	Strongly Acidic	EthioSIS (2016)
Buffer pH	5.4	--------	---------
pH-$CaCl_2$	4.49	Acidic	Moore (2001)
pH-KCl	4.27	Acidic	Moore (2001)
Exchangeable acidity	3.87	-------	--------
Exchangeable Aluminum	2.64	Very high	EthioSIS (2016)
Cation exchange capacity	23.2	Medium	Landon (1991)
Available phosphorous	8.58	Very low	EthioSIS (2016)
Organic carbon	2.11	Low	Landon (1991)
Total nitrogen	0.11	Low	EthioSIS (2016)

The low values of soil pH could be attributed to high rainfall, resulting loss of cation by runoff and leaching, continuous use of ammonium based fertilizers and the types of the soil also affect pH. Nigussie Abebe *et al*. (2013) reported that high rainfall leads to leaching of basic cations, continuous use of ammonium based fertilizers like ammonium phosphate

[$(NH_4)_2HPO_4$)] reduced the pH value of the soil. On the other hand, Nitisols are acidic by nature as reported by Yihenew G.Selassie (2002). Thus, it is needed to raise the soil pH through liming to increase crop productivity. Liming is the most widely used long-term methods of soil acidity amelioration as its success is well documented by earlier studies (Kaitibie *et al*., 2002). Remediation of acidic soil with application of lime has been widely practiced and recommended by several researchers to adjust the lower soil pH to optimum soil pH condition to increase crop productivity (Rowell, 1994; Anetor and Ezekiel, 2007; Brady and Weil, 2008).

4.1.2. Exchangeable acidity and Exchangeable Aluminum

The result of this study showed that, the soil had exchangeable acidity and exchangeable Al^{+3} of 3.87 and 2.64 $Cmol_{(+)}kg^{-1}$, respectively (Table 4.1). According to the rating of EthioSIS (2016), the Aluminum concentration of the soil was very high. The higher the exchangeable Al^{+3}, the lower the pH of the soil and vice versa. The result is in agreement with Lindsay (1996) and Moore (2001) who reported that the solubility of Al containing minerals increase as the soil pH falls below 5.5 and suggested that the probability of Al toxicity to plants become higher. Furthermore, when soil pH is lowered much below 5.5, aluminosilicate clays and Al - hydroxide minerals begin to dissolve, releasing Al - hydroxyl cations and Al - H then exchange other cations from soil colloids and fractions of exchange sites occupied by Al – H (Kinraide, 1995; Parfitt *et al.* 1995; Achalu Chimdi *et al.*, 2012). Thus, liming material as a management practice could be used to alleviate acidification of the soil (Achalu Chimdi *et al.*, 2012).

4.1.3. Cation exchange capacity (CEC)

The result showed that, the Cation exchange capacity of the experimental soil was 23.2 $Cmol_{(+)}kg^{-1}$ (Table 4.1) rated as moderate according to Landon (1991). The relative small amount of CEC in the sampled soil could be because of the amount and nature of the clay. Kebede Fassil and Charles (2009), reported that the amount of clay and mainly the type of clay mineral are responsible factors for CEC. The clay assemblage of Nitisol is dominated by kaolinite which has the CEC value of 3-15 $Cmol_{(+)}/kg$ (WRB, 2006).

4.1.4. Available P

According to the rating EthioSIS (2016), the available soil P of the experimental site was very low which was 8.58 mg kg^{-1} (Table 4.1). The low level of available phosphorous in the study area might be due to the acidic nature of the soil and its type (Nitisols). Nurlaeny *et al.* (1996) reported that, acidic soils are naturally deficient in available P and significant portions of applied P are immobilized due to precipitation of P as insoluble Al phosphates, but the use of liming materials could reverse this situation and increase available soil P to desire levels. Likewise, Achalu Chimdi *et al.* (2012) stated that P fixation by Al and Fe, as their presence is expected at the lower pH values of the soils. Moreover, high P sorption calls for application of P fertilizers, usually provided as slow-release in Nitisols (WRB, 2006). Nitisols and other acid soils are known to have low P contents (Murphy, 1968; Eylachew Zewdie, 1987).

4.1.5. Organic carbon

The laboratory analysis of the experiment showed that the organic carbon content of the soils was 2.11 % (Table 4.1), which was rated as low by Landon (1991). This could be attributed the removal of plant residue from cultivated fields for various reasons and intensive tillage practices. The result is in consistent with several other works in different areas (Gregorich *et al.,* 1998; Palm *et al.,* 2001; Chroth *et al.,* 2003; Abreha Kidane Mariam *et al.,* 2012). They revealed that the low OM content in soils of cultivated land could be attributed to increased rates of mineralization of organic matter mainly caused by tillage activities; the decline in total organic matter inputs: litter, crop residues and manures, increased soil temperatures due to exposure of the soil surface and increased wetting and drying cycles and the loss by soil erosion.

4.1.6. Total nitrogen

The result of laboratory analysis revealed that, the total nitrogen percentage was 0.11 (Table 4.1), which was low as per the rating of EthioSIS (2016). This low deficiency in soils of the study area could be due to repeated cultivation, high rainfall, application of fertilizer below the recommendation and the types of the soil (Nitisols). Masresha Mitiku (2014) reported low amount of N content on soils which are cultivated repeatedly due to N leaching and N mining.

In high rainfall areas, the decline of total nitrogen could be the result of leaching as they are not adsorbed by the negatively charged colloids that dominate most soils. Therefore, they move downward with drainage water and are thus readily leached from the soil (Nigussie Abebe *et al.*, 2013). TN decreases in the soil surface layers of research and farmers' fields compared to virgin land (Heluf Gebrekidan and Wakene Negassa, 2006; Yihenew G.Selassie and Getachew Ayanna, 2013). In addition, nitrogen is usually deficient in most of the cultivated land of Nitisols.

4.2. Effect of Micro Dosing of Lime on Selected Soil Chemical Properties

4.2.1. Water pH

Based on the analysis of variance (ANOVA), pH-H_2O of all limed plots showed a significant difference ($P<0.01$) as compared to the control plot. The highest pH-H_2O registered (7.21) in full dose (15 t ha^{-1}) application using buffer method while the lowest pH-H_2O (5.41) was registered with application of lime in micro doses (0.06 t ha^{-1}) (Table 4.2). Whereas, the pH-H_2O in control plot was 5.16, reduced by 0.1 units from the baseline value measured before planting. The rate of increments of water pH per kg of lime application was 0.0001 and 0.0025 with the application of 15 and 0.06 t ha^{-1} lime, respectively. The increments of water pH associated with the presence of basic cations particularly $Ca^{2+}$and replaced H^+ on exchangeable site resulting to the rise of pH. Fageria *et al*. (2007) reported that water pH associated with the presence of basic cations and anions (CO_3^{-2}) in lime that are able to exchange H^+ from exchangeable sites to H_2O and CO_2. Cations adsorbed on the sites available on removal of H^+ on the exchange leading to the rise in pH.

Application of high quantities of lime increases the pH of soil. However, micro doses application of lime increases pH more efficiently. Twomlow *et al.* (2010) stated that micro dosing provides sufficient nutrients, especially on poor soils or degraded lands reducing application cost and maintaining favorable environment. Therefore, small scale farmers could afford micro dosing (0.06 t ha^{-1}) application of lime with limited expenditure by increasing its pH significantly from unlimed plot. However, one the of factors of lime application in Sub-Saharan Africa was high hauling costs of liming materials (Okalebo *et al.,* 2009). According to Brady and Weil (2008), for most grain and vegetable crops soil pH in range of 5.5 to 7.0 is the most suitable. Hence, heavy application of lime was found to be close to the optimum pH ranges as presented (Table 4.2). However, micro dose application of lime was recorded below the critical value by 0.09 units, but the Duncan multiple regression test showed significant difference between the unlimed plot and micro dose application of lime. The target pH was fixed to be 6.5 using buffer method due to the requirement of potato crop is 5.2 to 6.5 (Biswas *et. al*.,1991) and to save liming cost. The low pH in the control treatment than the baseline value is because of oxidation of the NH_4^+ ions from the added NPS and absence of the buffer to reduce the activity of the released H^+ due to nitrification process in the soil (Sparks, 2003).

Table 4.2 Change in water and buffer pH due to application of different rates of lime

	Water pH			Buffer pH		
Lime rate (t ha^{-1})	pH*	ΔpH after harvest.	ΔpH kg^{-1} of lime	pH*	Δ pH	ΔBuffer pH kg^{-1} of lime
0	5.16^{g}	-0.1	----	5.38^{f}	-0.02	--------
0.060	5.41^{f}	+0.15	0.0025	5.79^{e}	+0.39	0.0065
1.016	5.73^{e}	+0.47	0.0005	5.99^{de}	+0.59	0.0006
2.032	5.94^{d}	+0.68	0.0003	6.21^{d}	+0.81	0.0004
3.570	6.38^{c}	+1.12	0.0003	6.52^{c}	+1.12	0.0003
4.064	6.41^{c}	+1.15	0.0003	6.67^{c}	+1.27	0.0003
7.500	6.80^{b}	+1.54	0.0002	6.97^{b}	+1.57	0.0002
15.000	7.21^{a}	+1.95	0.0001	7.40^{a}	+2.00	0.0001
Critical value	5.5	Landon(1991)		--------		
CV	0.66			1.69		
SE ±	0.12			0.11		
LSD(0.01)	0.08			0.22		
P	**			**		

LSD = Least significance difference, SE± = Standard error; CV = Coefficient of Variation, p = probability level; **significantly different at p<0.01. *Means followed by the same letters in a column are not significantly different at p<0.01

4.2.2. Buffer pH

According to the analysis of variance (ANOVA), buffer pH of the soil had a significant difference (P<0.01) among treatments. The highest value (7.4) was observed from application of full dose of lime using buffer method (15 t ha^{-1}) and the lowest value (5.38) was registered from control plots. Buffer pH increment of 2.0 and 0.39 units from the control were registered from application of 15 t ha^{-1} using buffer method and micro-dose rate (0.06 t ha^{-1}), respectively (Table 4.2). In contrast to the above description, the rate of increments per kg of lime applied was reversed. It was found that micro-dose (0.06 t ha^{-1}) gave increase of 0.0065 units' kg^{-1} of lime and full dose of buffer method (15 t ha^{-1}) gave 0.0001 units' kg^{-1} of lime. Therefore, a micro dose application can increase the buffer pH of the soil with small amounts of lime. According to Van Reeuwijk (1992), soil above 6.9 buffer pH could not need lime application. Application of 15 and 7.5 t ha^{-1} gave buffer pH value of above 6.9 while other treatments gave below this value.

4.2.3. Soil pH in 0.01M $CaCl_2$ and 1M KCl

Based on the analysis of variance (ANOVA), both pH-$CaCl_2$ and pH-KCl showed a significant ($P<0.01$) difference among treatments. Both pH-$CaCl_2$ and pH-KCl recorded higher result in full dose (15 t ha^{-1}) based on buffer method with the values of 6.57 and 6.33, and the control plot gave 4.38 and 4.21, respectively (Table 4.3).

Table 4.3 Change in pH-$CaCl_2$ and pH-KCl due to application of different rates of lime

	pH in 0.01*M* $CaCl_2$			pH in 1*M* KCl		
Lime (t ha^{-1})	pH*	ΔpH	ΔpH kg^{-1} of lime	pH*	Δ pH	ΔpH kg^{-1} of lime
0	4.38^{e}	-0.11	----	4.21^{f}	-0.06	----
0.060	4.68^{de}	+0.19	0.00317	4.40^{ef}	+0.13	0.00217
1.016	4.89^{dc}	+0.40	0.00039	4.55^{de}	+0.28	0.00028
2.032	5.02^{c}	+0.53	0.00026	4.66^{d}	+0.39	0.00019
3.570	5.71^{b}	+1.22	0.00034	5.15^{c}	+0.88	0.00025
4.064	5.64^{b}	+1.15	0.00028	5.19^{c}	+0.92	0.00023
7.500	5.97^{b}	+1.48	0.00020	5.76^{b}	+1.49	0.00020
15.000	6.47^{a}	+1.98	0.00013	6.33^{a}	+2.06	0.00014
Critical value	4.5	Jones (2003)		4.5	Moore (2001)	
CV	3.02			2.18		
SE ±	0.12			0.12		
LSD (0.01)	0.32			0.22		
P	**			**		

LSD = Least significance difference, SE± = Standard error; CV = Coefficient of Variation, p = probability level; **significantly different at $p<0.01$. *Means followed by the same letters in a column are not significantly different at $p<0.01$.

The full dose (15 t ha^{-1}) using the buffer methods raised pH-$CaCl_2$ by 1.98 units from the control; while the micro dose of 0.06 t ha^{-1} treatment raised the same by 0.19 units. Similarly, pH-KCl raised by 2.06 and 0.13 units of due to the application 15 t ha^{-1} and micro- dose (0.06 t ha^{-1}) application of lime, respectively. The pH-$CaCl_2$ and pH KCl - increase by a kg of lime added for the micro-dosing (0.06-t ha^{-1}) was 0.00317 and 0.00217 for pH-$CaCl_2$ and pH-KCl, respectively. Whereas, the same increased by 0.00013 for pH-$CaCl_2$ and 0.00014 for pH-KCl with application of 15 t ha^{-1} (Table 4.3).

In all treatments, soil pH measured in water was higher by 0.67-0.92 units than pH values measured by pH-$CaCl_2$ solution and 0.88 -1.28 units higher than pH-KCl (Table 4.3). The result was in agreement with Traian (2011) who reported the difference between water and pH-$CaCl_2$ was 0.3 - 1.0 units and also water pH and pH-KCl was 0.680 – 1.171 units. Likewise, Abera Donis and Kefyalew Assefa (2017) reported that water pH and pH-KCl had a difference of 1.25 and 1.17 units in grazing and cultivated lands, respectively with a soil depth of 0-0.25 cm. Moore (2001) also reported that, the difference of water pH and pH-$CaCl_2$ is between 0.2 to 1.5 units. The low pH-$CaCl_2$ and pH-KCl indicates the presence of a substantial quantity of exchangeable hydrogen and aluminum ions. According to Mekaru and Uehara (1972), high soil acidity with KCl solution determination showed the presence of high potential acidity and weatherable minerals.

4.2.6. Exchangeable Acidity and Exchangeable Aluminum

As revealed by the analysis of variance (ANOVA), there was a highly significant ($p<0.01$) variation in exchangeable acidity among treatments. The result showed that, the highest exchangeable acidity (3.90 $Cmol_{(+)}kg^{-1}$) value was measured from the control plot while the lowest (0.23, $Cmol_{(+)}kg^{-1}$) from a plot that received 15 t ha^{-1} of lime using the buffer method (Table 4.4). Therefore, addition of lime from the lower rate to higher rates reduced exchangeable acidity.

Even though the addition of lime from the lower rate to higher rates produced a reduction in exchangeable acidity, the reduction of the same by application of a kg of lime gave lower values from application of 15 t ha^{-1} using the buffer method while the highest was obtained from the incorporation of lime micro-dose rate (0.06 t ha^{-1}) with values of -0.0002 and -0.0122 $Cmol_{(+)}kg^{-1}$, respectively (Table 4.4). The reduction of exchangeable acidity of the soil might be due to the increased replacement of Al by Ca in the exchange site and by the subsequent precipitation of Al as Al $(OH)_3$ (Havlin *et al.,* 2005). The other reason for the reduction of exchangeable acidity could be due to the increase in soil pH resulted from the application of lime. Ritchie (1989) stated that an increase in soil pH results in precipitation of exchangeable and soluble Al as insoluble Al hydroxides reduce the concentration of Al in soil solution. Lowering of exchangeable acidity and rising of pH can provide a wide range of benefits in terms of soil quality, notably by chemically improving the availability of plant nutrients, and in some cases by reducing the availability of detrimental elements such as Al (Brady and Weil, 2008).

Similarly, there was a highly significant ($p<0.01$) variation of exchangeable aluminum among the treatments. The highest value (2.77 $Cmol_{(+)}$ kg^{-1}) found in the control plot and the lowest (0.00 $Cmol_{(+)}kg^{-1}$) from the treatment that received 15 t ha^{-1} lime in full buffer method, and the control, respectively (Table 4.4). The application of 2.032 t ha^{-1}, 1.016 t ha^{-1} and 0.06 t ha^{-1} revealed 0.87, 1.23, 2.17 $Cmol_{(+)}kg^{-1}$ exchangeable aluminum contents, respectively. Whereas, other treatments completely removed the amounts of exchangeable aluminum from the exchangeable site. The decrements of exchangeable aluminum per application of a kg of lime was 0.0002 to 0.0078 from the incorporation of 15 t ha^{-1} and 0.06 t ha^{-1} lime, respectively. The solubility and release of Ca from lime in to the soil solution reduces the amount of exchangeable Al (Peter *et al*., 2006; Crawford *et al*., 2008; Awkes, 2010). The result of this study was in agreement with the findings of Fox (1979); Oates and Kamprath (1983); Conyers *et al,* (2003) and Caires *et al.* (2008) who reported that, adequate application of lime reduces exchangeable Al in acidic soils. Exchangeable Al is generally precipitates when soil water pH is between 5.5 to 6.0, resulting in little or no exchangeable Al to be found at higher soil pH values (Sanchez, 1976).

The finding is also in agreement with Endalkachew Fekad *et al*. (2017) who reported that application of 10 t ha^{-1} of lime reduced exchangeable acidity from 4.04 to 0.07 $Cmol_{(+)}kg^{-1}$

and the exchangeable aluminum minimized from 1.77 to 0.00 $Cmol_{(+)}kg^{-1}$. Likewise, Asmare Melese and Markku (2016) also stated that, addition of 11.2 and 9.2 t ha^{-1} of lime reduced the exchangeable acidity of a very strong acid soil from the original value of 2.31 to 0.23 and 0.14 $Cmol_{(+)}kg^{-1}$, respectively. Similarly, exchangeable aluminum decreased from 1.50 to 0.07 and 0.07 $Cmol_{(+)}kg^{-1}$ due to application of 11.2 and 9.2 t ha^{-1}, respectively. Moreover, Anteneh Abewa *et al.* (2013) reported that, application of 2 t ha^{-1} of lime reduce exchangeable acidity from 0.6 to 0.44 $Cmol_{(+)}kg^{-1}$. According to EthioSIS (2016) the critical value of exchangeable aluminum was 0.5 $Cmol_{(+)}$ kg^{-1}. The three treatments (2.032,1.016 and 0.06 t ha^{-1}) of this study could not drop the level of exchangeable aluminum to the critical level while other application rates (15, 7.5, 3.75, and 4.064 t ha^{-1}) reduced exchangeable Al levels not only below the critical value but also completely removed from the exchange site (Table 4.4).

Table 4.4 Change in exchangeable acidity and exchangeable aluminum due to application of different rates of lime

	Ex. Ac ($Cmol_{(+)}kg^{-1}$)			Ex. Al. ($Cmol_{(+)}kg^{-1}$)		
Lime (t ha^{-1})	Ex. Ac*	ΔEx. Ac	ΔEx. Ac kg^{-1} of lime	Ex. Al*	Δ Ex. Al	ΔEx. Al kg^{-1} of lime
0	3.90^{a}	+0.03	--------	2.77^{a}	+0.13	---------
0.060	3.13^{b}	-0.74	0.0122	2.17^{b}	-0.47	0.0078
1.016	1.97^{c}	-1.90	0.0019	1.23^{c}	-1.41	0.0014
2.032	1.13^{d}	-2.74	0.0013	0.87^{d}	-1.77	0.0009
3.570	0.84^{de}	-3.03	0.0008	0.00e	-2.64	0.0007
4.064	0.52^{ef}	-3.35	0.0008	0.00^{e}	-2.64	0.0006
7.500	0.49^{ef}	-3.38	0.0005	0.00^{e}	-2.64	0.0004
15.000	0.23^{e}	-3.64	0.0002	0.00^{e}	-2.64	0.0002
Critical value	-------			0.5	EthioSIS (2016)	
CV	11.81			15.36		
SE ±	0.23			0.19		
LSD(0.01)	0.36			0.27		
P	**			**		

Ex. Ac = Exchangeable Acidity, Ex. Al = Exchangeable Aluminum, LSD = Least significance difference, SE± = Standard error; CV = Coefficient of Variation, p = probability level; ** significantly different at $p<0.01$.
*Means followed by the same letters in a column are not significantly different at $p<0.01$

4.2.7. Cation Exchange Capacity (CEC)

The analysis of variance (ANOVA) showed that, there was a significant difference ($p<0.01$) in cation exchange capacity (CEC) among treatments. The highest CEC value was 38.40 $Cmol_{(+)}kg^{-1}$due to the application of 15 t ha^{-1} lime; while, the lowest was 21.95 $Cmol_{(+)}kg^{-1}$ CEC value in the control plots (Table 4.5). The extent of each treatment on CEC showed increasing trends with increasing the amounts of lime. Application of 15 t ha^{-1} lime increase the CEC values by 15.20 $Cmol_{(+)}$ kg^{-1} from the control, and by 9.60 $Cmol_{(+)}$ kg^{-1} due to the application of 0.06 t ha^{-1} lime. The increment of CEC per kg of lime was more effective in micro-dosing (0.06 t ha^{-1}) application compared to the other treatments. The result showed that, application of 0.06 t ha^{-1} lime increased CEC by 0.160 $Cmol_{(+)}kg^{-1}$ while, application of 15 t ha^{-1} lime increased the CEC value by 0.001 $Cmol_{(+)}kg^{-1}$.

The correlation analysis showed there was a strong positive correlation between CEC and soil pH-H_2O (r = 0.814**) while a strong negative correlation was found between CEC and exchangeable acidity and exchangeable aluminum with r = -0. 887** and -0.875**, respectively (Appendix Table 19). The direct relationship of CEC with soil pH may be attributed to the presence of pH dependant negative charges which can increase CEC with increasing soil pH due to applied lime (Achalu Cimdi *et al.*, 2012). Another author Pionke and Corey (1967) reported that liming could change pH and the release of the initially blocked amorphous and interlayer substitutional negative charge by deprotonation of the variable charge minerals and functional groups of humic compounds. The greater amount of negative charge available on the surfaces of these minerals results in the increase in CEC.

The result of this study also in agreement with the report of different authors. Buni Adane (2014) reported that, application of 3.75 t ha^{-1} increases CEC from 17 to 33.34 $Cmol_{(+)}kg^{-1}$. In addition, Anteneh Abewa *et al*. (2013) also reported that application of 2 t ha^{-1} increased CEC of soil by 41.1 % from unlimed plot. According to Landon (1991), the critical value of CEC of the soil was 15 $Cmol_{(+)}kg^{-1}$. All treatments were found to have above the critical value, including the control plots.

4.2.8. Available Phosphorus

Application of lime significantly ($P < 0.01$) increased available P. The highest value was from application full dose of buffer method (15 t ha^{-1}) while the lowest value was in the control plots with the respective value of 19.32 and 8.46 mg kg^{-1} (Table 4.5). Application of lime at the rate of 0.06 t ha^{-1} also raised available P to 14.66 mg kg^{-1}. The increment of P per kg application of lime was higher in 0.06 t ha^{-1} of lime (0.0680 mg kg^{-1}) and the lower (0.0006 mg kg^{-1}) was with application of 15 t ha^{-1} of lime.

Table 4.5 Change in CEC and available phosphorous due to application of different rates of lime

	CEC ($Cmol_{(+)}$ kg^{-1})			Available P (mg Kg^{-1})		
Lime (t ha^{-1})	CEC*	ΔCEC	ΔCEC kg^{-1} of lime	P*	Δ P	ΔP kg^{-1} of lime
0	21.95^{d}	-1.25.00	--------	8.46^{f}	-0.12	-------------
0.06	32.80^{c}	+9.60	0.160	14.66^{d}	6.08	0.1013
1.016	31.20^{c}	+8.00	0.008	13.86^{de}	5.28	0.0052
2.032	36.60^{b}	+13.40	0.007	13.09^{e}	4.505	0.0022
3.570	37.00^{ab}	+13.8	0.004	15.86^{c}	7.28	0.0020
4.064	37.20^{ab}	+14.00	0.003	16.31^{c}	7.73	0.0019
7.500	38.00^{ab}	+14.80	0.002	17.77^{b}	9.19	0.0012
15.000	38.40^{a}	+15.20	0.001	19.32^{a}	10.74	0.0007
Critical value	15	Landon (1991)		15	EthioSIS (2016)	
CV	2.40			3.88		
SE ±	0.94			0.56		
LSD (0.01)	1.64			1.16		
P	**			**		

LSD = Least significance difference, SE± = Standard error; CV = Coefficient of Variation, p = probability level; **significantly different at $p<0.01$. *Means followed by the same letters in a column are not significantly different at $p<0.01$.

The increment of available P in the soil might be due to the application of NPS fertilizer as a source of P and lime at different dose and its effect on the released of P fixation by Al and Fe and the direct relation of soil pH. Bolan and Hedley (2003) and Achalu Cimdi *et al*. (2012) reported that by liming of acidic soil, phosphorus could be released due to the reduction of P fixation by Al and Fe. Likewise, Tisdale *et al.* (2002) stated that lime increases availability of phosphorus in the soil system. The result was in line with Miller and Donahue (1997) who reported that maximum availability of phosphorus generally occurs in a pH range of 6.0 to

7.0. Tisdale *et al*. (2002) also described that P availability is at maximum in the pH range 5.5-6.0. Therefore, the water pH of the soil was between 5.16 to 7.21 after lime application except the control plot. It is also reported that by adjusting the soil water pH nearest to 6.5, phosphorus will most available for mineral soils (Miller and Donahue, 1997). Maintaining a soil pH in this range also favors the presence of $H_2PO_4^-$ which is more readily absorbed by the plant than HPO_4^{2-} and occur at pH values above 7.0 (Tisdale *et al.*, 2002).

The correlation analysis showed that, available P had a strong and positive correlation with water pH and CEC (r =0.888** and r = 0.872**, respectively), while a strong negative correlation was found exchangeable acidity and exchangeable aluminum (r = -0.819** and r = -0.828 **, respectively) (Appendix Table 19). It revealed that available P was affected by lower water pH and higher exchangeable acidity and aluminum. EthioSIS (2016) suggested optimum P content for most Ethiopian soil as 15 mg kg^{-1}. Based on this, the application of 15, 7.5, 4.064, 3.57, t ha^{-1} gave P value above the critical value. Nevertheless, the other treatments (2.032, 1.016, and 0.06 t ha^{-1}) did not raise P level above the critical level (Table 4.5). In the control plot, available P was not only found below the critical value, but also decreased at the measurement taken after harvest by 0.12 mg kg^{-1} from the baseline value. These might be due to the reduction in water pH value of the treatment that might have caused P fixation. The availability of P under most soils of Ethiopia decline by the impacts of fixation (Murphy, 1968; Eylachew Zewdie, 1987).

4.2.9. Organic Carbon

Based on the analysis of variance (ANOVA), an application of lime was significantly ($P < 0.01$) affected soil organic carbon. The highest value was 2.73 % was registered due to the incorporation of 15 t ha^{-1} while the lowest value (2.29 %) was from the control plot (Table 4.6). The total increments of OC with the application of lime ranged from 0.18 to 0.62 % with the respective amounts of 0.06 t ha^{-1} and 15 t ha^{-1} lime; whereas, its increment per kg of lime was 0.00004 and 0.003%, respectively. The increment of OC in the soil might be the addition of lime on soil which increases the water pH and it creates good environmental conditions for the activities of soil microorganism; they are responsible for the decomposition of soil organic matter. The result of this research was agreed with Achalu Chimdi *et al.* (2012) who stated that application of lime to acidic soil, increase the soil organic carbon. This is due to the rise of soil pH in a short period of time that favors soil microbes to decompose crop residues. Moreover, Anteneh Abewa *et al.* (2013) reported that, application of 2 t ha $^{-1}$ of the lime increase OC from 1.66 to 1.91 % as compared to the control plots. However, Chan and Heenan (1996) reported that liming resulted in an initial decrease in soil organic carbon because it initially promotes carbon mineralization.

4.2.10. Total Nitrogen

Application of lime was significantly ($P < 0.01$) increased TN of the soil. The highest value was in full dose of buffer method (15 t ha^{-1}) while the lowest value was in the control plots, which were 0.14 and 0.11%, respectively (Table 4.6).

The correlation analysis showed that, TN had a strong positive correlation with water pH and OC ($r = 0.766^{**}$ and $r = 0.575^{**}$, respectively) and had a strong negative correlation with exchangeable acidity and exchangeable aluminum ($r = -0.770^{**}$ and r = -0.774**, respectively) (Appendix table 19).

The increments of TN might be due to the direct relation of soil water pH and OC. Burgmann *et al*. (2004) stated that, the increase of total nitrogen could be attributed to the decomposition of organic matter in the soil as a result of increased soil pH which favors soil microbial activities. Moreover, Bolan *et al.* (2003) also reported that, the accumulation of organic matter in acidic soils could be exploited by liming to release nutrients including nitrogen. The result also in agreement with Anteneh Abewa *et al.*, (2013) that reported, an increase in TN from 0.17 to 0.19% with the application of 2 t ha^{-1} lime.

Table 4.6 Change in organic carbon and total nitrogen due application of different rates of lime

Lime (t ha^{-1})	OC (%)			TN (%)		
	OC*	Δ OC	ΔOC kg^{-1} of lime	TN*	Δ TN	ΔTN kg^{-1} of lime
0	2.21^{c}	+0.10		0.11^{c}	0.00	
0.060	2.29^{bc}	+0.18	0.00300	0.11^{c}	0.00	0.000000
1.016	2.57^{abc}	+0.46	0.00045	0.11^{c}	0.0 0	0.000000
2.032	2.59^{ab}	+0.48	0.00024	0.13^{ab}	0.02	0.000010
3.570	2.65^{ab}	+0.54	0.00015	0.13^{ab}	0.02	0.000006
4.064	2.69^{a}	+0.58	0.00014	0.13^{ab}	0.02	0.000005
7.500	2.71^{a}	+0.60	0.00008	0.13^{ab}	0.02	0.000003
15.000	2.73^{a}	+0.62	0.00004	0.14^{a}	0.03	0.000002
Critical value	2	Landon (1991)		0.15	EthioSIS (2016)	
CV	6.99			6.54		
SE ±	0.04			0.00		
LSD (0.01)	0.36			0.02		
P	**			**		

OC = Organic Carbon, TN = Total Nitrogen, LSD = Least significance difference, SE ± = Standard error; CV = Coefficient of Variation, p = probability level; ** significantly different at $p<0.01$. * Means followed by the same letters in a column are not significantly different at $p<0.01$.

4.3. Investigation of the association between soil acidity indices

4.3.1 The correlation between soil acidity indices

Pearson's simple correlation analysis was carried out to investigate the association between soil acidity indices. Both positive and negative associations between the parameters have been observed. Based on the correlation analysis, the soil acidity indices of water pH positively and strongly correlated to pH-$CaCl_2$, pH-KCl and buffer pH (r = 0.977**, 0.971** and 0.984**, respectively). Whereas, pH-H_2O, pH-$CaCl_2$, pH-KCl and buffer pH strongly and negatively correlated with exchangeable acidity with the respective correlation (r) values of -0.915**, -0.878**, -0.817** and -0.895**. However, exchangeable aluminum had a strong positive correlation with exchangeable acidity (r = 0 .979**); while negatively correlated with other soil acidity indices (Table 4.7). The finding agreed with Kabala *et al.* (2016) who reported that the values of pH-KCl and pH-H_2O are highly correlated. Moreover, Beery and Wilding

(1971) who reported that the relation between KCl and pH-H_2O with (r) value of 0.96. Exchangeable acidity is a function of soil pH composed of compounds such as Al $(OH)^{3+}$ or Al $(OH)^{2+}$, and weak organic acid ions held on the colloidal surfaces of the soil (Matzher *et al*, 1998; Hinrich *et al.*, 2001). Furthermore, the concentration of the H^+ to cause acidity is pronounced at pH values below 4 while the excess concentration of Al^{3+} is observed at pH below 5.5 (Nair and Chamuah, 1993).

Table 4.7 Correlations amongst soil acidity indices due to application of lime

Acidity indices	pH-H_2O	pH-$CaCl_2$	pH-KCl	B. pH	E. Ac.
pH-$CaCl_2$	.977**				
pH-KCl	.971**	.963**			
B. pH	.984**	.969**	.957**		
Ex. Ac.	-.915**	-.878**	-.817**	-.895**	
Ex. Al.	-.906**	-.882**	-.808**	-.878**	.979**

B. pH = Buffer pH, Ex. Ac = Exchangeable Acidity, Ex. Al = Exchangeable Aluminum, ** Correlation is significant at $p < 0.01$.

4.3.2 The regression between soil acidity indices.

Simple regression was carried out to determine the association between soil acidity indices. The values of pH-H_2O highly correlated with pH-$CaCl_2$, pH-KCl and buffer pH (r = 0.952, 0.967 and 0.940, respectively), and also their relationship is linear (Figure. 4.1). The exchangeable acidity and exchangeable aluminum also had linear relationships (r = 0.957). The linear relationship between water pH and salt solution extracted pH had been reported by Lierop (1981). Likewise, Gavriloaiei (2012) who reported that the relationships between pH-H_2O and pH measured in other electrolyte solutions by linear regression and a strong correlation coefficient r = 0.984 for $CaCl_2$ solution and r = 0.992 for KCl solution, respectively.

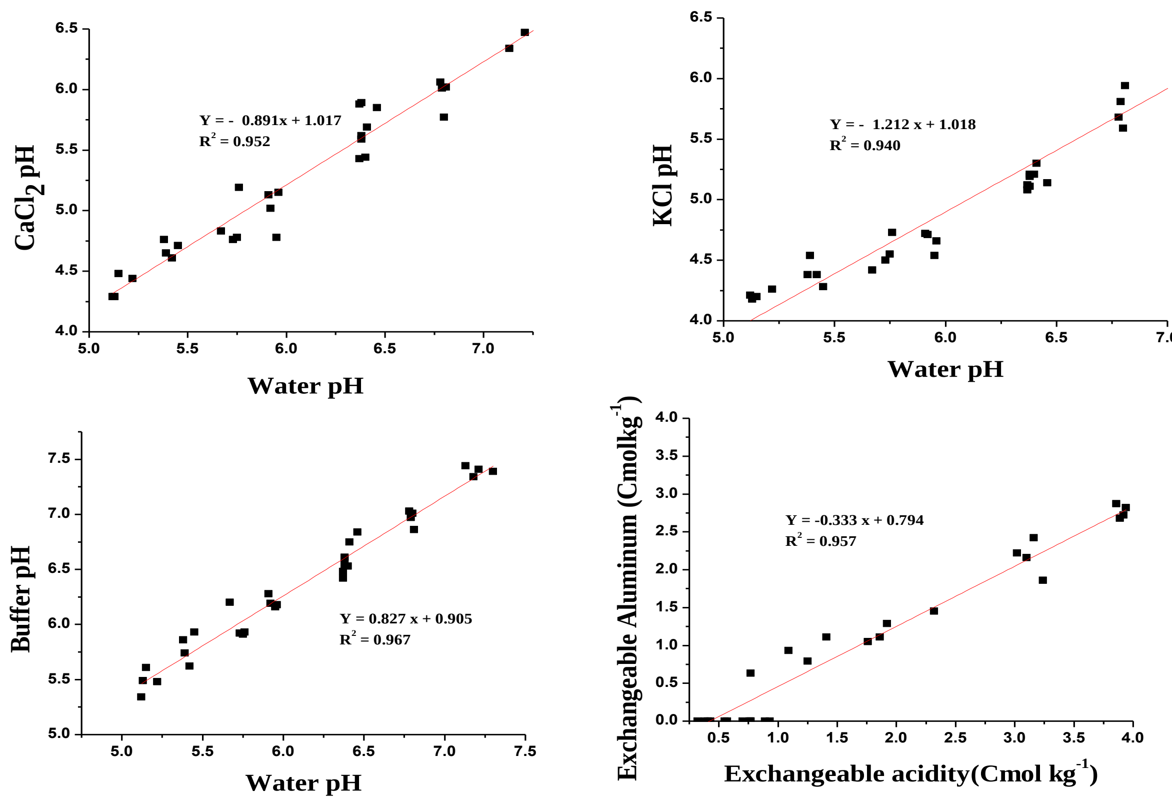

Figure 4.1 Relationship among soil acidity indices

4.4. Lime recommendation equations from soil acidity indices

Based on the regression analysis, a correlation coefficient (r) = 0.999 (Appendix able 21) was obtained for all soil acidity indices. The results were in agreement with Shoemaker (*et al*. 1961) and Van Reeuwijk (1992). Lime requirement moves downwards with increasing the soil buffer pH, pH-H_2O, pH-$CaCl_2$, pH-KCl soil acidity indices with the application of broadcast and drilling along the row methods (Figure 4.2 and 4.3). However, the proportion between lime requirements moves upward with the application of broadcast and drilling along the row increasing exchangeable acidity of the soil. This is due to the inverse relationship between soil pH and lime requirement and the direct relationship between exchangeable acidity and lime requirements (Figure 4.4). The proportion of calculated lime requirement by using of different acidity indices is not linear, rather curvilinear (Figure 4.2, 4.3 and 4.4). The curvilinear relationship between lime requirement and soil acidity indices is reported by several authors (Shoemaker *et al*., 1961; van Lierop, 1990; Van Reeuwijk, 1992)

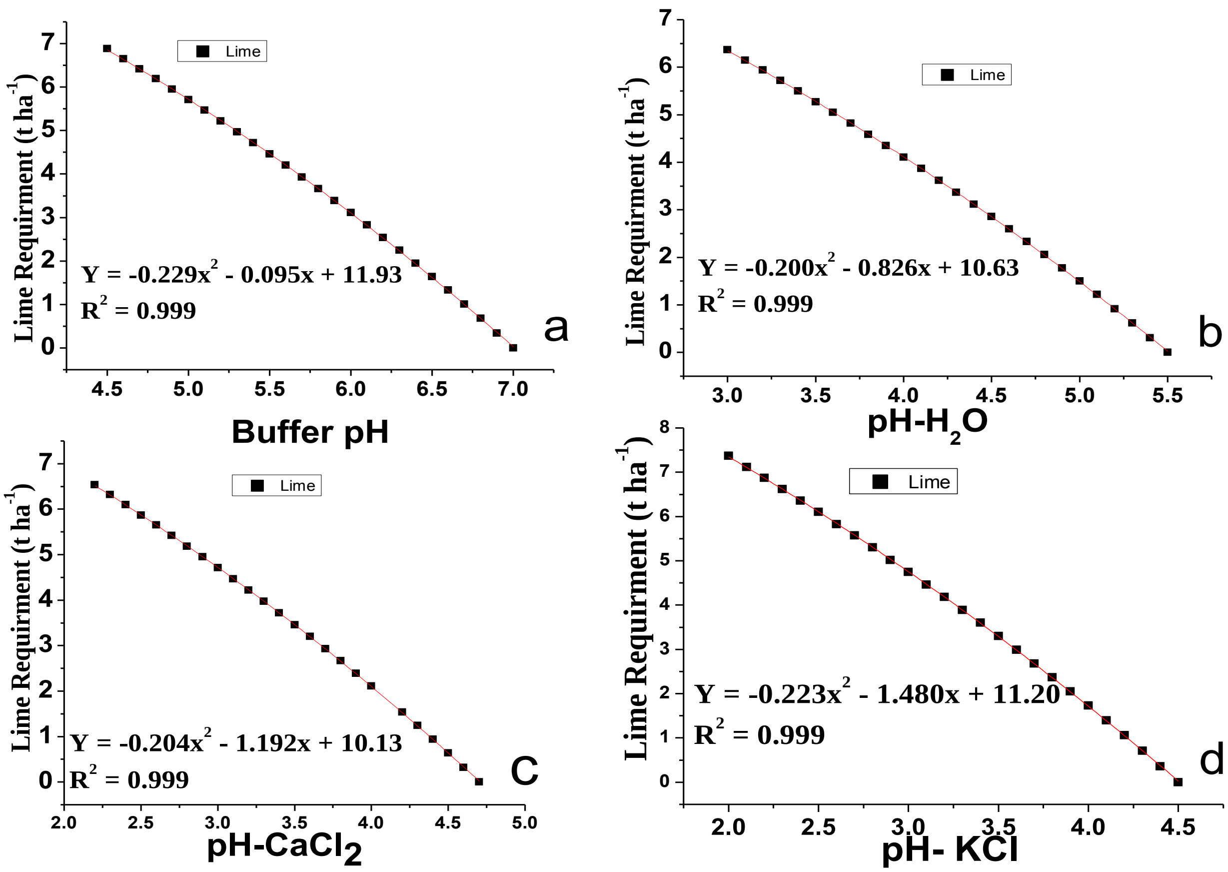

Figure 4.2 Lime requirements of soils using indices of buffer pH (a), pH-H_2O (b), pH-$CaCl_2$ (c) and pH- KCl (d) for broadcast application method

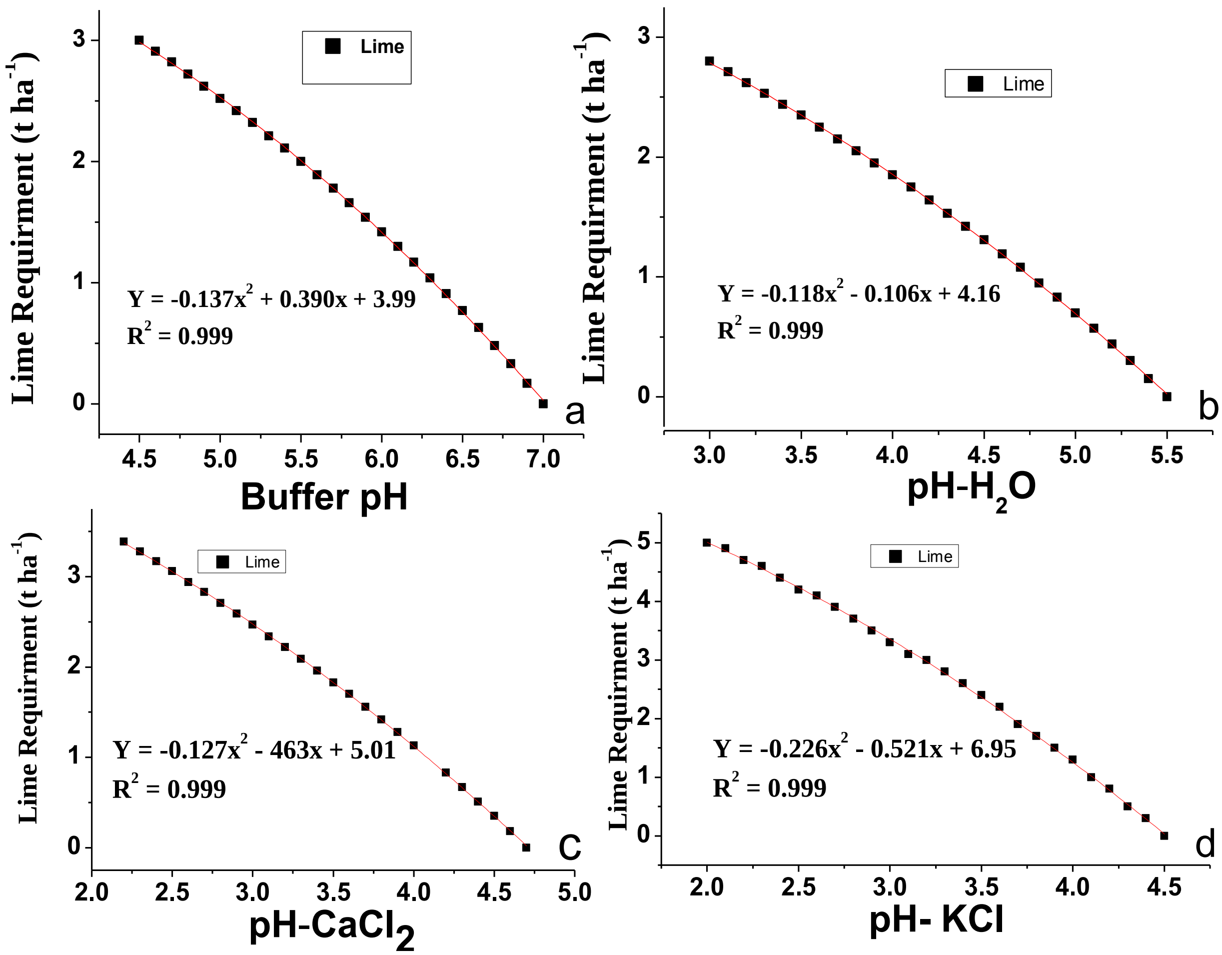

Figure 4.3 Lime requirements of soils using indices of buffer pH (a), pH-H_2O (b), pH-$CaCl_2$ (c) and pH- KCl (d) for drilling along the row application method

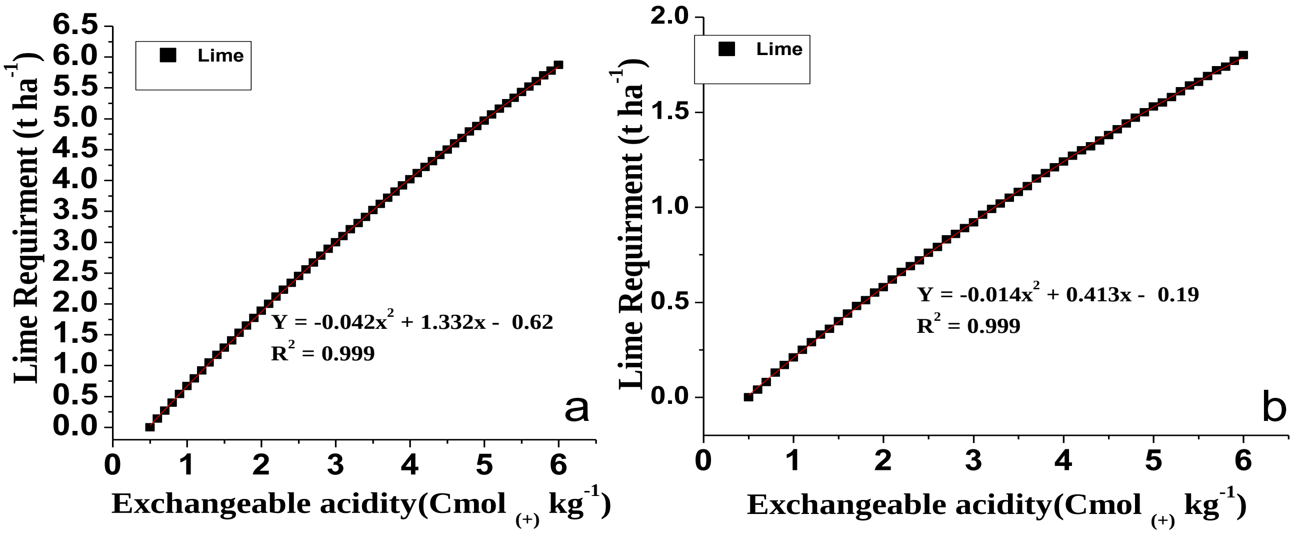

Figure 4.4 Lime requirements of soils determined by exchangeable acidity index for a) broadcast application and b) drilling along the row methods

As seen in appendix table 22, the calculated lime requirement for broadcast methods of lime application ranged from 0.34 to 6.88, 0.31 to 6.37, 0.32 to 6.54 and 0.36 to 7.37 t ha^{-1} for buffer pH, pH- H_2O, pH-$CaCl_2$ and pH-KCl, respectively. However, the calculated lime requirement for drilling along the row methods of lime application ranged from 0.17 to 3.00, 0.15 to 2.80, 0.18 to 3.39 and 0.3 to 5.0 t ha^{-1} for buffer pH, pH- H_2O, pH-$CaCl_2$ and pH-KC, respectively. In addition, the calculated amounts of lime based on exchangeable acidity with the application of lime in broad cast and drilling along the row methods ranged from 0.14 to 5.87 and 0.04 to 1.80 t ha^{-1}, respectively (Appendix table 23). The calculated lime amount was underestimated from the original SMP buffer pH recommendation and exchangeable acidity methods, which could be due to the different in soil type and geographical areas of the soil (Shoemaker *et al.*, 1961; Tran and van Lierop, 1981).

4.5. The effect of micro dosing of lime on agronomic parameters, yield and yield components of potato

4.5.1. Days to 50% of Emergence

Based on the analysis of variance, days to 50% of emergence were not significantly affected ($p>0.05$) by the application of lime. The result revealed the minimum and the maximum days of germination was 19.25 and 20.75 days due to the application of 15 t ha^{-1} lime and control plot, respectively (Table 4.8). The emergence of potato due to the application of 0.06 t ha^{-1} (micro-dosing) was 19.5 days. Emergence of potato was largely dependent on the utilization of reserve material and metabolites in the mother tuber (Wurr *et al.,* 1993; Love and Thompson Johns, 1999; Kabir *et al*., 2004). Furthermore, the result agreed with the finding of Khandakar *et al.* (2004) that reported, percent emergence of potato plant was not significantly influenced by lime application.

4.5.2. Days to 50% of Flowering

Days to 50% flowering was highly and significantly ($P < 0.01$) influenced by the application of lime. The result (Table 4.8) shows that, dates to 50% of flowering showed increasing trend as the amount of lime decreased and the longest days to flowering (58.50 days) was found from application of the full buffer method (15 t ha^{-1}) while shortest was from the control (48.50 days) and micro-dosing of lime (0.06 t ha^{-1}) was 53.75 days. The days of flowering increase due to the positive effects of available P through the application of lime. Zelalem *et al* (2009) reported that, P increased the days to reach flowering. In addition, Mulubrhan Haile (2004) reported that, P prolonged the days of flowering.

4.5.3. Plant Height

The statistical analysis of the data revealed that there was significant ($p < 0.01$) difference in plant height among the treatments. The tallest mean plant height (46.08 cm) was recorded in plots treated with 15 t ha^{-1} (full buffer method) while, the shortest (36.28 cm) was observed in the control plot (Table 4.8). The significant potato plant height increment in response to the increasing lime rates. These might be the neutralize capacity of lime in acidic soil toxicity effect and increase soil nutrient availability by enhancing mineralization. Liming might have reduced the detrimental effect of soil acidity on plant growth due to high concentration of H^+ and Al^{3+} ions in acid soils. Activities of Ca^2 cations, orthophosphate (H_2PO_4), nitrate (NO_3^-) and sulfate (SO_4^{2-}) anions with soil organic matter content and their availability to plant roots might be hampered by acidifying ions (Thomas and Hargrove, 1984; Achalu Chimid *et al.*, 2012; Abreha Kidane Mariam *et al.*, 2013).

Plant height had a positive and highly significant correlation ($r = 0.451^{**}$, n = 32) with total tuber yield and marketable yield (r = 0.544**, n = 32) (Appendix table 20). The positive and significant association of plant height indicates that plant height is an important tuber yield attribute that should be considered in the selection criteria for yield improvement (Ara *et al.*, 2009). These results were coinciding with the findings of Khandakar *et al.* (2004) who reported that applications of lime increased the height of potato plants.

4.5.4. Number of Main Stem

According to the analysis of variance, application of different levels of lime had a significant ($p < 0.01$) effect on the number of stems per hill. The maximum number of main stems (3.63) was observed in 15 t ha^{-1} (full buffer method) treatment; whereas, the minimum number of main stems (2.25) was observed in unlimed treatment (Table 4.8). Khandakhar *et al.* (2004) reported that, stem number per hill increased significantly with increasing the level of lime application. This may be attributed to the positive role the lime may have played in bringing the soil pH to normal levels for growth and development of the potato plant.

A positive and highly significant ($P < 0.01$) correlation was observed between the number of main stems per hill and total tuber yield ($r = 0.619^{**}$). Likewise, positively correlated with marketable tuber yield ($r = 0.684^{**}$) (Appendix table 20). These relationships indicated that factors that lead to increase in the number of main stems per hill might also increase the total tuber yield and marketable tuber yield. Hammes (1985) reported that an increase in stem numbers markedly increased total tuber yield per unit area of land. Similarly, the number of main stems had positive relationships between and total yield (Lynch and Rowberry, 1977b).

Table 4.8 The effect of lime rates on agronomic parameters of potato

Lime (t ha^{-1})	50% Germ.	50% Flow§	P.H§	NMS§
0	20.75	48.50^{b}	36.28^{b}	2.25^{b}
0.060	19.50	50.50^{b}	39.35^{ab}	2.45^{b}
1.016	19.50	50.75^{b}	41.95^{ab}	2.50^{b}
2.032	19.50	51.00^{b}	41.45^{ab}	2.75^{b}
3.570	19.50	52.50^{b}	41.70^{ab}	2.85^{b}
4.064	20.00	53.00^{ab}	43.28^{ab}	2.85^{b}
7.500	20.00	53.75^{ab}	45.93^{a}	2.90^{b}
15.000	19.25	58.50^{a}	46.08^{a}	3.63^{a}
CV	5.82	5.27	7.63	12.58
SE ±	0.19	0.65	0.73	0.09
LSD (0.01)	2.3	5.52	6.42	0.70
P	ns	**	**	**

P.H = plant height, NMS= no of main stem, LSD = Least significance difference, SE± = Standard error; CV = Coefficient of Variation, p = probability level; **significantly different at p<0.01; ns =not significantly different at p>0.05. § Means followed by the same letters in a column are not significantly different at p<0.01 and p<0.05, respectively

4.5.5. Percent of Tuber Dry Matter Yield

Based on the analysis of variance, application of lime had a significant effect ($p < 0.05$) on potato tuber dry matter. The highest dry matter content (23.21%) was obtained in potato tubers harvested in control plots while the lowest dry matter content (19.46%) due to the high lime application 15 t ha^{-1} (full buffer method) (Table 4.9). This could be attributed to the differential loss of water content in big and small size potato when dried. It is an indication that when fresh yield increased, the water content in potato also increased and could reduce dry matter accumulation. The plots that yielded the highest quantity of fresh tubers were found to have the lowest quantity of potato dry matter. This result was in agreement with the findings of Yamoah *et al. (*1992) who reported that the positive effects of liming on soil properties and increase in tuber yield in acidic soils, which consequently affected dry matter inversely.

4.5.6. Marketable Potato Tuber Yield

A significant difference (P< 0. 01) was observed in the amounts of marketable tuber yields due to application of different lime rates. The highest marketable yield was gained from 15 t ha^{-1} (full buffer method) with tuber yield of 19.71 t ha^{-1}; whereas, the lowest was found in the control plot had (15.07 t ha^{-1}) (Table 4.9). The above result showed that the increments of lime application had the direct relation to marketable tuber yield of potato production. These indicated that lime might enhance the nutrient availability of the soil by increased soil pH and available phosphorous (Tisdale *et al.,* 2002); released nitrogen (Bolan *et al.,* 2003) and also reduced aluminum toxicity (Brady and Weil, 2008). The result also agreed with Kara (2002) who found that Nutrients enhance the quality of tubers and make them more marketable. Potato yield was attributed to the availability of phosphorus, potassium and mineral nitrogen in the soil (Vos, 1999; Shield *et al.,* 1997).

4.5.7. Unmarketable potato tuber Yield

Based on the analysis of variance there was highly significance difference ($P< 0.01$) in the amounts unmarketable tuber yields. The highest unmarketable yield (2.10 t ha^{-1}) gained from control plot had (15.07 t ha^{-1}) while the lowest was (1.10 t ha^{-1}) with the incorporation of 15 t ha^{-1} (full buffer method) (Table 4.9). The result indicated that the amount of lime applied in the soil and its unmarketable tuber yield inversely related which means, as the lime rate decreased, the soil pH, available phosphorous and CEC reduced and aluminum toxicity increased. Thus, as these parameters are reduced the size of potato tuber also diminished. Al toxicity at low pH level seemed to be the major limiting factor in the growth of plants in highly weathered acid soil of the tropics (Scott *et al*., 2000; Achalu Chimdi *et al*. 2012; Eduardo *et al*., 2005). Furthermore, Mujaya and Mereki (2010) indicated that the importance of phosphorus in potato production and lack of it during growth drastically reduced yield.

4.5.8. Total potato tuber Yield

The amounts of lime applied with different rates significantly ($p< 0.01$) affected the total tuber yield of potato. Application of 15 t ha^{-1} (full buffer method) gave the highest fresh total potato tuber yield (20.80 t ha $^{-1}$) and the lowest was obtained in the control plot (17.17 t ha $^{-1}$) (Table 4.9). The highest yield obtained in plots that were limed, was probably due to the positive effects of liming on soil properties. Liming improved overall soil properties: soil pH increased from 5.26 to 7.21, available P increased from 8.58 to 19.32 mg kg $^{-1}$ and total nitrogen from 0.11 % to 0.14 % CEC from 23.2 to 38.4 $Cmol_{(+)}kg^{-1}$. In contrary to this, exchangeable acidity reduced from 3.87 to 0.23 $Cmol_{(+)}kg^{-1}$and exchangeable Al reduced from 2.64 to 0.00 $Cmol_{(+)}kg^{-1}$. This implies that, the soil systems become good for crop production.

Likewise, the significant effect of potato yield due to liming was attributed by increased availability of calcium, magnesium, sulphur, phosphorus, organic carbon and other micronutrients and decreased the availability of iron and manganese in soil (Bolan *et al*.,2003; Ezekiel, 2006 and Fageria and Beligar, 2008). Application of lime increased calcium uptake as well as tuber formation. Field research on potato has documented that calcium application to low CEC can improve the yield of tuber (Khandakar *et al*. 2004). These findings are in agreement with Hamilton *et al.* (1973) who reported that the maximum yield of potato being obtained at the highest rate of limestone application. Furthermore, Wassie Haile and Shiferaw Boke (2011) also reported that, application of 3.5 t ha^{-1} lime with NPK produced significantly superior potato tuber yield compared with the control. The national average tuber yield of potato reported by FAOSTATA (2018) is 13.76 t ha^{-1}. The highest tuber yield of this study was 20.80 t ha^{-1}. Even though the total tuber yield of potato gained was above the national average it was still below the reports by Henok (2018) who reported that Belete potato variety produced 40.257 t ha^{-1} yields of potato tuber over the testing year of 2013 and 2014. The observed variation may be probably due to the difference in its seed sources.

However, application of micro-dose (0.06 t ha^{-1}) produced 18.44 t ha^{-1} of total potato tuber yield (Table 4.9). The result implies that, there was no significance difference among the treatments except full dose (15.07 t ha^{-1}) and half buffer (7.5 t ha^{-1}). Therefore, small amounts of lime, micro-dosing (0.06 t ha^{-1}) application in acidic soil produced more or less the same amounts of potato tuber yield as application of doses of 4.064, 3.57, 2.032 and 1.016 t ha^{-1} of lime. These result agreed with Beernaert (1999) who stated that, little amount of lime was applied in acidic soils; it resulted in the changes in soil pH and other nutrients which can affect potato production positively. Hester (1936) reported application of small amount of lime with 5.2 pH increases potato tuber yield by 25 to 29%. Jafer Dawid and Gebresilassie Hailu (2017) also reported that, without a significant yield loss and harming soil health, splitting lime into one third and half and applying in three and two consecutive years, give similar yield with the full rate of lime applied once in the first year. This confirms that micro dose of lime is more effective than single heavy applications of lime.

Table 4.9 The effect of lime rates on yield of potato tuber

Lime (t ha^{-1})	% of TDM¤	Marketable yield (tha^{-1}) *	Unmarketable yield (tha^{-1}) *	Total tuber. Yield (tha^{-1}) *
0	23.21^{a}	15.07^{c}	2.10^{a}	17.17^{c}
0.060	22.88^{a}	16.58^{bc}	1.86^{b}	18.44^{bc}
1.016	21.94^{ab}	16.70^{bc}	1.87^{b}	18.57^{bc}
2.032	21.93^{ab}	16.73^{bc}	1.61^{c}	18.34^{bc}
3.570	21.29^{ab}	16.85^{bc}	1.24^{d}	18.10^{bc}
4.064	20.69^{ab}	17.41^{b}	1.16^{d}	18.56^{bc}
7.500	20.34^{ab}	18.54^{ab}	1.10^{d}	19.64^{ab}
15.000	19.46^{b}	19.71^{a}	1.10^{d}	20.80^{a}
CV	6.31	5.79	5.98	5.21
SE ±	0.30	0.28	0.07	0.23
LSD (0.01 and 0.05)	2.71	1.99	0.18	1.95
P	*	**	**	**

LSD = Least significance difference, SE± = Standard error; CV = Coefficient of Variation, p = probability level; TDM = Tuber dry matter. **significantly different at $p<0.01$ and *significantly different at $p<0.05$. ¤, * Means followed by the same letters in a column are not significantly different at $p<0.01$ and $p<0.05$, respectively.

4.6. Economic Analysis

As shown in Appendix 24, total variable costs, which are responsible for yield increase in each treatment, were listed. The economic analysis revealed that application of 0.06, t ha $^{-1}$ of lime gave MRR values above 100% which is accepted (Table 4.10). All the treatments were dominated by micro-dose lime application (0.06 t ha^{-1}). The net benefit and the MRR were 92,352 Birr ha^{-1} and 2348.64%, respectively from the application of 0.06 t ha^{-1} of lime. The lowest net benefit was 83,662 Birr ha^{-1} (Table 4.10) recorded from the control plot. Therefore, micro dosing application is the most economically affordable treatments after all treatments. The result is in agreement with Chianu and Tsujii (2005) and Twomlow *et al.* (2010) who reported that micro dosing is one technology that can be affordable to farmers and ensures that poor farmers get the highest returns from are able to purchase.

Table 4.10 Dominance and marginal analysis of potato yield

Lime amount in t ha^{-1}	MTY	TVC (Birr ha^{-1})	GB (Birr ha^{-1})	NB (Birr ha^{-1})	MRR
0	15070	6758	90420	83662	-
0.060	16580	7128	99480	92352	2348.64
1.016	16700	8622	100200	91578D	-
2.032	16730	10286	100380	90094D	-
3.570	16850	12663	101100	88437D	-
4.064	17410	13614	104460	90846D	-
7.500	18540	19258	111240	91982D	-
15.000	19710	31558	118260	86702D	-

D = Dominated treatment, MYT= Marketable Tuber Yield, TVC= Total Variable Cost, GB = Gross Benefit, NB= Net Benefit, MRR= Marginal Rate of Return (1 kg of lime costs = 1.50 Birr and 1 kg of MTY costs = *6* Birr)

Chapter 5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The study was conducted to investigate the effect of micro-dosing of lime on selected soil chemical properties and yield and yield components of potato. Using the information obtained from the results of this study, the following conclusions were made. Micro-dosing as well as full rate application of lime affected selected soil chemical properties (soil pH, exchangeable acidity, exchangeable aluminum, available P, cation exchange capacity and organic carbon). The soil acidity indices (H_2O-pH, buffer pH, pH-$CaCl_2$ and pH-KCl) were found to have a direct relationship with one another and indirect relationships with exchangeable acidity and exchangeable aluminum. The developed lime recommendation equation underestimated the amounts of lime required compared to the lime rates determined for the experiment following buffer and exchangeable acidity methods. Micro dose application of lime in acidic soil produced more or less the same amounts of potato tuber yield compared to the application of full dose of lime applications. The economic analysis result indicated that applying lime in micro dosing was economically feasible. Therefore, micro dosing application of lime is an efficient and economically affordable method for small scale farmers.

5.2. Recommendations

From the conclusions of the study, the following recommendations can be drawn.

- Since soils of the study area are affected by soil acidity, lime application is recommended for achieving higher yield of potato.
- Micro-dosing of liming is more effective than full dose due to low cost, ease of transportation, possibility of mixing it to the soil during planting and to save wastage of lime.
- Small scale farmers could use micro dosing application of lime to sustain the soil acidity problems of the soil without compromising yield of potato.
- Further study should also be done to the residual effects and on other methods of lime rate determination and application methods.

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APPENDIX

Appendix Table 1. ANOVA table for water pH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Replication	3	0.00231250	0.00077083	0.47	0.7073
Treatment	7	13.62483750	1.94640536	1183.48	<.0001
Error	21	0.03453750	0.00164464		
Corrected Total	31	13.66168750			

Appendix Table 2. ANOVA table for pH in 0.01*M* $CaCl_2$

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Replication	3	0.02095937	0.00698646	0.27	(0.8472)ns
Treatment	7	14.26614688	2.03802098	78.38	(<0.0001)**
Error	21	0.54606563	0.02600313		
Corrected Total	31	14.83317188			

Appendix Table 3. ANOVA table for pH in 1*M* KCl

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Replication	3	0.03213437	0.01071146	0.89	(0.4610)ns
Treatment	7	14.75852188	2.10836027	175.81	(0.0001)**
Error	21	0.25184062	0.01199241		
Corrected Total	31	15.04249687			

Appendix Table 4. ANOVA table for Buffer pH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Replication	3	0.03126250	0.01042083	0.90	0.4577
Treatment	7	11.29748750	1.61392679	139.40	<.0001
Error	21	0.24313750	0.01157798		
Corrected Total	31	11.57188750			

Appendix Table 5. ANOVA table for exchangeable acidity

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Replication	3	0.02618438	0.00872813	0.27	0.8471
Treatment	7	51.26292188	7.32327455	225.60	<.0001
Error	21	0.68169062	0.03246146		
Corrected Total	31	51.97079688			

Appendix Table 6. ANOVA table for exchangeable aluminum

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Replication	3	0.02543437	0.00847812	0.47	0.7095
Treatment	7	33.79844688	4.82834955	265.06	<.0001
Error	21	0.38254063	0.01821622		
Corrected Total	31	34.20642188			

Appendix Table 7. ANOVA table for Cation Exchange Capacity

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Replication	3	1.2125000	0.4041667	0.60	0.6232
Treatment	7	582.6400000	83.2342857	123.20	<.0001
Error	21	14.1875000	0.6755952		
Corrected Total	31	598.0400000			

Appendix Table 8. ANOVA table for available phosphorous

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Replication	3	0.7418125	0.2472708	0.74	0.5418
Treatment	7	306.3522875	43.7646125	130.42	<.0001
Error	21	7.0468875	0.3355661		
Corrected Total	31	314.1409875			

Appendix Table 9. ANOVA table for organic carbon

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Replication	3	0.09662500	0.03220833	1.01	0.4068
Treatment	7	1.09255000	0.15607857	4.91	0.0021
Error	21	0.66777500	0.03179881		
Corrected Total	31	1.85695000			

Appendix Table 10. ANOVA table for total nitrogen

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Replication	3	0.00037500	0.00012500	1.91	0.1591
Treatment	7	0.00360000	0.00051429	7.85	0.0001
Error	21	0.00137500	0.00006548		
Corrected Total	31	0.00535000			

Appendix Table 11. ANOVA table to 50% germination

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Replication	3	1.75000000	0.58333333	0.44	0.7258
Treatment	7	6.50000000	0.92857143	0.70	0.6698
Error	21	27.75000000	1.32142857		
Corrected Total	31	36.00000000			

Appendix Table 12. ANOVA table for days to 50% flowering

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Replication	3	6.1250000	2.0416667	0.27	0.8470
Treatment	7	251.3750000	35.9107143	4.73	0.0026
Error	21	159.3750000	7.5892857		
Corrected Total	31	416.8750000			

Appendix Table 13. ANOVA table for plant height

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Replication	3	16.4025000	5.4675000	0.53	0.6651
Treatment	7	295.3200000	42.1885714	4.11	0.0055
Error	21	215.6775000	10.2703571		
Corrected Total	31	527.4000000			

Appendix Table 14. ANOVA table for number of main steam

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Replication	3	0.40593750	0.13531250	1.11	0.3659
Treatment	7	4.82718750	0.68959821	5.68	0.0009
Error	21	2.55156250	0.12150298		
Corrected Total	31	7.78468750			

Appendix Table 15. ANOVA table for tuber dry matter content

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Replication	3	4.41622500	1.47207500	0.80	0.5062
Treatment	7	45.63610000	6.51944286	3.56	0.0112
Error	21	38.50282500	1.83346786		
Corrected Total	31	88.55515000			

Appendix Table 16. ANOVA table for total tuber yield ha^{-1}

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Replication	3	0.86147500	0.28715833	0.30	0.8235
Treatment	7	32.91665000	4.70237857	4.95	0.0020
Error	21	19.96302500	0.95062024		
Corrected Total	31	53.74115000			

Appendix Table 17. ANOVA table for Marketable yield ha^{-1}

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Replication	3	0.72213750	0.24071250	0.24	0.8657
Treatment	7	54.46168750	7.78024107	7.84	0.0001
Error	21	20.84346250	0.99254583		
Corrected Total	31	76.02728750			

Appendix Table 18. ANOVA table for unmarketable yield ha^{-1}

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Replication	3	0.03681250	0.01227083	1.51	0.2401
Treatment	7	4.57373750	0.65339107	80.60	<.0001
Error	21	0.17023750	0.00810655		
Corrected Total	31	4.78078750			

Appendix Table 19. Correlations among soil acidity indices and other soil parameters

Parameters	H_2O-pH	$CaCl_2$-pH	KCl-pH	Buffer pH	Ex. acidity	Ex. Al	CEC	AVP	OC
$CaCl_2$-pH	.977**								
KCl-pH	.971**	.963**							
Buffer pH	.984**	.969**	.957**						
Ex. acidity	-.915**	-.878**	-.817**	-.895**					
Ex. Al	-.906**	-.882**	-.808**	-.878**	.979**				
CEC	.814**	.787**	.711**	.807**	-.887**	-.875**			
AVP	.888**	.884**	.858**	.897**	-.819**	-.828**	.872**		
OC	.696**	.639**	.602**	.691**	-.735**	-.708**	.672**	.615**	
TN	.766**	.787**	.752**	.784**	-.770**	-.774**	.637**	.641**	.575**

** Correlation is significant at the 0.01 level. * Correlation is significant at the 0.05 level.

n = 32

Appendix Table 20. Correlations among agronomic parameters, yield and yield components

	GER	FLO	PH	SN	TDM	TY	MY
FLO	.249						
PHE	-.022	-.486**					
SN	-.354*	-.455**	.591**				
TDM	.072	.326	-.602**	-.504**			
TY	-.415*	-.409*	.455**	.619**	-.457**		
MY	-.380*	-.516**	.544**	.684**	-.547**	.978**	
UMY	.125	.687**	-.644**	-.650**	.649**	-.546**	-.710**

GER = 50 % emergency, FLO = 50% flowering; PH = plant height; SN = stem number; TDM = tuber dry matter; TY= total tuber yield; MY = marketable yield and UMY = unmarketable yield. ** Correlation is significant at the 0.01 level. * Correlation is significant at the 0.05 level. n = 32.

Appendix Table 21. Lime recommendation equations developed from soil acidity indices for broadcast and drilling along the row application methods

Methods of lime application	Soil acidity index	Unit of index	Lime recommendation equation	R^2
Broad cast application	Buffer pH	---	$Y = -0.229x^2 - 0.095x + 11.93$	0.999
	Water pH	----	$Y = -0.200x^2 - 0.826x + 10.63$	0.999
	0.01*M* $CaCl_2$ pH	----	$Y = -0.204x^2 - 1.192x + 10.13$	0.999
	1*M* KCl pH	-----	$Y = -0.223x^2 - 1.480x + 11.20$	0.999
	Exchangeable Acidity	Cmol $_{(+)}$ kg^{-1}	$Y = -0.042x^2 + 1.332x - 0.62$	0.999
Drilling along the row application	Buffer pH	---	$Y = -0.137x^2 + 0.390x + 3.99$	0.999
	Water pH	----	$Y = -0.118x^2 - 0.106x + 4.16$	0.999
	0.01*M* $CaCl_2$ pH	----	$Y = -0.127x^2 - 463x + 5.01$	0.999
	1*M* KCl pH	-----	$Y = -0.226x^2 - 0.521x + 6.95$	0.999
	Exchangeable Acidity	Cmol $_{(+)}$ kg^{-1}	$Y = -0.014x^2 + 4.13x - 0.19$	0.999

Note: Y= lime rate; x = index value

Appendix Table 22. Calculated lime requirement from the level of soil acidity indices (buffer pH, H_2O-pH, $CaCl_2$-pH and KCl-pH) for broadcast (BCM) and drilling along the row application methods

	LR (t ha^{-1})			LR (t ha^{-1})		$CaCl_2$-	LR (t ha^{-1})			LR (t ha^{-1})	
Buffer pH	BCM	Drill	H_2O-pH	BCM	Drill	pH	BCM	Drill	KCl-pH	BCM	Drill
7.0	0.00	0.00	5.5	0.00	0.00	4.7	0.00	0.00	4.5	0.00	0.0
6.9	0.34	0.17	5.4	0.31	0.15	4.6	0.32	0.18	4.4	0.36	0.3
6.8	0.68	0.33	5.3	0.62	0.30	4.5	0.64	0.35	4.3	0.71	0.5
6.7	1.01	0.48	5.2	0.92	0.44	4.4	0.94	0.51	4.2	1.06	0.8
6.6	1.33	0.63	5.1	1.22	0.57	4.3	1.24	0.67	4.1	1.40	1.0
6.5	1.64	0.77	5.0	1.50	0.70	4.2	1.54	0.83	4.0	1.73	1.3
6.4	1.95	0.91	4.9	1.78	0.83	4.2	1.54	0.83	3.9	2.05	1.5
6.3	2.25	1.04	4.8	2.06	0.95	4.0	2.11	1.13	3.8	2.37	1.7
6.2	2.54	1.17	4.7	2.33	1.08	3.9	2.39	1.28	3.7	2.68	1.9
6.1	2.83	1.30	4.6	2.60	1.19	3.8	2.67	1.42	3.6	2.99	2.2
6.0	3.11	1.42	4.5	2.86	1.31	3.7	2.93	1.56	3.5	3.30	2.4
5.9	3.39	1.54	4.4	3.12	1.42	3.6	3.20	1.70	3.4	3.60	2.6
5.8	3.66	1.66	4.3	3.37	1.53	3.5	3.46	1.83	3.3	3.89	2.8
5.7	3.93	1.78	4.2	3.62	1.64	3.4	3.72	1.96	3.2	4.18	3.0
5.6	4.20	1.89	4.1	3.87	1.75	3.3	3.97	2.09	3.1	4.46	3.1
5.5	4.46	2.00	4.0	4.11	1.85	3.2	4.22	2.22	3.0	4.75	3.3
5.4	4.72	2.11	3.9	4.35	1.95	3.1	4.47	2.34	2.9	5.02	3.5
5.3	4.97	2.21	3.8	4.59	2.05	3.0	4.71	2.47	2.8	5.30	3.7
5.2	5.22	2.32	3.7	4.82	2.15	2.9	4.95	2.59	2.7	5.57	3.9
5.1	5.47	2.42	3.6	5.05	2.25	2.8	5.18	2.71	2.6	5.83	4.1
5.0	5.71	2.52	3.5	5.27	2.35	2.7	5.42	2.83	2.5	6.10	4.2
4.9	5.95	2.62	3.4	5.50	2.44	2.6	5.65	2.94	2.4	6.36	4.4
4.8	6.19	2.72	3.3	5.72	2.53	2.5	5.87	3.06	2.3	6.62	4.6
4.7	6.42	2.82	3.2	5.94	2.62	2.4	6.10	3.17	2.2	6.87	4.7
4.6	6.65	2.91	3.1	6.15	2.71	2.3	6.32	3.28	2.1	7.12	4.9
4.5	6.88	3.00	3.0	6.37	2.80	2.2	6.54	3.39	2.0	7.37	5.0

Appendix Table 23. Calculated lime requirement from level of exchangeable acidity for broadcast (BCM) and drilling along the row application methods

Exchangeable acidity	LR (t ha^{-1})		Exchangeable acidity	LR (t ha^{-1})	
	BCM	Drill		BCM	Drill
0.5	0.00	0.00	3.3	3.31	1.02
0.6	0.14	0.04	3.4	3.41	1.05
0.7	0.27	0.08	3.5	3.52	1.08
0.8	0.40	0.13	3.6	3.62	1.11
0.9	0.54	0.17	3.7	3.72	1.15
1.0	0.67	0.21	3.8	3.82	1.18
1.1	0.79	0.25	3.9	3.92	1.21
1.2	0.92	0.29	4.0	4.02	1.24
1.3	1.05	0.33	4.1	4.12	1.27
1.4	1.17	0.36	4.2	4.22	1.30
1.5	1.29	0.40	4.3	4.31	1.32
1.6	1.41	0.44	4.4	4.41	1.35
1.7	1.53	0.48	4.5	4.50	1.38
1.8	1.65	0.51	4.6	4.60	1.41
1.9	1.77	0.55	4.7	4.69	1.44
2.0	1.89	0.58	4.8	4.79	1.47
2.1	2.00	0.62	4.9	4.88	1.50
2.2	2.12	0.66	5.0	4.97	1.53
2.3	2.23	0.69	5.1	5.07	1.55
2.4	2.34	0.72	5.2	5.16	1.58
2.5	2.45	0.76	5.3	5.25	1.61
2.6	2.56	0.79	5.4	5.34	1.64
2.7	2.67	0.83	5.5	5.43	1.66
2.8	2.78	0.86	5.6	5.52	1.69
2.9	2.89	0.89	5.7	5.61	1.72
3.0	3.00	0.92	5.8	5.70	1.74
3.1	3.10	0.96	5.9	5.78	1.77
3.2	3.21	0.99	6.0	5.87	1.80

Appendix Table 24. Costs used for calculating partial budget analysis

Items	Treatments							
	LO	MD	¼ E	½ E	¼ 4B	FE	½ B	FB
Marketable yield(kg ha^{-1})	15070	16580	16700	16730	16850	17410	18540	19710
Price of Marketable yield kg^{-1}	6	6	6	6	6	6	6	6
GROSS BENEFIT	90420	99480	100200	100380	101100	104460	111240	118260
Cost of NPS Fertilizer	2586	2586	2586	2586	2586	2586	2586	2586
Cost of UREA Fertilizer	1772	1772	1772	1772	1772	1772	1772	1772
Cost of lime	0	90	1524	3048	5355	6096	11250	22500
Labor cost of lime application	0	280	140	280	350	560	1050	2100
Tillage	1200	1200	1400	1400	1400	1400	1400	1400
Weeding/cultivation	400	400	400	400	400	400	400	400
Top dressing of UREA	200	200	200	200	200	200	200	200
Harvesting	600	600	600	600	600	600	600	600
TVC	6758	7128	8622	10286	12663	13614	19258	31558
NP	83662	92352	91578	90094	88437	90846	91982	86702

Cost of 1kg lime 1.50 Birr, Cost of NPS fertilizer = 13.26 Birr kg^{-1}, Cost of UREA fertilizer = 10.74 Birr kg^{-1}, FB = 15000kg, ¼ B = 7500 kg, FE = 4064 kg, ¼ E = 1016 kg, ½ B = 3750 kg, ½E = 2032 kg, MD = 60 kg lime, Lo = No lime; Amounts of NPS fertilizer used = 195 kg ha^{-1} and UREA= 165 kg ha^{-1} for all treatments. One labor cost 70.00 birr.

Appendix Table 25. Raw data of selected soil chemical properties

Replica tions	Treat ments	pH-H_20	pH-$CaCl_2$	pH-KCl	Buffer pH	EX.AC	EX. AL	CEC	AVP	OC	TN
R1	2B	6.79	6.01	5.81	6.97	0.55	0	37.6	18.34	2.82	0.14
R1	2E	5.91	5.13	4.72	6.28	0.77	0.63	37.4	13.27	2.58	0.14
R1	4B	6.38	5.62	5.11	6.54	0.77	0	36.8	15.01	2.91	0.14
R1	4E	5.73	4.76	4.5	5.92	2.32	1.45	32	13.09	2.38	0.11
R1	FB	7.3	6.52	6.39	7.39	0.32	0	39.5	20.06	3.03	0.13
R1	FE	6.38	5.59	5.19	6.61	0.22	0	37.9	15.98	2.47	0.13
R1	LO	5.12	4.29	4.21	5.34	3.89	2.68	23.1	8.32	2.27	0.1
R1	MD	5.42	4.61	4.38	5.62	3.1	2.16	33.2	14.12	2.23	0.11
R2	2B	6.81	6.02	5.94	6.86	0.43	0	38.2	16.96	2.49	0.13
R2	2E	5.96	5.15	4.66	6.18	1.25	0.79	36.1	13.08	2.39	0.13
R2	4B	6.4	5.44	5.21	6.53	0.89	0	37.3	15.98	2.7	0.12
R2	4E	5.76	5.19	4.73	5.93	1.86	1.11	31.6	13.77	2.6	0.11
R2	FB	7.13	6.34	6.12	7.44	0.32	0	38.3	19.98	2.69	0.14
R2	FE	6.37	5.43	5.12	6.48	0.38	0	36.6	16.03	2.8	0.12
R2	LO	5.15	4.48	4.2	5.61	3.86	2.87	21.6	8.62	2.19	0.11
R2	MD	5.38	4.76	4.38	5.86	3.02	2.22	31.6	14.86	2.19	0.11
R3	2B	6.8	5.77	5.59	7.01	0.57	0	37.4	17.61	2.6	0.12
R3	2E	5.95	4.78	4.54	6.16	1.09	0.93	37.2	13.25	2.62	0.11
R3	4B	6.37	5.88	5.08	6.42	0.77	0	36.2	15.64	2.31	0.12
R3	4E	5.67	4.83	4.42	6.2	1.92	1.29	31	13.98	2.55	0.11
R3	FB	7.18	6.56	6.32	7.34	0.16	0	38.6	18.24	2.45	0.14
R3	FE	6.46	5.85	5.14	6.84	0.76	0	38.2	16.66	2.89	0.13
R3	LO	5.13	4.29	4.18	5.49	3.92	2.72	20.8	8.02	2.21	0.12
R3	MD	5.39	4.65	4.54	5.74	3.24	1.86	32.8	15.11	2.29	0.11
R4	2B	6.78	6.06	5.68	7.03	0.41	0	38.8	18.17	2.91	0.13
R4	2E	5.92	5.02	4.71	6.19	1.41	1.11	35.7	12.74	2.77	0.13
R4	4B	6.38	5.89	5.21	6.6	0.93	0	37.7	16.81	2.66	0.14
R4	4E	5.75	4.78	4.55	5.91	1.76	1.05	30.2	14.6	2.75	0.12
R4	FB	7.21	6.47	6.48	7.41	0.12	0	37.2	19	2.73	0.15
R4	FE	6.41	5.69	5.3	6.75	0.7	0	36.1	16.57	2.58	0.14
R4	LO	5.22	4.44	4.26	5.48	3.94	2.82	22.3	8.88	2.15	0.11
R4	MD	5.45	4.71	4.28	5.93	3.16	2.42	33.6	14.55	2.43	0.11

Appendix Table 26. Raw data of yield and yield components of potato.

Replications	Treatments	GER	FLO	PHE	SN	TDM	TY	MY	UMY
R1	2B	21	51	46.1	2.6	20.27	18.87	17.71	1.16
R1	2E	20	53	41	2.4	20.74	17.31	15.59	1.72
R1	4B	18	48	43.2	3.2	22.31	18.65	17.33	1.32
R1	4E	18	56	40.2	3.2	21.17	19.94	18.06	1.88
R1	FB	19	49	46.7	3.8	19.21	21.75	20.62	1.13
R1	FE	20	54	46.3	3.4	20.07	19.61	18.46	1.15
R1	LO	20	60	33.2	2.4	24.87	17.16	14.91	2.25
R1	MD	19	47	35.2	2.6	25.42	18.09	16.23	1.86
R2	2B	19	52	48.2	2.8	19.2	20.44	19.36	1.08
R2	2E	19	52	38.8	2.4	21.73	19.46	17.81	1.65
R2	4B	19	55	38	2.8	20.71	17.79	16.53	1.26
R2	4E	19	52	44.6	2.4	22.94	18.07	16.09	1.98
R2	FB	20	47	45.4	3.6	17.25	18.44	17.31	1.13
R2	FE	21	50	44.8	3.2	20.41	17.92	16.7	1.22
R2	LO	21	58	38.2	2.4	23.08	17.52	15.71	1.81
R2	MD	20	56	47.4	2.4	21.72	18.05	16.14	1.91
R3	2B	19	50	45.8	3.4	20.64	19.54	18.44	1.1
R3	2E	21	56	42.2	3.2	22.12	18.44	16.93	1.51
R3	4B	21	52	44	2.8	22.24	17.05	15.87	1.18
R3	4E	20	51	39.6	2.2	20.72	18.58	16.81	1.77
R3	FB	19	50	44.8	3.4	20.53	22.43	21.32	1.11
R3	FE	20	48	38.2	2.2	23.07	18.65	17.52	1.13
R3	LO	22	57	40.1	2.2	22.97	16.52	14.35	2.17
R3	MD	18	57	36.2	2.6	22.22	18.65	16.87	1.78
R4	2B	21	49	43.6	2.8	21.25	19.69	18.63	1.06
R4	2E	18	49	43.8	3	23.11	18.16	16.6	1.56
R4	4B	20	49	41.6	2.6	19.9	18.89	17.68	1.21
R4	4E	21	53	43.4	2.2	22.92	17.67	15.83	1.84
R4	FB	19	48	47.4	3.7	20.84	20.59	19.57	1.02
R4	FE	19	51	43.8	2.6	19.21	18.07	16.94	1.13
R4	LO	20	59	33.6	2	21.92	17.49	15.31	2.18
R4	MD	21	55	38.6	2.2	22.16	18.95	17.07	1.88

BIOGRAPHICAL SKETCH

The author, Selomon Afework, was born on 12 May 1981 E.C in Debre-Work Town, Ethiopia. He attended elementary education (grade 1-8) at Keraniyo Elementary School from 1986 - 1994 E. C. After completing elementary education, he was enrolled at Motta Senior Secondary School in Motta town from 1995 –1996 E. C (grade 9-10). He then joined Kombolcha Agricultural TVET College in October 1997 E. C and graduated with Diploma on Natural Resource in July 1999 E. C. Following his graduation, he was a Natural Resources Expert and Kebele Manager at different Kebeles from October (2000-2006 E.C). During these times, he joined Saint Mary University, College of Open and Distance Program from 2004 to 2007 E.C graduated with Bachelor of Science in Agricultural Economics in August 2007 E.C. From October 2007 E.C till now he is employed at Bahir Dar University as senior technical assistant. Then after, in October 2009 E.C the author joined the school of graduate studies of Bahir Dar University, College of Agriculture and Environmental Sciences, Department of Natural Resources Management in the regular program as a candidate for Master of Science degree in Land Resource Management.